ECN 275/375 – Natural resource and environmental economics
12:15-15:15 April 23, 2024

All help aids allowed except assistance from others.
This test consists of 3 questions, for a total score of 100 points.
All questions are to be answered. You may answer in English or Norwegian.

In the case that you find a question unclear, or you are uncertain about what is meant, state the extra assumptions you need to be able to answer the question.

This test has been designed to limit the benefits of using Chat GPT and similar artificial intelligence tools. If AI use is detected beyond reasonable doubt, unreported use leads to a score of zero. Students can use AI tools if they self-report such use at a cost: A question with self-reported AI use reduces the score by 40%.

When I submit my answers on this test, I confirm that I have worked alone on my answers and not cooperated with others. I am aware that cooperation with others is considered an attempt or a contribution to cheating.
I am aware of the consequences of cheating (Ch. 39, Academic regulations for NMBU).

Your name: NN (+ ECN 275 or ECN 375)

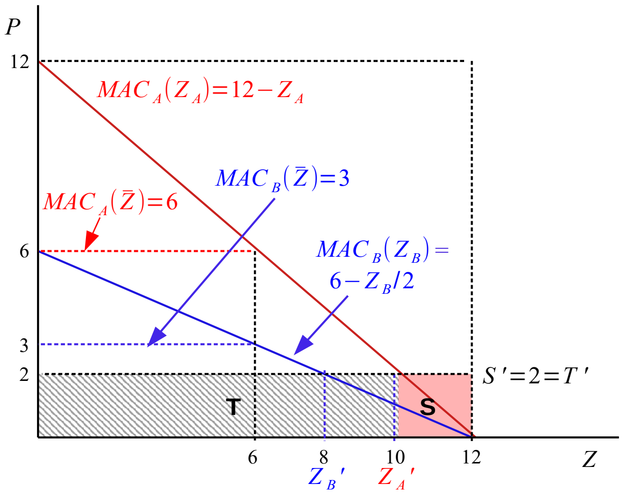
Question 1 (30 points – 10 points for each part a-c)

There are 2 firms, A and B, each with total abatement cost functions equal to: For the A-firm: $TAC_A(M_A)=12M_A-M_A^2/2$, and for the B-firm: $TAC_B(M_B)=6M_B-M_B^2/4$.

(a) (i) Currently, both firms emit 12 units each. Draw the marginal abatement cost functions for the two firms in the same graph. Mark the axes and the two firms' respective marginal abatement cost functions. Explain how each of the two firms responds to a subsidy rate $S'=2$ for reducing emissions, *Z*. In the graph, mark the two firms' responses to the subsidy with Z_A' and Z_B'. **For firm A** mark the total amount of subsidies received in your graph.

(ii) Replace the subsidy by the tax rate, $T'=S'=2$, and mark the area of taxes paid **by firm A** in your graph. Explain the difference in the impact on firm A from the subsidy and the tax. What kind of effect does the subsidy-tax example illustrate?

Answer: (i) Differentiating the two types of firms' total abatement cost functions gives $MAC_A(Z_A)=12-Z_A$ and $MAC_B(Z_B)=6-Z_B/2$. The two firm types choose to adapt such that their respective marginal costs equal the subsidy rate, which gives $Z_A'=2$ and $Z_B'=4$. The graph to the right illustrates this with the subsidy rate $S'=2$ inserted and the total subsidy incomes S for firm A.



Answer: (ii) The tax $T'=2$ gives the total taxes paid **T** (gray shaded area), and in theory the same emitted quantities as the subsidy, i.e., $Z_A'=10$ and $Z_B'=8$. The taxes paid, **T** for firm A, reduces the firm's profits. If margins are low, this could render firm A unprofitable. This illustrates the entry-exit conditions using subsidies or taxes. Note that the same actually holds for firm B but to a lesser extent than for firm A.

For parts (b) and (c) you do not need to present your solutions graphically.

(b) (i) Each firm is required to reduce their emissions to half of their initial emission level, such that $\bar{Z}_A=\bar{Z}_B=6=Z_0/2$ where $Z_0=12$ is the initial emission level for both firms. Show that this is not a cost-effective policy.

(ii) Find the cost-effective way of reducing total emissions to 12, i.e., $Z_A''+Z_B''=12$.

Answer: (i) Valuing the two firms' marginal abatement cost functions at $\bar{Z}_A=\bar{Z}_B=6$ gives $MAC_A(\bar{Z}_A)=12-\bar{Z}_A=6$ and $MAC_B(\bar{Z}_B)=6-\bar{Z}_B/2=3$, which violates the cost-effectiveness condition of equal marginal abatement costs evaluated at the chosen emission levels, i.e., $MAC_A(Z_A')=MAC_B(Z_B')$.

Answer: (ii) Total maximum allowed emissions are $Z_A''+Z_B''=12 \Rightarrow Z_A''=12-Z_B''$. Inserting $Z_A''=12-Z_B''$ into the cost-effectiveness condition $MAC_A(Z_A')=MAC_B(Z_B')$ gives $MAC_A(Z_B'')=12-(12-Z_B'')=6-Z_B''/2=MAC_B(Z_B'')$. Hence, $(3/2)Z_B''$ = 6, which gives $Z_B'=4$. From $Z_A'=12-Z_B'$ we get $Z_A'=8$.

Remark: Using Lagrange gives $\mathcal{L}=(12Z_A-Z_A^2/2)+(6Z_B-Z_B^2/4)+\lambda(12-Z_A-Z_B)$, which when solved gives the same result as above.

(c) Suppose that there is *N* firms of each firm type A and B, such that the total maximum allowed emission is 15 *N*, i.e., $NZ_A+NZ_B=15N$.

(i) Formulate the Lagrangian for this problem.

(ii) The solution to the Lagrange problem is $Z_A=9, Z_B=6,$ and $\lambda=3$, where λ is the Lagrangian multiplier. What is the price of tradable emission permits? Show or explain how you arrived at your answer.

Answer: (i) Rewrite the total allowed emission level to $N(Z_A+Z_B)=15N$ to get rid of *N*. This simplifies the Lagrange expression (nice to get rid of *N* to reduce the risk of algebraic errors) to get $\mathcal{L}=(12Z_A-Z_A^2/2)+(6-Z_B^2/4)+\lambda(15-Z_A-Z_B)$.

Remark: Full score is also given without this simplifying step.

Answer (ii) The price for tradeable emission permits equals 3, the size of the Lagrangian multiplier λ .

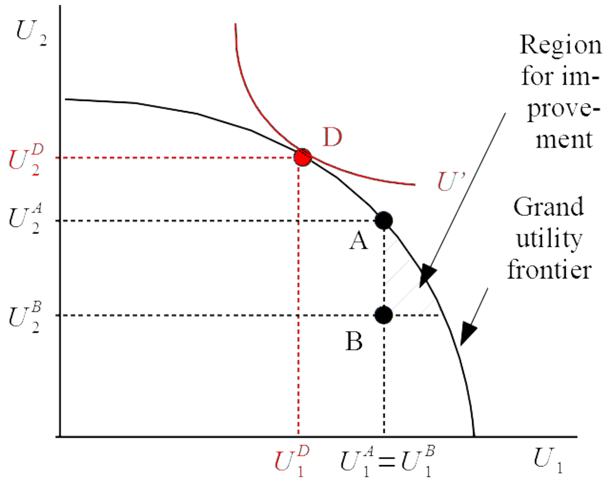
Remark: No need to calculate the permit price by inserting the values of Z_A or Z_B into the respective MAC-functions to find the permit price. Maximum score for the easy solution via the Lagrangian multiplier. Partial credit for going the extra route via the MAC-functions.

Question 2 (30 points – 10 points for each part a-c)

An objective of (modern) economics is to enhance societal welfare (utility). Pareto improvements are frequently used as a condition for improvements in the well-being of agents.

(a) (i) Define *Pareto optimality*.

(ii) Draw a graph for a two-person economy to supplement your definition, clearly indicating a *Pareto optimal allocation*, A. Label the axes in the graph, and add an allocation that is *Pareto inferior*, B, relative to A.



Answer: (i) Pareto optimality means it is impossible to make somebody better off without making someone else worse off.

Answer: (ii) Agents' utilities are marked on the axes. Point A is an example of a Pareto optimal allocation, while B is an example of a Pareto inferior allocation compared to A. Black relates to this answer (red to (b)).

(b) Explain why a *Pareto improvement* may be a too restrictive requirement in the sense that potential welfare improvements are not realized. Provide an illustration in the figure you drew in (a) clarifying your reasoning.

Answer: Requiring a Pareto improvement may imply that it is impossible to reach a welfare maximizing allocation (in the graph on the previous page marked D) where society's indifference curve *U'* tangents the grand utility frontier.

A Pareto improvement implies that it is possible to make someone else better off without making someone else worse off. That is therefore only possible when we have a Pareto inferior allocation to start with, for example point B from the graph in (a). The allocation that maximizes welfare is marked as point D. A Pareto improvement restriction makes it impossible to reach D, the point that maximizes welfare if we initially were positioned at point A (because agent 1 is worse off in D than in A).

(c) (i) Define *Pareto irrelevancy* in the context of environmental issues.

(ii) Explain how cost effectiveness can make environmental regulations welfare enhancing.

Answer: (i) An environmental externality is *Pareto irrelevant* when the costs (welfare losses) of correcting an environmental externality is larger than the benefits (welfare gains) of this correction.

Answer: (ii) A regulation is cost effective when it produces the least cost way of reaching an environmental objective. Lower costs make it more likely that benefits are larger than costs, and hence that the regulation will be welfare enhancing.

Question 3 (40 points – 10 points for each part a-d)

Acid rain results when sulfur dioxide (SO_2) and nitrogen oxides (NO_X) are emitted into the atmosphere and transported by wind and air currents. Emitted SO_2 and NO_X react with water, oxygen and other chemicals to form sulfuric and nitric acids. These then mix with water and other materials before falling to the ground.

A major source of SO_2 and NO_X in the atmosphere is burning of fossil fuels to generate electricity. Two thirds of SO_2 and one fourth of NO_X in the atmosphere come from electric power generators.

Winds can blow SO_2 and NO_X over long distances, making emissions cross borders and cause acid rain a problem for everyone and not just those who live close to where emissions of SO_2 and NO_X take place. For example. in the US acid rain from the rust belt states caused problems downwind states. (source: US Environmental protection agency).

Once the acid rain problem was recognized, the US environmental protection agency required installation of sulfur scrubbers, an end-of-pipe cleaning device, on all major emitters of sulfur. Sulfur scrubbers were expensive, but they reduced the negative externalities associated with acid rains. In some cases, the high costs of installing and running scrubbers made the benefits of scrubbers less than their costs. The US therefore eased the scrubber requirement and introduced a system of tradable sulfur emission permits.

(a) The initial US sulfur permits were sold in an auction rather than given away ("grandfathered") to sulfur emitters based on their historical sulfur emissions. Why was auctions in this case an economically better decision than "grandfathering"?

Answer: Compared to "grandfathering" a properly designed auction leads to following:

(i) It does not reward existing polluters as any firm or legal entity could buy permits. Note that "grandfathering" based on historical emissions is equivalent to giving a higher reward the higher the past emission level. "Grandfathering" also rewards firms who were late in installing cleaning technologies. Auctions of permits therefore create more correct entry-exit incentives.

(ii) It opens for others including victims, to buy permits. This would be particularly beneficial if victims think the aggregate emission level is set too high as they can buy permits and retire them. Remark: In a tradable permit market victims can also enter in later stages and buy permits for retirement.

(iii) It provides the government with revenues that could be used to reduce other distorting taxes. The double-dividend literature suggests particularly large economic benefits from reducing labor taxes.

In Europe acid rain from the burning of fossil fuels in Poland led to environmental damages in Norway and Sweden.

(b) It has proven far more difficult to agree on reducing the Polish emissions causing acid rain in Sweden and Norway than it was to get the "acid rain" program going in the US. One proposal to break the deadlock on the Polish emissions has been using side-payments. Why are side-payments (i) difficult to implement in general, and (ii) why is it particularly challenging to agree on side-payments in this case?

Answer: (i) Side-payments are difficult to implement in general because there are advantages to wait for the other parties to take the first initiative (last mover advantage).

Answer: (ii) In the textbook cases we had in class, the payoff structure was known. Here, the compensation needed for Poland to agree to reduce its emissions is not known with certainty. Sweden and Norway are therefore reluctant to propose side-payments as they could end up paying more than the necessary compensation to induce Poland to reduce their emissions. Moreover, there are two victims here, Sweden and Norway, and they may also disagree on the share of the total side-payment bill each of them should pay in the case of side-payments were chosen to induce polluters to reduce emissions.

(c) Suppose that an agreement on side-payments from Sweden and Norway to Poland was to be made. (i) Why would some environmental groups still oppose this agreement, and (ii) what are the welfare implications of not implementing a side-payment agreement to induce Poland to reduce its emissions compared to doing nothing?

Answer: (i) Paying polluters to reduce emissions conflicts with the *polluters pay principle* (here victims end up paying).

Answer: (ii) This follows from the *participation constraint* in RAMS: All parties who accept an agreement will only do so if they perceive the agreement to improve conditions over the current situation, and they see no other feasible welfare enhancing solution that works better.

(d) Explain why a tradable permit regime for Polish emissions is a viable and more efficient solution in this case than side-payments?

Answer: Under a tradable permit scheme each Polish polluter would reduce its emissions to the point where its marginal costs of emissions reductions, Q_i', equal the permit price, i.e., $MC_i(Q_i')=p_Q$. This happens regardless of the size of the aggregate quota. Polish polluters are likely to accept a "grand fathered" initial quota $\bar{Q}\geq M_0$, where M_0 are current emissions. The reason for this is that such quotas represent an income potential (polluter *i* will reduce emissions for $MC_i(Q_i)\leq p_Q$. In the beginning the quota price would be quite low. That implies that the costs for Sweden or Norway to buy permits for retirement would also be quite low. As the quota price, p_Q increases, aggregate Polish emissions, $Q=\sum_{i\in I} Q_i$ would fall. Sweden and Norway would continue to buy permits for retirement until $p_Q=MD(M_0-Q^*)$, where Q^* is the aggregate emission level in Poland that corresponds to optimal emission damages in Sweden and Norway.

Remark: This solution also suffers from some of the weaknesses that Sweden and Norway may disagree on how to split the bill, but less so than in the case of side-payments, as their total outlays for buying permits gradually increase rather than being paid at once. Sweden and Norway could therefore learn about the impacts on their marginal damages from aggregate Polish emissions reductions, *Q*.