Lecture 2

ECON 4910, Environmental Economics

Spring 2008

Benefits and damages of pollution

- Last time:
- Benefits of pollution: Pollution contributes to production of private goods
  - For given inputs of labor and capital (not explicitly modelled), more private goods can be produced if pollution is allowed to increase (up to a certain point).
  - $B(M)=\sum_j f_j(m_j)$
  - Concave production functions give concave B(M).
- Today:
- Damages:
  - Consumers prefer good environmental quality; pollution decreases this quality

Today and next time

- Pareto efficiency
- Market outomes
- Bargaining
- Environmental policy instruments
  - Taxes
  - Subsidies
  - Licences (emission caps, abatement requirements)
  - Tradeable permits

From last time

- If we allow production functions to differ between firms, model equations from last time can be written

(1) $y_j = f_j(m_j)$ Firm *j*'s production of *x*

(2) $\pi_j = f_j(m_j) - b - \tau m_j$ Firm *j*'s profit

(3) $f_j'(m_j) = \tau$ 1.o.c. for profit max.

- If the price of emissions $\tau = 0$: Firm j emits $m_j^{\wedge}$, where $f_j'(m_j^{\wedge}) = 0$

Environmental quality

- Uniformly mixing flow pollutant
  - Environmental quality E (e.g. visibility, water quality) depends on the sum of emissions, not on the distribution between emitters

(4) $E = E^0 - z(M) = E^0 - z(\sum_k m_k)$

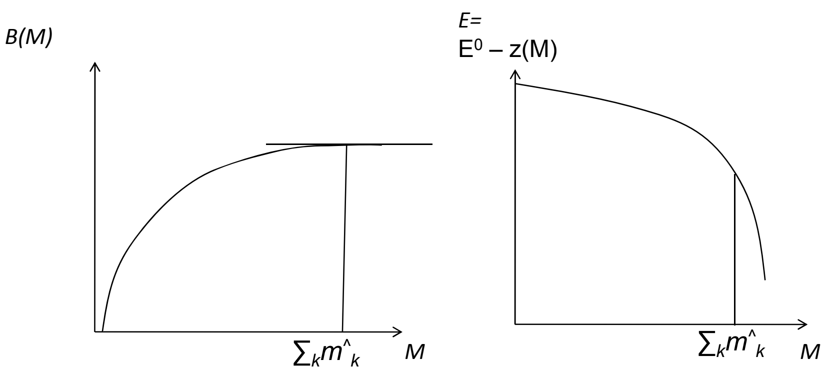
for $k = 1,\dots,K$, where K = # of firms, E^0=initial env. quality

- z(M) = physical damages
- Assume z increasing and convex: $z' > 0$, $z'' \geq 0$
  - marginal physical damages increasing in M
- If $\tau = 0$, and firms max. profits, environmental quality will be

$$E = E^0 - z(\sum_k m^{\wedge}_k)$$

– because no firm will abate.

Emissions and environmental quality; no regulation, production to consumption externality



The damage function D(M)

- Damages to what, or whom, valued how?
- Physical damages of emissions, z(M)?
  - How can those be compared to benefits B(M) in units of the numeraire good (or money)?
- Individual utility of M?
  - How to compare utility to B(M) (consumption good units)?
  - Preferences vary: Whose utility?
- Social welfare?
  - If conflicts of interest: Which normative criterion/ social welfare function to use?
- Here: Consumers' preferences
- How to find an *aggregate* benefit measure in units of the numeraire, *x*?

Preferences

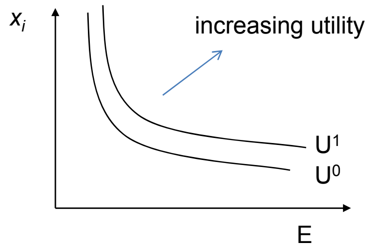
- Population: *n* consumers
- Consider a single consumer *i*
- *i*'s preferences:

  (5) $U_i = u_i(x_i, E)$

  where u_i = *i*'s utility function (preferences may differ from others'), and x_i = *i*'s private good consumption
- Assume u_i quasiconcave:
  - Indifference curves curved towards origo: The more available of one good, the more one is willing to give up of this good to get more of the other (keeping utility constant)

Quasiconcave utility

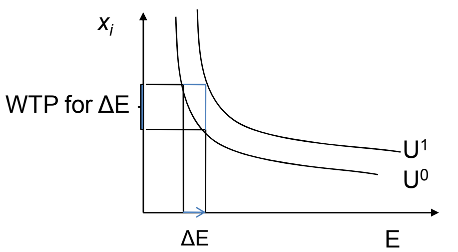
- We cannot measure utility (”utils”) directly
- But as long as the consumer is unsatiated, increasing consumption of one good while keeping the other fixed will increase utility.



- If we change E and keep x_i fixed, U_i increases
- How much?

Willingness to pay

- Consider a discrete change in E, ΔE
- E is a public good
  - If provided, *i* gets ΔE regardless of who provided/who paid
  - Consider only benefits, disregard costs here.
- How much *x* can we take from the consumer while keeping her at U^0?



- On the margin: WTP for increased E = Required compensation for red. E = marg. rate of substitution

Formal derivation of MWTP

- How large change in income dx_i offsets exactly, in utility terms, a marginal change dE in environmental quality?
- Utility is $U_i = u_i(x_i, E)$
- Differentiating, assuming utility is kept constant:
- $dU_i = u'_{ix}dx_i + u'_{iE}\, dE = 0$

  $u'_{ix}dx_i = - u'_{iE}\, dE$

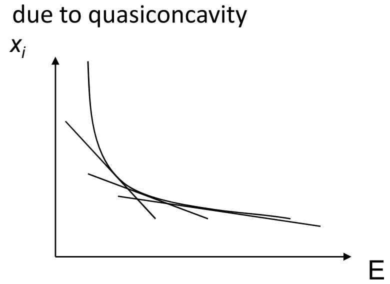
  $dx_i = -(u'_{iE} / u'_{ix})dE$
- Marginal WTP (required compensation) dx_i is given by the marginal rate of substitution times the increase (reduction) in E:
- $dx_i = MWTP_i = -(u'_{iE} / u'_{ix})dE$

  $= (u'_{iE} / u'_{ix})z'dM$ (ref. physical damages, eq. 4)

- Measure of benefits to *i* from a marginal change in the pollution level, in units of the numeraire *x*.

Properties of individual damages

- MWTP= the amount of x the consumer can give up in exchange for a marginal increase in E, without changing her utility
- For a *given* utility level, MWTP decreases with E
  - due to quasiconcavity



- $MWTP_i = -(u'_{iE} / u'_{ix})dE = (u'_{iE} / u'_{ix})z'dM$
- $z' > 0$ (by assumption)
- (u'_{iE} / u'_{ix}) is decreasing in E and thus decreasing in M
- $MWTP_i$ is increasing in M: Individual damages are convex

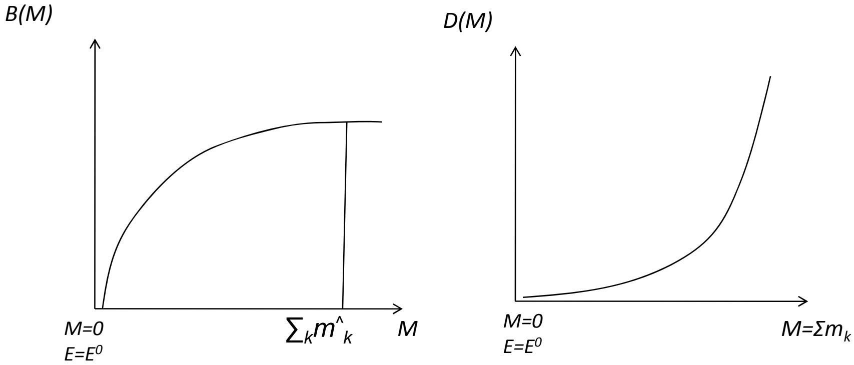
Aggregation of damages: Pareto efficiency

- For now: Focus on Pareto efficiency
- Assume
  - Perfect information (e.g., preferences are known)
  - Feasible lump-sum transfers
- Consider an increase in emissions, dM
- If the sum of all consumers' MWTP to avoid this increase is less than the productivity gain, B'dM, every consumer can be compensated for his/her loss and be at least as well off as before
  - Interests of conflict can potentially be eliminated
  - We can focus on efficiency, leaving distributional issues to be considered separately.

Properties of damage function D(M)

- D(M): Aggregate willingness to pay to avoid pollution level M
  - the value of physical damages, measured in units of *x*
- Physical damages to E: increasing and convex in M
  - If consumers' MWTP are constant or increasing in M, D(M) would be increasing and convex too
- This is secured by quasiconcave preferences
- Usually: More relevant to consider small changes than elimination of all pollution
  - marginal properties of the damage function more interesting than D(M) itself

Aggregate production (benefits) and damages



From last time: Max NB when B'=D'

Can this hold at $\sum_k m^{\wedge}_k$?

Pareto optimality

- In the specific model,
  - $B'(M) = f_j'(m_j)$
  - $D'(M) = \sum_i (u'_{iE} / u'_{ix}) z'(M)$ for all $i = 1, \ldots, n$
- Max NB is equivalent to PO under our conditions
- Hence, PO requires
  - $f_j'(m_j) = \sum_i (u'_{iE} / u'_{ix}) z'(M)$
  - That is, the **marginal abatement cost equals the sum of marginal willingness to pay** to avoid the marginal unit of pollution
  - Samuelsonian condition

Pareto efficiency, analytical solution

Max $u_i(x_i, E) = u_i(x_i, E^0 - z(\sum_{k=1}^{K} m_k))$ with respect to $x_i, ..., x_n, m_1, ..., m_K$
s.t.

$$\sum_{j=1}^{n} x_j = \sum_{k=1}^{K} f_k(m_k) \quad (1)$$

$$u_j(x_j, E^0 - z(\sum_{k=1}^{K} m_k)) = U_j^0 \text{ for every } j \neq i \quad (2)$$

This gives the Lagrangian

$$\begin{aligned} \mathcal{L} \;=\; & u_i(x_i, E^0 - z(\sum_{k=1}^{K} m_k)) \\ & -\lambda[\sum_{j=1}^{n} x_j - \sum_{k=1}^{K} f_k(m_k)] \\ & -\sum_{j \neq i} \mu_j [u_j(x_j, E^0 - z(\sum_{k=1}^{K} m_k)) - U_j^0] \end{aligned}$$

First order conditions, PO

$$f'_k = f'_l$$

$$f'_k = \sum_{j=1}^{n} \frac{u'_{jE}}{u'_{jx}} z'$$

That is:
Marginal productivity (marginal abatement cost) should be equal for each firm
This marginal productivity should equal *the sum* of all marginal willingness to pay to reduce M.
In other words: The benefit of increasing M, in terms of more production of x, should equal the costs of increasing M, in terms of consumers' valuation of the reduced environmental quality.

Unregulated market outcome

- Profit max. producers: $f_j'(m_j) = 0$ (*)
- PO requirement: $f_j'(m_j) = \sum_i (u'_{iE} / u'_{ix}) z'(M)$ (**)
- (*) and (**) cannot hold simultaneously
  - by assumption: u'_{iE} and $u'_{ix} > 0$
  - by assumption: $z'(M)>0$
  - The market solution is not Pareto efficient: It gives too much pollution.
- Is public regulation needed, or are there other solutions?

The role of consumers

- So far, consumers make no choices
- Firms pollute because it is profitable
- Why don't consumers offer firms a payment to reduce their pollution?
  - If firms accept, we may get a Pareto improvement
- Coase (1960):
  - If there are no transaction costs, and property rights are established, bargaining can ensure Pareto efficiency, even when there are external effects
  - This holds regardless of who has the property right: The polluter or the victim
- Let us introduce consumers' option of "bribing" firms to reduce pollution

Paying for a better environment: Voluntary contributions to a public good

- Let consumer *i*'s budget constraint be

  (6) $x_i + g_i = F_i$

  where g_i is *i*'s payment to reduce emissions, and F_i is *i*'s exogenously fixed income.
- The marginal abatement cost is f'_k
- If there is initially no regulation (and no bargaining): $f'_k = 0$
- Then, if a consumer offers a firm a price >0 for reducing emissions marginally, the firm can profit from accepting

The consumer's problem

- Assume that the price of reduced emissions corresponds to the marginal abatement cost f'_k
  - Individual consumers consider this "price" fixed
  - Then, $g_i = f'_k a_i$ where a_i is the abatement purchased by *i*
- The consumer's problem is

  Max $U_i = u_i(x_i, E^0 - z(M))$

  s.t. $x_i + f'_k a_i = F_i$ and

  $M = \sum_k m_k^W - (\sum_j a_j)$

where m_k^W= emissions from firm k without bargaining.

Inserting:

$u_i(F_i - f'_k a_i, E^0 - z(\sum_k m_k^W - (\sum_j a_j)))$

Max this wrt a_i gives f.o.c.:

$-u'_{ix} f'_k + u'_{iE} z' = 0$ or $(u'_{iE}/u'_{ix}) z' = f'_k$

- The consumer contributes until his MWTP = abatement cost
- Condition for PO: *Sum* of MWTP should equal abatement cost

Bargaining

- Single consumer: Will prefer to ”bribe” firms until MWTP=marg. abatement cost
  - assumes no transaction cost
  - solves the problem of external effects
  - does not solve the free-ride problem of public goods
- To reach Pareto optimal level through bargaining:
  - Make binding contract, where each contributes his WTP, such that $\sum_j (u'_{iE}/u'_{ix})\, z' = f'_k$
  - In that case: Each has an incentive to break the contract and free-ride on others’ contributions
- Consumers may contribute something voluntarily
  - but not enough
  - altruistic preferences/moral motivation /social sanctions: more on this later!

Next time

- More on environmental policy:
- Command and control measures
- Environmental taxes
- Abatement subsidies
- Tradable permits