Markets and the Environment

Academic year 2015/16
Fall Term

Markets and the Environment: Central questions

Fundamental problem in economics:
How to allocate goods and scarce resources in an optimal fashion?

Natural Resource Economics:

- *At what moment* should we use *how much* of our resources? (optimal intertemporal allocation)

Environmental Economics:

- Do market mechanisms lead to optimal resource use? Or are there market failures?
- And if the market fails to allocate resources optimally, how can we *correct* this failure?

Markets and the Environment: Course Program

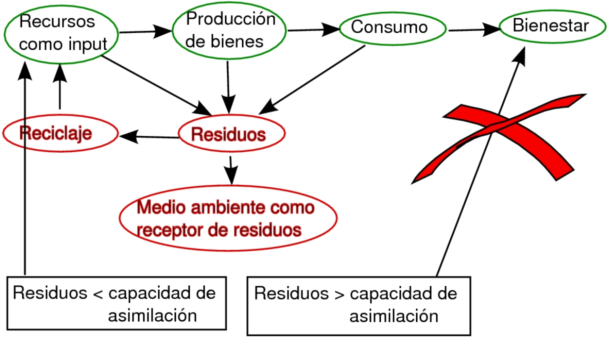
1. Introduction
2. Resource Management
    - Non-renewable resources
    - Renewable resources
3. Instruments for correcting market failures
    - The optimal level of pollution
    - Interventionist solutions
    - Market instruments
4. Valuation of natural resources
    - Revealed preferences
    - Stated preferences
    - Cost Benefit Analysis
5. International aspects and international environmental agreements

Topic 1
Introduction

1. Functions of the environment
2. Market failures
3. Environmental regulation
4. International aspects
5. Growth and sustainability

1. Functions of the environment

- provider of resources
- receptor of residuals
- generator of utility



2. Market failures

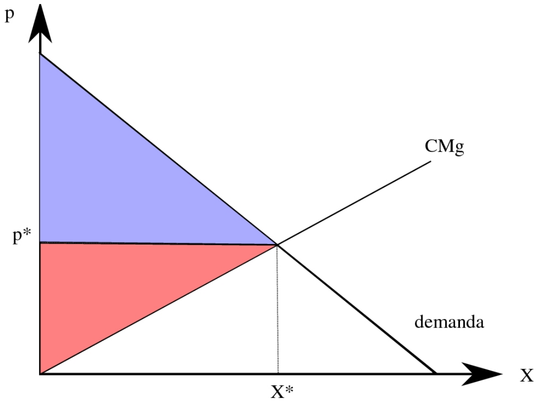
Fundamental problem in economics:
How to allocate goods and scarce resources efficiently?

First Theorem of Welfare Economics

The allocation of scarce resources through competitive markets is Pareto efficient if market prices exist for each good and they reflect the social opportunity cost of resource use.

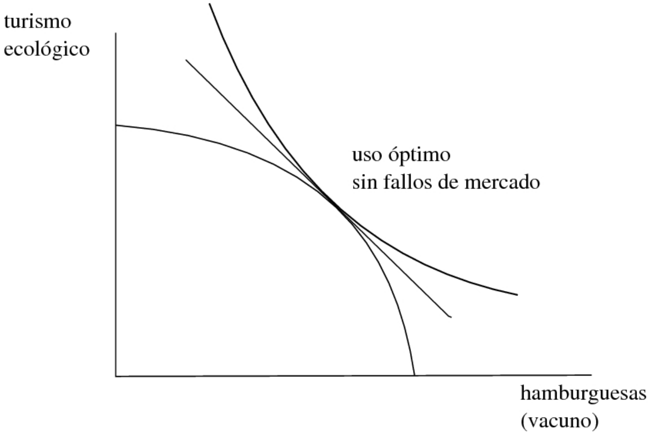
2. Market failures

The market equilibrium maximizes the sum of consumer surplus and producer surplus.



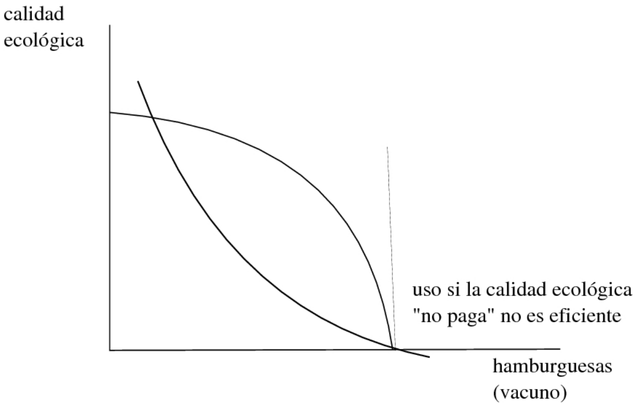
2. Market failures

Example 1: Tropical forest; can clear-cut and use the area
for pasture or conserve the forest for eco-tourism.
(for simplicity, abstract from commercial timber and other forestry benefits)



2. Market failures

Example 2: Tropical forest; Tropical forest; can clear-cut and use the area for pasture or conserve because of its ecological benefits
which have no market value
(for simplicity, abstract from commercial timber and other forestry benefits)



2. Market failures

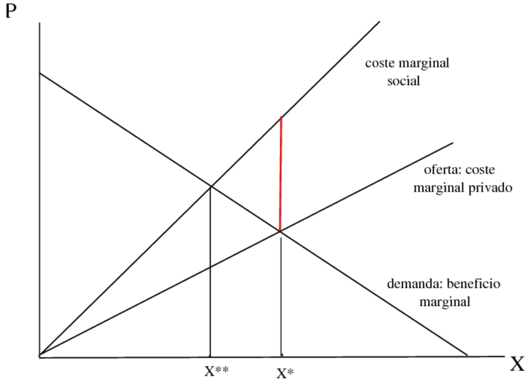
Why do market prices not always reflect the economic value and opportunity cost of goods, giving rise to inefficient allocations?

Market failures:

- externalities
- public goods
- asymmetric information
- market power
- non convexities

2. Market failures: Externalities

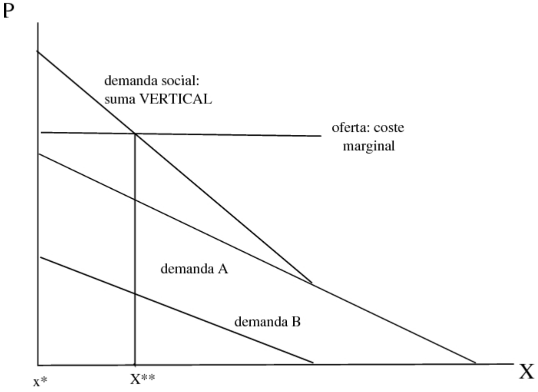
When the economic activity of one agent **affects the profits or welfare of another agent** and this effect is not properly reflected in prices, the level of economic activity is not optimal.



2. Market failures: Public goods and the commons

When a good is **non rival and/or not excludable** in consumption, the following problems arise:

- non rivalry: the social benefits of the good are given by the *sum* of all individual WTPs



2. Market failures: Public goods and the commons

When a good is **non rival and/or not excludable** in consumption, the following problems arise:

- non rivalry: the social benefits of the good are given by the *sum* of all individual WTPs
- non exclusion: free-riding ⇒ provision of the public good is less than optimal under a voluntary provision mechanism. This occurs (among others) with goods for which property rights are not well defined.

	excludable	non excludable
rival	private good	common good
non rival	club good	public good

Exercise

Think of an example for each type of good

3. Environmental regulation

Regulatory instruments

Most prominent market failures in the use of natural resources:

- externalities: pollution of the air, water and soil
- public goods: transboundary pollution (climate change, ozone layer...)

Environmental policy aims at correcting these market failures.

national level: taxes, standards, tradable permits

international scale: international agreements between souvereign states to protect the environment.

3. Environmental regulation

Cost benefit analysis

ENVIRONMENTAL REGULATION

$$\text{COSTS} \quad \gtreqless \quad \text{BENEFITS}$$

Economists: choose the policy that maximizes Benefits−Costs.
To do this, it's necessary to estimate the costs and benefits associated with the measures under consideration.

3. Environmental regulation

Valuation

Environmental policy aims at improving air quality, water quality and the eco-system.
⇒ these are non-market goods and amenities, so they have no market price.

Fundamental problem in cost-benefit analysis: How to compare the cost and the benefits of a measure when the latter are not measured in monetary terms (e.g. avoided deaths or diseases)?

⇒ Need to "translate" environmental benefits into monetary values.
For a given measure, figure out *willingness-to-pay (WTP)* for the benefits among those who pay for its costs. Methods:

- Stated preferences: surveys about WTP
- Revealed preferences: infer WTP from other choices that people make and which involve similar trade-offs.

4. International aspects and multilateral agreements

Transboundary environmental problems

- Examples: pollution of oceans and rivers, climate change, depletion of the stratospheric ozone layer, ...
- Each country indiviudally has an incentive to overuse the common resource.

⇒ countries are souvereign and they can behave strategically

Question:

- Is it possible that all souvereign countries cooperate to ensure an efficient use of natural resources?
- If so, what aspects are important in designing a multilateral agreement of cooperation?
- If it's not possible, what is the level of cooperation that an international treaty such as the Kyoto Protocol can achieve?

5. Growth and sustainability

Can we sustain current rates of economic growth indefinitely, given that natural resources are finite?

The Limits to Growth (1972 Club of Rome report)

"If the present growth trends in world population, industrialization, pollution, food production, **and resource depletion** continue unchanged, the limits to growth on this planet will be reached sometime within the next one hundred years. The most probable result will be a rather sudden and uncontrollable decline in both population and industrial capacity. (...) **the collapse occurs because of nonrenewable resource depletion**."

Sustainable Development (1987 "Brundtland Commission" report)

"Meeting the needs of the present generation, without compromising the ability of future generations to meet their own needs."

5. Growth and sustainability:

Pessimist view: (Malthus, Club of Rome, environmentalist groups, ...)

- growth of population / production requires ever more resources

$\Rightarrow$ eventually using up the resources with severe consequences for the quality of life

$\Rightarrow$ some are in favor of "zero growth"

Optimistic view: (many economists,...)

- market forces prevent exhaustion of non-renewable resources:

$$\left.\begin{array}{l}\text{reserves } \downarrow \\ MC \text{ of extraction } \uparrow\end{array}\right\} \Rightarrow \text{ price } \uparrow \Rightarrow \left\{\begin{array}{l}\text{demand } \downarrow \\ \text{alternative resources,} \\ \text{technologies for substitution} \\ \text{and recycling } \uparrow\end{array}\right.$$

- point out that environmental quality tends to **rise with per-capita income** in developed countries ("Kuznets curve")

5. Growth and sustainability

If technological change and alternative resources can replace natural capital, why should we preserve it?

Reasons

- Natural capital necessary for the construction of built capital, substitutes not always available
- Uncertainty about when new technologies become available to substitute natural resources
- Scientific uncertainty and irreversibility
- Natural capital can improve capacity to adapt to environmental shocks
- Intergenerational equity
- Ethical concerns
- **Market failure**: without intervention, resources will be overused

Topic 2
Natural Resource Management

1. International Treaties

2. International Trade and the Environment

Natural resources: Concept and typology

- **Natural resources**: goods provided by nature (not manmade) that are consumed or used in the production of other goods; "natural capital".
- **Non-renewable resources**: use or consumption leads to a permanent reduction in the *stock*, as there is no regeneration (or whose regeneration would take excessive amounts of time).
  Ex.: fossil fuels such as oil
- **Non-renewable resources with recyclable services**: use or consumption leads to a reduction in the *stock* which is subsequently (partially) reverted or transformed into another useful state by means of an industrial process of recovery (reuse or recycling).
  Ex.: aluminium, waste water
- **Renewable resources**: their use or consumption does not lead to their exhaustion because of the ability to regenerate. The *stock* can increase or decrease, depending on the quantity used.
  Ex.: forests, surface water, fisheries, atmospheric air

Natural Resource Management: Non-renewable resources (NRR)

1. International Treaties
2. International Trade and the Environment

1. Non-renewable resources: Concept

Non-renewable resources(NRR)

Usage or consumption of a unit of the NRR entails the destruction of the same unit of reserves, and its regeneration would take an immense amount of time.

Essential questions: What is...

- the rate of extraction that gives rise to an optimal exploitation of the NRR?
- optimal period of time for depleting the resource stocks?

also: question of intergenerational equity

1. Non-renewable resources: Concept

- **Demand:** for direct consumption ($U = U(C, Z)$) and for the production of other consumption goods ($Q = f(K, L, Z)$).
- **Price elasticity** of demand: depends on the availability of substitute goods
- **Supply:** Resource deposits are limited and possibly not all of them are known. The *reserves* are known deposits of adequate quality to be used with current technology; they determine the supply. Offer curve: $P = CMg$ where..
- **Opportunity cost:** costs of extraction of the resource + *user costs* (foregone future profits.)

2. The Hotelling Rule

Assumptions:

- Exact amount of the resource stock ($\bar{R}$) is known
- Zero extraction cost
- Amount of resource extracted has no influence on the price (individual acts in *perfect competition*)
- Price is a *known* function $p(t)$ of time

2. The Hotelling Rule

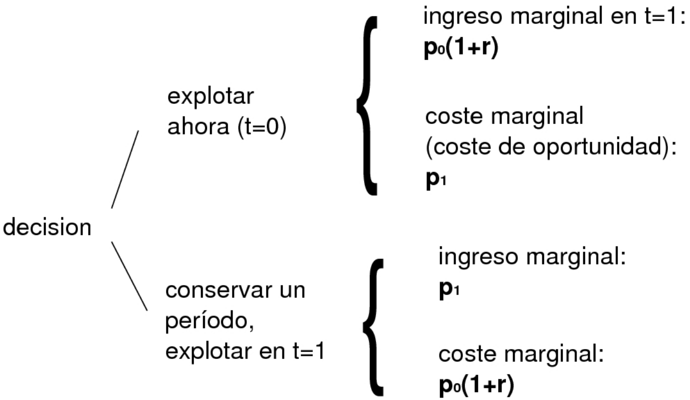
Hotelling: Resource owners have two options

1. extract resource and put proceeds in the bank $\Rightarrow$ interests
2. leave resource in the ground while its value appreciates

Exercise

What are the opportunity costs of each of the two alternatives?

2. The Hotelling Rule



If $p_1 > p_0(1+r)$ it is beneficial to extract in $t = 1$

If $p_1 < p_0(1+r)$ it is beneficial to extract in $t = 0$

2. The Hotelling Rule
Small quantity, 2 periods, no extraction cost

Example

Normalize the endowment of the resource owner to 1 unit. She can sell it in $t = 0$ ("now") or in $t = 1$ ("tomorrow").

t	0	1
$p(t)$	120	130

The risk-free interest rate equals $r = 10\%$ and marginal extraction cost $c = 0$.

Compare the benefit of selling "now" $p_0 = 120$ with the present value of selling "tomorrow" $\frac{p_1}{1+r} = 118, 18 \Rightarrow$ sell now.

2. The Hotelling Rule
Small quantity, 2 periods, positive extraction cost

Exercise

What is the profit-maximizing decision if the owner of one unit of the resource has a cost of $c = 40$?
The interest rate is $r = 10\%$ and prices are as in the previous example.

t	0	1
$p(t)$	120	130

Solution: Table after subtracting extraction cost:

t	0	1
$p(t)$	80	90

Sell today: 80. Sell tomorrow: $90/1,1 = 81, 81 > 80$, hence selling tomorrow is the better option.

2. The Hotelling Rule
All reserves, 2 periods, no extraction cost

So far: **individual** decision in a market with perfect competition.
Now consider the entire resource-depleting industry:

- si $p_0 > (<) \frac{p_1}{1+r}$ $\Rightarrow$ all owners want to sell "now" ("tomorrow")

$\Rightarrow$ supply "now" increases (declines) by a lot

$\Rightarrow$ relative prices have to change until **equilibrium** obtains where

$$p_0 = \frac{p_1}{1+r}$$

- indifference between extracting and postponing: market interest rate equals the rate of appreciation of the resource *in situ*.

2. The Hotelling Rule
Equilibrium price path

The Hotelling rule (2-period case)

At the equilibrium, the price of the NRR increases at a rate equal to the market interest for risk-free assets:

$$\hat{p} = \frac{\Delta p}{p_0} = \frac{p_1 - p_0}{p_0} = r$$

Exercise

Calculate the condition that characterizes equilibrium in the model with two periods and *positive* extraction cost c.

Solution: $p_0 - c = \frac{p_1 - c}{1+r} \Leftrightarrow p_0 - c + r(p_0 - c) = p_1 - c \Leftrightarrow p_1 - p_0 = r(p_0 - c) \Leftrightarrow \frac{p_1 - p_0}{p_0 - c} = r$

2. The Hotelling Rule

Continuous time, no extraction cost

In reality, there are more than 2 periods when resources can be sold, and resource owners can own more than a single unit.
At every moment t choose the extraction level $Z(t) \geq 0$ such that the present discounted value of the resource

$$\int p(t)Z(t)e^{-rt}dt$$

is maximized subject to the limited stock R of the resource.

$$\int Z(t)dt = \bar{R}.$$

$\Rightarrow$ Dynamic optimization problem with

- control variable Z and state variable R
- equation of motion: $\dot{R}(t) = -Z(t)$
- initial condition: $R(0) = \bar{R}$ and terminal condition: $R(T) \geq 0$

2. The Hotelling Rule
Continuous time, no extraction cost

The optimal solution requires that $p(t) = e^{rt} p_0$, whence

The Hotelling Rule (in continuous time)

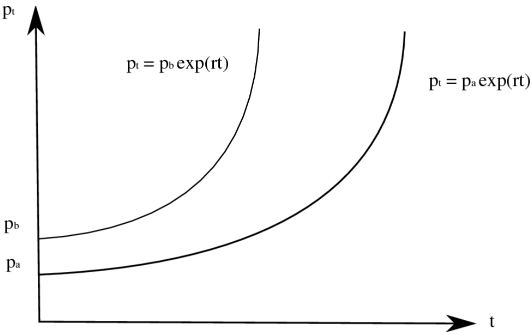
The price of the NNR increases at a rate equal to the market rate of interest on risk-free assets:

$$\hat{p} = \frac{\dot{p}}{p} = \frac{r e^{rt} p_0}{e^{rt} p_0} = r$$

And the quantity sold?
The present value of a unit of the resource is equal at every moment, that's how we obtain a continuous supply of the resource (instead of everything now or in the indefinite future)

2. The Hotelling Rule

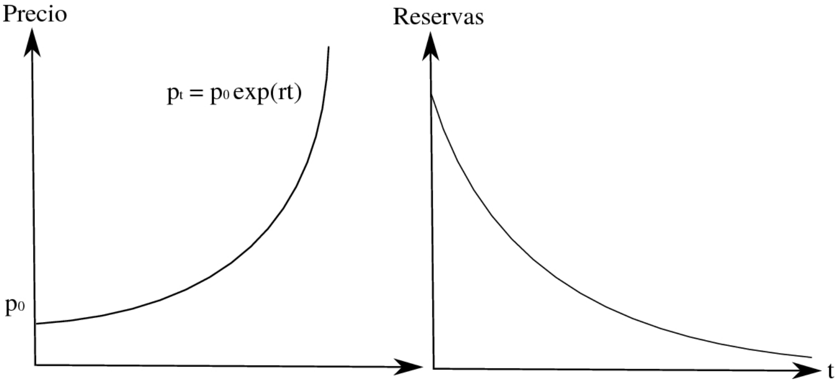
The Hotelling Rule provides the **growth rate** of the resource price.



But how do we know the optimal **level** of the price path?
Need to exploit the initial and terminal conditions to solve the optimization problem.

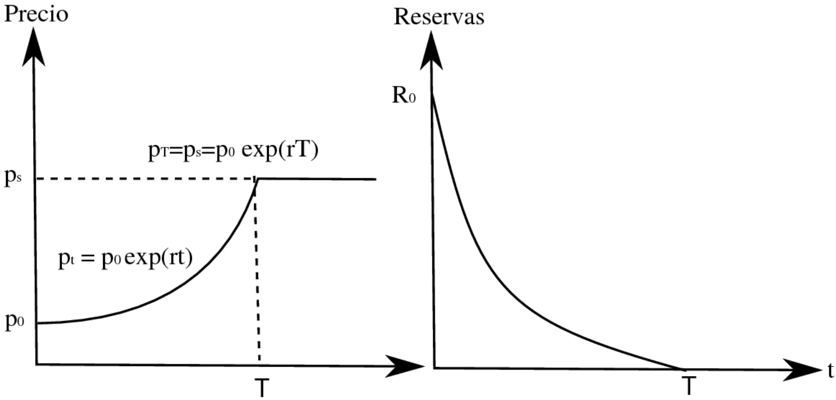
2. The Hotelling Rule

Example I: without substitute, the resource will never be completely depleted



2. The Hotelling Rule

Example II: if there is a substitute with cost p_s, the resource will be depleted when the resource price reaches this level



2. Non-renewable resources: optimal extraction

Reference scenario:

the optimal use of the resource maximizes welfare W in the society (including future generations!)

$$\max W = \int U_t(Z(t)) \cdot e^{-\rho t} dt$$

Assumptions:

- $U(Z)$ is the net utility of all uses of the resource Z, be it in consumption or production
- W is additive in utility U_t over time
  (this assumption is not undisputed but it guarantees a Pareto optimum)
- $U' > 0$ y $U'' < 0$
- social discount rate $\rho > 0$ (somewhat controversial)

$$\text{subject to } \int Z(t)dt = \bar{R}\ ,\ Z(t) \geq 0$$

2. Non-renewable resources: optimal extraction

First-order condition:
Equalize *discounted marginal utility* in every moment. The marginal utility without discounting must grow at the social discount rate:

$$\hat{U}' = \frac{\dot{U}'}{U'} = \frac{\partial U'/\partial t}{U'} = \rho$$

$\Rightarrow$ consumption must decline over time

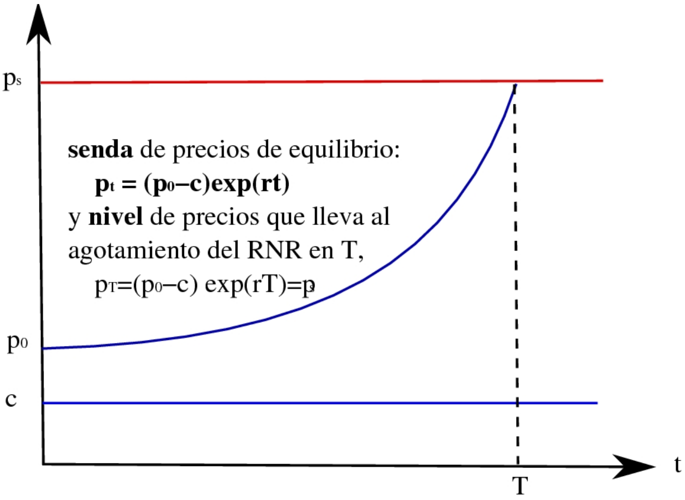
Beware: Extraction path and declining consumption obtained both with private resource ownership (Hotelling: increasing prices) and with a benevolent dictator (U' growing over time), but they only coincide ($\Rightarrow$ decentralized decisions are efficient) in special cases, in particular when social and private discount rates coincide. In other words, the competitive market does not guarantee an optimal allocation of the resource when the discount rates are different from each other.

3. Comparative statics

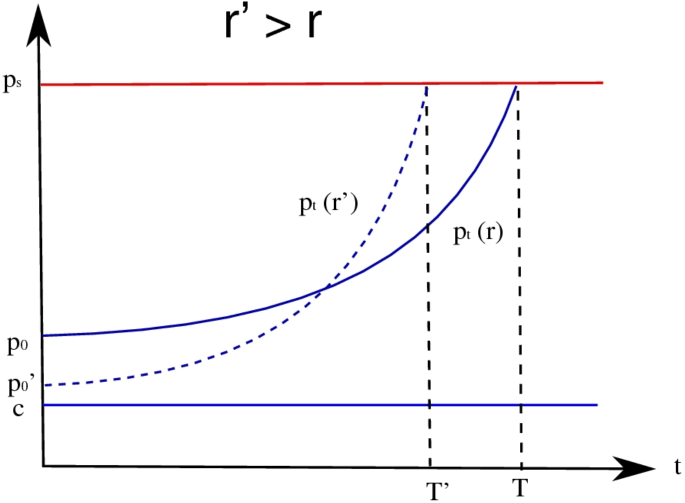
with respect to

1. discount rate
2. backstop technology
3. total resource stock
4. extraction costs
5. demand for the NRR

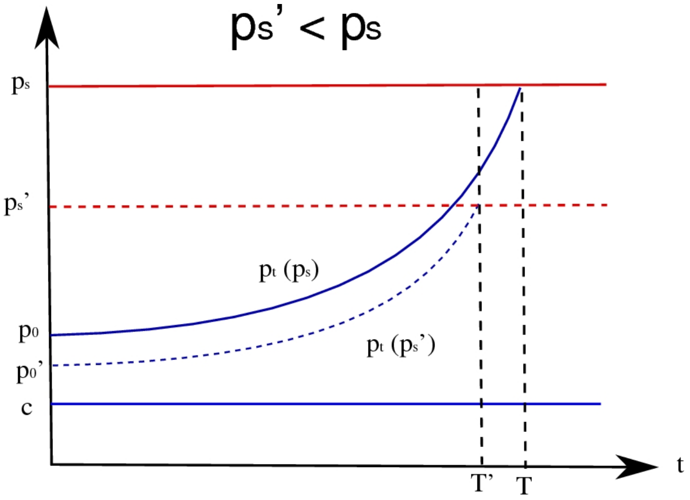
3. Comparative statics
Reference scenario



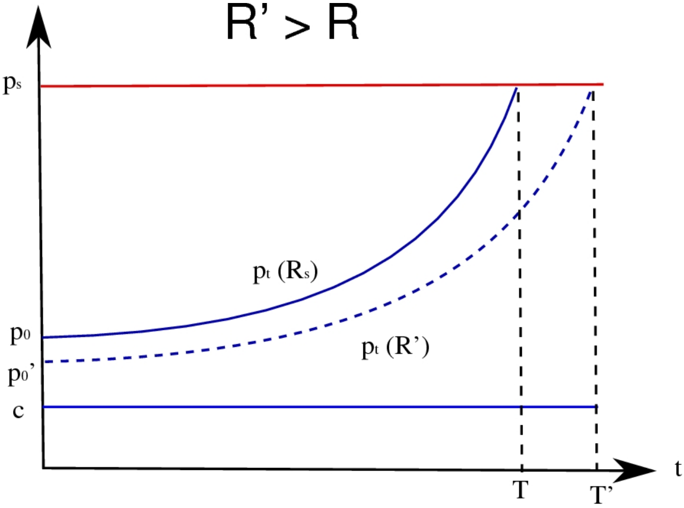
3. Comparative statics
The discount rate



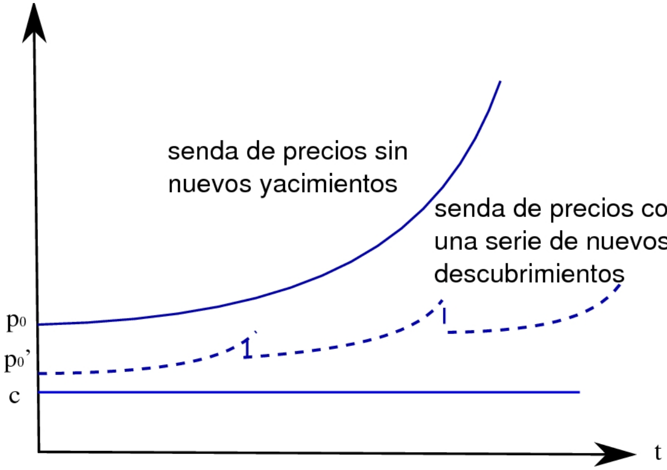
3. Comparative statics
Backstop technology



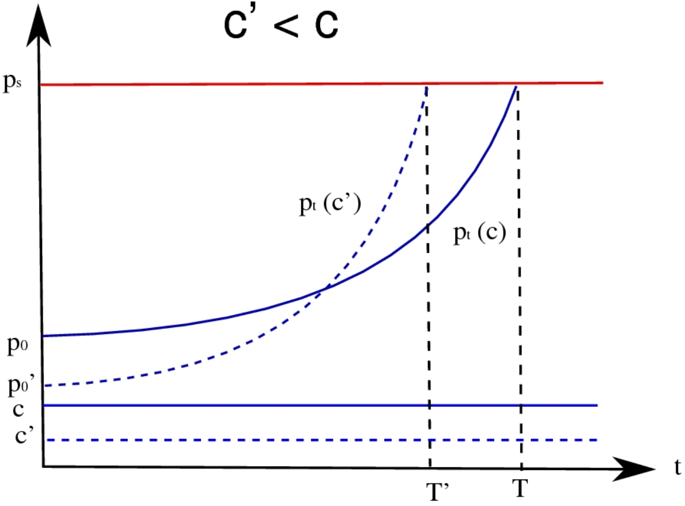
3. Comparative statics
Total stock of NRR



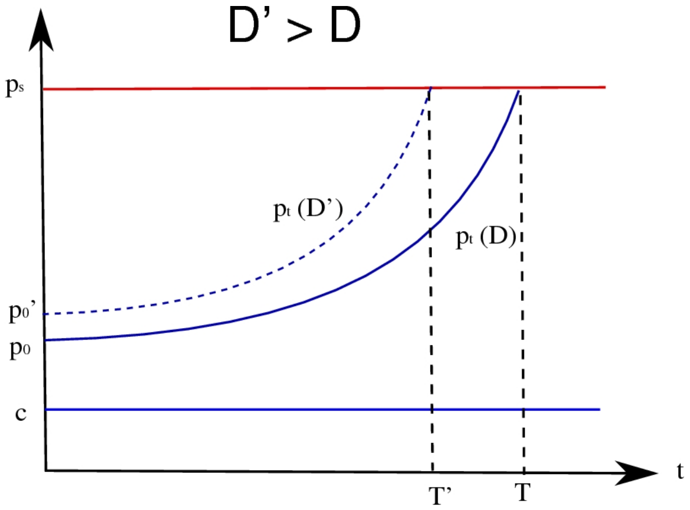
3. Comparative statics
Total stock of NRR



3. Comparative statics
Extraction cost



3. Comparative statics
Demand for the NRR



4. Monopoly

So far:

- Perfect competition or welfare maximization
- with $r = \rho$ decentralized decisions lead to socially optimal path of resource depletion

Are there arguments for public intervention in the resource market?

- Social discount rate $\neq$ discount rate r used by the resource owners
- Externalities arising from the resource use
- Imperfect information
- **Non-competitive markets**

4. Monopoly

Monopoly

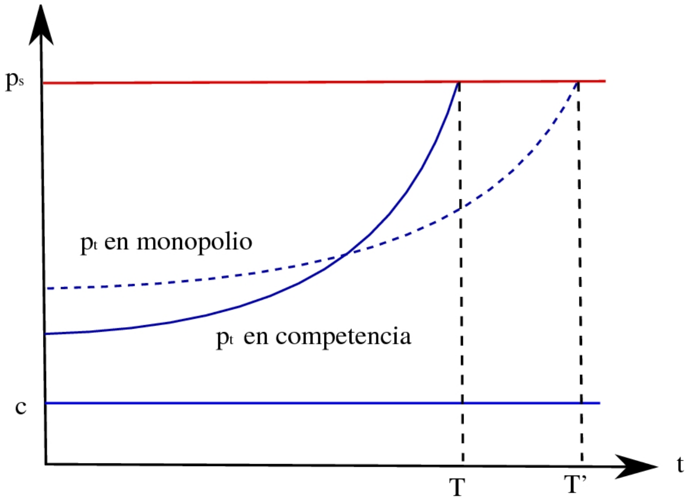
- Monopolist restricts output and raises prices compared to perfect competition
- P_0 (intial price) higher than under perfect competition
- with a given total resource stock, higher initial price ⇒ price path less steep over time

Effects:

Intuitively...
increases the lifetime of the NRR

.. but in practice
depends on the specific values and relevant parameters(e.g. the elasticity of the demand curve)

4. Monopoly and the extraction rate



5. Recycling

If after being used or consumed a resource preserves certain physical or chemical properties etc.

$\Rightarrow$ the material can be recovered

Recycling...

- increases total supply of the resource
- reduces the quantity that needs to be extracted

$\Rightarrow$ extends the lifetime of the resource

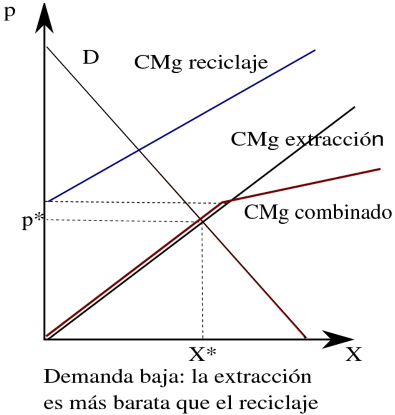
- buys us time for discovering substitutes

Recycling and sustainability

Recycling allows us to produce *more* while extracting *smaller* amounts of scarce resources.

5. Recycling

Competition between extractiong and recycling:



5. Recycling

Recovery of recycled materials is only partial but may increase total supply by a significant amount

Example: Initial extraction Q; of the amount used during one year 80% can be recycled and reused the following year.

t	0	1	2	...	k	...
$z(t)$	Q	$0,8\,Q$	$0,8^2\,Q$	...	$0,8^k\,Q$	...

5. Recycling

Total use:

$$
\begin{aligned}
Z = \sum_{i=0}^{T} z(t) &= Q(1 + 0,8 + 0,8^2 + ... + 0,8^T) \\
0,8\,Z &= Q(0,8 + 0,8^2 + 0,8^3 + ... + 0,8^{T+1}) \\
Z - 0,8\,Z &= Q(1 - 0,8^{T+1}) \\
Z &= Q\frac{1 - 0,8^{T+1}}{1 - 0,8} \\
\lim_{T\to\infty} Z &= \frac{Q}{1 - 0,8} = 5\,Q
\end{aligned}
$$

$$\lim_{T\to\infty} Z = \frac{Q}{1 - \text{recycling rate}}$$

5. Recycling

Consumer decisions:

	Buy and throw away	Buy and recycle
Price	100	100
Marginal Benefit to consumer	160	160
Net utility	60	60
Costs of final deposit		
private	10	40
environmental damage	40	0
value of recycled material	none	20
Net Benefits		
private	50	20
social	10	40

How can be consumers be given incentives for recycling?

- Tax household waste
- introduce deposit programs on recyclable containers

Natural Resource Management: Renewable resources (RR)

1. Renewable resources: concept

Renewable resources

Usage or consumption entails a reduction in the stock, but over time the resource stock regenerates itself.

- renewable resource flow
  - e.g. solar energy (photovoltaic or thermal), wind
  - usage does not lead to resource depletion
- renewable resource stock
  - e.g. fisheries, forests, atmosphere, soils
  - regeneration follows a biological, physical or chemical process
  - usage can lead to resource depletion

1. Renewable resources: Concept

- Sustainable usage level: does not compromise the future availability of the renewable resource stock
- Long-term problem: maximize social welfare
- Problem of resource depletion: avoid definitive extinction
- we use "bio-economic models": it's key to know the natural growth rate in order to decide on the rate of exploitation
- typical cases:
  - fisheries (rapid growth)
  - forests (slow growth)

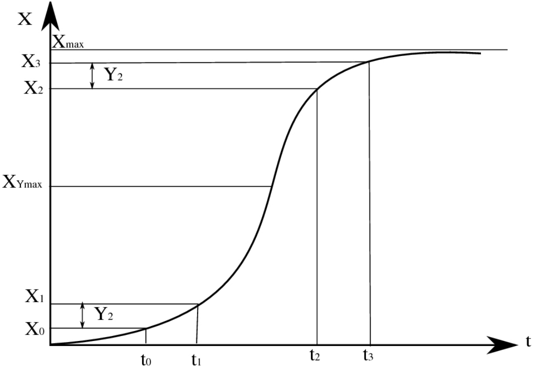
2. Growth and renewable resource use

Example: fisheries

- Area where a population of fish (a particular species) resides and where several firms undertake fishing activities.
- Mobile resource: difficult to assign property rights
- Bio-economic model: Natural growth curve $F(X)$
- Total growth of the stock: $X_{t+1} - X_t = F(X) - Y$
- "Carrying capacity" X_{max} of the system: An equilibrium where availability of food and other natural factors limit further growth of the stock X
- Sustainable catch/harvest: quantity caught in a period, Y $=$ natural growth of the resource in this period, $F(X)$

2. Growth and resource extraction

Natural growth curve $F(X)$ of resource X (biomass),
e.g. logistic growth function $F(X) = g\,X\left(1 - \frac{X}{X_{max}}\right)$

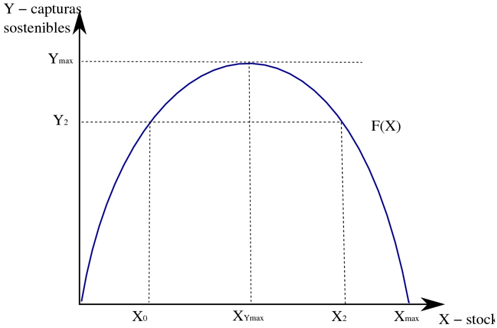


Sustainable resource use depends on the stock: with X_1 and X_3 it's Y_2/year

Maximum sustainable yield corresponds to the stock X_{Ymax}

2. Growth and resource extraction
Profit maximization – Static model

Sustainable catches for different stocks



Catches $\bar{Y}$ are sustainable with a stock of X_{τ} or with $X_{\tau'}$.

2. Growth and resource extraction
Profit maximization – Static model with a single resource owner

What size of the resource stock maximizes the **static profits** (in a single period), if it is extracted in a **sustainable** way?

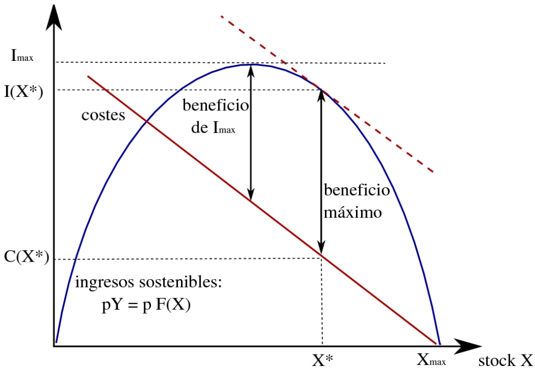
$\Rightarrow$ maximize (revenue – cost) as a function of X

- sustainable revenue?
  - sustainable catch Y = growth of the biomass as a function of the stock $F(X)$

  $\rightarrow$ Sustainable revenues $I = p \cdot Y$
  assumptions: perfect competition, p constant
- cost of harvest Y?
  - when the stock X is small, more *effort* is needed to extract Y (use more trawlers, spend more time at sea, etc.)

  $\rightarrow$ the cost of harvesting *diminishes* as X *increases*

2. Growth and resource extraction
Profit maximization – Static model



Maximum profit at X^*, where MR=MC.
X^* different from the maximum sustainable yield with stock X_{Ymax} .

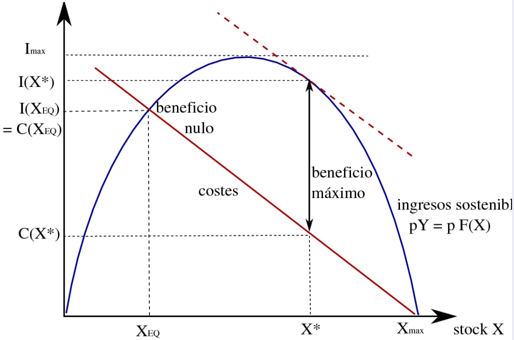
2. Growth and resource extraction
Profit maximization – Free entry

- Without owner of the resouce (ill-defined property rights) individual fishermen have no incentive to maximize social welfare

$\Rightarrow$ keep fishing as long as profits are positive :
until $X_{EQ} < X^*$ where the profit becomes 0 as revenue exactly covers the cost.

- In the bio-economic equilibrium X_{EQ}, there is over-exploitation of the resource compared to the socially efficient equilibrium X^*
- Although there is no extinction, the system is less stable and more vulnerable towards it, e.g. if the natural growth rate of the fish population is over-estimated.

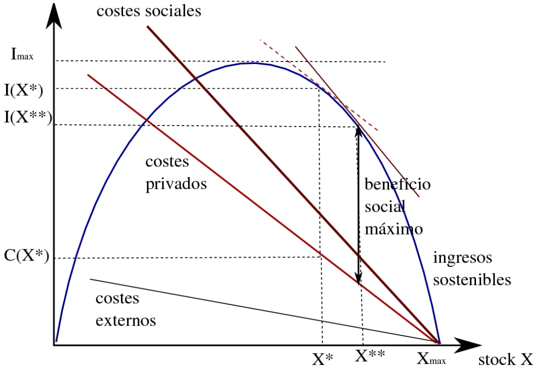
2. Growth and resource extraction
Profit maximization – Free entry



H. Scott Gordon 1954:

"There appears, then, to be some truth in the conservative dictum that **everybody's property is nobody's property**. Wealth that is free for all is valued by no one because he who is foolhardy enough to wait for its proper time of use will only find that it has been taken by another."

2. Growth and resource extraction
Profit maximization – Negative externalities



2. Growth and resource extraction
Profit maximization – Negative externalities

With negative externalities (e.g. disequilibrium in the food chain or famine of native people who subsist on the basis of the fish grounds.)

- optimal catch at X^{**}, equalizes social MC = MR
- $X^{**} > X^{*}$, private profits are smaller, social benefits are larger, and the negative externality is smaller.
- How to internalize the externalities in the production costs? answer: taxes, tradable catch quotas etc.

2. Growth and resource extraction
Profit maximization – two-period model

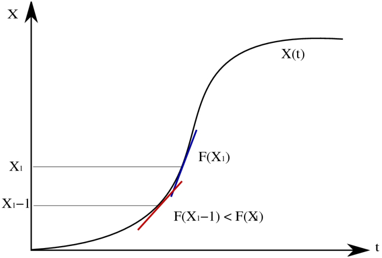
Dynamic model: maximize the **present value of profits** (resource owner's problem with free entry, or social planner's problem).
Intertemporal consequences of increasing the catch?

- increase catch today $\mathrm{d}Y_t > 0$

$\Rightarrow$ diminish stock in the next period $\mathrm{d}X_{t+1} < 0$

$\Rightarrow$ affects the *speed of recovery* of the resource $F(X)$

2. Growth and resource extraction
Profit maximization – two-period model



- $dF(X)/dX = F'(X)$ is the *change in the speed* (acceleration).
  $\Delta X = -1 \Rightarrow \Delta F(X) = F(X_1 - 1) - F(X_1)$
- Up until the inflection point,
  $F(X_1) > F(X_1 - 1) \Rightarrow F'(X) > 0$.
  The speed of recovery grows with the stock; extracting an additional unit of the stock reduces $F(X)$.
- After that, $F(X)$ diminishes with the stock (deceleration):
  $F(X_1) < F(X_1 - 1) \Rightarrow F'(X) < 0$

2. Growth and resource extraction
Profit maximization – two-period model

Two periods t_0, t_1, no extraction costs, all expressions in future values.
Intertemporal consequences of increasing the catch in t_0?

- MR of catching an additional fish in t_0: $p_0(1+r)$
- MC of not catching that fish in t_1 and foregone regeneration:
  $p_1 + p_1 F'(X) = p_1 + p_0 F'(X) + \Delta p F'(X)$.
  For $\Delta\, p\, F'$ close to 0 $\rightarrow$ $CMg \approx p_1 + p_0 F'(x)$
- Decision:
  - If MR$>$ ($<$)MC $\Rightarrow$ increase (decrease) the catch in $t = 0$
  - If MR $=$ MC $\Rightarrow$ indifferent about changes catches

$\Rightarrow$ for there to be a continuous supply in equilibrium, prices in the two years have to satisfy: $\mathbf{p_0(1+r) = p_1 + p_0\, F'(x)}$

2. Growth and resource extraction
Profit maximization – two-period model

Using the equilibrium condition: $p_0(1 + r) = p_1 + p_0\, F'(x)$ we can calculate the following

Fundamental equation (two-period model)

Optimal exploitation of a renewable resource satisfies

$$\frac{\mathbf{\Delta p}}{\mathbf{p_0}} + \mathbf{F'(x) = r}$$

Economic interpretation: Conservation of one unit of the renewable resource offers two returns:

- the increase in the price of this unit
- the change in the rate of regeneration of the stock

The sum must be equal to the return to the best alternative (interest rate)

2. Growth and resource extraction
Profit maximization – dynamic model

General case: continuous time, infinite time horizon, positive extraction cost

- objective: $\max \int_{t=0}^{\infty} (p_t Y_t - cY_t)\, e^{-rt}$
- control variable: extraction Y_t
- state variable: stock X_t
- equation of motion: $\dot{X}_t = F(X_t) - Y_t$
- initial condition: $X_0 = X(0)$, terminal condition: $\lim_{t\to\infty} X(t) \geq 0$

2. Growth and resource extraction
Consequences of the fundamental equation

Fundamental equation (Continuous-time model)

$$\frac{\dot{p}}{p_t - c} + F'(x) = r$$

- The larger the price and the smaller the extraction cost, the smaller the first term
  If r is constant, the resource owner requires a larger $F'(X)$
  $\Rightarrow X^*$ is smaller
- the larger the discount rate, the smaller will be X^*
- the larger $F'(X)$, the smaller is X^*.

3. Fishery policy in the European Union

The EU, like many other national governments, regulates the exploitation of fishing grounds because of two problems:

- Over-fishing (and risk of extinction)
- Excess capacity in the fishing fleet (excessive fixed cost)

3. Fishery policy in the European Union

- Multi-year program with measures to mitigate...
  - ... overfishing: Total Admissible Catch (TAC);
    admissible quantity that can be harvested of a given species in a given area in one ear
  - ... excess effort: Total Admissible Effort (TAE);
    effort = capacity (size of the boat and engine) per time of activity
- The TAC and TAE are subdivided in national quotas, and EU countries can manage their quotas in different ways (subsidiarity principle)
- Problem: TAC and TAE are political decisions, and do not necessarily correspond to bio-economic principles

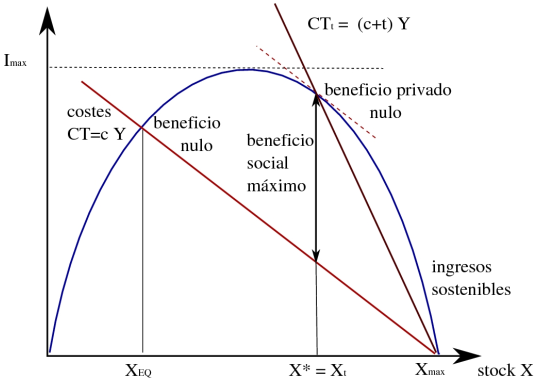
3. Fishery policy

Other measures aimed at reducing overfishing and excess effort:

1. Regulation of utilized technology
2. Individual transferrable quotas (ITQ)
3. Taxation:
   raise the cost of effort to reduce the profit-maximizing effort level

3. Fishery policy

Regulation via taxation



Private benefits before and after taxes,
Tax revenue = social welfare

4. Economic aspects of forest management

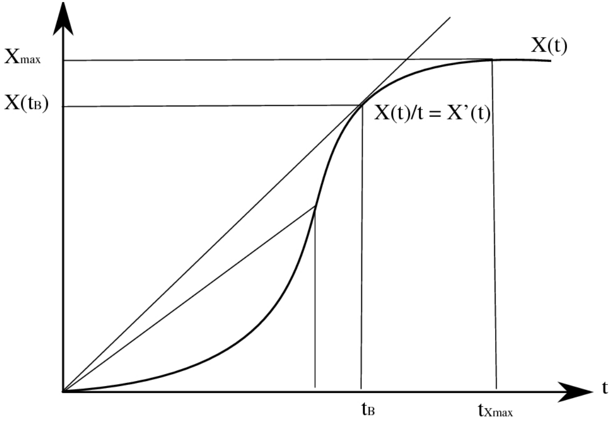
Special characteristics of forests (compared e.g. with fisheries):

- Prolonged period of regeneration
  (depending on the species, environmental factors and human influences)
- multiple functions:
  - **productive/commercial** (plantations)
  - leisure/recreation
  - environmental

  ⇒ external effects due to its multiple functions
- easier to control than fisheries because not a mobile resource
- need land ⇒ opportunity cost
- traditionally no partial extraction, all trees of forest were cut at the same time

4. Economic aspects of forest management

Forest growth:



- **Average product** of the resource (by time period) $X(t)/t$
- **Marginal product** of the resource $X'(t)$
- average product is maximized if $X(t)/t = X'(t)$
  Maximum sustainable yield (MSY)

4. Economic aspects of forest management

Central question in forest management

- determine the optimal timing for cutting the trees, the "optimal rotation time"

Two different criteria:

1. Optimal *biological* rotation time maximizes the average product
2. Optimal *economic* rotation time also takes into account the costs (of planting, maintaining, cutting and opportunity cost of land use) and discounting

4. Economic aspects of forest management
Optimal economic rotation time for a single rotation

We want to find the best **moment** to cut down the trees (not the largest quantity, because all is cut at the same time):

$$\max_t pX(t)e^{-rt}$$

To simplify we assume a constant price of timber p

$$p\dot{X}e^{-rt} + pX(t)e^{-rt}(-r) \stackrel{!}{=} 0$$

$$\Rightarrow \quad rpX(t) = p\dot{X}$$

- MC of waiting a bit longer: foregone interests on the timber revenue
- MB of waiting a bit longer: value of the additional timber grown during that time $p\dot{X} = p\partial X/\partial t$
- optimal economic rotation time is given when MC=MB of waiting

4. Economic aspects of forest management
Optimal economic rotation time for a single rotation

Alternative interpretation of the optimality condition: Simplifying somewhat more we obtain

$$r = \frac{\dot{X}}{X(t)}$$

- with the optimal rotation length, the *percentage* growth in the resource equals the market interest rate (return on an alternative investment: opportunity cost)

4. Economic aspects of forest management
Optimal economic rotation length with an infinite series of rotations

What to do when all trees were cut?

- plant new trees or
- sell the land
  maximum price = present-discounted value of all future plantations

Delaying the harvest by one period also delays all following harvests (or the sale of the land): using the land for one more period has an **opportunity cost**

4. Economic aspects of forest management
Optimal economic rotation length with an infinite series of rotations

We are looking for the rotation length for an infinite series of rotations (of equal length) which maximizes the present value of revenue

$$V(T) = pX(t)\left(e^{-r\cdot T} + e^{-r\cdot 2T} + e^{-r\cdot 3T} + e^{-r\cdot 4T} + \ldots\right)$$

$$V(T) = pX(T)e^{-rT}\sum_{i=0}^{\infty} e^{-r\cdot iT} = \frac{pX(T)e^{-rT}}{1-e^{-rT}} = \frac{pX(T)}{e^{rT}-1}$$

With replanting cost $C > 0$:

$$V(T) = (pX(t)e^{-r\cdot T} - C)\sum_{i=0}^{\infty} e^{-r\cdot iT} = \frac{pX(T)e^{-rT} - C}{1-e^{-rT}}$$

This formula is due to Martin Faustmann (1849).

4. Economic aspects of forest management

Optimal economic rotation length with an infinite series of rotations

To maximize the present value of all harvests $V(T) = \frac{pX(T)}{e^{rT}-1}$ we take the derivative

$$\frac{\partial V}{\partial T} = \frac{p\dot{X}(e^{rT}-1) - pX(T)e^{rT}r}{(e^{rT}-1)^2} \overset{!}{=} 0$$

multiply by r $(e^{rT}-1)$ and rearrange to get

$$\Rightarrow \quad p\dot{X} = \frac{rpX(T)}{1-e^{-rT}} \quad \Rightarrow \quad p\dot{X} = rpX(T) + e^{-rT}p\dot{X}$$

$$\Rightarrow \quad p\dot{X} = r(pX(T) + V)$$

- MB of increasing the rotation length: value of the resource growth
- MC: foregone interests on timber revenues **and on the value of the land**

5. Species extinction

The new Red List of Endangered Species maintained by the IUCN (International Union for Conservation of Nature, $\rightarrow$ **link**):

- entre 5.487 mammals evaluated,
  1.141 species in danger of extinction

- of 44.838 species evaluated in total
  (out of about 1.600.000 known species),
  16.928 are in danger of extinction

5. Species extinction

- Renewable resources stock, if smaller than a minimum critical size faces the danger of extinction
- These resources are at risk of extinction if the principle of sustainability is not followed (extraction $\leq$ growth)
- Extinction is irreversible
- High discount rates threaten the survival of renewable resources, especially those that grow slowly

5. Species extinction

Economic arguments against species extinction:

- Species generate direct benefits in terms of welfare.
- Many present-day pharmaceuticals are derived from wild plants.
- Wild plants are of critical importance for genetic diversity.
- Living species fulfil many supportive functions for humanity.
- Living species also serve as a basis for scientific research.

5. Species extinction

Economic drivers of species extinction

- high resource prices
- low extraction cost
- low natural growth rates
- high discount rates
- open-access to the resource
- high volatility in the natural growth rate

In many cases the extinction is a consequence not of direct exploitation of a species but of the exploitation of and anthropogenic changes to its natural habitat.

⇒ Conflicting values: development versus conservation.

Tema 3
Instruments for correcting market failures

Economics of Pollution

Anthropogenic environmental degradation:
Inevitable by-product of many production processes and of the consumption of many goods and services

What is the utility derived from these goods and services? $\longleftrightarrow$ What is the cost of providing this utility?

$\Downarrow$

Public policy

Determine the level of environmental quality that maximizes the difference between social welfare and social cost

Economics of Pollution

Actual level of environmental quality $\neq$ desired level of environmental quality ?

$\Downarrow$

Public policy

Modify the behavior of economic agents

1. command and control policies
   - standards and norms
2. incentive-based policies ("pricing pollution")
   - taxes and subsidies
   - tradable emission permits
3. decentralized policies
   - liability rules
   - changes in property rights

Instruments for correcting market failures: Optimal level pollution

Optimal level pollution

Pollution is the archetypical **negative externality**

Pollution: Detrimental change in environmental quality

- biological
- chemical
- acoustic

Remark: The use of natural resources causes many externalities. We look at pollution as **one example** out of many.

Optimal level pollution: Externalities

Externalities

An **externality** exists whenever the welfare of some agent, either a firm or household, depends not only on his or her activities, but also on activities under the control of some other agent who does not take into account the effects of his actions on the other agent (they are external to his decision problem).

- "Origin": Economic activity, production or consumption
- "Destination": Third person not taken into account by the one emitting the externality

Optimal level pollution: Externalities

Externalities matter because they cause **market failures**

- Agent causing the externality doesn't take it into account, doesn't pay or receive compensation for the cost or benefit caused by it.

⇒ Externality acts outside the market, its effect is not included in the price system

⇒ Inefficient allocation of resources in the market equilibrium

⇒ correction needed in order to maximize social welfare

Optimal level pollution: Externalities

Classifying externalities:

- positive vs. negative
- consumption vs. production externalities
- environmental vs. other externalities

Environmental externality

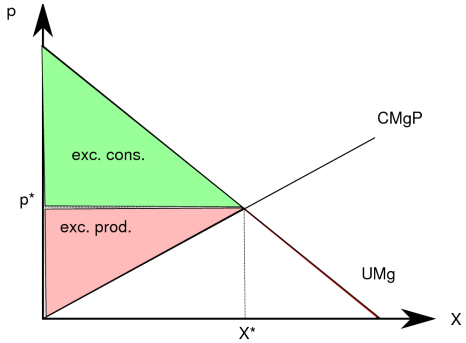
If the welfare of a third person is impacted through the environment

- pollution
- overuse of renewable resources and exhaustion of non-renewable resources
- land use change
- congestion

Optimal level pollution

Optimal allocation without externalities:

$$\max U(X) - C(X) \quad \Rightarrow \quad MU(X^*) = MC(X^*)$$

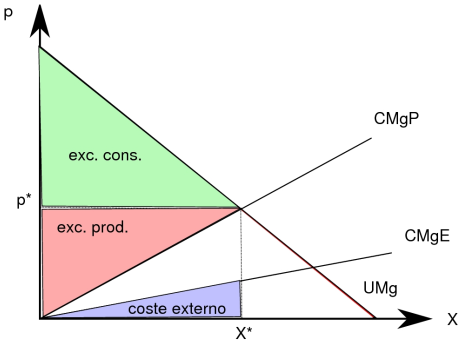


The market equilibrium maximizes social welfare:

$$\text{consumer: } MU(X) = p \quad \text{and producer: } p = MC(X)$$

Optimal level pollution

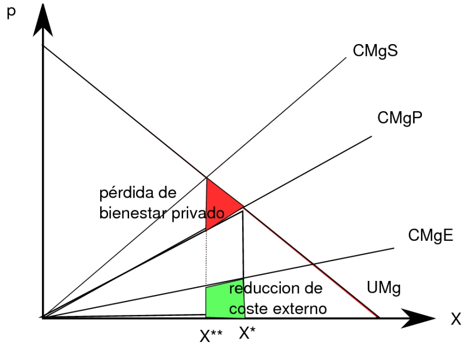
Production of X causes external costs to third parties
$\Rightarrow$ diminishes social welfare



Optimal level pollution

Optimal level pollution:

$$\max U(X) - C(X) - EC(X) \quad \Rightarrow \quad MU(X^{**}) = MCP(X^{**}) + MEC(X^{**})$$



Reduce X to X^{**}: reduce costs more than welfare.
conversely $\Rightarrow$ it is not efficient to reduce the externality to 0!

Instruments for correcting market failures: Interventionist solutions

Interventionist solutions

Recall: the problem is that part of the consequences of an economic activity are **external** to the price system

Internalization

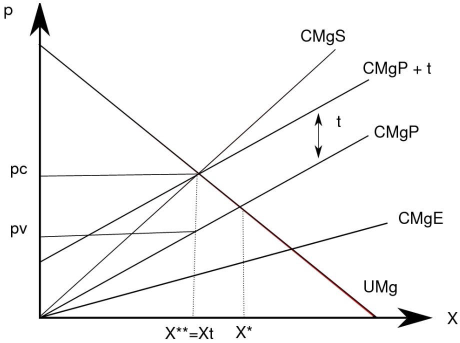
Correcting an inefficient allocation of resources generated by an externality by inducing the emitter of the externality to take it into account when deciding on the level of his/her activity

Different options for internalizing externalities:

- Pigou: **taxes** (for negative externalities) and **subsidies** (for positive externalities)
- Coase: **market solutions** (negotiation between agents who receives the externality and those who emit them) put a price on the externality

1. Pigouvian tax

Pigouvian tax levied on production process **with externalities**:



1. Pigouvian tax

Pigouvian tax levied on production process **with externalities**:

Recall: optimal level of X requires

$$MU(X^{**}) = MC(X^{**}) + MEC(X^{**}) = MSC(X^{**})$$

Private decisions with tax:

1. Consumers: $MU(X) = p_c$
2. Firms: $\max \Pi = (p_c - t)X - C(X) \quad \Rightarrow p_c - t = p_v = MC(X)$

$$MU(X) = p \quad \text{y} \quad p = MC(X) + t$$

Hence, private decisions will be optimal with a

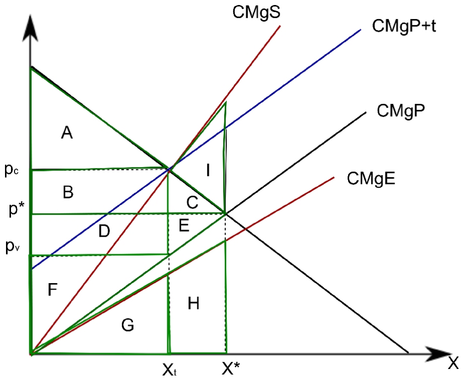
Pigouvian tax

$$t = MEC(X^{**})$$

At the optimal level of pollution: Per unit tax = Marginal external cost (MEC)

1. Pigouvian tax

Pigouvian tax: effect on welfare



without tax:

- CS = A+B+C
- PS = D+E+F
- EC = -G-H

with tax:

- CS = A
- PS = F
- tax revenue T = B+D
- EC = -G

welfare change due to tax

- loss = -C-E
- gain = H = C+E+I

Social welfare **increases** by an amount equal to area I

1. Pigouvian tax: Example

Externalities of **road transport**:

- greenhouse gas emissions (global pollution)
- air pollution (local pollution)
- accidents, noise, congestion
- externalities of car production
- ... and disposal of old cars
- externalities of the construction of infrastructure
- ... and of its existence (disruption of biological habitats etc.)

1. Pigouvian tax: Example

Pigouvian taxes for the transportation sector:

1. Vehicle registration tax
   - increases the price of a vehicle $\Rightarrow$ reduces the quantity of cars $\Rightarrow$ internalizes the external costs of production and disposal
   - once paid, the tax is a sunk cost $\Rightarrow$ no effect on the cost of a trip $\Rightarrow$ no effect on the decision to use the car and on the externalities related to use
2. Gasoline tax
   - increases the cost of a trip $\Rightarrow$ decreases total km driven $\Rightarrow$ internalize external cost of using the vehicle (air pollution, noise, congestion, accidents)
   - no discrimination between different times of the day or different routes $\Rightarrow$ the internalization of pollution, noise, congestion and accidents is imperfect
3. Road toll
   - can discriminate between routes and even time of use $\Rightarrow$ most adequate measure to internalize externalities
   - problem: to differentiate the toll adequately one needs advanced technologies. Cost of installing this technology $\gtrless$ benefit?

1. Pigouvian tax

In practice, the problem boils down to knowing

- which activity creates the pollution
- (part of) the marginal external cost function
- MU (to calculate X^{**})

Example

Two estimations of MEC from emitting a ton of carbon:

- Stern-Report (2006): US-$ 300 or more
- W. Nordhaus (2007): US-$ 30, increasing up to US-$ 85 by year 2050

Discrepancy because of the uncertainty about the magnitude of the effects, disagreement about the appropriate tax rate , ...

1. Pigouvian tax: Use of the tax revenue

What should be done with the revenues from a Pigouvian tax?

- return a revenue back in a lump-sum fashion (fixed amount)
- reduce other taxes (green tax reform) ⇒ "double dividend "!

Double dividend

- weak:
  1. Pigouvian tax enhances efficiency ✓
  2. reducing other taxes reduces the distortions ✓
- strong :
  1. environmental effect: cleaner ✓
  2. fiscal effect: Pigouvian tax increases distortions, reducing another tax reduces distortions. Positive net effect ?

⇒ more details: Public economics

2. Subsidies

Difficulties with the implementation of Pigouvian taxes:

- calculate the correct values for t
- opposition from interest groups that lose welfare

$\Rightarrow$ easier to use subsidies (when possible) instead of taxes

$\Rightarrow$ subsidize the **reduction of polluting activity**

2. Subsidies

Let

- s: per unit subsidy for pollution abatement
- $\bar{X}$: permissible level of pollution
- X: actual level of pollution

The subsidy payment is calculated as

$$S = s(\bar{X} - X)$$

To the extent that the polluter increases production, he/she loses part of the subsidy. Private decision:

$$\max \Pi = pX - C(X) + s(\bar{X} - X) \Rightarrow p = C' + s$$

With $s = MEC(X^{**})$ the incentives are to choose the optimal level of abatement.

2. Subsidies

Disadvantages of subsidies (compared to taxes):

- government transfers welfare to the polluter
- finance public expenditures instead of public revenue: need to increase other distortionary taxes

$\Rightarrow$ reduces the efficiency of this method of internalization

- how to determine the value of $\bar{X}$?

Advantages:

- easier to convince the electorate

2. Subsidies: investment tax credits

Real Decreto 283/2001, March 16

Los sujetos pasivos podrán deducir de la cuota íntegra el 10% del importe de las inversiones realizadas en elementos patrimoniales del inmovilizado material destinadas a la protección del medio ambiente, consistentes en instalaciones que tengan por objeto ciertas finalidades determinadas en la norma

Real Decreto-Ley 2/2003, April 25

Gives incentives for investment into renewable resources by extending the deduction of 10% to corporate tax law.

3. Environmental standards

Intention behind the Pigouvian tax: reduce X to the optimal level.
This objective can be reached directly by using a

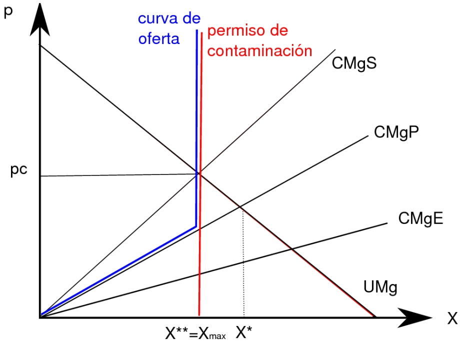
Standard

Maximum allowed concentration level of a pollutant,
equivalent to fixing a maximum quantity X_{max} of permissible emissions.
If $X_{max} = X^{**}$, the level of pollution is optimal.

Practical examples:

- (Non-transferable)pollution rights
- Prohibit the circulation of vehicles with certain digits of the license number on certain days ($\rightarrow$ 'hoy no circula' program in Mexico DF, Beijing)

3. Environmental standards



Effect on prices:

$$p = MC \qquad X < X_{max}$$
$$p = MU \quad \text{para} \quad X = X_{max}$$
$$p = \infty \qquad X > X_{max}$$

3. Comparison of Pigouvian Tax and Standards
Under ideal conditions

Tax vs. Standard (basic model):

- Static, partial-equilibrium analysis: effects on social welfare are equivalent
- Difference between the distribution of welfare:
  - Tax generates revenue for the government
  - Standard increases revenue of polluter

$\Rightarrow$ Double dividend of the tax:
its effect on social welfare is larger than that of the standard

In order to make both options equivalent, one would have to trade pollution rights

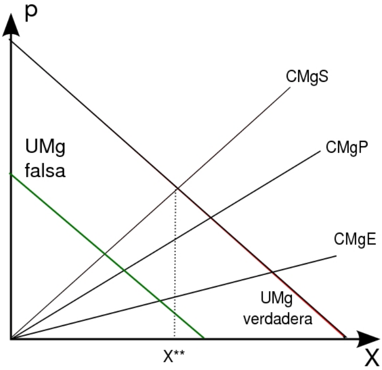
3. Comparison of Pigouvian Tax and Standards
With uncertainty

Tax vs. standard under uncertainty about costs and benefits:

- Whether erring causes higher welfare loss with the tax or the standard depends on parameters (elasticities of demand, supply and external cost functions).

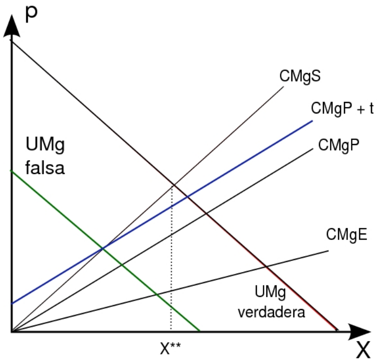
3. Comparison of Pigouvian Tax and Standards With uncertainty

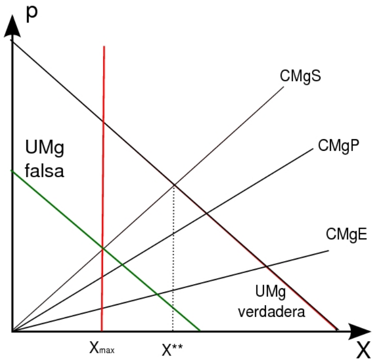
Case I - Moderate externality, inelastic demand



3. Comparison of Pigouvian Tax and Standards
With uncertainty

Case I - Moderate externality, inelastic demand

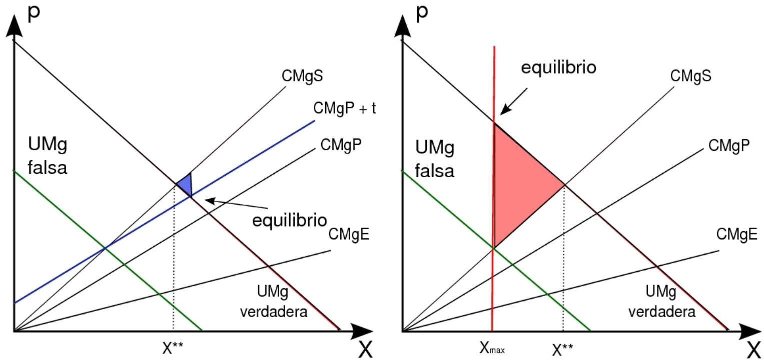




Measures based on incorrect perception of MU

3. Comparison of Pigouvian Tax and Standards
With uncertainty

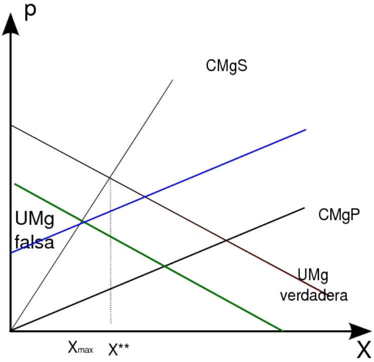
Case I - Moderate externality, inelastic demand

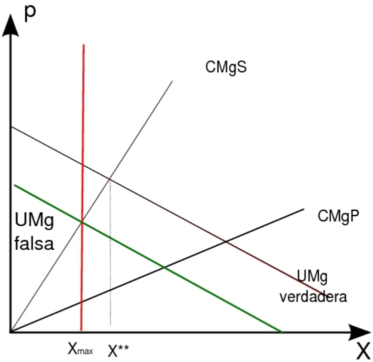


Here: smaller welfare loss with the tax

3. Comparison of Pigouvian Tax and Standards With uncertainty

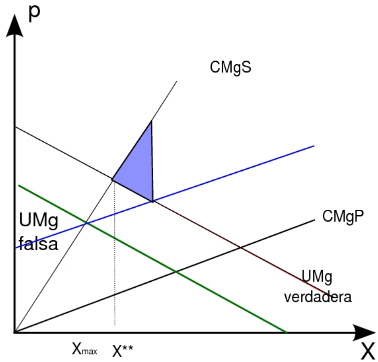
Case II - Strong externality, elastic demand





3. Comparison of Pigouvian Tax and Standards With uncertainty

Case II - Strong externality, elastic demand



Here: Welfare loss is smaller with standard ⇒ ranking depends on parameters

3. Comparison of Pigouvian Tax and Standards
With heterogeneous polluters

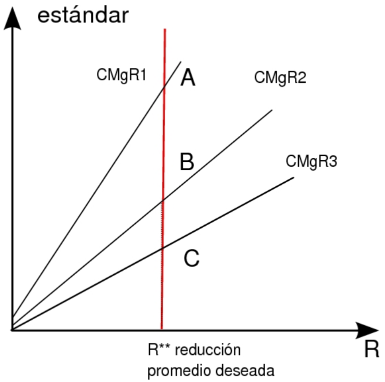
Tax vs. standard with different technologies to reduce emissions:

- If **pollution abatement cost** $C_i(R)$ differ between pollutants, the tax achieves the same total reduction $\bar{R}$ at lower costs than the standard.

Reference solution:

$$\min \sum_i C_i(R_i) \quad \text{s.t.} \quad \sum_i R_i = \bar{R}$$
$$\Rightarrow \quad MC_i(R_i) = \lambda = MC_j(R_j) \quad \forall i, j$$

3. Comparison of Pigouvian Tax and Standards
With heterogeneous polluters



Standard:

- Requires that each firm abates the same amount R^{**}

$$\Rightarrow R_i = R_j \ \forall i, j$$

- **Inefficient**: it's cheaper for 3 to reduce a bit more and 1 a bit less, such that the same total reduction is achieved at lower cost.
- Total cost of the reduction: $0R^{**}A + 0R^{**}B + 0R^{**}C$

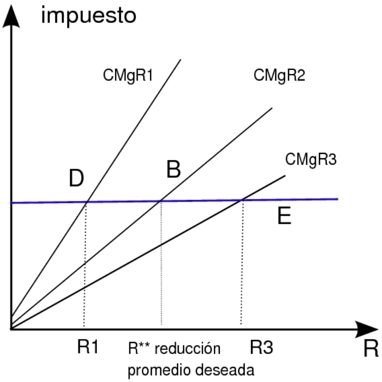
3. Comparison of Pigouvian Tax and Standards
With heterogeneous polluters

Tax:

- Firm 3 *has incentives* to clean up more than R^{**}, firm 1 less so

  $$\Rightarrow MC_i(R_i) = t = MC_j(R_j) \ \forall i, j$$

- Total cost of abatement: $0R1D + 0R^{**}B + 0R3E$
- **Efficient**: the cost saving in 1 is larger than the additional cost in 3 (compared to the standard)



Instruments for correcting market failures: Market-based instruments

1. The Coase Theorem

Idea: The agents can solve the externality problem without government intervention.

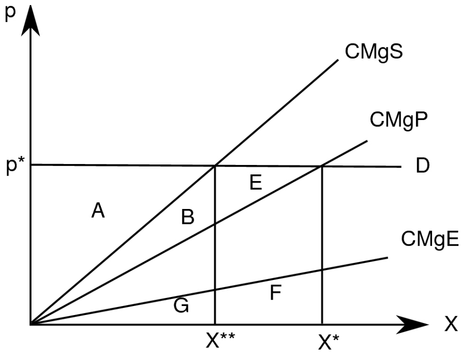
Your room mate is listening to loud music while you are trying to study. What are the alternatives to solve this conflict of interest?

Essential condition: property rights well-defined:
one agent must have the right to use the environment
(or prohibit its usage by someone else)
$\Rightarrow$ negotiations = creating a market for the externality
$\Rightarrow$ include the effect of the price system = **internalization**

$\Rightarrow$ efficient allocation

1. The Coase Theorem

1. Polluter owns the property rights:
produces the profit-maximizing quantity X^*

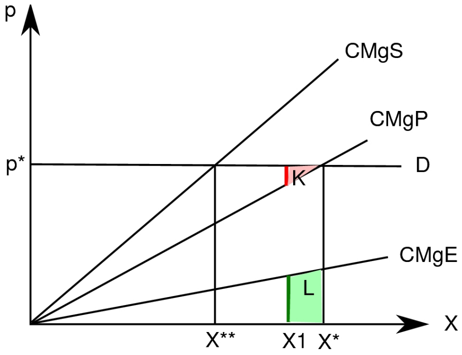


Reference situation compared to the social optimum

- overproduction $X^* > X^{**}$
- too much pollution
- producer surplus: A+B+E
- external cost: G+F

1. The Coase Theorem

1.a) Polluter owns the property rights : can sell them
Victim has the bargaining power : can offer a price



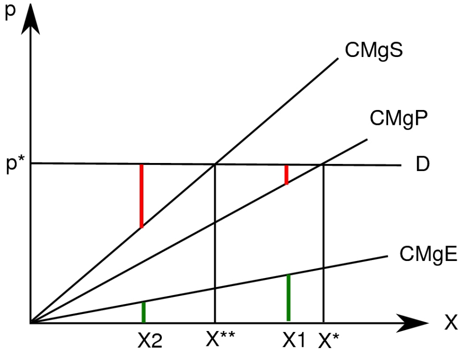
Negotiation:
The victim offers compensation for
the foregone profits of the polluter
if he curbs the polluting activity.

E.g. if the polluter produces X_1, the victim pays $K + \epsilon$ ($\epsilon =$ very small quantity)
⇒ polluter doesn't lose anything in the transaction

External cost is reduced by L, this the maximum amount the victim is willing to pay

1. The Coase Theorem

1.a) Polluter owns the property rights
Victim has bargaining power

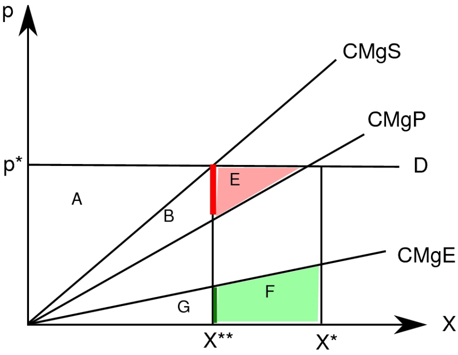


X_1: to reduce pollution a bit more ,
the victim is willing to pay more than necessary to convince the polluter
⇒ negotiate a lower X

X_2: the victim is not willing to pay what would be necessary to curb the las unit of pollution
⇒ won't reduce X by this much

1. The Coase Theorem

1.a) Polluter owns the property rights
Victim has the bargaining power

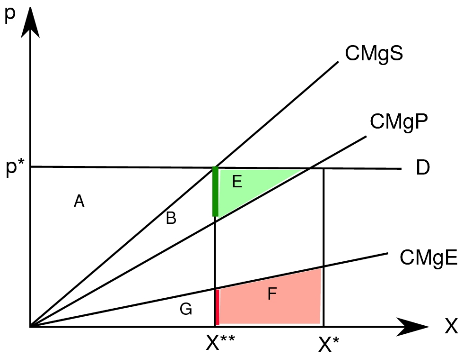


The last unit of X the two agree upon is X^{**}
$\Rightarrow$ this is the socially optimal level of pollution

victim pays $E + \epsilon$,
its benefit is $F - (E + \epsilon)$
$\Rightarrow$ victim fully appropriates the increase in social welfare

1. The Coase Theorem

1.b) Polluter owns the property rights and has the bargaining power



The polluter offers to reduce X if the victim pays him the full welfare gains from the reduction.

Reduce X as long as it is beneficial for the polluter.

Equilibrium: X^{**} = social optimum

Polluter receives a payment F, loses surplus E
$\Rightarrow$ appropriates the increase in the social welfare F-E

1. The Coase Theorem

1.c) It is also possible that

- polluter and
- victim

have part of the bargaining power.
In this case the payment of the victim to the polluter is

- more than E and
- less than F

$\Rightarrow$ they share the increase in social welfare.

1. The Coase Theorem

The Coase Theorem

If

- property rights are well-defined
- and transaction and negotiation costs are negligible

then voluntary agreements between the economic agents lead to Pareto efficient allocations.
This result does not depend on whether the property rights are with the polluter or with the victim. This will only change the distribution of rents.

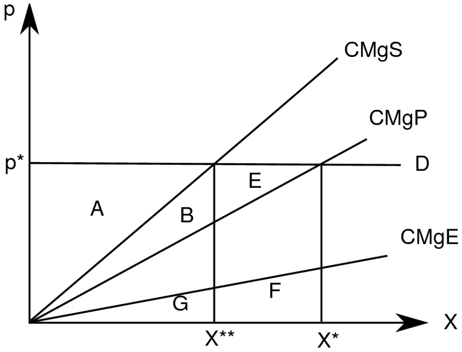
Let's see what happens when the victim owns the property rights.

1. The Coase Theorem

2. Victim owns the property rights

Initial situation:
Victim doesn't allow any production in order to avoid the externality.

- levels of production and pollution are inefficient $0 < X^{**}$
- zero external cost
- zero producer surplus



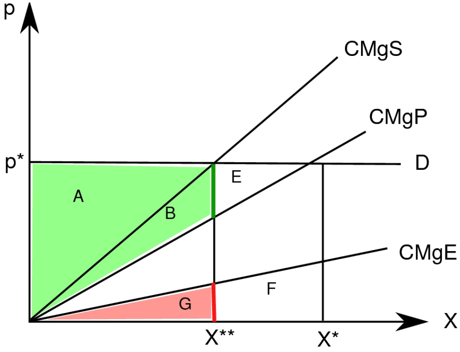
1. The Coase Theorem

2.a) Victim owns the property rights
Polluter has the bargaining power

The producer offers compensation for the external cost if the victim allows positive levels of production.

Compensate the victim up to X^{**}
$\Rightarrow$ efficient allocation!

Polluter gains A+B
has to pay G=B
profit is: A



1. The Coase Theorem – Summary: Who pays?

Distributional consequences of the allocation of property rights:

- Property rights determine *who* has to pay
  - Polluter pays principle
  - Victim pays principle
- The bargaining power determines *how much* to pay: whoever has it can appropriate the welfare increase

property rights		bargaining power: victim	polluter	both
polluter	victim pays	E	F	between E and F
victim	polluter pays	A+B	G	A and part of B=G

1. Coase theorem: transaction cost

Very important practical problem:
Negotiations between **all** stakeholders can be difficult and costly to implement.
If the transaction costs are larger than the possible increase in social welfare $\rightarrow$ it's *better* not to negotiate!

$\Rightarrow$ In this case, government intervention can be an alternative to reach the social optimum (provided that government failure doesn't create a higher cost...).

2. Tradable pollution rights

The markets for pollution rights are markets “created” for the allocation of property rights.

The scope of the market in terms of

- pollutants , e.g. CO_2, SOx, NOx
- firms or sectors
- geography – local (California), continental (Europa) or even global (Kyoto Protocol)

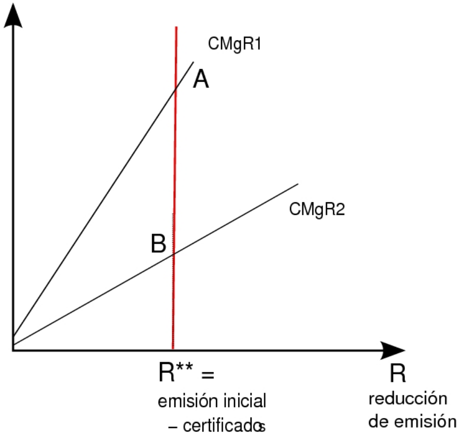
is called the *bubble*.

2. Tradable pollution rights

Practical implementation:

- establish a level of admissible pollution (the “cap” - like a standard)
- create a permit for each unit of pollution
- allocate permits to firms.
  - *grandfathering*: free permits (based on historical emissions)
  - *benchmarking*: free permits emissions of the most efficient plant (based on historical emissions)
  - auctions: firms buy as many permits as they need in an auction
- each permit entitles its holder to emit one unit of the pollutant
  - in order to emit more the firm must acquire additional permits
  - if it emits less, it has a surplus of permits.
- permits are **tradable**, they can be bought and sold in a market
- their price is determined by demand and supply

2. Tradable pollution rights

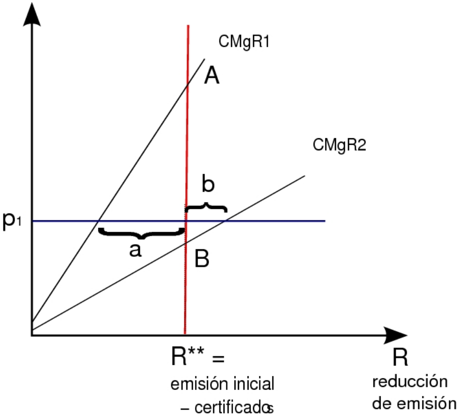


Initial situation: Given the allocated permits both firms have to reduce their emissions by R^{**}

- Firm 1 would pay up to R**A for an additional permit so as abate less.
- Firm 2 can reduce emissions by an additional unit at cost R**B; if it is paid more for a permit it can increase profits by selling the permit and abating pollution.

⇒ firms will trade permits with each other

2. Tradable pollution rights

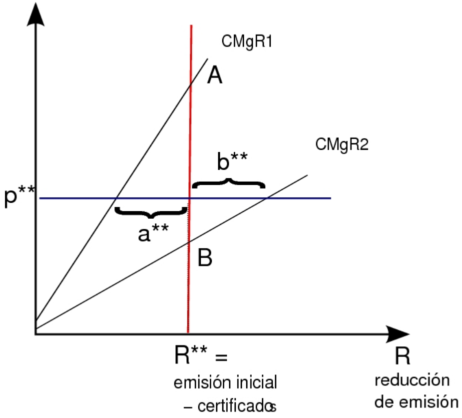


If the permit price is p. e.g. p_1:

- Firm 1 demands a permits in order to emit this additional quantity
- Firm 2 offers b permits: reducing this additional quantity costs less than the revenue from the sale of the permit

$\Rightarrow$ disequilibrium

2. Tradable pollution rights



Equilibrium: the price of permits must adjust until demand equals supply

Each firm minimizes its cost of abating and buying/selling permits:

$$\min C_i(R_i) - p \cdot (R_i - \bar{R})$$

$$\Rightarrow MC_i(R_i) = p = MC_j(R_j) \ \forall i, j$$

equalizing marginal costs
$\Rightarrow$ minimizes the social cost of abatement

2. Tradable pollution rights

Advantages of tradable permits

1. cost minimization: the firms with the lowest abatement cost are doing most of the abatement
2. flexibility: in order to change the level of pollution the regulator can either sell additional permits to increase the amount of permits or buy permits in order to retire them
3. opportunity for the victims of pollution: can buy and destroy permits
4. precision: it's easier to maintain a given level of environmental quality by limiting the amount of pollution (as opposed to a tax that regulates the price of pollution, not the quantity)

Disadvantages

- Since the amount of permits is a political decision, tradable permits can give worse results than taxes.
- With free permit allocation, there is no revenue raising effect.

2. Tradable pollution rights

Real-world examples:

- Clean Air Act in the USA: reduction of local pollution and of acid rain
- Kyoto Protocol: reduction of greenhouse gas emissions
- European Union Emissions Trading Scheme for CO_2
- other local systems underway (Australia, China, South Corea...)

EU Emissions Trading Scheme

Part of the EU strategy to meet the reduction target it assumed under the Kyoto Protocol:

Tradable permits for CO_2 among firms

- in place since 2005
- applied in 27 EU member states
  and (since 2008) in Norway, Iceland, and Liechtenstein
- CO_2 emissions from combustion installations and from certain energy intensive sectors.
  Covers approx. 50% of European emissions of CO_2
- does not cover emissions from household, transportation (25% of emissions), agriculture and other industrial sectors
- does not cover greenhouse gases other than CO_2

EU Emissions Trading Scheme

- National Allocation Plans (NAP):
  Allocate permits to installations based on their historical emissions, taking into account early action, clean technologies, ... (don't want to punish early efforts to cut emissions).
  A small share of all permits are sold in auctions.
- "European Allowance Unit" EUA gives the right to emit one ton of CO_2
- Permits are bought and sold in different markets; the most important one is the ECX (European Climate Exchange) in London
- Prices fluctuate a lot, currently at €8
- Fee for emitting without a permit: €100 + permit price

EU Emissions Trading Scheme

Price of one EUA

Source: Deutsche Emissionshandelsstelle 2009

Auction price of one EUA

Source: European Carbon Exchange 2012

EU Emissions Trading Scheme

Permit trade is subdivided in phases. Permits from phase I cannot be carried over to phase II (hence the price jump)

- Phase I 2005-2007: total number of permits was too generous ⇒ prices fell in 2006
- Phase II 2008-2012: corresponds to the compliance period under the Kyoto Protocol.
  Prices fell by 5,7% a year.
- Phase III 2013-2020: it is planned to ...
  - reduce the total number of permits
  - include more GHG gases and more sectors (e.g. airlines)
  - sell most permits in auctions

Topic 4
Valuation of Natural Resources

Introduction

Why is it important to know the value of natural resources, or the value of an improvement or deterioration of an environmental good?

Example

To take a decision on whether to make a development project or not, we have to estimate:

B_d benefits from development

C_d costs of development

B_p benefits of preserving the environment and of not developing the area

- Si $B_d > (C_d + B_p) \Rightarrow$ undertake the project
- Si $B_d < (C_d + B_p) \Rightarrow$ not undertake the project

B_d and C_d are relatively easy to measure: market inputs and outputs with observable prices. The problem is to estimate B_p.

Another example: Estimating the value of an externality $\Rightarrow$ determine the preferred state of nature and the efficient amount of interventions.

Introduction

Economic Value of a good:

- willingness to pay, reflecting people's preferences
- $=$ price$\cdot$quantity $+$ consumer surplus
- per unit: value of the inverse-demand curve for this unit
- **marginal value (of the last unit) = price**

This is not about the *objective* value of nature, but about economic agents' preferences!

Introduction

Problem: not all goods are traded in (perfect) markets ⇒ although they don't have a price, they may have economic value:

- value
  - use value
    - direct, with markets
    - direct, with imperfect/inexistent markets
    - indirect
  - non-use value
    - option value (from future use)
    - quasi-option value (from possible future use)
    - of existence (intrinsic value)

Exercise

How would you classify the following examples?

- fresh air
- medicinal plants still unknown
- landscape
- animal species with no commercial value

Introduction

How to express in monetary units the individual welfare changes induced by changes in environmental quality without observing market prices for this good?

Environmental valuation

Set of techniques and methods to measure the preferences of economic agents for the environment in a context in which they do not reveal them explicitly.

Expressed in monetary units. Methods:

- **revealed preferences** in existing markets for related goods (indirect methods)
  - hedonic prices
  - travel cost
- **stated preferences** in surveys (direct methods)

Valuation of Natural Resources: Revealed Preferences

1. Hedonic Price

Hedonic Price: Idea

How does environmental quality affect the price of complementary goods for which markets exist?

Find two identical goods, except for one feature (environmental quality).

$$\Delta P = \Delta \text{ value of this characteristic}$$

Example

Consider two identical apartments, except for the fact that one is less noisy than the other.
Rent difference $\Rightarrow$ household's willingness to pay for having less noise per month.

Social value from noise reduction: household's value times the amount of households in the affected area.

1. Hedonic Price

Difficulty: to find two goods that meet the requirements (identical in all but their environmental quality).

Example

One apartment is noisier because it is located on a major street (ALSO: better access to public transportation, more pollution, less attractive views) or because it is in a shopping area (ALSO: many entertainment supply) $\Rightarrow$ apartments differ not only in the noise but also in terms of other amenities.
And usually not only the environment is different, but also the apartments differ in more criteria (area, height, heating, ...)

We look for a method to decompose the value of different characteristics: estimate hedonic prices.

1. Hedonic Price

Econometric Model:

$$p = \beta_0 + \sum_i \beta_i X_i + \epsilon_i$$

where

- p market price (what is actually paid for the apartment in a transaction)
- X_i different characteristics of the good, including **environmental quality**
- β_i $= \partial p / \partial X_i$, marginal valuation of increasing the characteristic X_i (regression result, an " average" of the actual values observed)

The relationship between characteristics and price need not be linear:
$p = p(\mathbf{X}) \Rightarrow$ the marginal valuation of X_i would be $\beta_i = \partial p / \partial X_i$

1. Hedonic price

Exercise

The regression of the rental price of apartments in an area has resulted in the following expression:

$$p = 400 + 150\,\text{hab} - 6\,\text{years} - 30\,\text{polu} - 3\,\text{noise} - 10\,\text{dist\_metro}$$

"polu" is the number of days for which pollution is above a critical level, "noise" is the number of hours per month with more than 50 decibels.

- By how much would the rent of a flat increase if we declared one day a month as "car-free day", reducing "polu" by 1 and "noise" by 4?
- The area has a total of 200 apartments. By how much would external costs decrease with the introduction of the "car-free day", and who is benefiting after rents have been adjusted?
- What other welfare changes should be considered in determining whether a measure is efficient?

1. Hedonic price

Other examples of applications of the hedonic price method:

- differences in job characteristics $\rightarrow$ wage gaps.
- food prices (regular food vis-a-vis ecologic food;
  regular tuna vis-a-vis "dolphin-safe"; fair-trade coffee vis-a-vis regular coffee)
- computers (while the *value* of better models increases, the *prices* are almost constant – hedonic prices of a base year can adjust current expenditures to the *quality increase*)

1. Hedonic price

Difficulties:

- data (enough quantity, for all relevant characteristics, sufficient variability in the data)
- prices may not reflect the preferences correctly (decision-making processes without perfect information)
- transaction costs: prices do not adjust quickly, the observations may not reflect an equilibrium
- multi-collinearity among characteristics (flats on main streets simultaneously suffer pollution with SO_2, NO_x, particular matter and noise – hard to disentangle to which of them the price change is owed)
- applies only to marginal changes (second-bedroom's value vis-a-vis tenth-bedroom's value – the value of reducing pollution a bit vs. the value of eliminating pollution altogether)
- take into account the heterogeneity of different households (income, preferences for environmental quality)
- strong assumptions needed for interpreting regression coefficients as marginal willingness-to-pay

2. Travel Cost

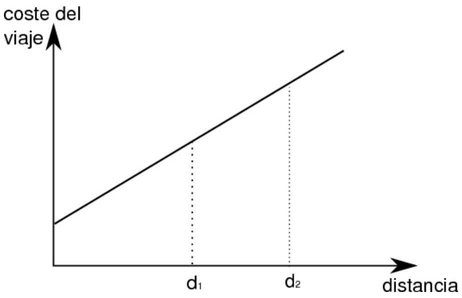
Travel Cost: Idea

Estimate the demand curve for a natural area using the data on costs incurred by visitors traveling there.
Recreational value of the natural area: the consumer surplus.

Total cost of visiting a natural park:

1. monetary cost from traveling (fuel etc.)
2. value of travel time (opportunity cost)
3. park-entrance cost

1 and 2 increase with distance

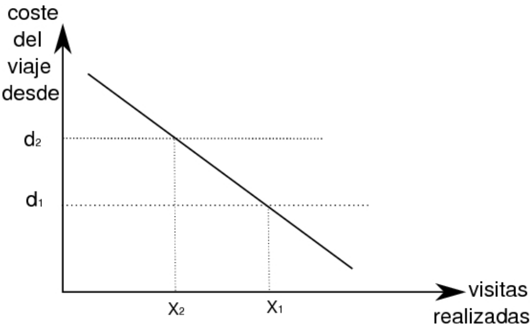


2. Travel Cost

Combining information (here: for two people) about

- travel costs
- number of visits over a period (year)

you can estimate the demand curve for the natural park:



Value for the natural park: $\sum_{i=1}^{2}$ visitor's surplus with travel d_i

2. Travel Cost: Individual demand

Get the *individual demand* for the services provided by the site for each individual based on the cost of accessing it and its own characteristics.

$$\#\text{ visits} = \beta_0 + \beta_1 c + \sum_i \beta_i X_i$$

Possible variables in vector X_i:

- Membership to environmental associations
- Local knowledge
- Knowledge of alternative sites
- Time spent at site
- Socio-economic characteristics of the individual

2. Travel Cost: Demand for home area

Get the *average propensity* (number of visits divided by population) to visit the place from different geographical areas h which differ in the cost of access.

$$\%\text{ visits } = \beta_0 + \beta_1 c + \sum_i \beta_i X_i$$

$\Rightarrow$ average demand in terms of the travel cost c

Possible variables in vector X_i:

- socioeconomic characteristics of population in area h
- site characteristics compared to alternative destinations

Calculate the value of the natural area:

$$\sum_h \text{average surplus from the area } h \cdot \text{ population of area } h$$

Valuation of Natural Resources: Stated Preferences

Contingent Valuation

Contingent Valuation: Idea

When there is no market, create a virtual market.

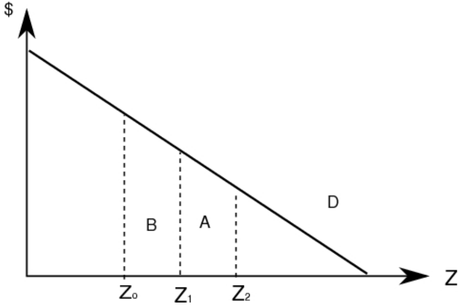
- direct method: survey
- advantage: it can be used to measure **non-use values**

How much are you **willing to** ...

1. ... pay for an environmental improvement?
   (**compensatory variation CV** gives you the same utility as after the change)
2. ... accept for **not** receiving that improvement?
   (**equivalent variation EV** gives you the same utility as *before* the change)
3. ... pay for **avoiding** an environmental damage? (**EV**)
4. ... being compensated for tolerating that damage? (**CV**)

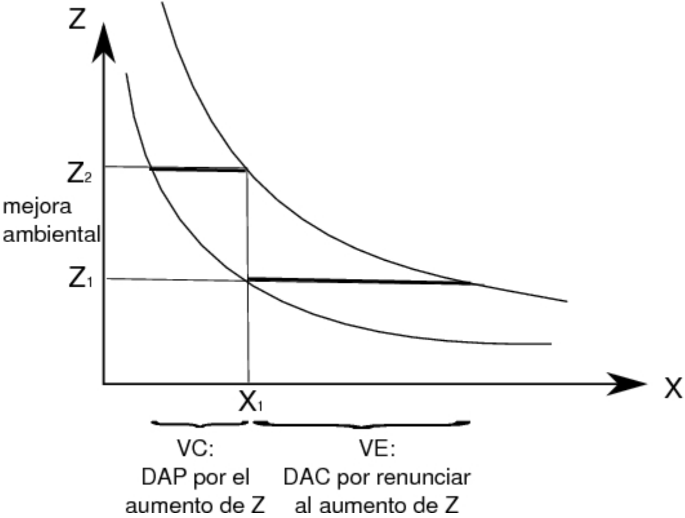
Contingent Valuation

The four question may look identical, but in fact they are not:



- increasing vis-a-vis reducing Z in a discrete quantity
- rent effect of a payment vis-a-vis a compensation (WTP$<$WTA)

Contingent Valuation



Contingent Valuation

The utility of an individual with income Y depends on the level of good X with price P, and on an environmental (non-market) good Z:

$$u(X, Z) = u(X(P, Y), Z) = v(P, Y, Z)$$

The individual compares (indirect) utility before the environmental improvement with hypothetical utility thereafter (from Z_1 to Z_2) plus a payment A :

$$v_1 = v(P, Y, Z_1) \quad \text{vs.} \quad v_2 = v(P, Y - A, Z_2)$$

- $v_1 > v_2 \Rightarrow$ reject: he would not pay A for the environmental improvement, $A > WTP$
- $v_1 < v_2 \Rightarrow$ accept: he would pay A, $A < WTP$

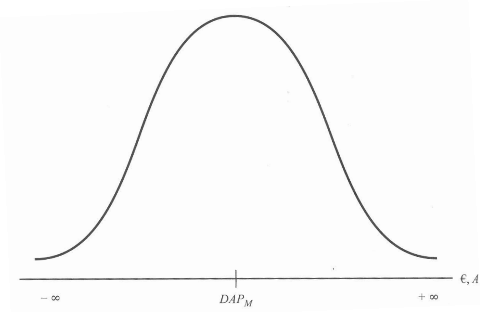
Contingent Valuation

⇒ the maximum willingness-to-pay (WTP) is given by

$$v(P, Y, Z_1) = v(P, Y - WTP, Z_2)$$

WTP depends on P, Y, Z_1, Z_2 (observables) and preferences v (private information, non-observable)

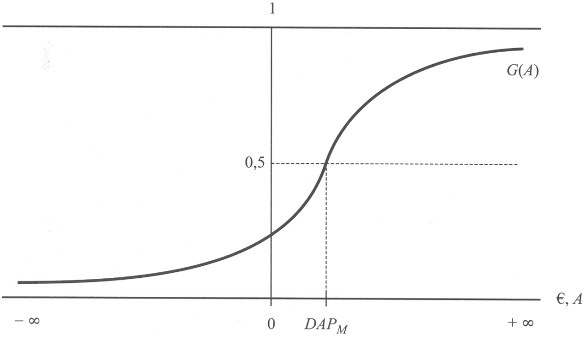
Empirical model:
Random variable $WTP = WTP(P, Y, Z_1, Z_2, \epsilon)$, with some distribution (normal, logistic, ...) in population (density curve):



Contingent Valuation

We want to learn the probability of acceptance
$\Pr\{accept\} = \Pr\{WTP \geq A\}$ for different payments A

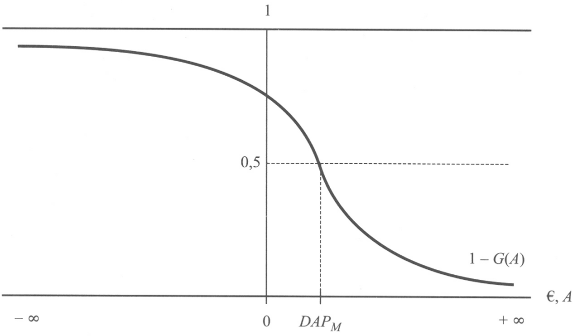
First Step: $\Pr\{reject\} = Pr\{WTP(\cdot) < A\}$ (cumulative density):



Contingent Valuation

We want to learn the probability of acceptance
$\Pr\{accept\} = \Pr\{WTP \geq A\}$ for different payments A

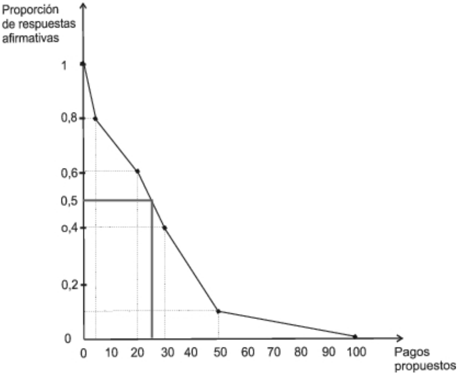
Second step: $\Pr\{accept\} = 1 - \Pr\{reject\}$ (survival function)

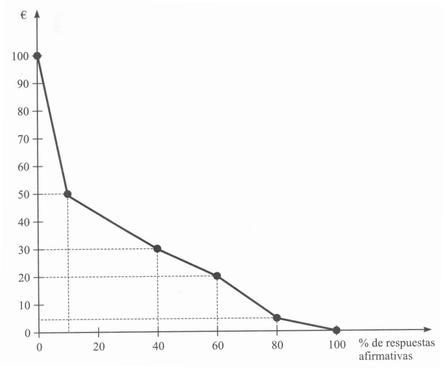


Ask *Would you be willing to pay A?* for several values of A
$\rightarrow$ estimate the parameters for the WTP distribution from the percentage of affirmative answers

Contingent Valuation

Example:
Acceptance probability and demand curve / surplus





source: Riera et al. 2005, p. 162-3

Contingent Valuation in practice
Survey design

The survey can be obtained through:

- personal interviews
- telephone interviews
- mail interviews
- e-mail interviews
- laboratory experiments

⇒ important aspects: representativeness and costs

Contingent Valuation in practice
Survey design

Important:
Specify the context and the proposed change very specifically!

Some question formats:

- open: the interviewer waits for an answer
  - *how much would you pay for...?*
  - problem: to many "no-answers"
- closed: the interviewer suggests a limited number of answers to choose from
  - dichotomous/binary: *Would you pay X, or not?*
  - auction: the interviewer gives some number and adjusts it up or down until the interviewee ask for no further adjustments
  - multiple: the interviewer asks the interviewee to choose a number from a table with several numbers

Contingent Valuation in practice
Survey design

Possible bias in the survey: the response may be influenced by ...

- ... the information given by the interviewer if it is not neutral
- ... what the interviewee believes is the “right” answer to please the interviewer
- ... the belief of influencing the final decision by overstating WTP
- ... the initial question, influencing the perception of the following questions
- ... purely hypothetical situation: no consequences on mistakes

⇒ Try to avoid these problems when designing the survey, not when analyzing the results

Topic 5
International aspects and multilateral environmental agreements

International Treaties

Many uses of natural resources have trans-border impacts

- sulfur emissions in a country → acid rain in neighboring countries
- pollution of rivers → affects downstream
- greenhouse gases are emitted mainly in developed countries → more serious consequences occur in developing countries

Currently there is no supranational institution responsible for these issues and capable of *coercing* countries to take action (like a national government would do regulating private companies) ⇒ (voluntary) cooperation is needed to correct these externalities

International Treaties

Some examples of international environmental cooperation:

- **Climate and atmosphere**
  - Ozone layer: CFC ban, Montreal Convention 1987
  - Climate change: reducing greenhouse gas emissions, Kyoto Treaty 1997
- **Biodiversity**
  - Whales: Convention for fishing regulation 1946
  - Endangered Species of Wild Fauna and Flora: restrictions to trade (CITES) 1975
- **Sustainable Development**: Agenda 21
- **Desertification**: United Nations Agreement 1996
- **Rivers and Seas**: Several agreements for local and/or global protection and/or global
- **Waste**: Rules for the export of dangerous wastes, Basel Convention 1989
- Treaty to limit **nuclear tests** 1963

International Treaties

These treaties/agreements have been difficult to negotiate. One may doubt whether they implement the first-best solutions.

What incentives do countries have to cooperate in the mitigation of environmental damage by signing and complying with an international treaty?

To answer this question we will use **game theory**:
Analysis of the **strategic interaction** between several countries. When making decisions (rational decisions), each country has in mind what everyone else does.

Game Theory – some basic concepts

Strategy

A set of rules on how to react at any given moment and under any given circumstances throughout the interaction.

Dominant Strategy

A strategy that gives a better (or at least not worse) result than the outcome of any other strategy, whatever the actions taken by the other players.

Nash Equilibrium

A combination of actions such that no actor can improve his outcome unilaterally by changing his behavior (given the strategies adopted by others.)

It is a 'non-cooperative' equilibrium concept.

International Treaties: Two countries

Example: Contamination in two countries, each country benefits from less **total** pollution (2 units if only one country reduces it, 4 units if both do that), but it also incurs costs (slower growth, 3 units) of reducing its **own** emissions.

A B	reduce	no reduce
reduce	1,1	-1,2
no reduce	2,-1	0,0

Exercise

- Identify the Pareto optimum
- Identify the Nash equilibrium. Explain why there is only one equilibrium here.

International Treaties: Two countries

Problem: Voluntary participation (*non-cooperative game*), deviations from agreements cannot be punished ⇒ **Prisoner's Dilemma**

A **binding treaty** (*cooperative solution*) may resolve the dilemma in the case of two countries!

Options:

- to sign the treaty (voluntary) and to reduce (compulsory after signing)
- not to sign the treaty
  - and to reduce (voluntarily)
  - and not reduce

Exercise

Use the payment from previous slide. Given that the treaty will only enter into force if both parties sign it, determine equilibriums and payments of this new game.

International Treaties: Many countries

Problem: a binding treaty cannot always solve the inefficiency of equilibrium.

With more than two countries and voluntary participation (but binding), the *free riding* problem arises:

- some sign the treaty and reduce, because it is individually optimal
- others neither sign nor reduce, but benefit from other's reductions

International Treaties: Many countries

Exercise

There are 5 symmetrical countries, that initially emit a toxic unit each. Reducing the emission has a private cost, but the total benefits from reductions are publicly achieved. As each country can reduce a unit, total reduction is $R =$ number of countries that reduce. Private net benefits of a country that continues polluting (cont) and of one that reduces pollution (reduced) are

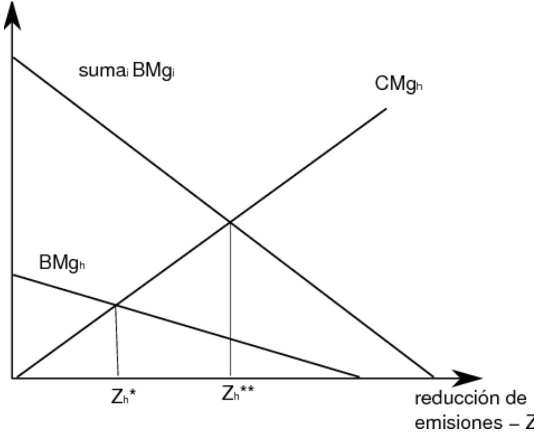
$$B^{cont} = 10R \quad \text{y} \quad B^{redu} = -3 + 8R$$

Fill in the table and determine the Nash equilibrium and the Pareto optimum.

R	0	1	2	3	4	5
B^{cont}						–
B^{redu}	–					
$\sum B$						

International Treaties: Many countries

What if the decision is not “reducing all or nothing”?



Individual solution/non-cooperative:
Each country reduces less than it would in the Pareto optimum because it ignores the positive externalities of its reduction.

International Treaties: Many countries

Objective function of country h:

$$\max B_h(R) - C_h(R_h)$$

Non-cooperative solution: each country takes the reduction of others as given: $R = R_h + \sum_{i \neq h} R_i$
Individually optimal reduction:

$$\frac{dB_h}{dR} \cdot \frac{dR}{dR_h} = \frac{dB_h}{dR} \cdot 1 = \frac{dC_h}{dR_h}$$

Cooperative solution (symmetric in this case): the country takes into account that the $N-1$ other countries reduce emissions by the same amount: $R = N \cdot R_h$
Individually optimal reduction:

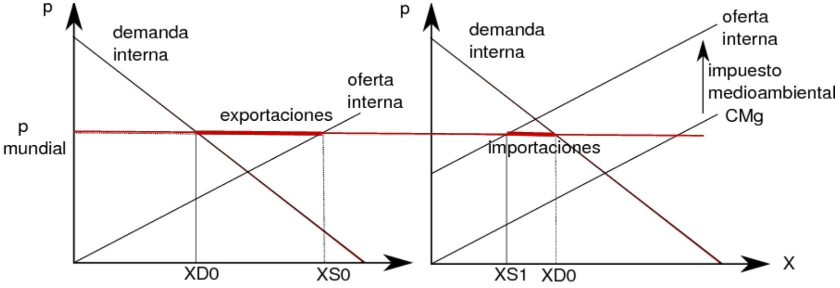
$$\frac{dB_h}{dR} \cdot \frac{dR}{dR_h} = \frac{dB_h}{dR} \cdot N = \frac{dC_h}{dR_h}$$

International trade and the environment: Small open economy

Paradox

In the context of international trade in goods, more environmental regulation in one country **could** lead to **more pollution** globally.

Explanation: Substitution of (relatively dirty) imports for (relatively clean) domestic production ⇒ More emissions from production and transportation



International trade and the environment: Small open economy

Variations of the model:

- if technology abroad is cleaner than at home
  $\Rightarrow$ global emissions fall
- if the regulated sector has an important share in the trade balance
  $\Rightarrow$ reduction of exports / increase in imports depreciates the domestic currency
  $\Rightarrow$ imports become more expensive with respect to exports, mitigating the contraction in the trade balance
- if the other countries introduce the same environmental regulation ("harmonized pollution tax")
  $\Rightarrow$ global effect same as with a pollution tax in a single country (cf. chapter 3)

International trade and the environment: Unilateral tax

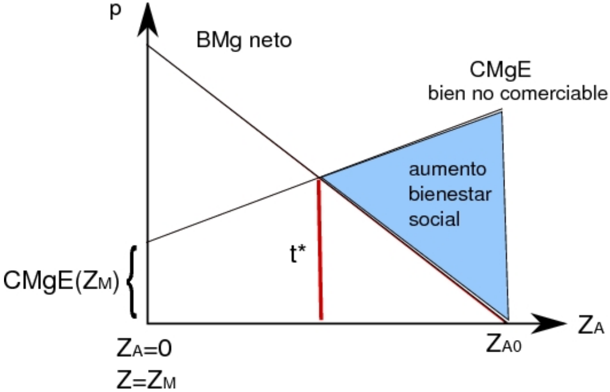
Country A unilaterally imposes an environmental tax to reduce domestic pollution emissions Z_A .
The external cost depends on global emissions

$$CE(Z) = CE(Z_A + Z_M)$$

- Case 1: Emissions result from the production of a **non-tradable good** (protected or not transportable)
  $\rightarrow$ lower domestic production is not replaced by foreign production: $dZ = dZ_A$, Z_M constant

$$CMgE(Z_A) = \frac{dCE}{dZ}\frac{\partial Z}{\partial Z_A} = \frac{\partial CE}{\partial Z} \cdot 1$$

International trade and the environment: Unilateral tax



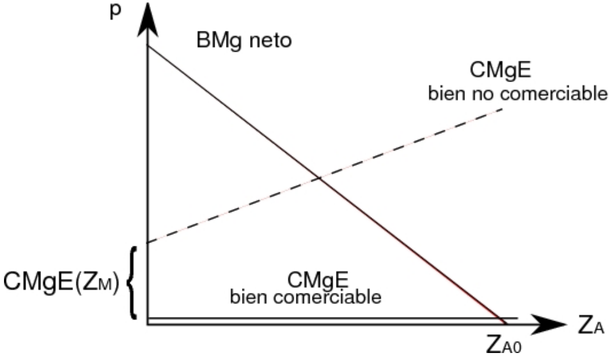
Unilateral tax reduces the environmental externality by an amount that is optimal from the p.o.v. of the individual country.

International trade and the environment: Unilateral tax

- Case 2: Emissions result from the production of a **tradable good** $\rightarrow$ lower domestic production is replaced one-for-one by foreign production (with the same amount of emissions): $dZ_M = -dZ_A, \quad dZ = 0$

$$CMgE(Z_A) = \frac{dCE}{dZ}\frac{\partial Z}{\partial Z_A} = \frac{\partial CE}{\partial Z} \cdot 0$$

International trade and the environment: Unilateral tax



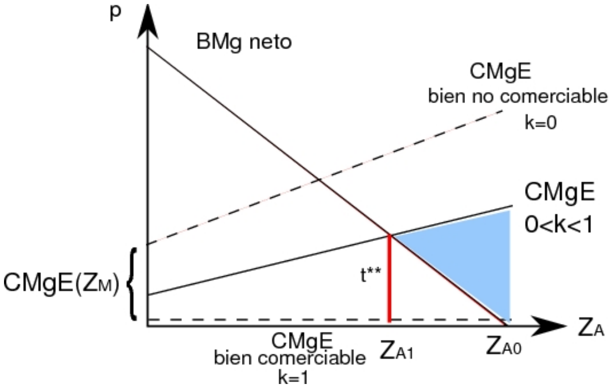
Intuition: The tax reduces pollution ⇒ loss in private benefits but total emissions remain constant ⇒ external cost is fixed ⇒ no saving in external cost

Comercio internacional y medio ambiente: Unilateral tax

- Case 3: The reduction in domestic production is replaced partially by imports ;
  Alternative interpretation: imports replace production one-for-one but they are produced with a cleaner technology:
  $dZ = dZ_A + dZ_M = (1-k)dZ_A$ where $0 < k < 1$

$$CMgE(Z_A) = \frac{dCE}{dZ}\frac{\partial Z}{\partial Z_A} = \frac{\partial CE}{\partial Z} \cdot (1-k)$$

International trade and the environment: Unilateral tax



International trade and the environment

Is there a trade-off between internacional trade and environmental protection?

Unilateral environmental regulation (=in one country only) can affect that country's trade volumen in various ways:

- lower competitiveness as exporter $\Rightarrow\downarrow$
- domestic production is substituted by imports (foreign producers or domestic producers who relocate to foreign countries) $\Rightarrow\uparrow$
- barriers to imports: "green protectionism", "Technological barriers to trade"
  (can also serve as a pretext for protectionism) $\Rightarrow\downarrow$
- if regulation provides producers of clean products with a larger market that makes production profitable (increasing returns to scale) $\Rightarrow\uparrow$
- stimulate growth and competitiveness (Porter hypothesis) $\Rightarrow\uparrow$

International trade and the environment

Economic integration affects the environment and the conservation of natural resources:

- "scale effect": growth, more production, more transportation $\Rightarrow\downarrow$
- "composition effect": further specialization according to comparative advantage
  $\rightarrow$ redistribution of emissions across countries $\Rightarrow\updownarrow$?
  (Pathological case: production of dirty goods shifts to "pollution havens" in the South where environmental standards are low.)
- "technique effect": growing incomes increase the demand crecientes, aumenta la for environmental goods and may induce a structural change towards less polluting sectors (from industry towards services); technology transfer helps diffusion of clean technology; more competition induces firms to increase their efficiency $\Rightarrow\uparrow$
- "race to the bottom" of environmental standards in order to attract more investment $\Rightarrow\downarrow$

International trade and the environment: the WTO

The principal objective of the WTO is free trade. WTO

- is worried about possible negative effects of environmental policy on free trade,
- trusts that free trade will have positive effects on the environment

However, there are exceptions to the GATT rules (General Agreement on Tariffs and Trade; prohibition of import quotas, non-discrimination, reciprocity) that allow the protection of the environment

The WTO seeks to prevent that such exceptions are abused to disguise illegal protectionism:

- only allows measures that are necessary and scientifically proven to achieve the objective of environmental regulation.
- such measures must not violate the principle of non-discrimination

International trade and the environment: the WTO

Preamble of the Marrakesh Accord 1994 (founding the WTO)

Recognizing that their relations in the field of trade and economic endeavour should be conducted with a view to raising standards of living, ensuring full employment and a large and steadily growing volume of real income and effective demand, and expanding the production of and trade in goods and services, while allowing for **the optimal use of the world's resources in accordance with the objective of sustainable development, seeking both to protect and preserve the environment** *and to enhance the means for doing so in a manner consistent with their respective needs and concerns at different levels of economic development, ...*

International trade and the environment: the WTO

Article XX of the GATT

Subject to the requirement that such measures are not applied in a manner which would constitute a means of arbitrary or unjustifiable discrimination between countries where the same conditions prevail, or a disguised restriction on international trade, nothing in this Agreement shall be construed to prevent the adoption or enforcement by any contracting party of measures: ...

(b) *necessary to* **protect human, animal or plant life or health***;...*

(g) *relating to the* **conservation of exhaustible natural resources** *if such measures are made effective in conjunction with restrictions on domestic production or consumption. ...*