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Environmental and Resource Economics

(30-hour lecture in Winter semester 2024/2025)
Tuesday 9:45-11:20
Auditorium A101

My office hours: Tuesday, 8:45-9:30

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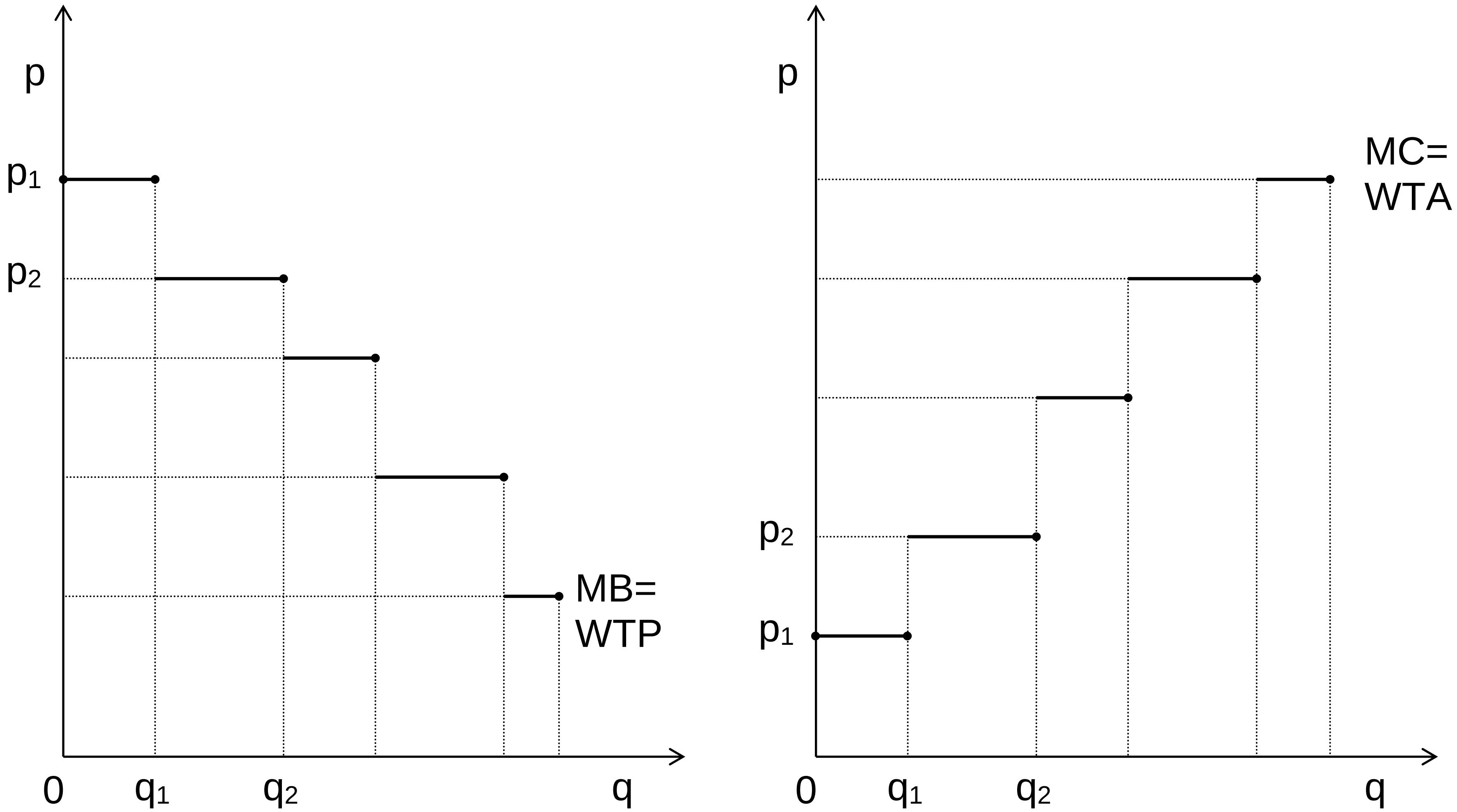
Basic economic concepts

- Economics is about how people make choices in routine voluntary transactions

- Environmental and resource economics is about how people make choices regarding environmental quality and natural resource use

- People's decisions base on the demand and supply of what they are interested in

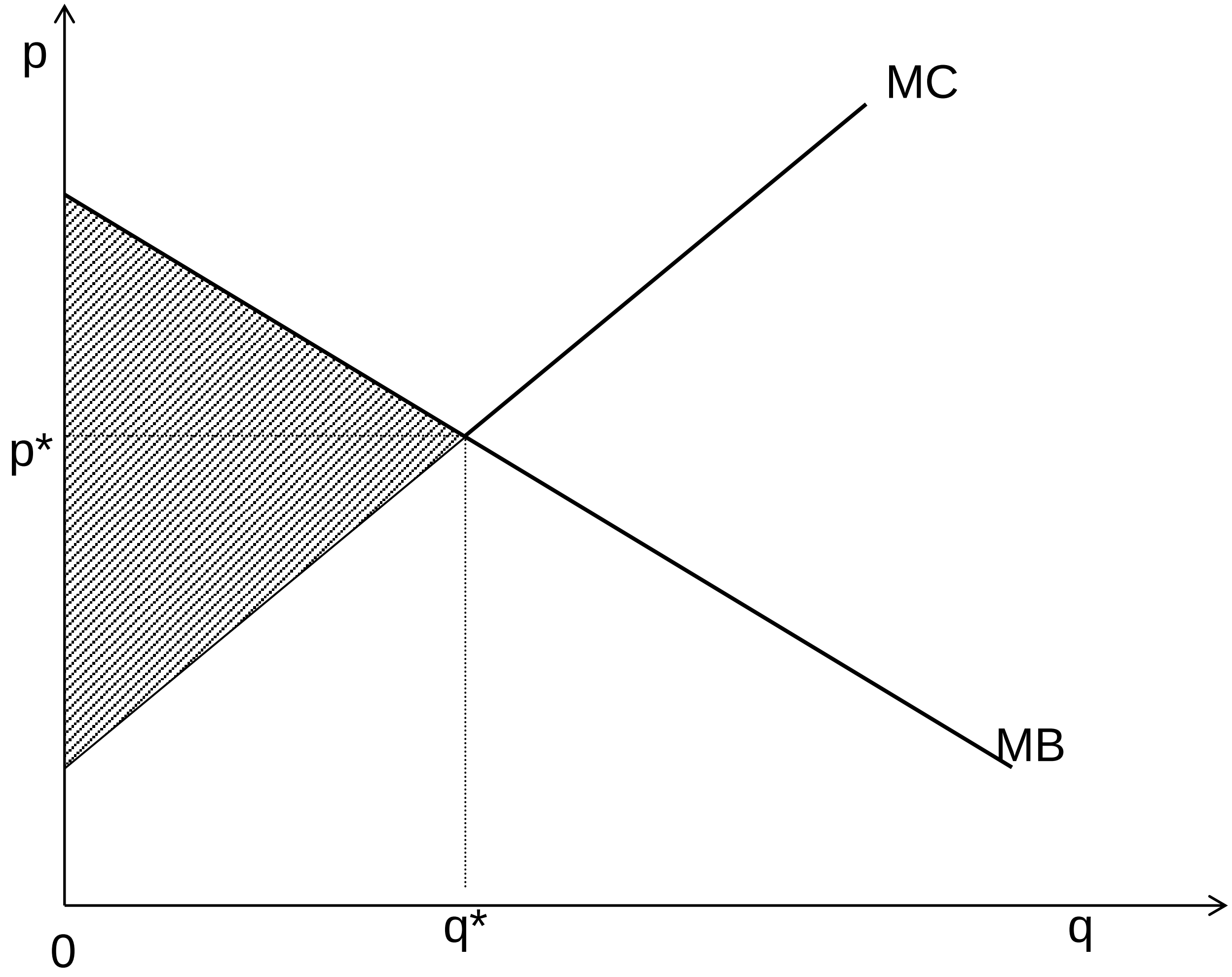
- Willingness To Pay (WTP) and Willingness To Accept (WTA) are key concepts that help understand how people make choices



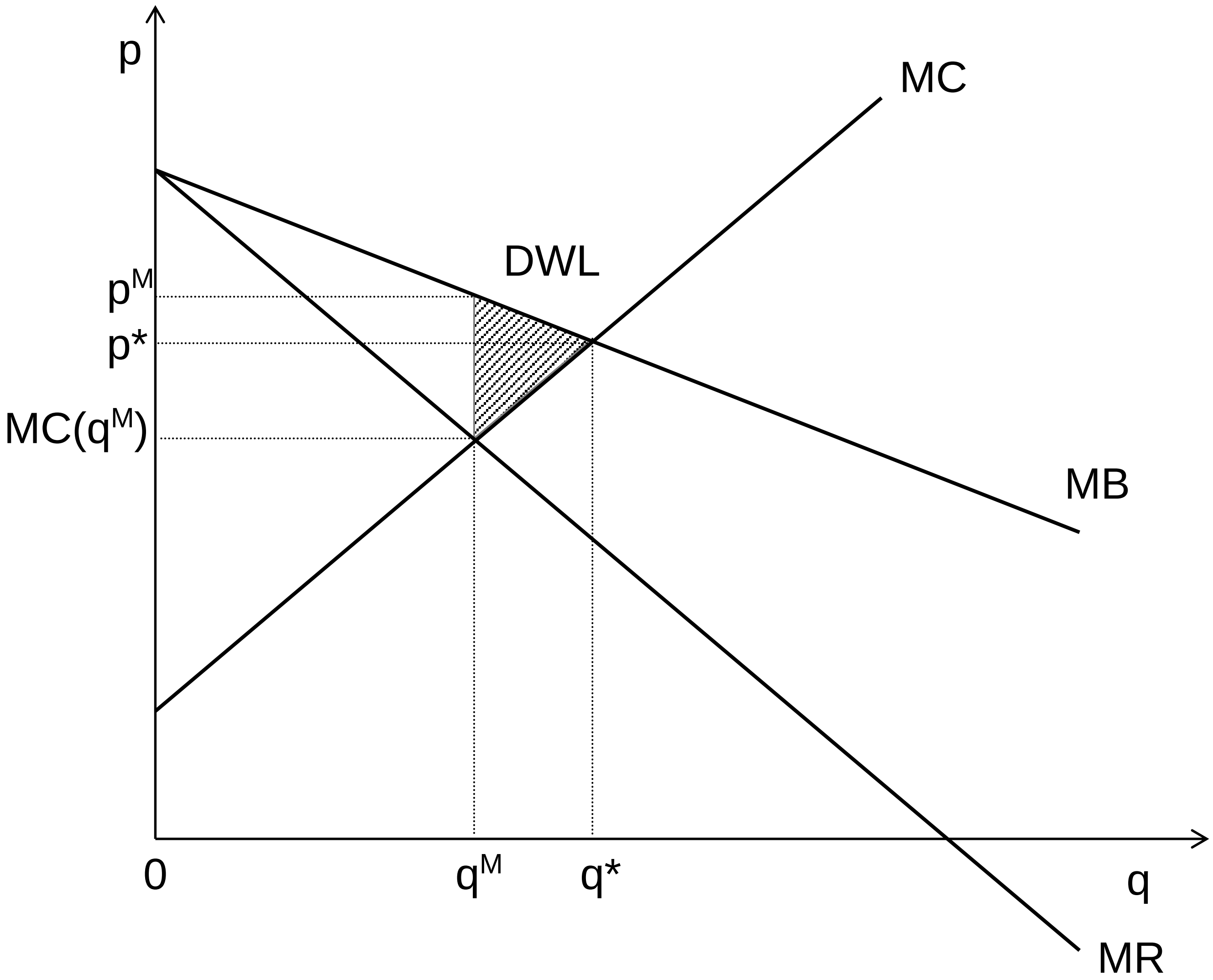
Demand and supply schedules link quantities to values (prices)

Continuous or step-wise?

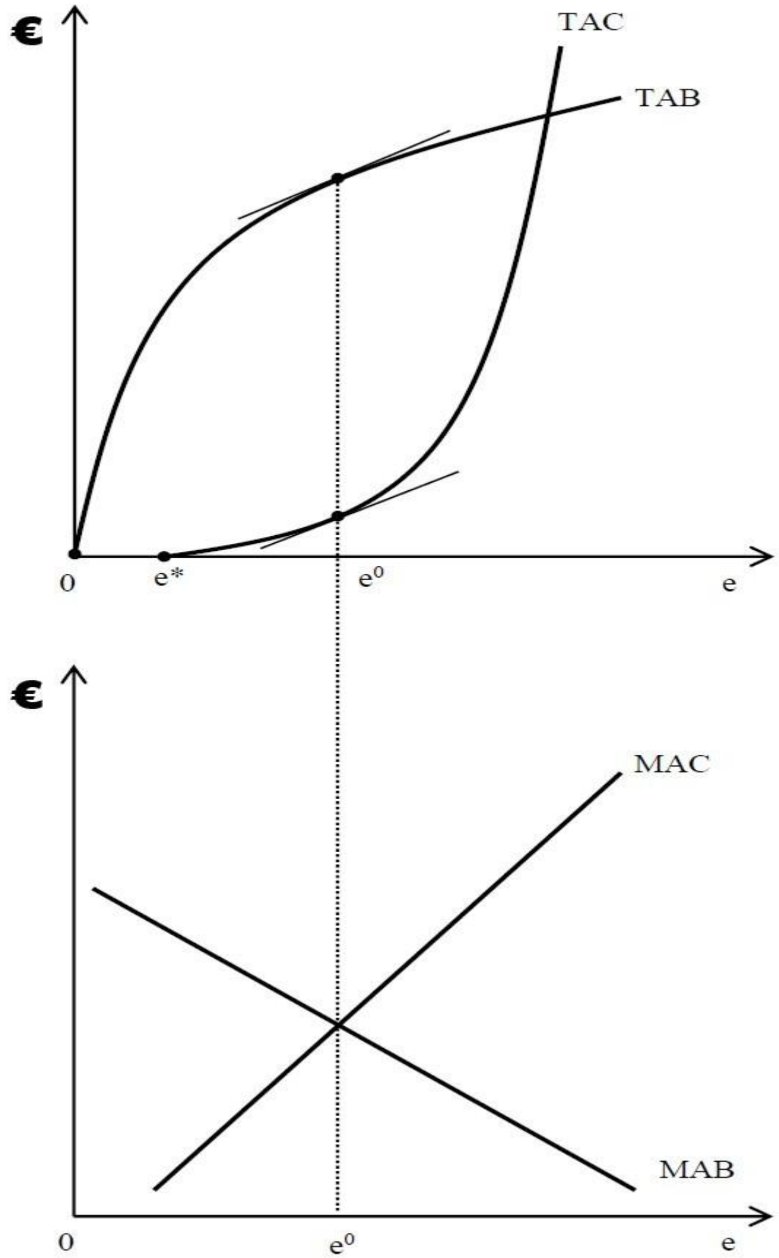
1x 8x 64x



- Demand and supply curves can be approximated by straight lines
- When agents are price-takers, market equilibrium maximizes economic surplus



In general, market equilibrium may not maximize economic surplus


€
TAC
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Basic principle of socially optimal environmental protection

- MAC=MAB as a guiding rule
- MAC>MAB – „overshooting” caused by neglecting costs of protection
- MAC<MAB – inadequate protection caused by underestimation of damages

Questions

Q-1. An economically justified level of environmental protection is where

[a] average citizens consider the environmental quality sufficient.

[b] environmentally conscious citizens feel that tightening standards may trigger social unrest.

[c] environmental professionals provide scientific justification for the requirements introduced.

[d] marginal damages are equal to marginal abatement costs.

[e] none of the above.

Exercises

E-1It is possible to limit the noise gradually from 60 dB to 40 dB. The cost of an appropriate arrangement is estimated at $c(x)=x^2/10$, and the benefit at $b(x)=6x-x^2/10$ per every dB decreased (measured by x; i.e. $x\in[0,20]$; x=0 corresponds to no reduction, and x=20 to the maximum reduction available through this arrangement). Please calculate the socially optimum (economically efficient) level of noise reduction.

Definition

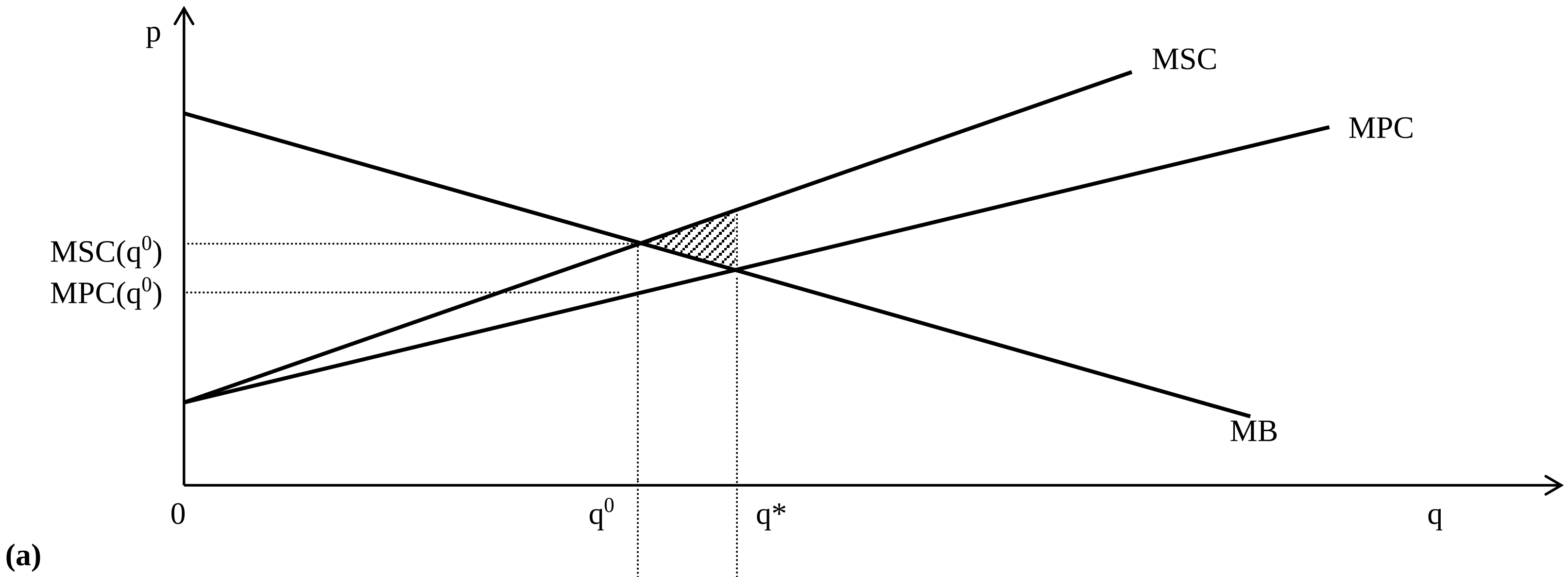
A (non-pecuniary) externality happens when a firm's profit depends on other agent's actions or a consumer's utility depends on other agent's actions and the impact does not confine to the price mechanism.

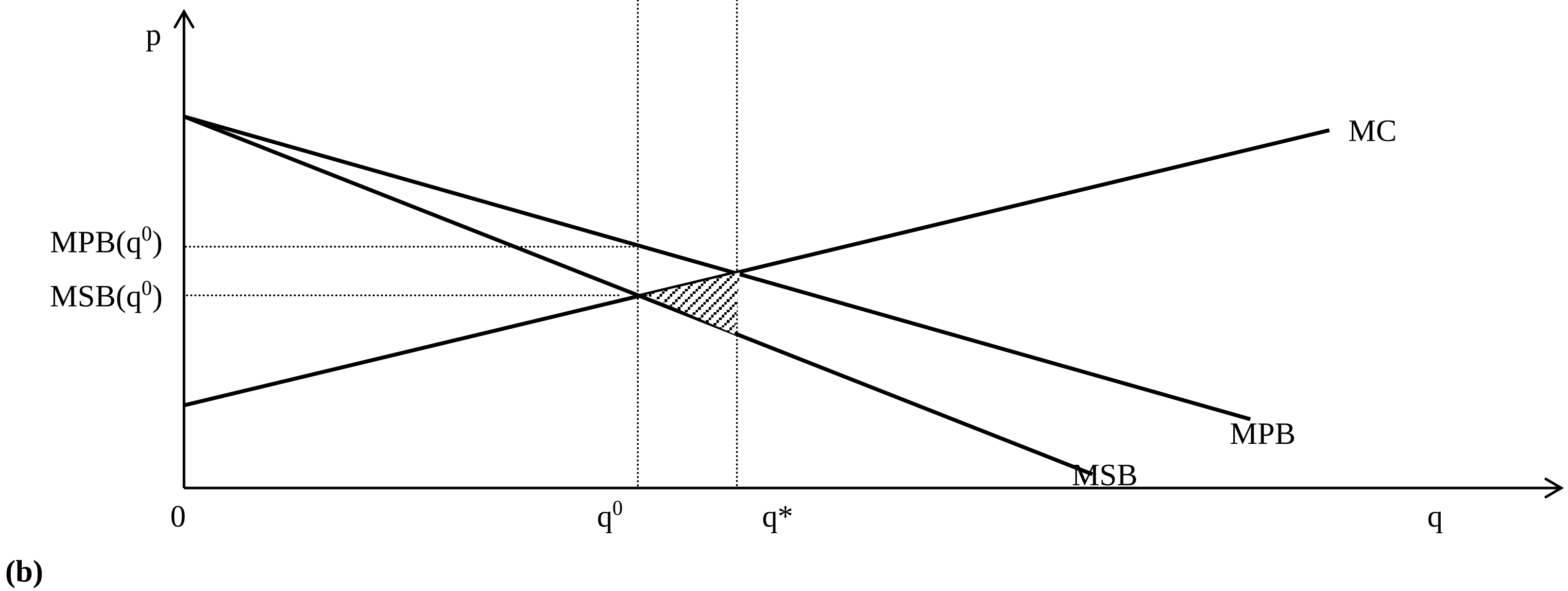
Note

An externality is created by another agent's action who does not bear its consequences. A positive externality (external effect) increases a firm's profit or a consumer's utility, while a negative externality (external cost) decreases them.

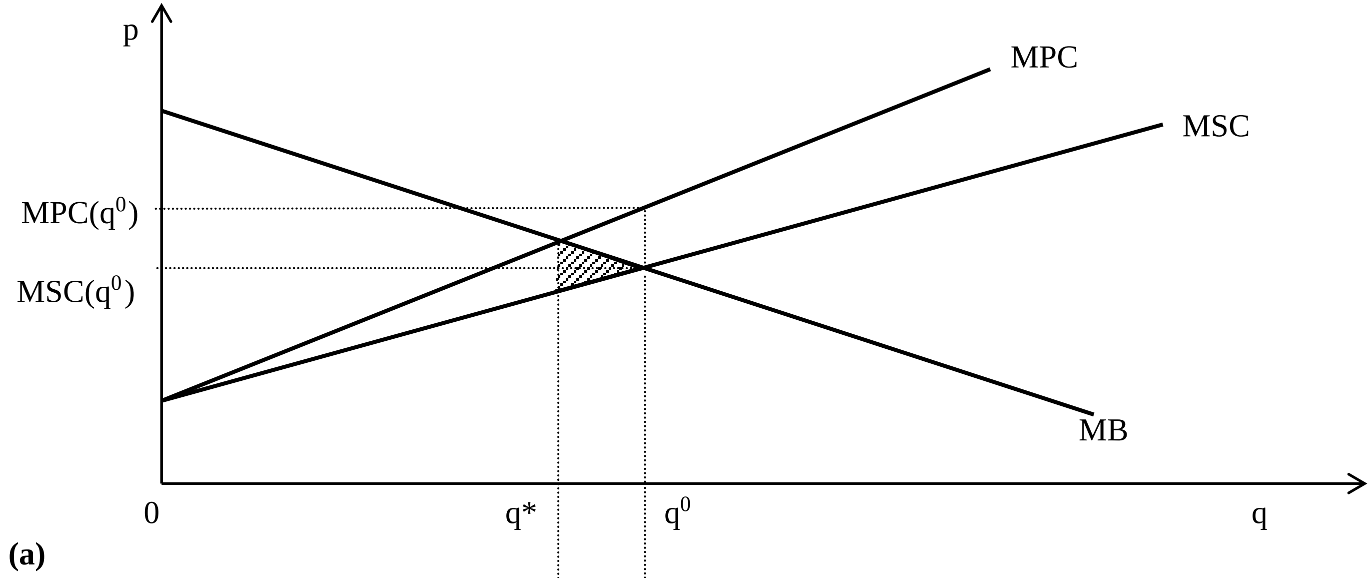
Note

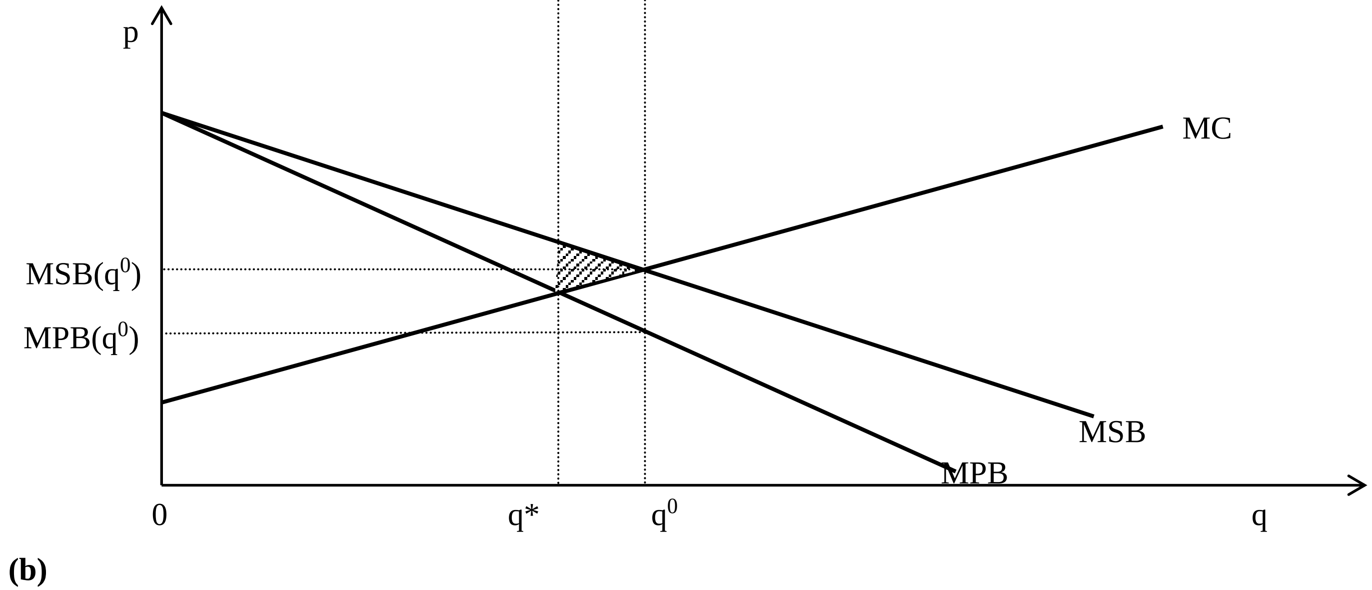
An externality arises when there is no market for the factor responsible for the externality (e.g. when property rights are ill-defined).





Negative externality ($q^0 < q^*$)





Positive externality ($q^0 > q^*$)

Definition

Social effect (cost) = private effect (cost) + external effect (cost)

Definition

Generalized Pareto optimum (social optimum) an allocation that maximizes economic surplus, i.e.

TSB-TSC

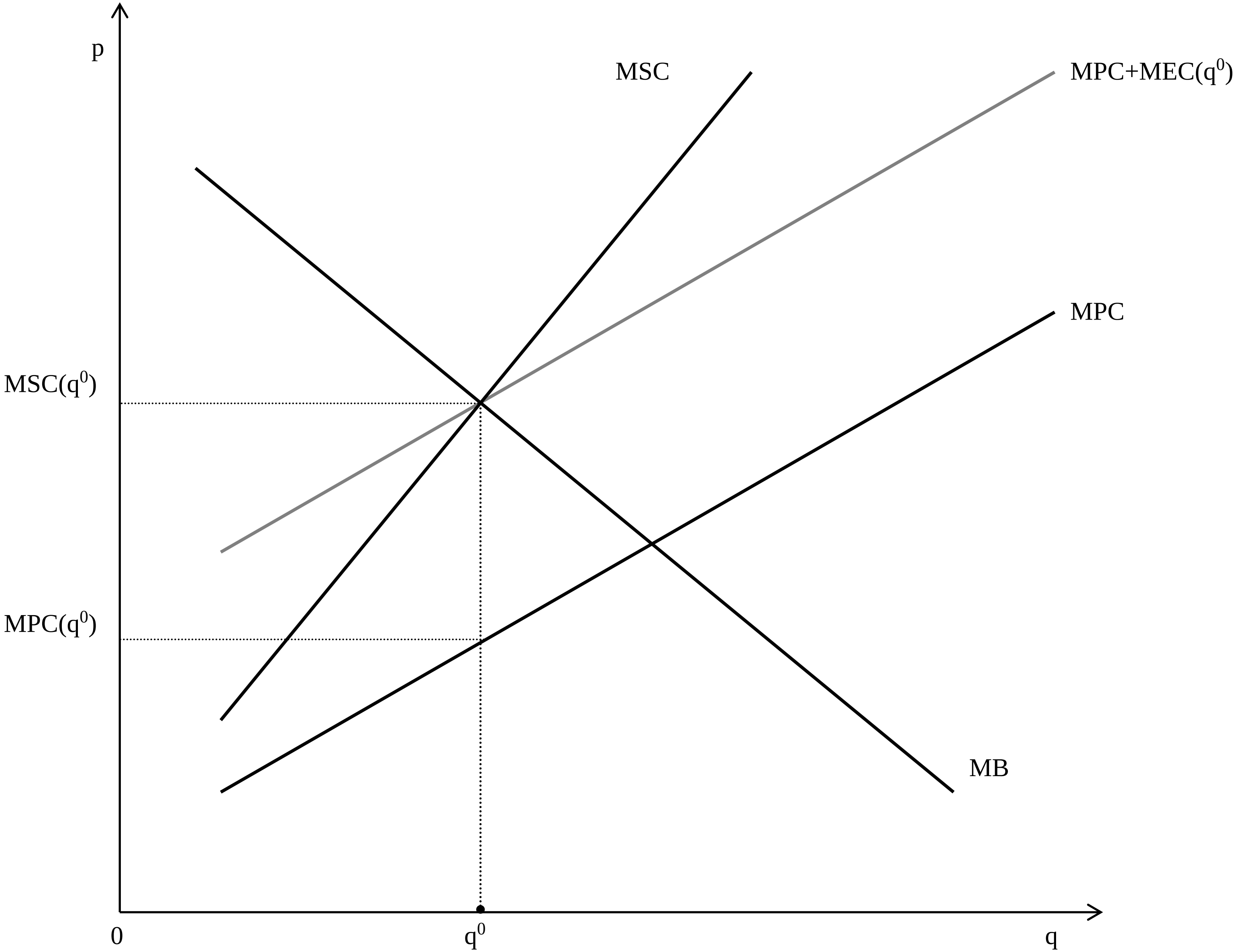
(total social benefits over total social costs).

Note

The first order condition for a Generalized Pareto optimum is:

MSB=MSC, where

MSB=TSB' and MSC=TSC'; *Marginal External Cost*, MEC = MSC–MPC; MPC – *Marginal Private Cost*.


p
MSC
MPC+MEC(q0)
MPC
MSC(q0)
MPC(q0)
MB
0
q0
q

Pigouvian taxation

$$PT(q)=MEC(q^0)(q-q_{threshold})$$

Derivation of the Pigouvian tax:

$$\max_q \, (B(q)-PC(q)-PT(q))$$
$$(B(q)-PC(q)-PT(q))' = 0,$$
$$\text{i.e. } MB(q)-MPC(q)-MEC(q^0) = 0,$$
$$\text{or } MB(q) = MPC(q)+MEC(q^0).$$

- If $q_{threshold}=0$, the polluter pays for all the units
- If $q_{threshold}=q^0$ the tax payment is 0 (if the polluter emits exactly what is socially desirable)
- If the threshold is set at a sufficiently high level (so that $q<q_{threshold}$), the polluter gets a subsidy

Questions

Q-2. Collecting pollution charges in Poland may not necessarily internalize external costs, since

[a] the charges are regulated by the European Commission and thus may be higher than necessary.

[b] the charges are collected only for pollution not exceeding an allowable level.

[c] revenues collected are not always spent on compensating damages caused by the pollution.

[d] as a rule, charge rates are modified only once a year (or at even less frequent intervals).

<u>[e] none of these.</u>

Exercises

E-2. Please argue that a solution to some problem can be a Pareto Optimum, but not a Generalized Pareto Optimum.

Theorem

Unless the demand is perfectly inelastic (the demand curve is vertical), and if MPC<MSC (i.e. MEC>0), then $q^0<q^*$, where q^0 is a Generalized Pareto optimum (social optimum), and q^* is a market equilibrium allocation (private optimum). In other words, a market equilibrium will not be a Pareto optimum (a so-called market failure).

Definition

Transaction cost – cost of preparing and carrying out a transaction (including the cost of contract enforcement); ignored in the wording of welfare economics theorems (as well as in many conventional economic analyses)

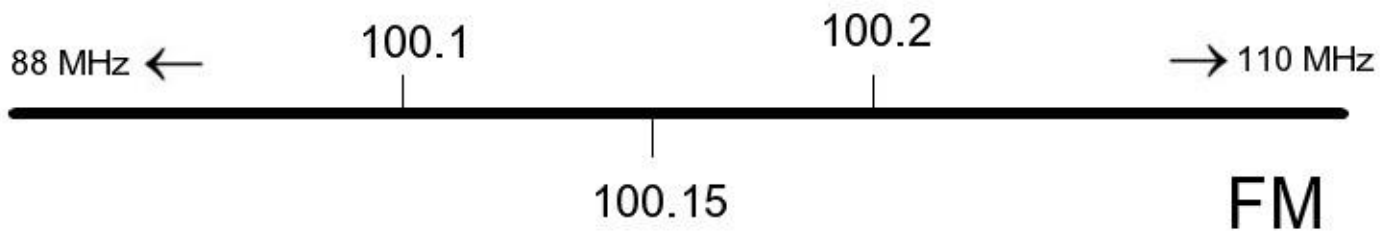
Coase theorem

In the absence of transaction costs, if two rationally behaving agents can negotiate about the amount of an externality imposed by one of them on the other, if property rights are well defined and if distribution of welfare does not affect marginal values, then

(1) the final allocation of resources will be Pareto optimal (thus there will be no *market failure*); and
(2) the final allocation will not depend on the allocation of property rights (initial allocation).

Note

In Coase theorem, (1) holds even if the distribution of welfare does affect marginal values.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Note

If the Coase theorem does not apply then eliminating a market failure requires some sort of intervention, such as:

- quantity regulation, i.e. a constraint $q \leq q^0$ (in the case of a negative externality); or
- Pigouvian tax, i.e. $PT(q)=MEC(q^0)(q-q_{threshold})$, where $q_{threshold}$ is an arbitrary threshold; or
- merging agents that create and suffer externalities ('*institutional internalization*')

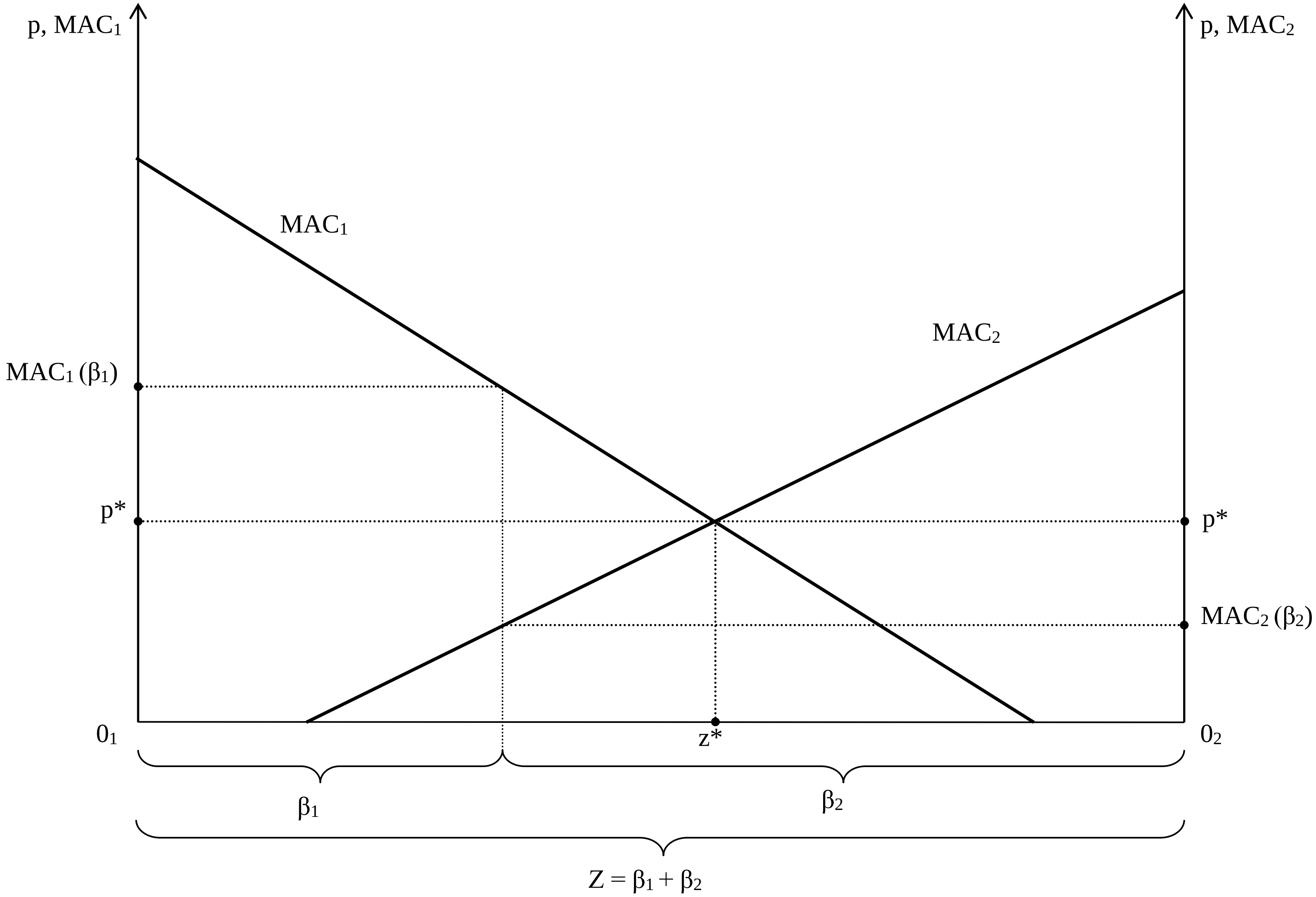


Illustration of the Coase theorem

Questions

Q-3. The Coase theorem implies that

[a] Pigouvian tax rate should be equal to marginal damages resulting from the pollution.

[b] a response from polluters is independent of whether pollution charges are considered production costs or they subtract from after-tax profits.

[c] subject to some additional assumptions, an economically efficient level of environmental protection can be reached without a Pigouvian tax.

[d] environmentally damaging activities shall be taxed according to general principles.

[e] none of these.

Exercises

E-3. Total private and social cost functions are, respectively, TPC(q) = q2+3q+10, TSC(q) = 4q+2q2. Total private and social benefit function is TPB(q) = TSB(q) = 22q–q2. Calculate the Pigovian tax rate aimed at correcting the market failure created by external costs. How will the production change as a result of the tax? Is it necessary to impose the Pigovian tax on every unit produced?

<u>Non-exclusion principle</u>:

If a unit of a good was provided, then nobody can be excluded from using it

<u>Non-rivalry principle</u>:

The same unit of a good can be simultaneously used by more than one user

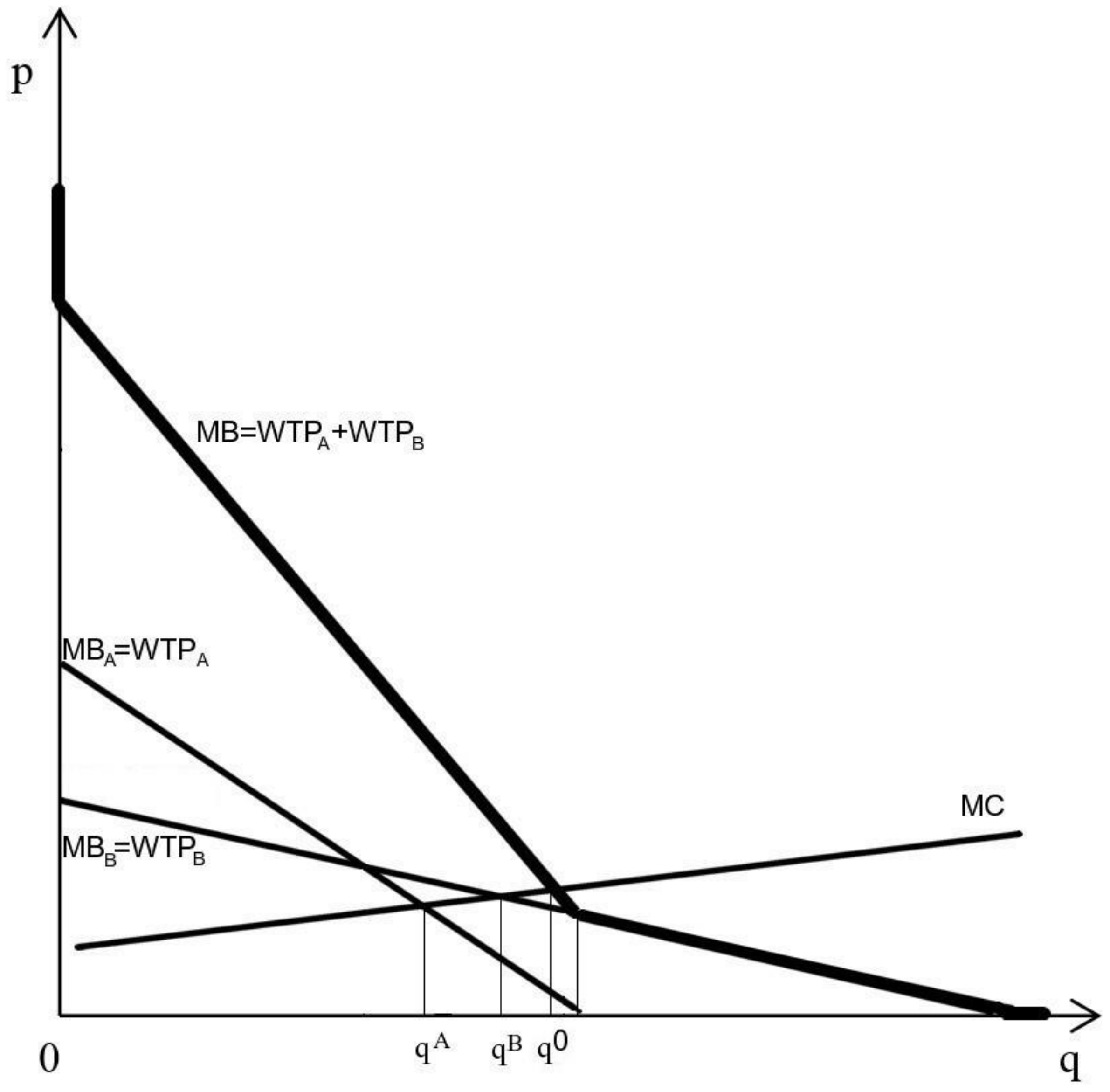
<u>Public good</u>:

Any good that complies with the non-exclusion and non-rivalry principles

<u>Private good</u>:

Any good that does not comply with non-exclusion, and does not comply with non-rivalry principles

ERE-4-2



Socially optimal level of provision of a public good

Note

The non-exclusion principle implies so-called *free-riding* behaviour; users avoid purchases of the good, anticipating that they will use the good purchased by somebody else. As a result, in an unregulated market, the supply of a public good is lower than socially optimal.

Public policy and external effects: prospects for spontaneous cooperation

(1) One-polluter, one-victim case

Profits without protection (-) and with protection (+)

Steel mill's profits	Laundry's profits	
	-	+
-	20; 10	20; 13 (NE)
+	17; 15	17; 17 (PO)

Compensation (bribe) is possible to move the steel mill from NE to PO

(2) One-polluter, multi-victim case

Profits without protection (-) and with protection (+)

Steel mill's profits	Profits of a laundry (1 of 10)	
	-	+
-	20; 1.0	20; 1.3 (NE)
+	17; 1.5	17; 1.7 (PO)

Compensation (bribe) is possible to move steel mill from NE to PO, even if 2 laundries *free ride*; its likeliness is doubtful

(3) Multi-polluter, multi-victim case

Profits without protection (-) and with protection (+)

Profits of a steel mill (1 of 10)	Profits of a laundry (1 of 10)	
	-	+
-	2.0; 1.0	2.0; 1.3 (NE)
+	1.7; 1.5	1.7; 1.7 (PO)

Compensation (bribe) is possible to move one steel mill from NE to PO, but even less likely

Conclusion

A public good equivalent to a positive externality is likely to be supplied at a lower level than socially optimal. Coasian bargains are unlikely to correct for the market failure. So-called Groves-Clarke Tax (GCT) forces economic agents to reveal their true preferences.

Definition of the Groves-Clarke Tax

- $GCT_i = \sum_{j\neq i} s_j$ if $\sum_{j\neq i} s_j \geq 0$ and $\sum_j s_j < 0$, (1)
- $GCT_i = -\sum_{j\neq i} s_j$ if $\sum_{j\neq i} s_j < 0$ and $\sum_j s_j \geq 0$, (2)
- $GCT_i = 0$ otherwise. (3)

If (1) or (2) holds, the agent *i* is called *pivotal*.

Groves-Clarke Tax (GCT)

Benefits	Government intervention	No government intervention	GCT
Firm A (polluter)		20	0
Firm B (polluter)		10	0
Firm C (victim)	28		8 = -(22-20-10)
Firm D (victim)	22		2 = -(28-20-10)
Total	50	30	10

Improves the allocation of a public good, but lowers the allocation of a private good (GCT is a "loss")

Questions

Q-4. If the supply of a public good is set at a non-optimal level as a result of *free-riding*, the government may levy an incentive tax – the so-called Groves-Clarke tax – aimed at

[a] collecting revenues to provide an adequate supply of the good.

[b] identifying pivotal agents to let their preferences be changed in the light of other people's preferences.

<u>[c] providing incentives to declare preferences truthfully.</u>

[d] charging everybody a fee equal to the benefit one enjoys from having the good adequately supplied.

[e] none of these.

Exercises

E-4. So-called club good is a good complying with the non-rivalry principle, but not with the non-exclusion principle. Please argue that coded TV is an example of a club good.

Uncertainty

- Risk = uncertainty with known probabilities (insurability)

- Environmental risk – unknown consequences of environmental degradation

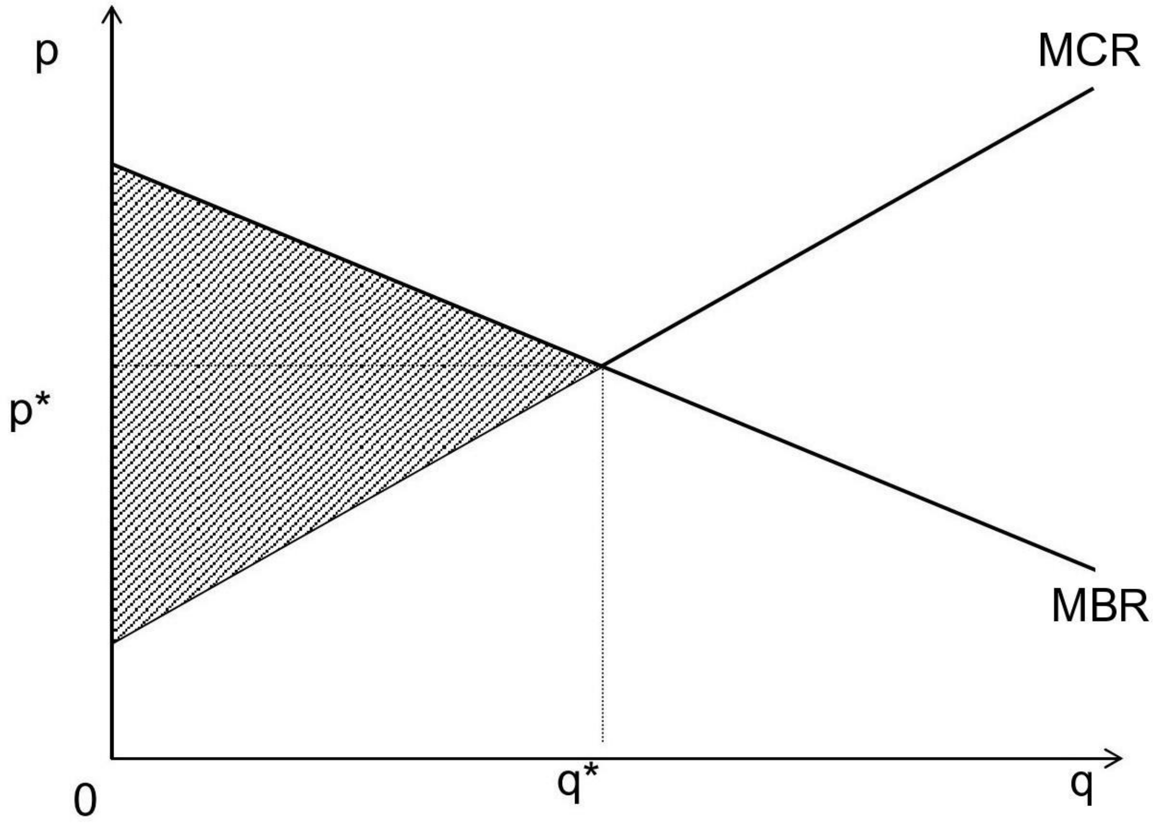
Risk *versus* insurability

- Flood protection
- Business failure

Witches, floods and wonder drugs

- Elimination of risk is impossible; logically, it resembles medieval witch-hunts
- Societies need to live with risks
- Acceptable level of risk – where MB=MC

How do economists define an "acceptable level of risk"?



Typical attempts to eliminate risk

- A chemical may turn out to be a carcinogen

- Bio-assay with mice
- Bio-assay with mice fed forcefully
- Bio-assay with rats
- …
- Can we trust the results?

Safety factor approach

- x_0 in mouse food not toxic

  Average man lives 40 times longer than mouse $\rightarrow$

- $x_0/40$ not toxic for men

  There are individuals 5 times more sensitive to poisons than average $\rightarrow$

- $(x_0/40)/5$ not toxic even for such people

  Safety factor of 3 – "just in case" $\rightarrow$

- $((x_0/40)/5)/3$ is accepted for consumption

Questions

Q-5. Economists define an acceptable level of risk
[a] by referring to what an average citizen can accept without panicking.
[b] by referring to what the society can accept without suffering excessive damages.
[c] by referring to what professionals are likely to accept.
[d] by referring to what risk-averse citizens can see as "natural".
<u>[e] none of these</u>.

Exercises

E-5. Economists demonstrate that not everything is insurable easily. Please analyse whether one can buy an insurance against being offended.

Intertemporal choice

Discount rate (r) lets compare money amounts that belong to different time periods

$$X_t = X_0(1+r)^t, \text{ or } X_0 = X_t/(1+r)^t, \text{ where}$$

X_t is the present value (in year t) of the value X_0 observed in year 0; or X_0 is the present value (in year 0) of the value X_t observed in year t.

$$NPV = X_0/(1+r)^0 + X_1/(1+r)^1 + X_2/(1+r)^2 + ... + X_T/(1+r)^T,$$

where T is the last year that the decision (project) is expected to imply a cost or a benefit.

If X_t=X=const – then the formula for the present value simplifies:

$$NPV = X/(1+r)^0+X/(1+r)^1+X/(1+r)^2+...+X/(1+r)^T =$$
$$X(1+1/(1+r)+...+1/(1+r)^T)$$

Internal Rate of Return (IRR)

IRR – a discount rate which makes the NPV=0. In other words, IRR is a discount rate r such that:

$$X_0/(1+r)^0 + X_1/(1+r)^1 + X_2/(1+r)^2 + ... + X_T/(1+r)^T = 0$$

If $X_0, X_1, \ldots, X_{\tau-1} < 0$, and $X_\tau, X_{\tau+1}, \ldots, X_T > 0$, then IRR is the only r which solves the equation above (IRR is unique).

For typical projects this condition is satisfied (i.e. one needs to bear some investment cost in the beginning, and then one benefits from it).

IRR is a useful indication of profitability:

- If IRR is higher than the interest rate available for investor (to borrow the money in order to finance it), the project is efficient (and it is worth financing)
- If IRR is lower than the interest rate available for investor (to borrow the money in order to finance it), the project is inefficient (and it should be abandoned)
- If IRR is negative then the project does not make sense irrespective of the terms of availability of the money (unless you do not have to pay for the credit; the bank pays you to borrow the money).

The present value of the future amount of X_T=1,000,000

	T=1	*T*=5	*T*=10	*T*=20	*T*=50	*T*=100	*T*=200
r=0%	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
r=1%	990,099	951,466	905,287	819,544	608,039	369,711	136,686
r=4%	961,538	821,927	675,564	456,387	140,713	19,800	392
r=8%	925,926	680,583	463,193	214,548	21,321	455	0.21
r=12%	892,857	567,427	321,973	103,667	3,460	12	<0.01

The present value of a flow of a constant amount of X=100

	T=10	T=50	T=100	$T=\infty$
r=0%	1,000	5,000	10,000	∞
r=1%	947	3,920	6,303	10,000
r=4%	811	2,148	2,451	2,500
r=8%	671	1,223	1,249	1,250
r=12%	565	830	833	833

Application of IRR

Windmill project

- 1 MW capacity
- works 2000 hours per annum
- costs 2 million euro
- sells electricity at 50 euro/MWh
- requires no maintenance costs for 30 years

Application of IRR (cont.)

- One-time investment cost of 2,000,000 € on January 1 (2,000 k€)
- The annual revenue of 100,000 € every December 31 (100 k€)

Application of IRR (cont.)

NPV =

$= -2{,}000k/(1+r)^0 + 100k/(1+r)^1 + 100k/(1+r)^2 + \ldots + 100k/(1+r)^{30} =$

$= -2.000k + 100k(1/(1+r) + 1/(1+r)^2 + \ldots +1/(1+r)^{30}) =$

$= -2{,}000k + 100k((1-q^{30})/(1-q)),$

where $q=1/(1+r)$, if $q\neq1$, i.e. $r\neq0$

Application of IRR (cont.)

- IRR=0.03, since NPV=0 if and only if q=0.97, i.e. r=0.03.
- Note: r needs to be calculated from the formula: q=1/(1+r). Hence r=1/q-1. Incidentally, it is 0.03 (it should not be calculated as 1-q, i.e. 1-0.97).

- If the discount rate is higher than 0.03, then the investment will never pay back.
- If the discount rate is lower than 0.03 then the investment makes sense.

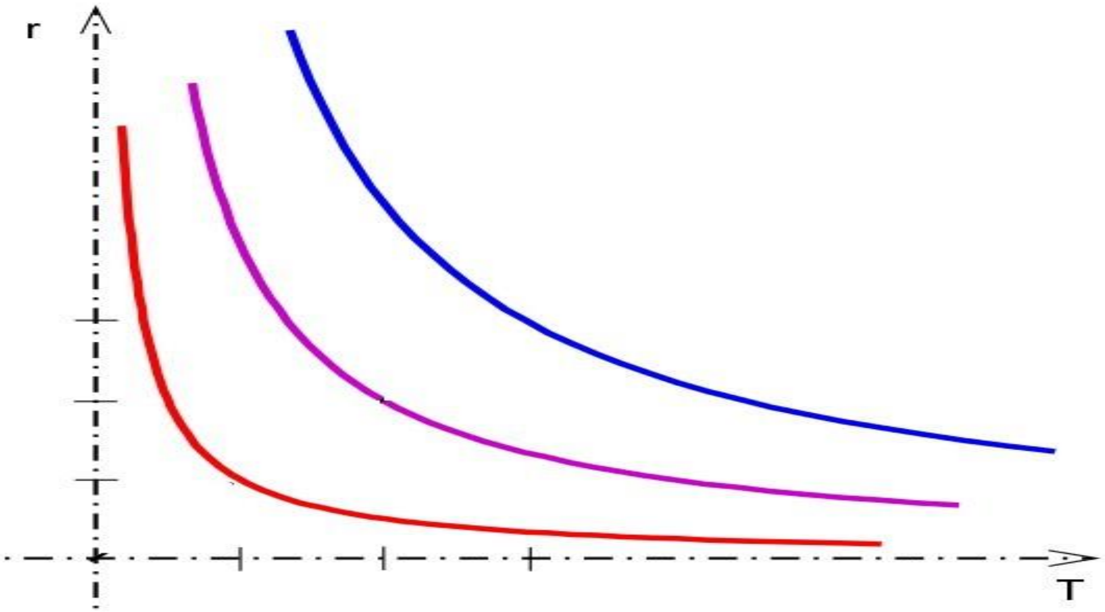
Time consistency

$$x^{a+b}=x^a x^b$$

E.g. $32 = 2^5 = 2^3 \mathrm{x} 2^2 = 8 \mathrm{x} 4$.

E.g. calculating NPV over a 10-year period you have to use the same discount rate when you discount over 4 years and 6 years.

Time consistency → "hyperbolic discounting"



Hyperbolic discounting (application)

Calculations of NPV cannot be carried out in two stages (if the long period is divided into two shorter ones then discount rates applied do not have to be the same, and the formula $x^{a+b}=x^a x^b$ does not hold).

Questions

Q-6. Discounting the future with a discount rate reflecting social time preference

[a] can be applied only in an economy where the rate of inflation does not exceed the rate of GDP growth.

[b] helps to justify investment projects characterized by low benefits which are spread over a long period of time.

[c] helps to justify investment projects characterized by high investment costs concentrated at the very beginning of the investment process.

<u>[d] allows to compare costs and benefits realized in different periods</u>.

[e] none of these.

Exercises

E-6. Calculate the IRR of the following windmill project. Investment cost is 1.5 Meuro (to be spent once on January 1). By the end of the year the windmill will start producing electricity of 2 GWh annually (we assume that revenues from these sales accrue to the windmill's account each year on December 31). It will operate for 30 years without any maintenance costs. We also assume that it will not require any repair expenditures. The wholesale price of electricity is 40 euro/MWh.

Natural resources

- Exhaustible
- Renewable
- Non-depletable

Economics of exhaustible resources

Hotelling rule (assumptions):

- An extraction rule to be found to maximize the present value of the flow of profits from sales of an exhaustible resource in a competitive market
- The size of the resource is known and it cannot be increased (i.e. no new discoveries)

Hotelling rule (formula):

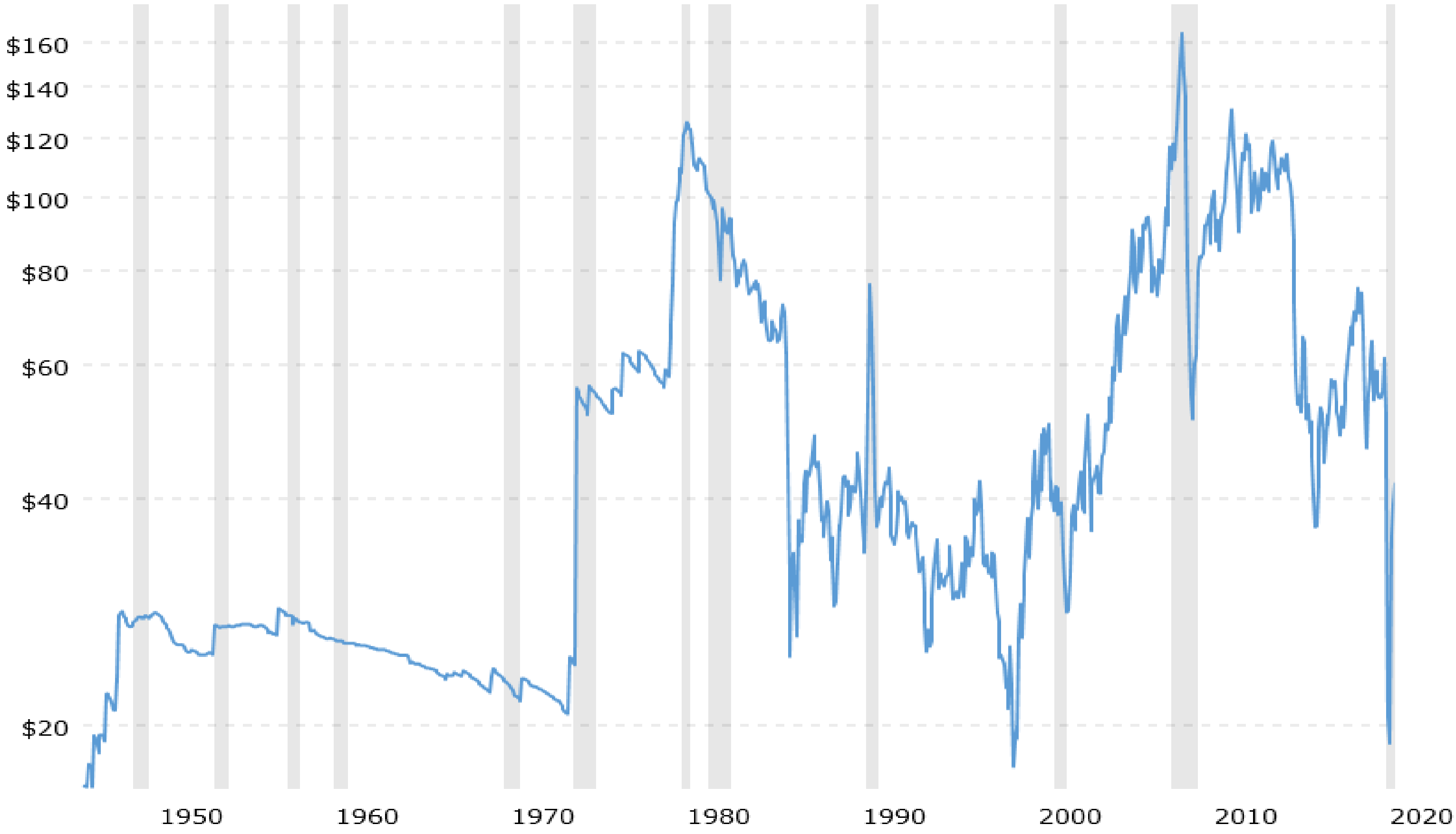
$$\mathbf{(d(p\text{-}MC)/dt)/(p\text{-}MC) = r}$$, where:

- p – price of the resource,
- MC – marginal cost of extraction,
- r – discount rate;
- p-MC – rent from the extraction

Hotelling rule (comments):

- Applications to other resources
- Monopolistic supply
- Empirical verification

Oil prices versus Hotelling model



Questions

Q-7. The Hotelling rule for optimal management of exhaustible resources

[a] is derived under the assumption that the owner of the resource wishes to maximize profits.

[b] calls for private ownership of all natural resources (including exhaustible resources).

[c] calls for public ownership of all natural resources (including exhaustible resources).

[d] requires that the discount rate used is higher than market interest rate.

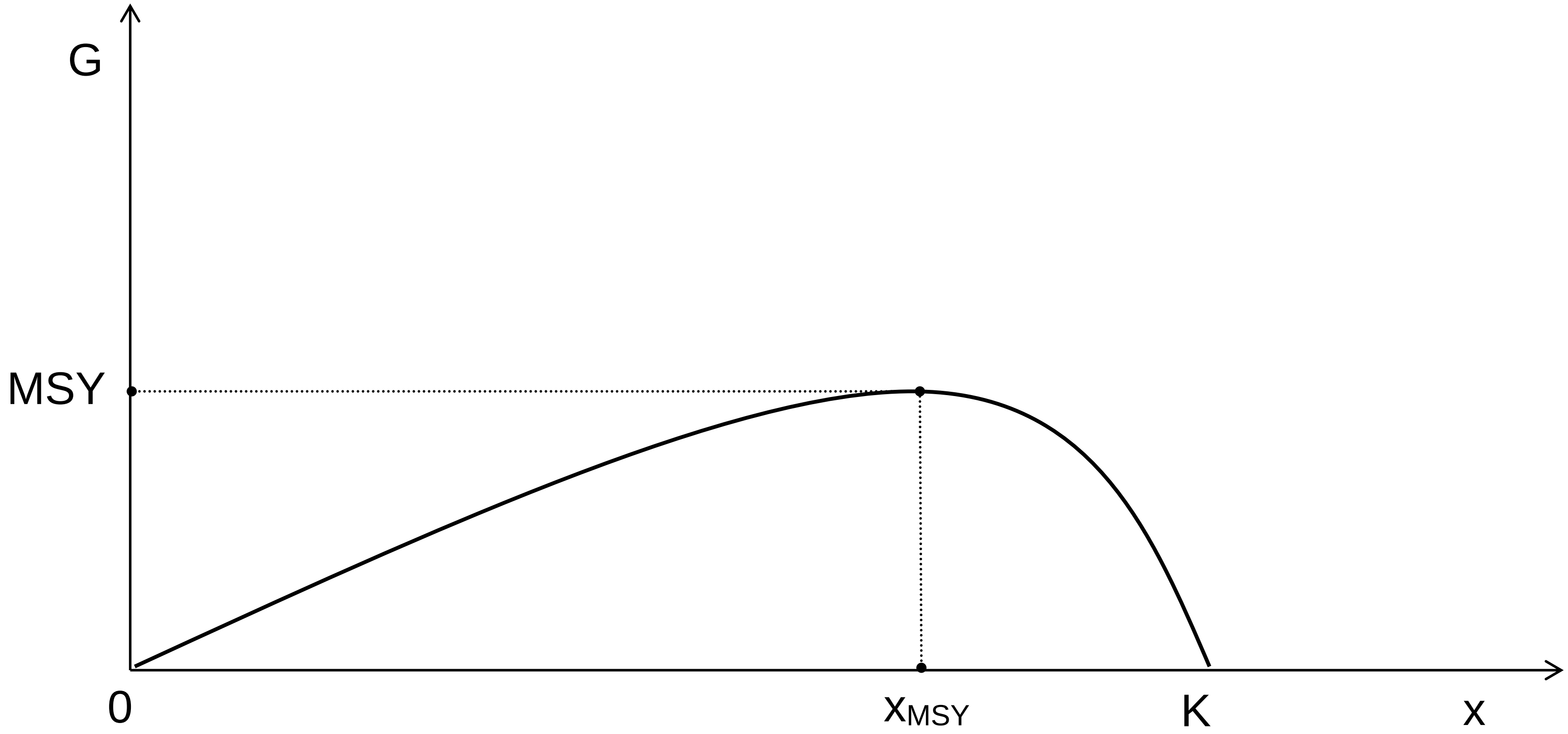
[e] none of these.

Exercises

E-7. What does the Hotelling rule say about buying works of art as financial investment?

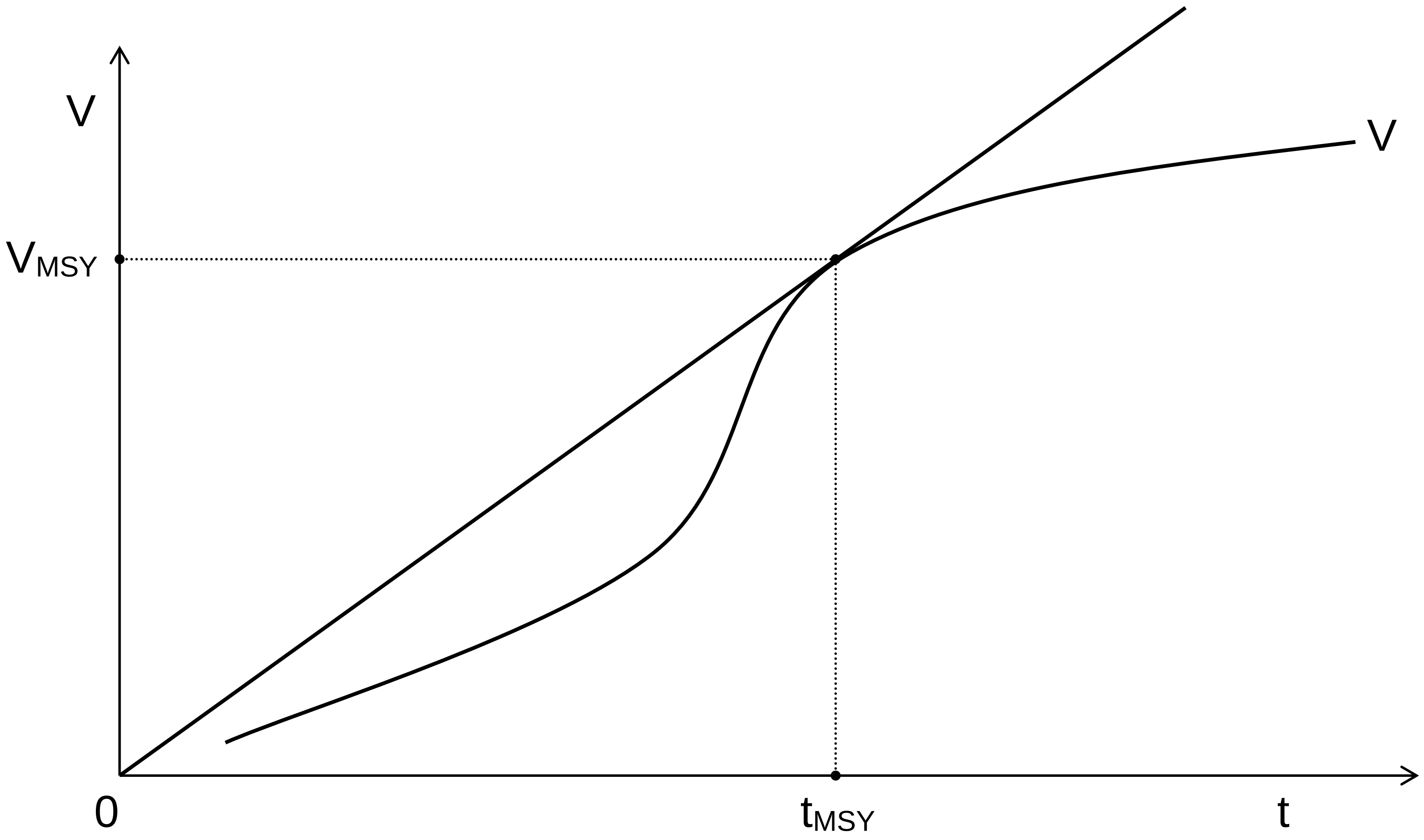
Economics of renewable resources

Maximum Sustainable Yield (MSY)



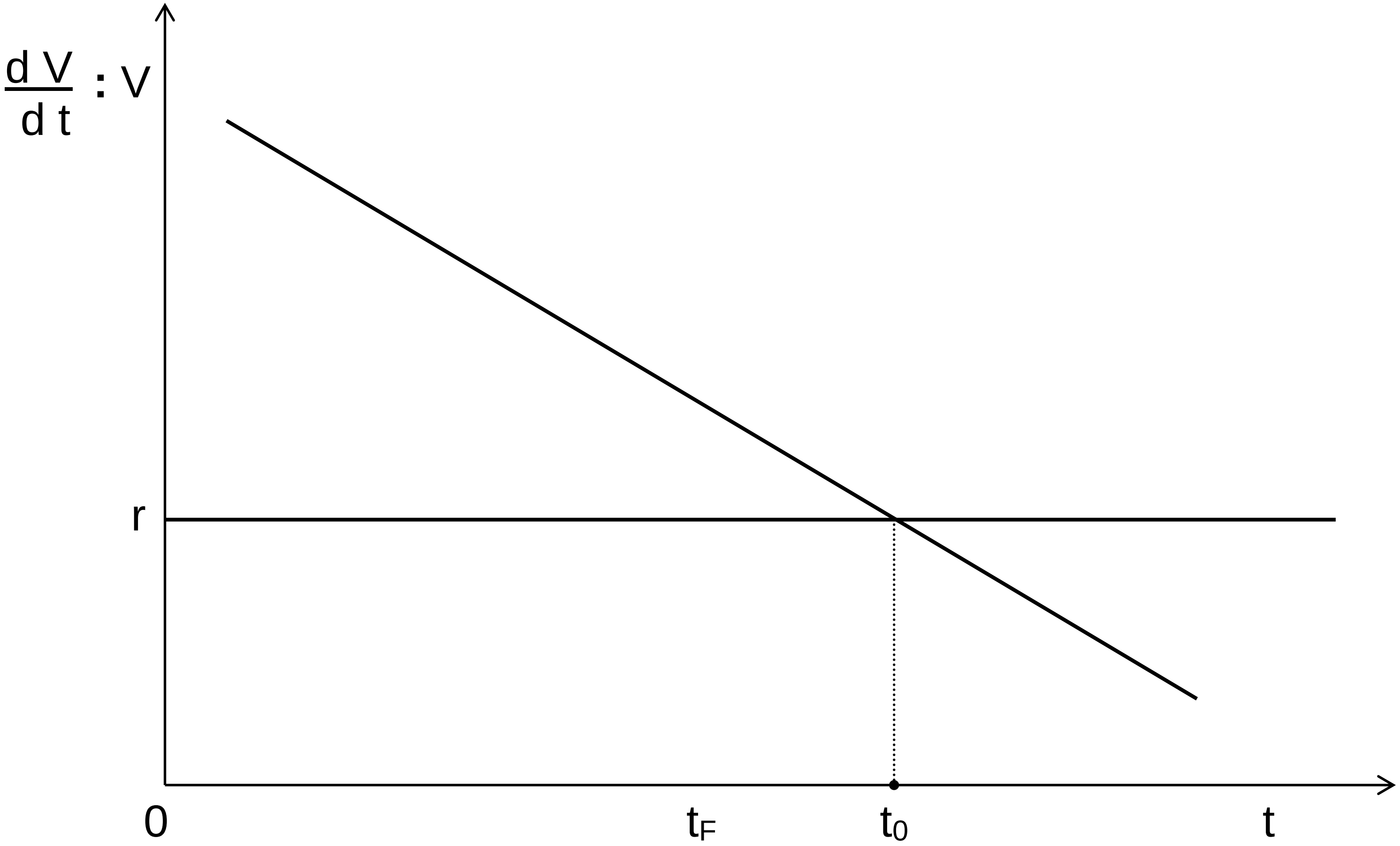
Derivation of the MSY

Immobile resources (e.g. forestry)



V – volume of timber

Immobile resources (e.g. forestry); continued



Economically optimum rotation period with no residual value (t_0), and Faustmann rotation period (t_F)

t_0 versus t_F

The revenue of forester: $Z(t) = X+V(t)p$, where

- X – the price of land,
- p – the price of timber.

- t_0 solves $(dV(t)/dt)/V=r$
- t_F solves $(dZ(t)/dt)/Z=r$

- $dX/dt+pdV/dt-rZ=0$, i.e. $pdV/dt-rZ=0$ (using the definition of $Z=X+V(t)p$, and multiplying both sides of the equation by Z)
- $(dV/dt)/V-rZ/(Vp)=0$ (dividing both sides into Vp)
- In the equation $(dV/dt)/V-r=0$ (solved by t_0), we substitute $rZ/(Vp)$ for r (that is a number higher than r, because $Z>Vp$); thus its solution must be lower.

Economics of forestry I

- Timber benefits
- Non-timber benefits
  - Support for ecosystems
  - Recreation

Economics of forestry II

Multifunctional forestry

- Production
- Ecosystem support
- Recreation

Can these functions be realised simultaneously?

Forestry in the Paris Agreement

1. Parties should take action to conserve and enhance, as appropriate, sinks and reservoirs of greenhouse gases as referred to in Article 4, paragraph 1 (d), of the Convention, including forests.

2. Parties are encouraged to take action to implement and support, including through results-based payments, the existing framework as set out in related guidance and decisions already agreed under the Convention for: policy approaches and positive incentives for activities relating to reducing emissions from deforestation and forest degradation, and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries; and alternative policy approaches, such as joint mitigation and adaptation approaches for the integral and sustainable management of forests, while reaffirming the importance of incentivizing, as appropriate, non-carbon benefits associated with such approaches.

Questions

Q-8. An economically optimum rotation period in forestry (from planting to harvesting) is determined by

[a] choosing a tree species with the maximum growth rate.

[b] empirically computing time required to achieve the maximum rate of timber volume growth.

<u>[c] identifying a point in time when rate of growth of the net value of timber falls below the relevant discount rate</u>.

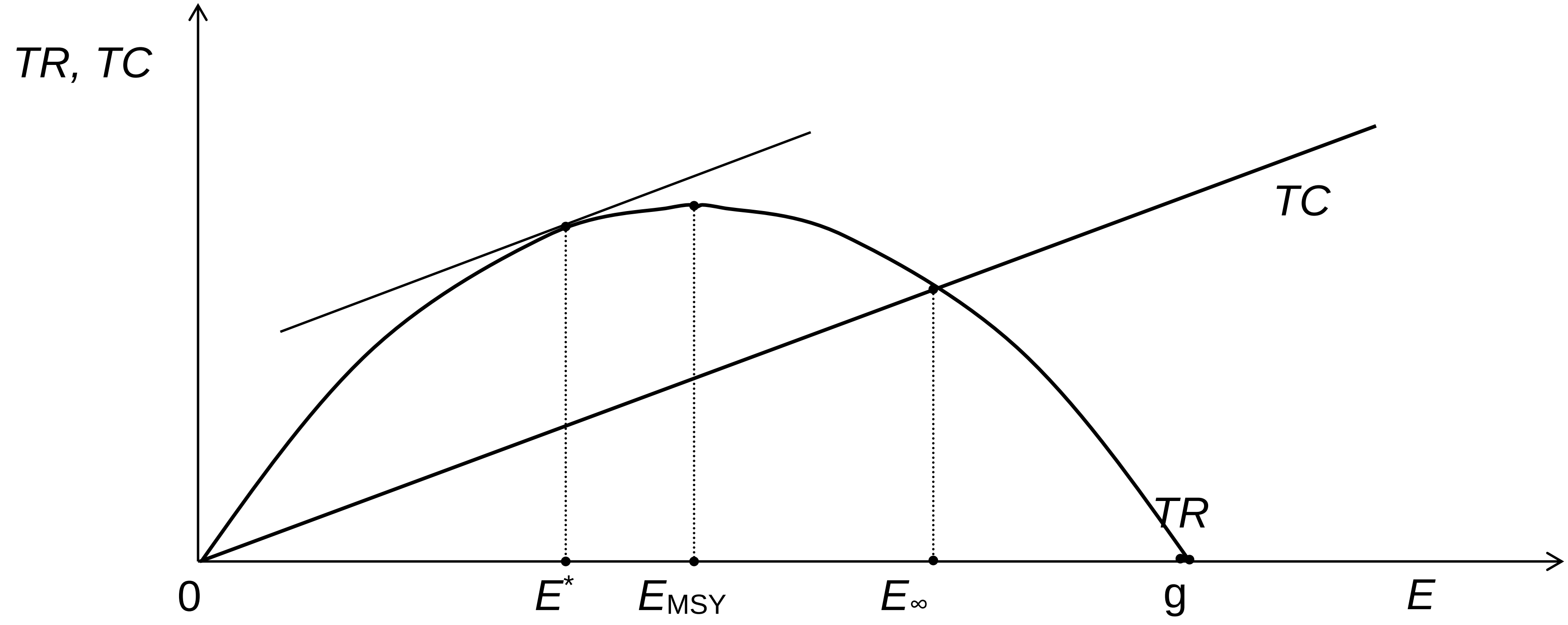
[d] computing capital intensity of foresters' efforts which tends to increase once the timber becomes older (because of the risk of fire, among other things).

[e] none of these.

Exercises

E-8. How to preserve old trees that are considered "mature" by the Faustmann rule and thus should be cut?

Mobile resources (e.g. fisheries)



Gordon-Schaefer model

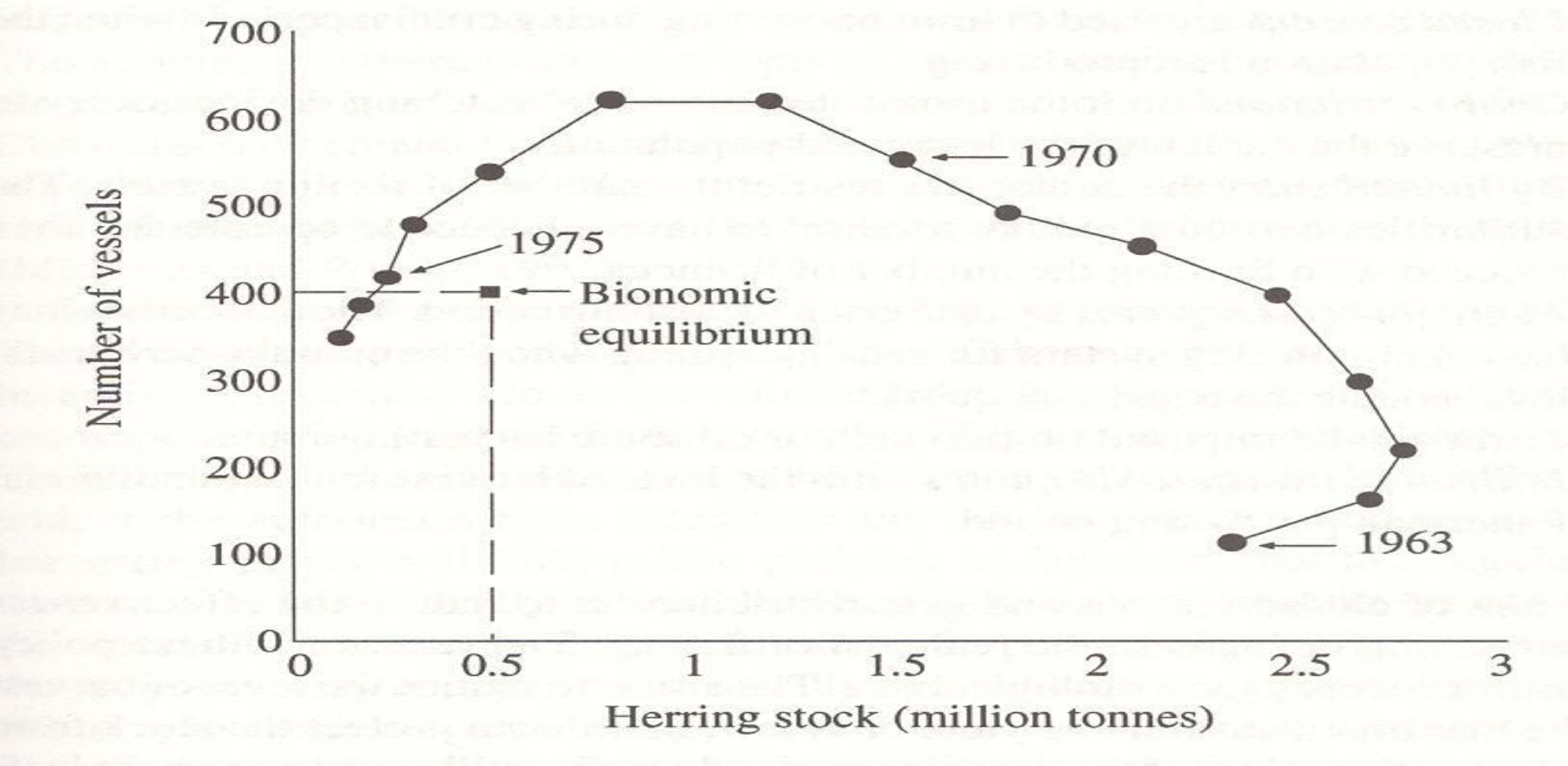
E – harvest effort (in terms of the natural growth rate g extracted)

E_{∞} – bionomic equilibrium

E_{MSY} – Maximum Sustainable Yield

E^{*} – profit maximization

Mobile resources (e.g. fisheries); continued



Source: Björndal and Conrad, 1987.

North Sea fishery

Colin Clark model

- A species has a single owner who wants to maximise the profit from its use
- Population X is kept at the level providing MSY
- The annual increment is gX
- The price of the resource is p (the revenue from the annual MSY is gXp)
- If the owner decides to harvest the entire population X rather than gX, then the (one-time) revenue is Xp
- This revenue can be invested giving the annual income of Xpr, where r is the discount rate

Colin Clark model (cont.)

- Which income is higher: gXp (based on MSY) or Xpr (based on a robber economy)?
- Is gXp < Xpr, i.e. g < r ?
- If a discount rate is, say, 4%, and the net growth rate of the resource is 2%, then MSY is less attractive than extinction.

Questions

Q-9. Bionomic equilibrium

[a] is the most desirable combination of fishing effort and sustainability of ecosystems.

[b] combines high costs with a low density of harvested populations.

[c] refers to the equality of deaths and births in harvested populations.

[d] is aimed at maximizing revenues from fishing net of harvest costs.

[e] none of these.

Exercises

E-9. Please analyse the Gordon-Schaefer model for the following harvest functions: for the fish population stock $x \in [0,400]$ (in thousand tonnes), the annual net growth is

$$G = -x^2/1250+8x/25, \text{ i.e. the growth rate is } r = -x/1250+8/25;$$

the sustainable harvest cost function (in million PLN) is $TC(x) = 48-3x/25$ (fishermen are allowed to harvest just a fraction of the annual increment; they are not allowed to deplete the stock); the fish price is $P = 500$ PLN/tonne.

Welfare indices and the environmental resource base

Does GDP count what counts, and does not count what does not count?

- Oil spills
- Forest protection

Social Accounting Matrix

	Households	Labour	Capital	Production	Abatement	Savings/ Investment	Environment
Households		Wages	Profits				Rent
Labour				Wages	Wages		
Capital				Profits	Profits		
Production	Consumption				Inputs	Gross investment	
Abatement				Abatement			
Savings/ Investment	Households' savings			Depreciation	Depreciation		
Environment	Environ. services			Environmental damages	Environmental improvement	Value of the net change of resources	

The "greening" of the GDP

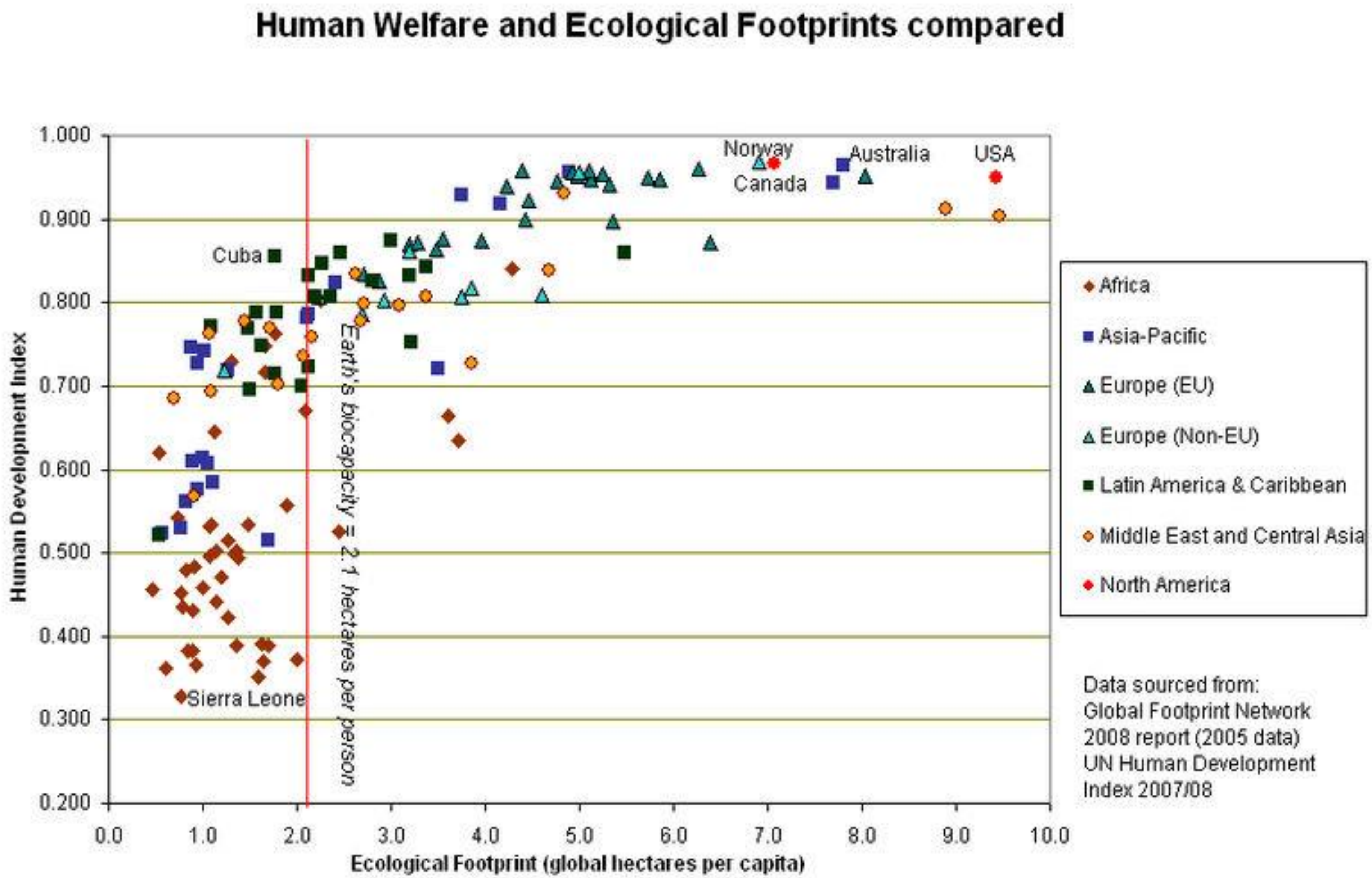
Net National Product (NNP)

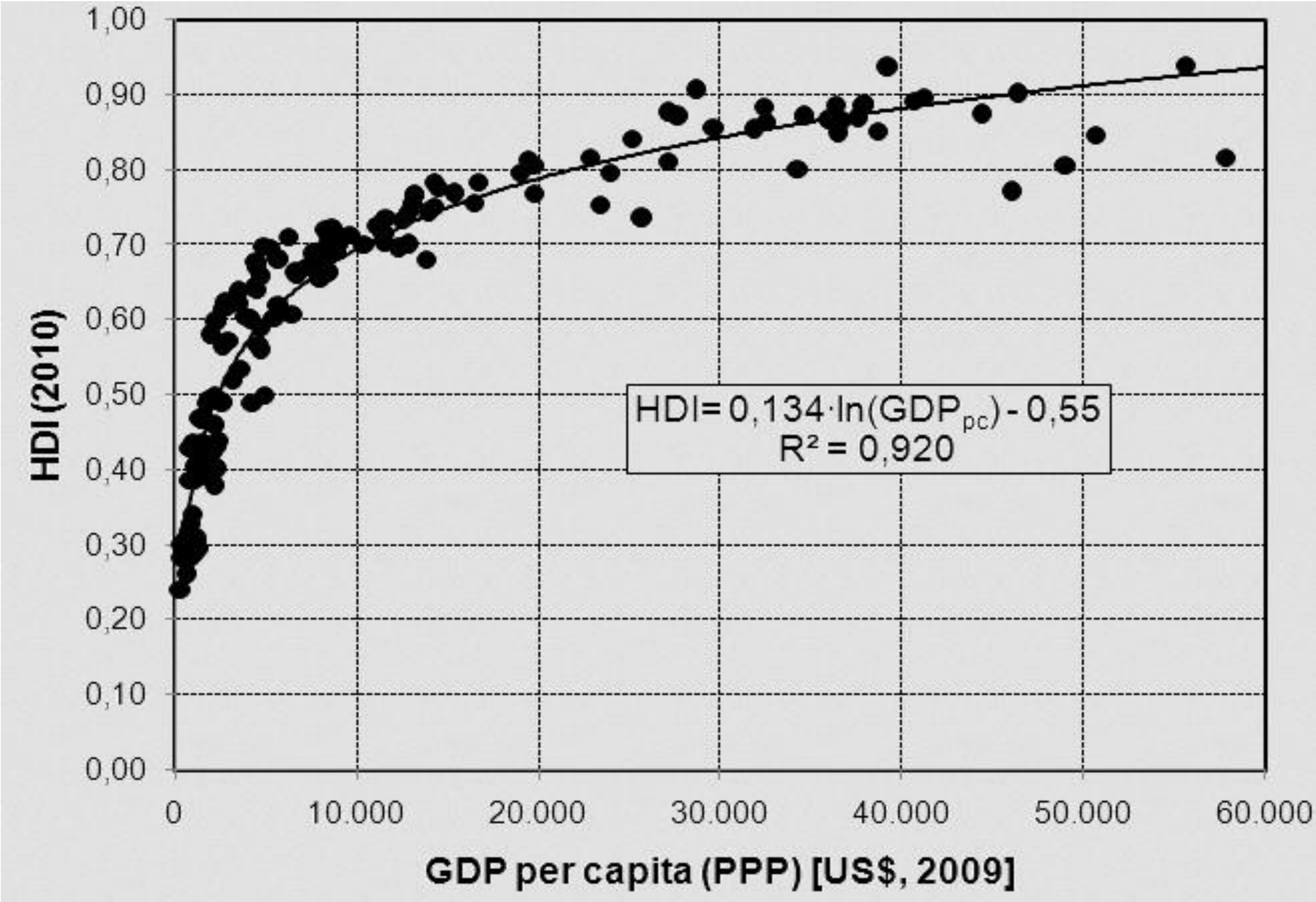
NNP =

Consumption of marketed goods
+ Public expenditures on consumption
+ The value of the net change of real capital
+ The value of the net change of human capital
– Flow of environmental damages
+ The value of the net increase in the environmental resource base (– if the net change is negative)

Types of capital

- man-made (real) capital;
- human capital; and
- natural capital


Human Welfare and Ecological Footprints compared
Human Development Index
Ecological Footprint (global hectares per capita)
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
Norway
Australia
USA
Canada
Cuba
Sierra Leone
Earth's biocapacity = 2.1 hectares per person
Africa
Asia-Pacific
Europe (EU)
Europe (Non-EU)
Latin America & Caribbean
Middle East and Central Asia
North America
Data sourced from:
Global Footprint Network
2008 report (2005 data)
UN Human Development
Index 2007/08



1,00
0,90
0,80
0,70
0,60
0,50
0,40
0,30
0,20
0,10
0,00
HDI (2010)
0
10.000
20.000
30.000
40.000
50.000
60.000
GDP per capita (PPP) [US$, 2009]
HDI= 0,134·ln(GDPpc) - 0,55
R² = 0,920

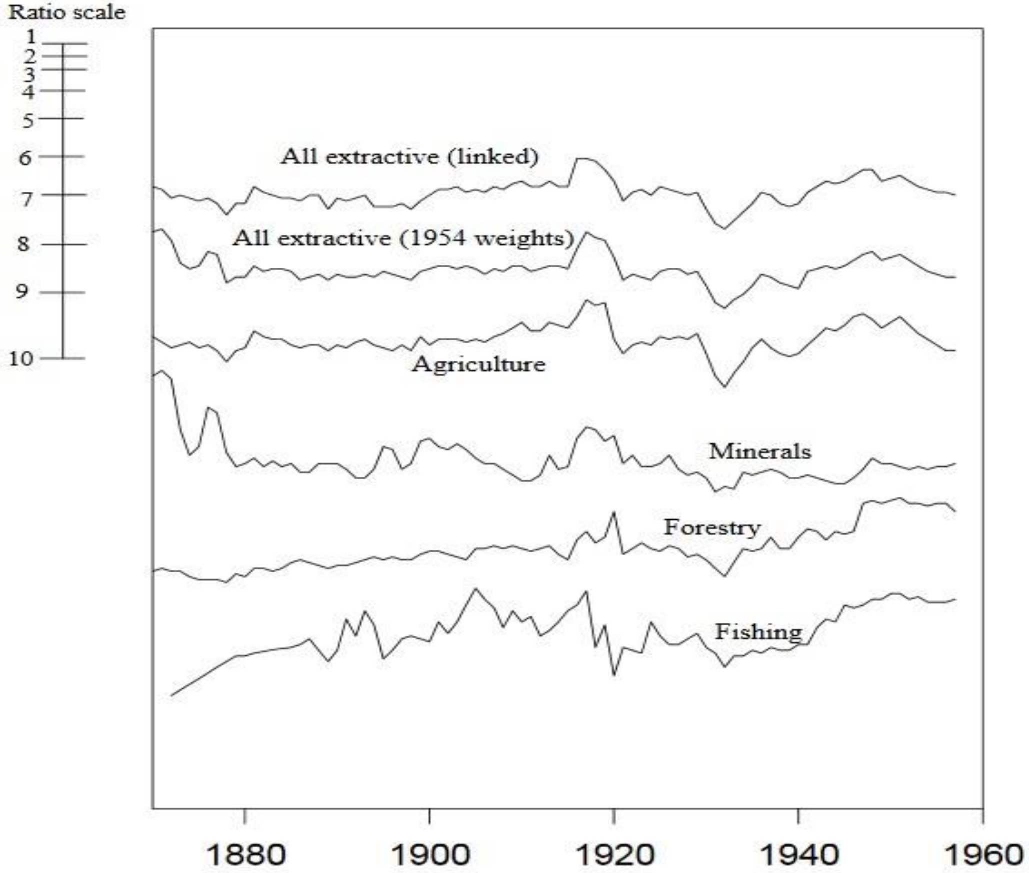
Perspectives for economic development

- Thomas Malthus:
  Absolute barrier of natural resources
- David Ricardo:
  The barrier of relative prices of natural resources
- John Stuart Mill:
  Technological progress removes both barriers

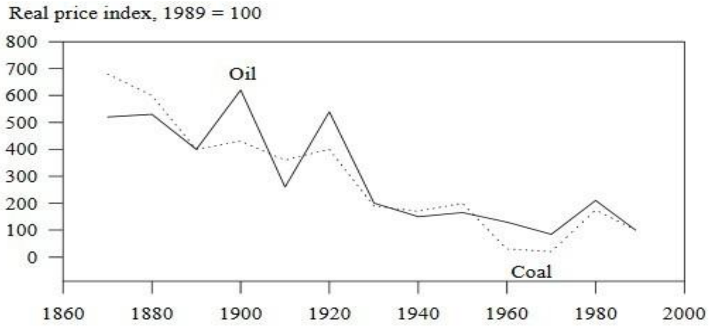
Scarcity and Growth

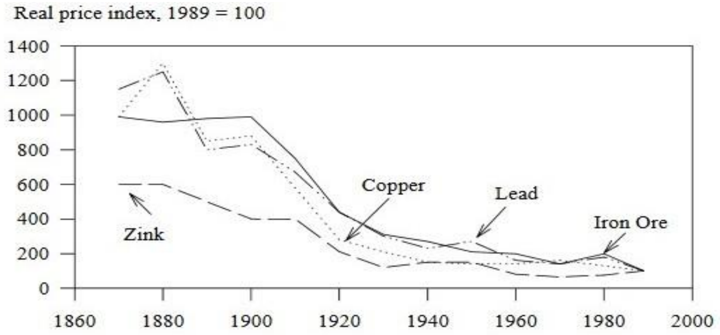
- H. J. Barnett & Ch. Morse (1962)
- Mill’s concept proved for most natural resources
- ‘Scarcity and growth reconsidered’ (1979)

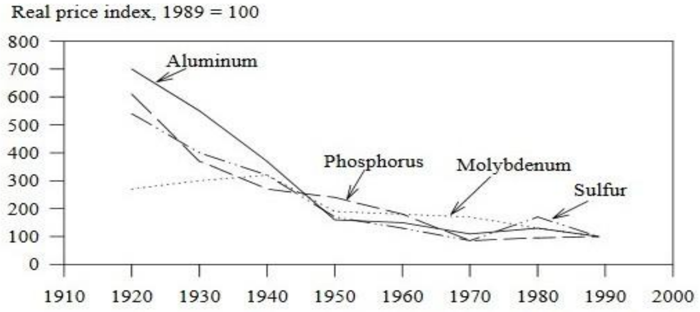
Barnett & Morse (1962):



Scarcity and growth reconsidered







Questions

Q-10. A traditional gross national product (GDP) as compiled according to the SNA (System of National Accounts) methodology does not fully reflect environmental values, since

[a] it ignores consumers' preferences with respect to non-market environmental goods.
[b] it subtracts the value of environmental damages such as e.g. disasters resulting from oil-spills.
[c] it ignores that GDP changes imply changes in the system of equilibrium prices.
[d] it ignores the rent received as a result of extracting exhaustible resources.
[e] none of these.

Exercises

E-10. Please explain why HDI is an increasing function of GDP per capita (see figure on page ERE-10-6).

Valuation of the environment

$$TEV = UV + NUV =$$
$$= DUV + IUV + EV + BV, \text{ where}$$

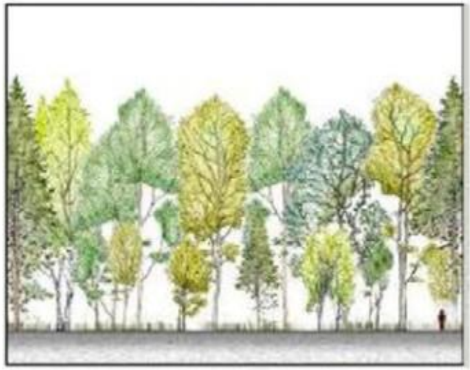
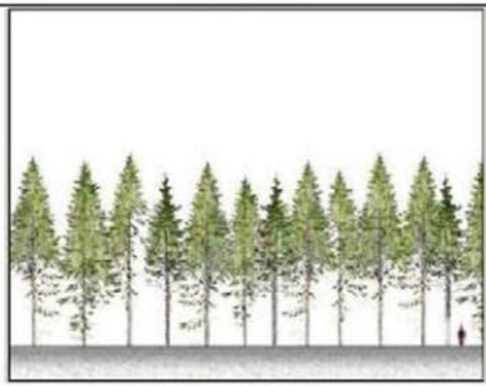
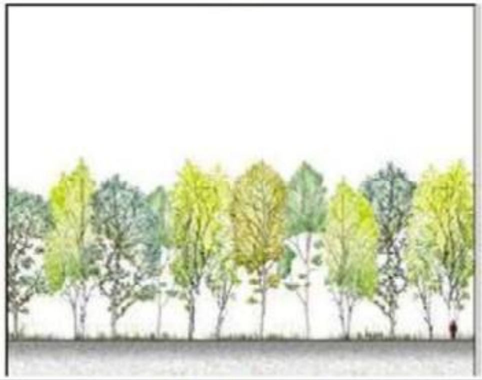
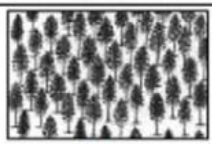
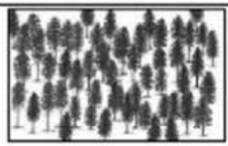
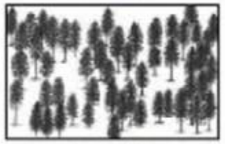
- TEV – *Total Economic Value*,
- UV – *Use Value*,
- NUV – *Non-Use* ("Passive Use") *Value*,
- DUV – *Direct Use Value*,
- IUV – *Indirect Use Value*,
- EV – *Existence Value*,
- BV – *Bequest Value*

Valuation techniques

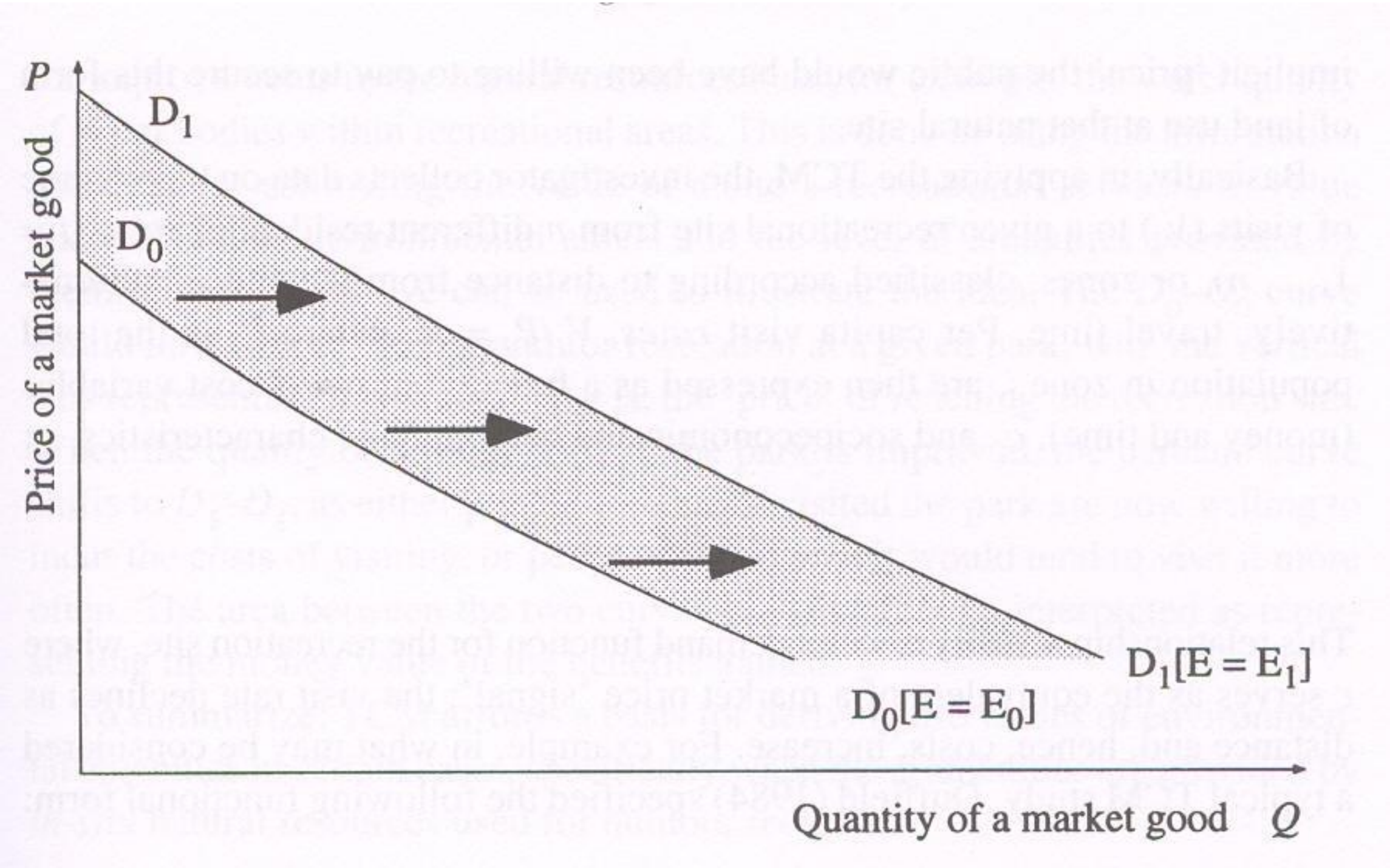
Indirect methods (surrogate markets)
- Travel Cost (TC)
- Hedonic Price (HP)

Direct methods (hypothetical markets)
- Contingent Valuation (CV)
- Choice Experiment (CE)

Example of a CE card

	Forest 1	Forest 2	Forest 3	None
				
Forest type Number of species Stand age Variation in tree age Ground vegetation	Mixed 5 100 years Two-aged Medium	Coniferous 1 70 years Even-aged Absent	Broad-leaved 4 70 years Even-aged Medium	
Tree spacing	 Regular	 Quasi-regular	 Irregular	
Forest edges	 Straight edges & no ecotone zone	 Convoluted edges & ecotone zone	 Convoluted edges & no ecotone zone	
Distance	5 km	30 km	15 km	
Your choice	○	○	○	○

<u>Idea of indirect valuation techniques</u> (after H. Folmer and H. L. Gabel 2000, p. 77)



Summary of the average global value of annual ecosystem services (Table 2 in Costanza *et al*. [1997])

- Numbers in the body of the table are given in 1994 \$ ha^{-1} $year^{-1}$.
- Row and column totals are in 10^9 \$ ha^{-1} $year^{-1}$,
- column totals are the sum of the products of the per ha services and the area of each biome, not the sum of the per ha services themselves.
- Empty cells indicate services that do not occur, are known to be negligible, or no data are available for.

Ecosystem serivces (1994 US$ $ha^{-1}\,yr^{-1}$)

Biome	Area ($ha \times 10^6$)	1 Gas regulation	2 Climate regulation	3 Disturbance regulation	4 Water regulation	5 Water supply	6 Erosion control	7 Soil formation	8 Nutrient cycling	9 Waste treatment	10 Pollination	11 Biological control	12 Habitat/ refugia	13 Food production	14 Raw materials	15 Genetic resources	16 Recreation	17 Cultural	Total value per ha ($ $ha^{-1}\,yr^{-1}$)	Total global flow value ($ $yr^{-1} \times 10^9$)
Marine	36,302																		577	20,949
Open ocean	33,200	38							118			5		15	0			76	252	8,381
Coastal	3,102			88					3,677			38	8	93	4		82	62	4,052	12,568
Estuaries	180			567					21,100			78	131	521	25		381	29	22,832	4,110
Seagrass/ algae beds	200								19,002						2				19,004	3,801
Coral reefs	62			2,750						58		5	7	220	27		3,008	1	6,075	375
Shelf	2,660								1,431			39		68	2			70	1,610	4,283
Terrestrial	15,323																		804	12,319
Forest	4,855		141	2	2	3	96	10	361	87		2		43	138	16	66	2	969	4,706
Tropical	1,900		223	5	6	8	245	10	922	87				32	315	41	112	2	2,007	3,813
Temperate/boreal	2,955		88		0			10		87		4		50	25		36	2	302	894
Grass/rangelands	3,898	7	0		3		29	1		87	25	23		67		0	2		232	906
Wetlands	330	133		4,539	15	3,800				4,177			304	256	106		574	881	14,785	4,879
Tidal marsh/ mangroves	165			1,839						6,696			169	466	162		658		9,990	1,648
Swamps/ floodplains	165	265		7,240	30	7,600				1,659			439	47	49		491	1,761	19,580	3,231
Lakes/rivers	200				5,445	2,117				665				41			230		8,498	1,700
Desert	1,925																			
Tundra	743																			
Ice/rock	1,640																			
Cropland	1,400										14	24		54					92	128
Urban	332																			
Total	51,625	1,341	684	1,779	1,115	1,692	576	53	17,075	2,277	117	417	124	1,386	721	79	815	3,015		33,268

Questions

Q-11. HPM (Hedonic Price Method) is a technique to value elements of the natural environment by

[a] asking consumers in order to estimate the demand for environmental goods or services whose market prices do not exist or they are difficult to be observed.

[b] <u>decomposing the price of a market good into elements linked to environmental quality, among other things</u>.

[c] identifying in the price of a good a component linked to its non-use value.

[d] estimating the demand based on econometrically splitting the price into use, option, and non-use values.

[e] none of these.

Exercises

E-11. In the Costanza *et al.* (1997) table (copied on page ERE-11-6) 1 hectare of boreal forest gives $50 of food production and $25 of raw materials. These numbers stay in sharp contrast with Polish empirical data. Why?

Environmental policy

- Effectiveness = reaching a goal
- Efficiency = maximizing the positive difference between benefits and costs (i.e. costs are justified in terms of benefits)
- Cost-effectiveness = reaching a goal at the least cost
- Equity = making the distribution of costs proportional to the distribution of benefits

Typical policy failures:

- Lack of cost-effectiveness
  - Use of standards
  - Politically motivated exemptions

- Compromising enforcement
  - Over-ambitious targets
  - Lack of monitoring capability

Environmental policy principles

Polluter Pays Principle (PPP) – two definitions in use

- In the broadest sense it means that the polluter is financially responsible for whatever harm its activities may cause
- PPP in a strict sense means that the polluter is financially responsible for complying with whatever environmental requirements are set by relevant authorities

Subsidies versus PPP

Subsidies considered consistent with PPP:

- The subsidy is granted for a determined time period, not longer than 5 years
- The subsidy does not favour specific economic agents (any agent who meets certain criteria is entitled)
- The subsidy does not lead to serious distortions in international trade

When strict financial responsibility of a polluter is difficult or impractical to enforce, governments sometimes apply the Polluters Pay Principle (note the plural form!) charging polluters the environmental protection costs at large

If an abatement facility is financially self-sufficient, then it can be said that the User Pays Principle applies, i.e. the users pay for its operation

Subsidiarity Principle – policy measures should be determined by the lowest level of authority suitable for a given problem.

Precautionary principle can be derived from game theory concepts and corresponds to the so-called minimax strategy, i.e. a strategy to minimize the worst possible outcome. Despite its popularity, it is not appropriate for "games" where the other player does not behave strategically.

Questions

Q-12. According to the OECD, the Polluter Pays Principle (in its narrow meaning) is not violated despite subsidizing environmental protection if the following condition holds:

[a] subsidies are offered not only to those who undertake more than required by environmental regulations.

[b] the level of subsidies is uniform for all polluters.

<u>[c] polluters are responsible for meeting the expenditures to abate up to what is required by law</u>.

[d] the subsidy programme has been adopted by a legislative body (e.g. the Parliament).

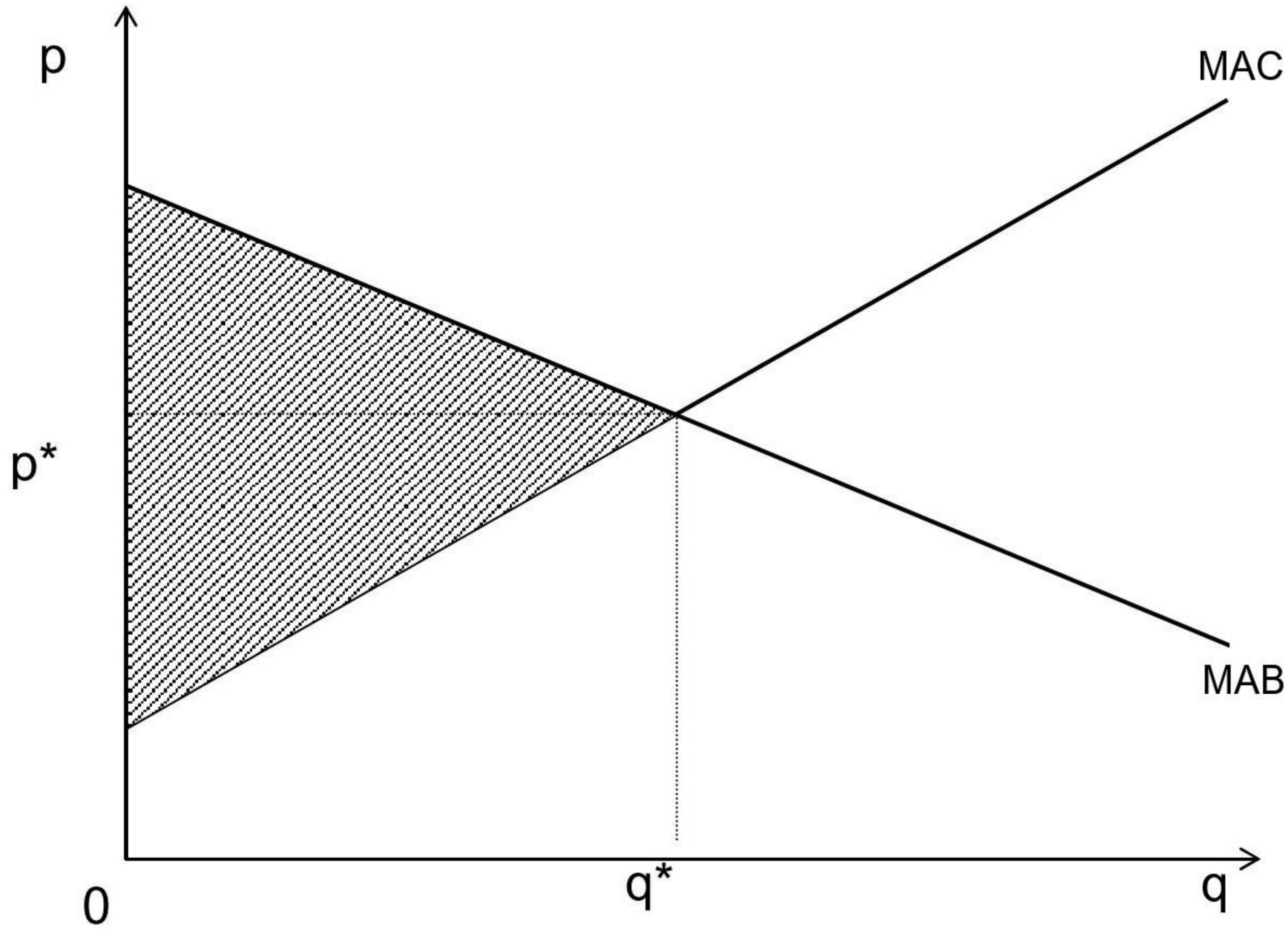
[e] none of these.

Exercises

E-12. Discuss implications of the precautionary principle for flying passenger airplanes.

Environmental policy instruments

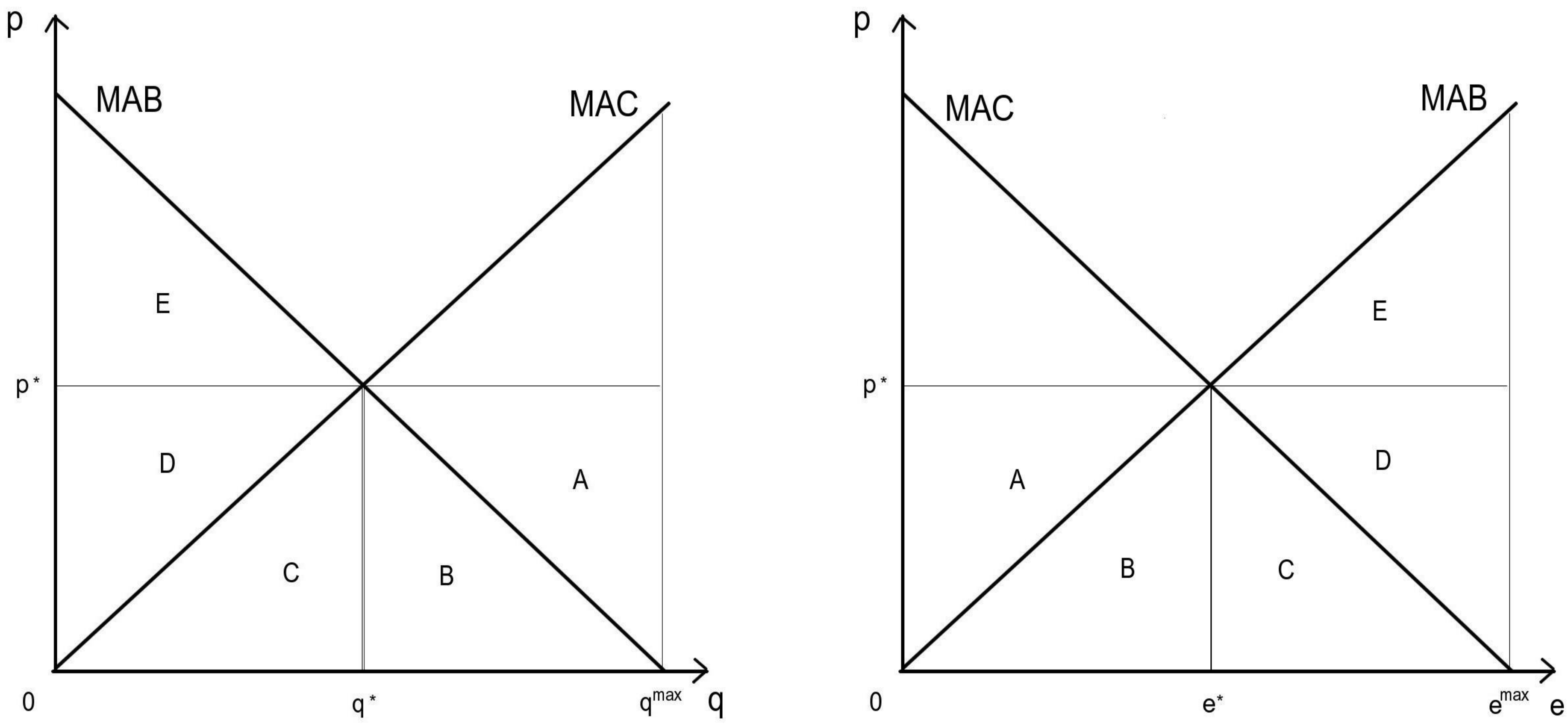
- Price (tax) instruments
  - Pigouvian taxes (with or without thresholds)
  - Sub-Pigouvian pollution charges
  - Non-compliance fees
- Quantity regulations
  - Standards
  - Non-tradable permits
  - Zoning
- Tradable permits
- Voluntary instruments
  - Moral suasion
  - Eco-labels
  - Voluntary agreements


p
MAC
p*
MAB
0
q*
q

Prevalence of quantity regulations

- Controversies about externality monetization
- Transaction and administrative costs

Political economy of environmental regulations



Controversies about voluntary instruments

- Is moral suasion fair?

- Do voluntary mechanisms deliver?
  - Example of the Dutch VOC 2000 agreement

- Are eco-labels reliable?
  - Example of the Finnish wood product certificates

Questions

Q-13. Eco-labels

[a] are gradually substituting for alternative instruments as they combine environmental certainty with consumer sovereignty.

[b] are trusted only when they are given by international environmental authorities.

[c] have been banned by most governments in developed market economies.

[d] unambiguously identify environmentally-friendliest products.

<u>[e] none of these</u>.

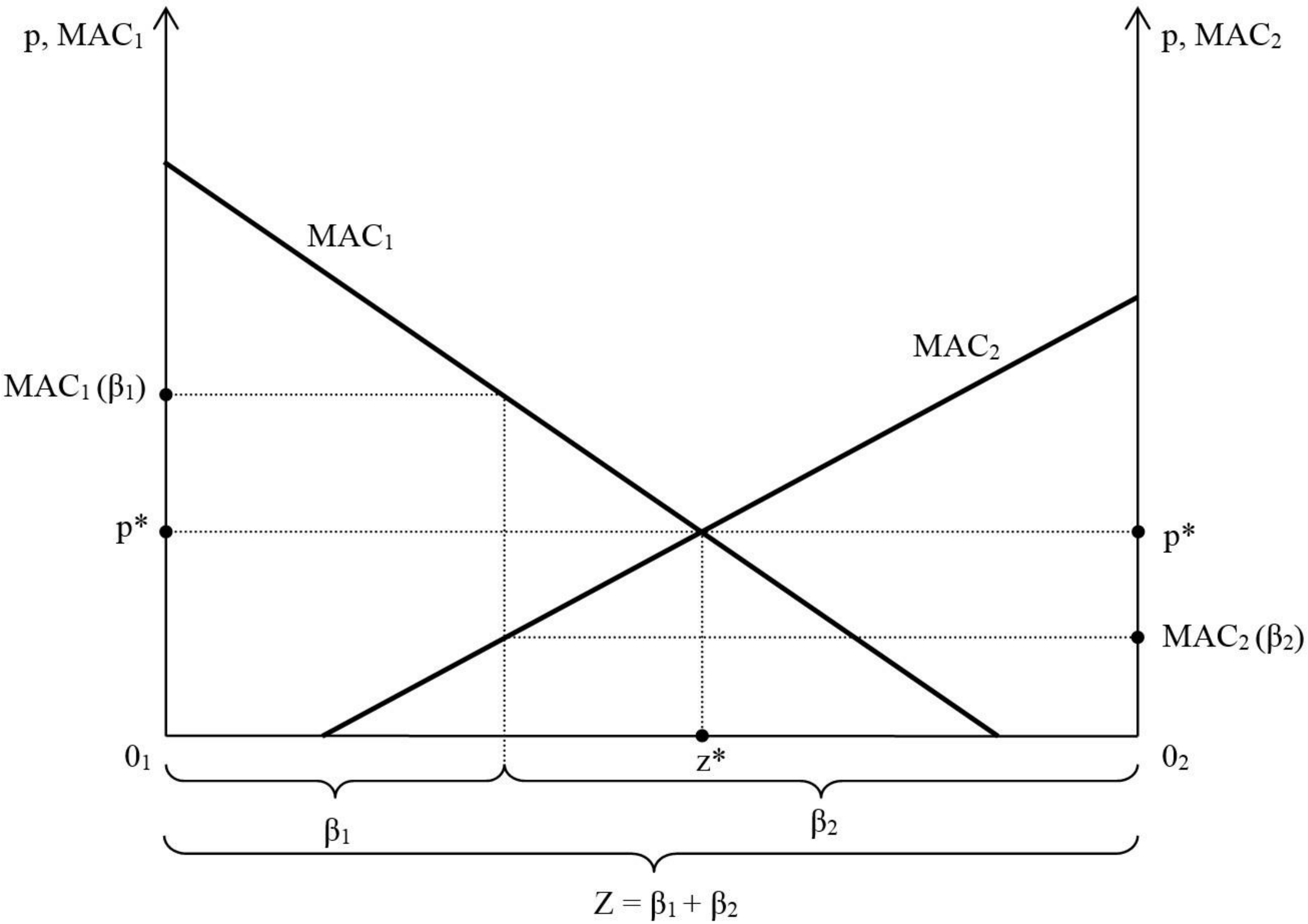
Exercises

E-13. In many countries there is a requirement to have catalytic converters in newly registered cars. Such converters reduce the emission of nitrogen oxides from 2 g/km to 0.2 g/km (i.e. by 90%). Please discuss the cost-effectiveness of this requirement.

Tradable permits

Theory

- Minimization of the cost of meeting whatever environmental targets adopted
- Crocker (1966)
- Montgomery (1972)
- Initial allocation
  - Grandfathering
  - Auction
  - Hybrid methods



p, MAC1
p, MAC2
MAC1
MAC2
MAC1 (β1)
p*
p*
MAC2 (β2)
01
z*
02
β1
β2
Z = β1 + β2

H.E. Daly (1992)

- Scale (to be determined by ecologists)
- Allocation (to be determined by market forces)
- Tradable permits separate scale and allocation decisions

In loading a boat we also have the problems of allocation and scale – allocating or balancing the load is one problem (a microeconomic problem), and not overloading even a well-balanced boat is another problem (a macroeconomic problem). To avoid overloading and sinking even a well-balanced boat we have a Plimsoll line defining an absolute scale limit. But the boat can be well or badly balanced even when the water line is far below the Plimsoll mark. And if the water line is above the Plimsoll mark, rearranging the load will be only a small help. Economists who are obsessed with allocation to the exclusion of scale really deserve the environmentalists' criticism that they are busy rearranging deck chairs on the Titanic.

Variants of tradable permits:

1. Absolute limit ("cap-and-trade", "harvest quota", etc.)
2. Credit system
3. Relative limit
4. Hybrid solutions

Early applications (USA)

- Offsets (in non-attainment areas)
- Bubbles (in any regions)
- Cap-and-trade (*versus* "reduction credits")
- Fox River

Phasing-out lead additives (USA)

- 1981-1986
- Flexibility
- Steady and gradual improvement
- Cost savings of 0.3 B$ per annum

Non-pollution applications

- Marketable Harvest Quotas
- Tradable Development Rights

European applications

- Scepticism until the late 1990s
- Kyoto Protocol (1997) promotes "emissions trading" of carbon dioxide and other greenhouse gases
- Directive 2003/87/EC
- Poor performance of ETS
  - "Pilot phases"
  - *Backloading* and other administrative "corrections"
  - Co-existence with other instruments

Advantages of tradable permits

1. Ideal implementation of the cost effectiveness
2. Separation of scale and allocation decisions
3. Freeing administration from the necessity to take into account individual circumstances of economic agents (polluters)
4. Possibility of reaching environmental objectives gradually

Questions

Q-14. The ETS

<u>[a] covers several thousands of European stationary emitters.</u>
[b] does not allow international transactions.
[c] takes into account all air pollutants.
[d] takes into account the growing European emission of greenhouse gases.
[e] none of these.

Exercises

E-14. Please explain why emissions trading cannot be easily reconciled with subsidies for emission reductions.

Environmental tax reform (ETR)

- Tax bads not goods!

- In Poland (2022), VAT, excise, CIT, PIT provided 230 BPLN, 80 BPLN, 70 BPLN, and 68 BPLN, respectively (the state budget revenues were 505 BPLN, of which tax revenues were 465 BPLN)

- Emission charges were less than 2 BPLN, i.e. much less than 1% of tax revenues

Tax bads not goods!

Polish 2022 budget [BPLN]

Total		505
Including taxes		*465*
Of which:		
	VAT	230
	Excise	80
	Including fuels	*34*
	PIT	68
	CIT	70

- Environmentally-motivated taxes = taxes levied on externality-generating activities and natural resource extraction
- In Poland excise tax on motor fuels (mainly gasoline and diesel oil) provides 34 BPLN
- In Poland, environmentally-related taxes account for 3% of GDP (2%-4% in EU); only in Denmark – 6%
- Except for energy taxes, they self-erode the tax base

The double-dividend argument:

Environmentally-related taxes:

- reduce externality (i.e. improve efficiency) – "the first dividend"; and
- can reduce labour/capital taxation – "the second dividend".

Critique:

- based on general equilibrium models, their effect can be ambiguous
- existence of distortionary taxes may lower or even eliminate "the second dividend"

No minister of finance in the world was convinced of the double-dividend argument

Reasons for not introducing ETR:

1. "Political economy"
2. Self-erosion of the tax base (energy is the only commodity without a risk of the total elimination of the tax base)
3. Doubts with respect to arguments about multiple dividends (double dividend, triple dividend, etc.)

Questions

Q-15. Environmental taxes

[a] have motivated Polish firms to achieve cost-effectiveness in their abatement activities.

<u>[b] may lead to eroding their base by the elimination of polluting activities and/or products</u>.

[c] allowed the Swedish government to significantly limit the budgetary role of traditional taxes such as VAT, PIT, CIT etc.

[d] are widely applied in developed market economies as an economically efficient instrument of environmental policies.

[e] none of these.

Exercises

E-15. Why does Italy have several times higher tax rate on gasoline than the USA. Please offer an explanation.

Outline solutions to exercises

E-1. According to the notation adopted, TAB(x)=6x-x^2/10, and TAC(x)=x^2/10. First of all we need to calculate MAB(x)=dTAB(x)/dx=10-x/5, and MAC(x)=dTAC(x)/dx=x/5. Solving the equation 6-x/5=x/5 yields x=15. The economically justified level of noise is thus 45 dB.

E-2. The difference between a Pareto Optimum and a Generalized Pareto Optimum is in the condition that the former refers to one welfare criterion only, while the latter admits that welfare may depend on something more, e.g. on the "utility" of enjoying a good or suffering from a bad. For instance, let two consumers have one apple each. Both would prefer to have two apples rather than one. Hence it is impossible to reallocate these two apples to let them both avoid losing welfare simultaneously. Consequently, the allocation is a Pareto optimum. However, let us assume that the first consumer derives the utility of 3 euros from having an apple, while the second consumer – only 1 euro. Under these circumstances, social welfare will increase if the second consumer gives his/her apple to the first one (the total welfare is 3+1=4 before the transfer, and 3+3=6 after the transfer). Thus the initial allocation (one apple per one consumer each) was not a Generalized Pareto Optimum. Please note that a Generalized Pareto Optimum can be achieved spontaneously if the first consumer makes an offer e.g. "I will pay 2 euros for one apple". If the transaction is carried out, the first one is better of (enjoying the utility of 3+3-2=4, instead of 3), but the second one is better of either (enjoying the utility of

0+2=2, instead of 1). Therefore the transaction is likely to occur if the consumers are free to negotiate.

E-3. Using the notation introduced in the lecture: $MEC(q) = 2q+1$; $MSC(q) = 4q+4$; $MSB(q) = MPB(q) = 22-2q$. Therefore the socially optimum production is: $q^{opt} = 3$ (solves the equation $4q+4 = 22-2q$). By definition of the Pigouvian tax, its rate is $MEC(q^{opt}) = 7$. The tax will let the production decrease to the social optimum of $q^{opt} = 3$ (from the private optimum of $q^{*} = 19/4$ calculated by solving the equation $MPC(q) = MPB(q)$). In order to correct the market failure the tax does not have to be imposed on every unit of production. The tax can be imposed above any given level (e.g. the private optimum). This can be demonstrated either graphically, or simply by looking at the definition

$$PT(q)=MEC(q^{opt})(q-q_{threshold}),$$

where $q_{threshold}$ serves as an arbitrary threshold.

E-4. The traditional (not coded) TV is a public good, since non-rivalry and non-exclusion principles hold (it would be very costly to chase TV users who do not finance a given broadcasting station while viewing its programme). However, if the programme is coded, then TV users cannot view a programme without paying for a decoder (which is a private good). Consequently it this case the non-exclusion principle does not hold: a broadcasting station that codes its programmes can easily exclude TV users who do not pay for decoding. Please note that the non-rivalry principle holds (the broadcasting cost does not depend on the number of users).

E-5. In principle, one can buy insurance against anything. In particular, I can ask for an insurance such that I pay the price of x euros every month and I get a compensation of y euros for an incident of being offended. However, professional insurance companies compare the revenues (x every month) with the risk of paying compensation (y per every incident per month). They offer the price x if they expect that – on average – they will not lose the money. The key element of this calculation is the probability of an incident. Some victims are more likely to be involved, and some are less. Let us assume for a while that 50% of the people ask for a trouble, and 50% try to avoid problems. When offering a price (x = E(y) + some markup), the insurance company has to take the average. As a result, the price offered will be attractive for a person who asks for a trouble (since the amount of expected compensation will be higher than the price), and not attractive for a person who tries to avoid problems. Consequently, people who belong to the first category will be overrepresented among prospective insured. More than 50% of buyers will come from the category of trouble-seekers. Economists call it "adverse selection" leading to the elimination of such a market. The probability of "being offended" cannot be easily estimated. Therefore "being offended" is not likely to be the subject of an insurance policy.

E-6. This is a slightly modified version of the example calculated in the class. The windmill project has the following cash flow: $X_1 = -1{,}500{,}000$, and $X_2 = X_3 = \ldots = X_{31} = 80{,}000$, since 2,000x40=80,000. By the way, if discounting is ignored, it will pay off after 18 years (in the year 19 – for the first time – the net accumulated revenue of 1,520,000 will be higher than the investment cost of 1,500,000). If a discount rate is taken into account, the analysis becomes more complex. One needs to calculate r^* such that

$$1{,}500{,}000=80{,}000/(1+r^*)+80{,}000/(1+r^*)^2+80{,}000/(1+r^*)^3+\ldots+80{,}000/(1+r^*)^{30}.$$

This is an algebraic equation of the 30th degree. There are no formulae to find its solutions analytically. However there are software packages that find solutions numerically. The problem can be solved using, for instance, Microsoft Excel. The result is 3.3%. If money is available to the investor at the price of, say, 3%, then the project makes sense. If the cost of money is, say, 4%, the project is economically inefficient.

E-7. First of all, one needs to check whether the Hotelling rule applies in this case. It does, if works of art cannot be reproduced (of course, everything – even Mona Lisa – can be reproduced, but only the original is characterized by the price that makes it interesting for an investor). Thus they are exhaustible, and the Hotelling rule applies. Investing in a work of art makes economic sense if one expects that the ownership rent will grow faster than money deposited in a bank (more precisely, if the rate of return will be more attractive than on alternative investments). Investors look at rents, not at prices, since – as a rule – they have to incur some costs of keeping a work of art (e.g. protection, insurance, air conditioning etc.). As stated in the class, the Hotelling rule ignores satisfaction from looking at a work of art. If investor derives some utility (or receives revenues from displaying the work of art) any additional benefits need to be subtracted from the costs that decrease the rent. Buying a work of art makes economic sense, if one expects that the rent's rate of growth will be higher than the discount rate. Selling a work of art makes economic sense, if one expects that the rent's rate of growth will be lower than the discount rate.

E-8. The Faustmann rule recommends that a tree is cut once it hits the optimum rotation period (tree is "mature" in a sense that its future growth will add to its market value less than the discount rate). For many tree species growing in Europe this optimum rotation period is 50 years or less. Older trees, however, are more attractive both from the recreation and biodiversity perspective (people prefer an old forest than a young one; many birds find food and nesting space in old – perhaps even somewhat rotten – trees; and so on). Timber sold contributes to foresters' profits. Keeping old trees is socially valuable, but it may not contribute to foresters' revenues. Thus from their financial perspective, old trees should be cut. If the foresters are to keep old trees, they need to be compensated. One way to solve the problem is to offer foresters a privileged tax status: they pay lower taxes (reflecting social benefits provided by old trees) if they keep old trees. An alternative solution is to "buy" ecosystem services from those who provide them. In some countries foresters who keep old trees are paid by the government. Yet another approach is to leave the solution to market forces. For instance, if old forest is more attractive to tourists then foresters can better "sell" camping or picnicking services. A hybrid solution is to let foresters sell commercially what can be sold in this way, and sign "conservation contracts" (with institutions sensitive to the value of other public goods provided by old forests). Of course, there is a "non-economic" solution to expropriate foresters and to establish public management there, but many people would like to avoid it.

E-9. Sustainable harvesting means that fishermen are allowed to harvest only the annual increment of the stock, i.e. G (which is an "inverted U" function with values 0 when the stock is 0 or it is equal to its maximum of 400). Thus the fishermen revenue function is

$$TR(x) = GP = -x^2/2500+4x/25$$

in million PLN (the price P=500 PLN/tonne is 0.5 MPLN/1000t). Its maximum, i.e. MSY (16), is for the stock x=200 thousand tonnes. For any $x \in [0,400]$, the profit function is

$$\pi(x) = TR(x)-TC(x) = -x^2/2500+4x/25-(48-3x/25) = -x^2/2500+7x/25-48.$$

Profit is maximised when x=350 (π_{max}=TR(350)-TC(350)=7-6=1). Profit vanishes, $\pi(x)=0$, when x=400 (maximum capacity, i.e. no cost and no increment to be harvested) or x= 300. Using the lecture definitions, the stock corresponding to the Maximum Sustainable Yield, x_{MSY}, is 200 (by the way, $\pi(x_{MSY})$=TR(200)-TC(200)=16-24=-8<0), the bionomic equilibrium – when TR(x)=TC(x)=12 – is 300 (x_∞=300), and the profit is maximised when the stock is 350 (x^*=350). These numbers are not very far from what can be observed in the Baltic Sea herring fishery. Please note that a graph in this exercise is a mirror image of the graph displayed in the class. The horizontal axis of the graph analysed in the class corresponded to E (harvest effort) rather than x (stock); in the Gordon-Schaefer model they go in different directions (when the population increases, the effort decreases, because the latter is defined in terms of a fraction of the annual increment harvested, and *vice versa*). Please also note that bionomic equilibrium can be either to the left or right of x_{MSY} (in this exercise it was higher than x_{MSY}); note that for $x<x_{\infty}$ the profit is negative; bionomic equilibrium always corresponds to the stock lower than x^* ($x_{\infty}<x^*$).

E-10. The fact that HDI increases when GDP per capita increases is obvious. If a country is wealthier it can spend more on everything that HDI captures (teachers, hospital beds, etc.). However, it is not a linear function. If the GDP per capita is low then every increase can correspond to spending more on social services; thus it translates into a rapid increase in HDI. If the GDP per capita is high then despite higher spending on everything (including health), it does not translate into a spectacular increase in HDI elements (say, life expectancy). If the relationship is such that absolute changes do not translate into proportional outcomes, economists try to fit a logarithmic function.

E-11. Costanza *et al.* (1997) numbers reflect global averages. Many people rely on forest resources to feed themselves. Also in Poland food collected in forests (e.g. berries and mushrooms) adds to the daily diet, but its contribution is rather small. On the contrary, commercially produced timber provides for significant revenues. Even on a sustainable basis (when foresters cut only the annual increment, i.e. 4 m^3/ha), these revenues make roughly 600 PLN/ha. Additional discrepancies are related to "Recreation" (column 16). It says $36, while empirical findings for Poland are much higher. This does not imply that the numbers quoted in the table are wrong (they may reflect world averages). It simply means that in specific geographical locations, the economic value of ecosystem services can be different.

E-12. Precautionary Principle implies the necessity of basing decisions on the worst scenario. In the case of a passenger flight it is a crash. Nobody would like to die in such a crash. Hence nobody should choose to fly airplanes. Of course, this contradicts to what most of us do. Therefore more nuanced versions of the Precautionary Principle are usually advocated for. However, when one takes into account probabilities of the worst scenario, and benefits from avoiding this worst scenario, then it turns out that meaningful decision rules have to apply concepts analysed traditionally in economic theory (such as costs and benefits).

E-13. The cost effectiveness is violated. To see this, please note that some cars make 1000 km per year, and some 100,000 km per year. The amount of nitrogen oxide emissions avoided is 1.8 kg per year (90% of 2 kg) in the first case, and 180 kg per year (90% of 200 kg) in the second case. Therefore the cost of the catalytic converter (the same in both cases) is paid in order to abate 100 times more in the second case. To be more specific, let us assume that the cost of the catalytic converter is 300 euro. Let us also assume that the damage done by 1 kg of nitrogen emission is 11 euro (the number adopted in many European projects on externalities). Thus, if a car drives 15,000 km per year, the cost of the catalytic converter is justified by the damages avoided in just one year (297 euro). Actually the converter works more than a year, and it reduces the emission of some other pollutants as well. Thus its installation is justified even in cars that drive less. The cost effectiveness requires that cars making, say, 100,000 km per year should be equipped with more sophisticated (and perhaps more expensive) converters, while those making less – with less sophisticated abatement equipment. Nevertheless there are other reasons behind the fact that many governments introduced the uniform catalytic converter requirements for all cars (irrespective of the expected intensity of usage).

E-14. Emissions trading starts from a certain cap for the total emission, and allows emitters to buy unused emission rights from those who reduced emission by more than required. For instance, in the European Union there is a cap for the total carbon dioxide emission (disaggregated to individual installations – power plants, and other polluters). Individual installations can emit more than the number of permits held, if they buy permits from those who emitted less carbon dioxide than allowed. A typical decision taken by a traditional power plant (i.e. burning fossil fuels) is to invest in renewable installations (windmills, photovoltaics, hydropower etc.). By doing so, the plant can increase its sales without buying extra permits, thus saving on costs; it would have done this anyway. If there is a subsidy for renewable energy, the plant claims additional revenues for what it would have done anyway. From the plant's point of view this is an extra gain. However, from the public budget point of view this is a waste of resources, since – without any detriment to the total carbon dioxide emission – the money could have been spent on something else.

E-15. The Italian tax on gasoline is almost 0.76 euro/litre, and the American – slightly more than 0.07 euro/litre. The former is thus roughly 10 times higher than the latter. There are several explanations of this phenomenon; they refer to history, political science, economics, geology etc. One interesting explanation refers to Fiat (a well-known Italian car manufacturer) and Ford (an American manufacturer). Fiat has always produced small fuel-efficient cars, while Fords are much larger and they used to be much less fuel efficient. At the same time, Italy is densely populated, and its citizens do not have to travel vast distances every day. On the contrary, United States is sparsely populated, and Americans have to travel long distances. Hence it is quite obvious that Italians (especially those who drive small Fiats) are less sensitive to fuel prices than Americans (especially those who drive large Fords). It is difficult, however, to indicate the direction of causality. Do Italians agree to high fuel prices because they do not have to spend a lot of money on travelling, or it is the other way around: fuel-efficient cars became a necessity as a result of high fuel prices? If the direction of causality is difficult to determine, economists (and ecologists) talk about "co-evolution", i.e. two evolving processes difficult to reverse, because of their mutually reinforcing relationship. In other words, the Italian evolution of car manufacturing towards small cars was at least partially driven by high fuel taxes, but perhaps it was the other way around: Italian governments were keen on increasing gasoline taxes, as it helped Fiat to win competition against cars imported from the USA. In the USA low gasoline prices helped to develop the production of large fuel-thirsty cars; or it was the other way around: Ford was successful at lobbying against gasoline tax increases. Irrespective of the direction of causality, the initial stimulus came probably from the fact that, unlike the USA, Italy is densely populated.