ECON1922 spring 2024

University of Oslo

SOLUTION PROPOSAL

Problem 1. Flow pollution (20 points)

Consider a simple static model with flow pollution. Emissions are given by E. Environmental damages (in \$) are given by an increasing and convex function of emissions, $D(E)$. Without any pollution control, total emissions are given by $E = E_0$. Abatement is denoted by R. Abatement costs (in \$) are given by an increasing and convex function of abatement $C(R)$. Total abatement is given by $R = E_0 - E$. Total welfare costs are given by the sum of environmental damages and abatement costs.

a) (10 points – words and figure)
Illustrate marginal environmental damages and marginal abatement costs in a diagram with emissions measured along the x-axis. Explain how the optimal level of pollution E^* is determined.

Solution key:

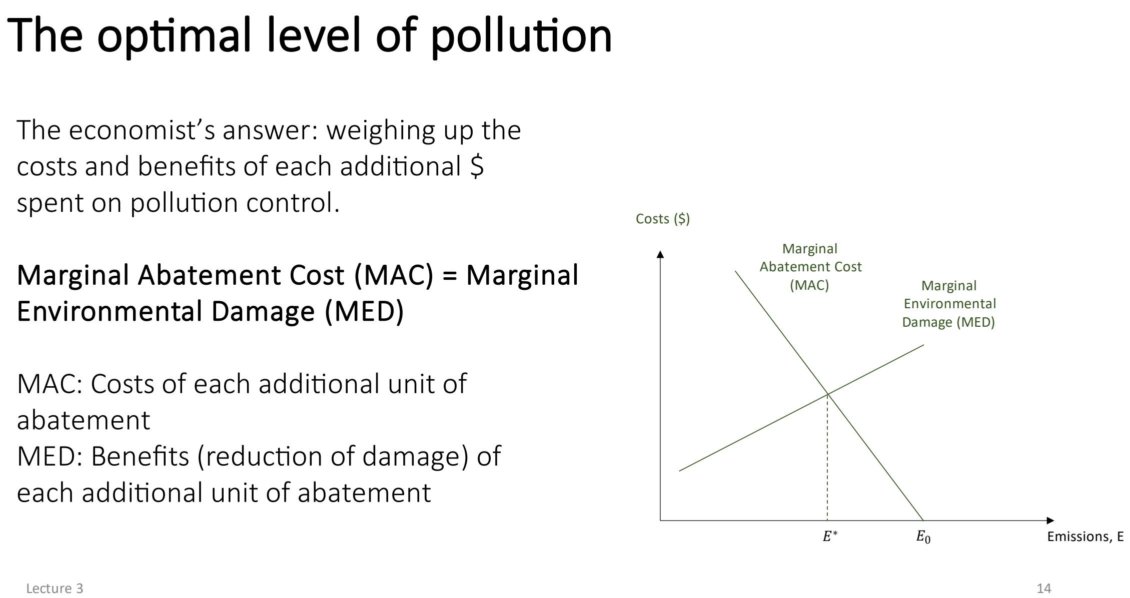
The optimal level of pollution is discussed in Smith, S. (2011), chapter 2.

The students are expected to explain what marginal abatement costs (MAC) and marginal environmental damages (MED) measure, and what it means that we assume that

(i) damages are given by an increasing and convex function of emissions
(ii) abatement costs are given by an increasing and convex function of abatement

The optimal level of pollution is determined by the emission level that equalizes MAC to MED. The students are expected to explain that MAC=MED maximizes the net benefit to society.

Relevant lecture slides:



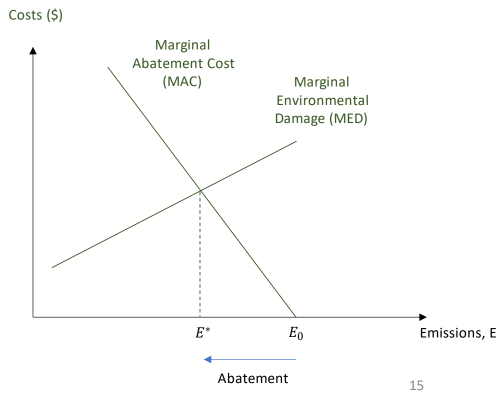
The optimal level of pollution

Assume, at the outset, that $E = E_0$.

The first tonne of pollution abatement is beneficial, because the benefit (reduced damage) exceeds the cost.

Abatement is beneficial until $E = E^*$, where (MAC=MED).

If $E < E^*$, MAC >MED, and increasing emissions by one unit saves abatement costs more than it causes damage



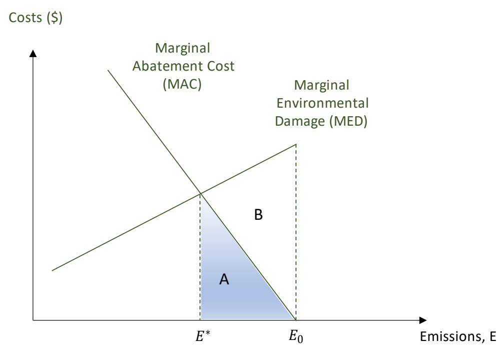
Lecture 3 15

The optimal level of pollution

Total abatement costs incurred reducing emissions from E_0 to E^* is the triangular area marked by A.

The total environmental benefit from this abatement is the sum of areas A and B.

The net benefit to society is B.



Lecture 3 16

b) (10 points - words)
Assume that an environmental regulatory authority wants to reduce the level of pollution to E^*. Give examples of policy instruments to reduce the level of pollution and explain the difference between command-and-control policies and emissions pricing (incentive-based) policies. What are their relative advantages?

Solution key:

Command-and-control is a type of environmental regulation that allows policy makers to specifically regulate both the amount and the process of abatement. Examples are prohibition, technology standards, and performance-based standards.

Emissions pricing policies influence behavioral change through altering prices in the market. Examples are taxes and tradeable emission permits.

For a given emission reduction, a policy is cost-effective if it achieves this reduction at least cost.

Command-and-control policies are seldom cost-effective, meaning that we can find alternative and less expensive ways to obtain the same environmental goal.

An equal emission price across firms minimizes total abatement costs for a given emission reduction.

If the regulated pollutant is of high risk or extremely toxic, command-and-control policies may be more accurate, as they give immediate results and a certain reduction (assuming perfect compliance).

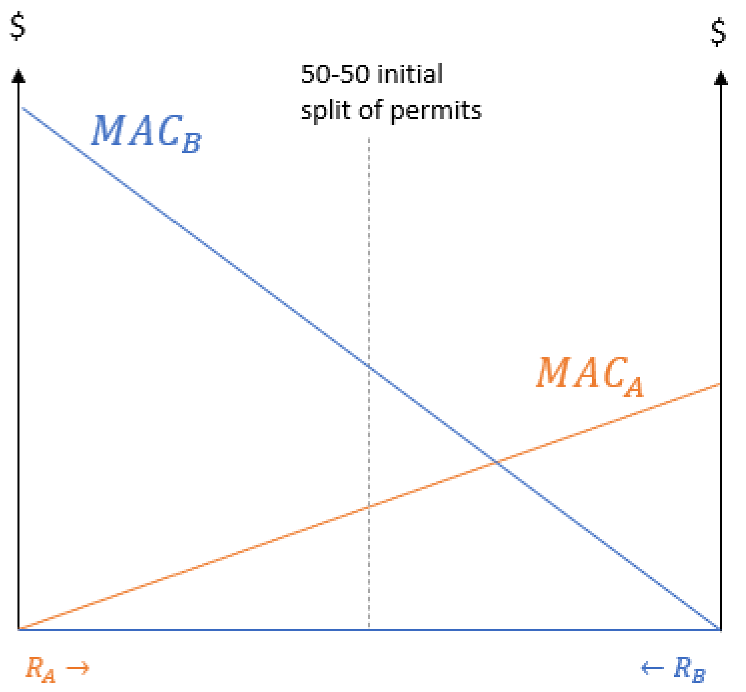
Problem 2. Cap-and-trade (20 points)

Consider an industry consisting of two polluting firms $i = A, B$ with different abatement technologies. In absence of any pollution control, the two firms emit $\bar{E}$ emission units in total.

The regulator wishes to reduce industry emissions down to a total of E^* emission units and implements a quota system with E^* permits. Each permit gives the right to emit 1 emission unit. The regulator grandfathers an equal number of permits to each firm.

Figure 1 illustrates the market for emission permits. R_A and R_B are the emission abatement of firm A and firm B, respectively. MAC_A and MAC_B are the marginal cost of abatement for firm A and firm B, respectively. The width of the diagram corresponds to the abatement required to limit emissions to E^*. The stippled line indicates the allocation of abatement corresponding to a 50-50 initial split of permits.

Figure 1: *The market for emission permits*



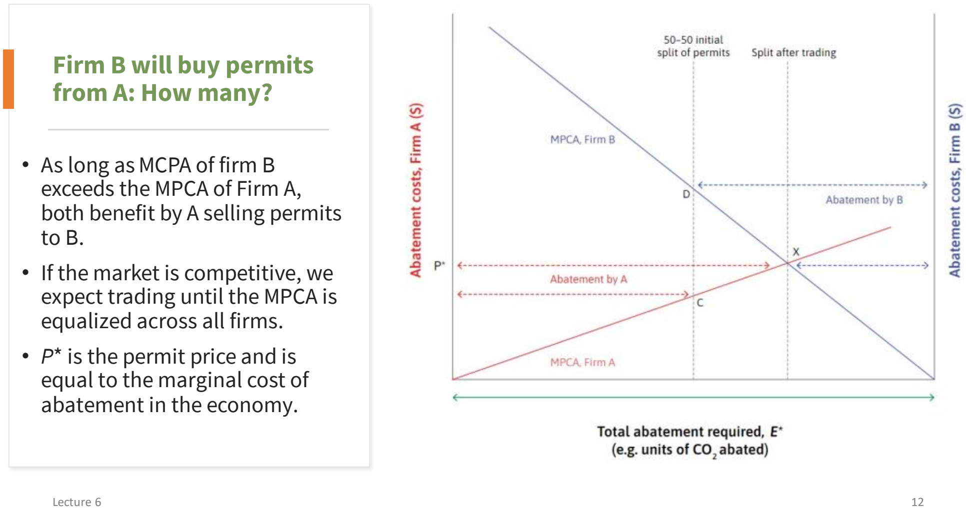
Assume that the two firms are allowed to trade permits.

a) (10 points – words and figure)
Reproduce Figure 1 and indicate the equilibrium allocation of permits as well as the equilibrium price. Explain the pattern of trade in permits from the initial split to equilibrium.

Solution key:

The market for emission permits is discussed in CORE unit 20.5 and Smith (2011) chapter 3. Firm B will buy permits from firm A, until marginal abatement costs are equalized between the two firms.

Relevant lecture slides:

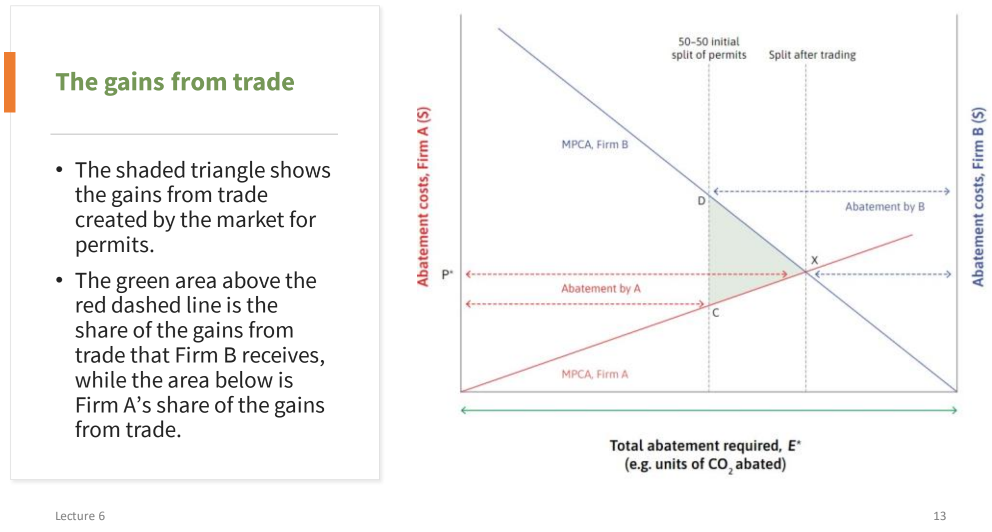


b) (10 points – words and figure)
Reproduce Figure 1 and illustrate the gains from trade created by the market for permits. Explain why a cap-and-trade system yields a cost-effective allocation of abatement across firms.

Solution key:

The students should explain that the equilibrium allocation after trading minimizes total abatement costs.

Relevant lecture slides:



The shaded triangle also illustrates the efficiency loss associated with a 50-50 initial split of permits. Only the equilibrium allocation after trading yields a zero efficiency loss, where total abatement costs are minimized.

Problem 3. Climate change policy (40 points)

Consider a country with a new green government that is eager to implement policies to mitigate climate change. However, before they make any policy decisions, they have asked for expert advice from an environmental economist.

a) (10 points - words)
Explain what the "social cost of carbon" is and discuss why estimates of the social cost of carbon have a wide range.

Solution key:

The "social cost of carbon" is discussed in Smith (2011) chapter 5.

The social cost of carbon is the damage caused by one more tonne of carbon emitted into the atmosphere at a particular point in time, expressed as a monetary value. The social cost of carbon can be calculated for emissions now, or at some future date. Typically, the social cost of future emissions will be higher than of emissions now because damage is caused by the accumulation of emissions in the atmosphere.

Estimates of the social cost of carbon for current emissions have a wide range. The reasons that underlie these diverse results for the social cost of carbon reflect important differences in approach and judgment. One thing they reflect is the inherent uncertainty in global warming policy: we do not know enough about the science to eliminate imprecision about the risks and scale of various effects.

The estimates also vary because there are some crucial ethical choices that have to be made in formulating policies towards global climate change. These include how effects on rich and poor are weighed up in the calculation, and how the interests of future generations are represented.

b) (10 points - words)
Explain why we discount future costs and benefits, and the implications of the choice of discount rate when determining the social cost of carbon.

Solution key:

There is a time delay between emissions today and the damage they cause in the future (climate change is a stock problem). To compare current mitigation costs with future benefits in terms of reduced environmental damage, we discount future benefits.

Discounting future benefits means valuing each $ of benefits experienced in some future year at a lower value than the equivalent benefits experienced in the current period.

Reasons for discounting future benefits include expected future productivity increases, and the risk of extinction of the human species.

A higher discount rate implies that we put less weight on future benefits. Since the consequences of climate change have a very long time horizon, the present value of future benefits of current mitigation costs will be very sensitive to changes in the discount rate.

c) (10 points - words)
Explain what "carbon leakage" means and discuss potential measures to mitigate carbon leakage in industry markets.

Solution key:

Carbon leakage is discussed in Böhringer et al. (2022):

When carbon emissions are priced unilaterally, the global environmental impact will be undermined to the extent that international markets transmit spillover effects that increase emissions in other countries. Dubbed 'carbon leakage', these effects occur primarily via two channels. The fossil fuel market channel transmits leakage when emissions regulations in open economies reduce the demand for fossil fuels, which causes global fossil fuel prices to fall and thus stimulates demand for fossil fuels in unregulated regions. Leakage through the competitiveness channel occurs when unilaterally regulated carbon-intensive businesses reduce production because of higher operating costs, while production by less regulated manufactures abroad increases.

In class, we discussed two potential measures to mitigate carbon leakage in industry markets: output-based allocation of emission permits (OBA), and border carbon adjustments (BCA).

Relevant lecture slides:

Output-based allocation

- Output-based allocation (OBA):
  - The more a firm produce, the more allowances it gets for free
  - Works like aproduction subsidy
- Stimulates domestic production → reduces incentives to relocate
  - Mitigates carbon leakage in industry markets
- Still gives incentives to reduce emission intensities
- Problem:
  - Subisidising emission-intensive industries would be a bad idea if leakage was not a problem
  - What if the «highly exposed» sectors are not that exposed to leakage after all?

Border carbon adjustments

- Böhringer et al. (Nature Climate Change, 2022)
- Border carbon adjustments (BCA):
  - Import tariffs – possibly supplemented with export rebates
  - Import tariffs:
    - Tariff on imported goods – proportional to embodied carbon and to the CO2 price
    - Embodied carbon: Direct emissions and possibly also indirect emissions
  - Export rebates:
    - Exported goods are rebated for their CO2 payments (proportional to exported volume)
- Several studies find:
  - Border carbon adjustments more effective than other measures
    - With respect to leakage and cost-effectiveness of climate policy

Border carbon adjustments

- BCA is being implemented in the EU – CBAM
  - CBAM: Carbon Border Adjustment Mechanism
  - Selected products: iron&steel, cement, aluminum, fertilizers, electricity, hydrogen
  - Only on import (“tariff”) – not on export
  - Gradually replace free allocation – starting in 2026
- BCA also proposed in the US as part of a potential ETS
- Important differences between BCA and OBA
  - OBA stimulates (domestic) supply – BCA depresses (foreign) supply at home
  - OBA has detrimental effects if leakage is not a problem – BCA has small impacts
  - When the «climate coalition» increases, the detrimental effects of OBA become gradually more important – no such negative effect wrt BCA

Norwegian University of Life Sciences 32

d) (10 points - words)
Explain how supply-side climate policies can supplement demand-side climate policies in restricting carbon emissions caused by fossil fuel combustion.

Solution key:

Supply-side climate policies are discussed in Asheim et al. (2019):

To restrict carbon emissions caused by fossil fuel combustion, one must regulate fossil fuel demand or supply, or both. Supply-side policies regulate exploration and extraction of fossil fuels, whereas demand-side policies regulate the combustion of fossil fuels. In the Paris agreement - a demand-side treaty - each country regulates combustion of fossil fuels by restricting emissions within its own borders.

Complementing the Paris agreement with a supply-side treaty need not be very costly. First, if fossil fuel production is reduced through cost-efficient policy instruments, the resources with the highest social costs of extraction will remain in the ground, limiting the profits forgone by not extracting these resources.

Second, the costs of participating in a supply-side treaty depends crucially on whether demand-side policies will turn out to be effective or not.

In class, we discussed two scenarios:

Scenario 1: Actors in the market believe in the success of the Paris agreement, and it succeeds.
Scenario 2: Many actors doubt that Paris will succeed, and it doesn’t succeed.

Supply-side policies as insurance

- <u>Case 1</u>

(Actors in the market believe in the success of the Paris agreement, and it succeeds)

- Supply-side policies will be superfluous
  - But: Fossil fuel extraction will be reduced nevertheless due to global climate policy

- <u>Case 2</u>

(Many actors doubt that Paris will succeed, and it doesn't succeed)

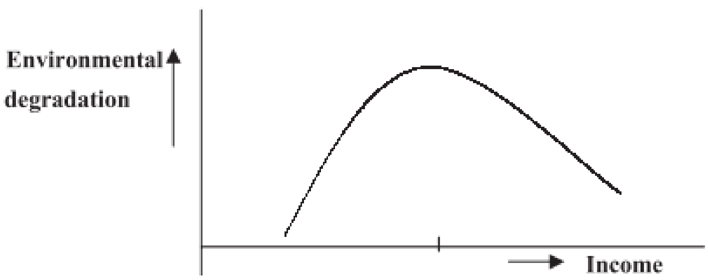
- Supply-side policies will contribute to lower global emissions
  - The more countries join, the bigger impact («supply-side agreement»)
  - Supplement to the Paris agreement / insurance
- Which case is most likely?
  - Most would probably say Case 2 (unfortunately)

Norwegian University of Life Sciences 45

Problem 4. The environmental Kuznets curve (20 points)

In this exercise you will be explaining concepts related to the so called Environmental Kuznets Curve (EKC). The curve is a hypothesized relationship between various indicators of environmental degradation and per capita income. See Figure 2 for an illustration.

Figure 2: The Environmental Kuznets Curve



(a) (10 points - words)
Discuss different mechanisms that might explain why we may have this inverted-U-shaped relationship between environmental degradation and per capita income.

Solution key:

Mechanisms that may explain the EKC is discussed in Dinda (2004).

Scale, composition and technique effects

- Economic growth affects the quality of environment in three channels:
  - Scale effect: More output requires more natural resources, and implies more wastes and emissions.
  - Composition effect: Structural change towards services and knowledge based technology-intensive industries
  - Technique effect: Dirty technologies are replaced by upgraded new and cleaner technology
- First stages of economic development: scale effect dominates
- At higher levels of economic development: composition and technique effects dominate

Income elasticity of environmental quality demand

- Income elasticity of demand: $\epsilon_d = \frac{\%\ change\ in\ demand}{\%\ change\ in\ income}$

  $\epsilon_d < 0$: Inferior goods
  $0 < \epsilon_d < 1$: Necessity good
  $\epsilon_d > 1$: Luxury good

- Environmental quality may be a luxury good
  - At low levels of income, high priority is given to increase material output. People are more interested in jobs and income than clean air and water.
  - At higher levels of income, the willingness to pay for a clean environment rises by a greater proportion than income.
    - Pressure for (costly) environmental protection, demand more «green» products

Regulation

- Economically efficient and cost effective environmental policy requires information and enforcement
- In lower-income countries,
  - Information is less detailed
  - Environmental regulatory institutions are weaker
- In higher-income countries,
  - Well-functioning regulation limits environmental degradation while allowing continued growth

Lecture 13 8

International trade

- Displacement hypothesis/Pollution Haven Hypothesis:
  - International trade allows pollution intensive industries to migrate from countries with stricter environmental regulations to those with weaker regulations
    - Countries with weaker regulations become net exporters of pollution-intensive goods
    - Countries with stricter regulations becomes net importers of pollution-intensive goods
- Poorer countries may have weaker regulations than richer countries
  - Trade liberalization may degrade the environment in the poor countries, while improving it in richer countries

Lecture 13 9

(b) (10 points - words)
On the y-axis in Figure 2 we measure the level of "environmental degradation". Discuss the empirical relationship between per capita income and different indicators of environmental degradation. For which indicators of environmental degradation is the Environmental Kuznets Curve hypothesis more likely to hold?

Solution key:
Empirical evidence for the EKC is discussed in Dinda (2004). The students are expected to discuss the free rider problem in relation to global pollution.

Air quality indicators

Several air quality indicators reveal an EKC relationship:

- Sulphur dioxide (SO_2)
- Suspended particulate matters (SPM)
- Carbon monoxide (CO)
- Nitrous oxides (NO_x)

Grossman and Krueger (1995), Selden and Song (1994), Stern and Common (2001), List and Gallet (1999), Shukla and Parikh (1992), Barbier (1997), Brandofordet al. (2000), Matyas et al. (1998), Jaeger et al. (1995), Ansuategi et al. (1998), Jha (1996), Horvatn (1997), Tucker (1995), Roca (2003).

Other environmental indicators

For other environmental indicators, evidence of EKC is mixed:

- Water quality indicators
- Municipal solid wastes
- Urban sanitation
- Access to safe drinking water

Indicators of global pollution have generally increased with income:

- Energy use
- CO2 emissions