ECN 275/375 – Natural resource and environmental economics
12:15-15:15 March 4, 2022

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.

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 to be considered an attempt or a contribution to cheat.
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)

The total cost function for producing quantity of a public good, *Z*, is $TC(Z)=bZ+cZ^2$, where *b* and *c* are coefficients in the cost function.

(a) (i) Find the marginal cost function for producing *Z*. (ii) Show that the conditions needed on the technical coefficients *b* and *c* to have a valid standard supply function are $b<0$, and $c>0$. Show mathematically and add comments if necessary. **(10 points)**

Answer: (i) Differentiate the total cost function by *Z* to get $MC(Z)=b+2cZ$.

(ii) A valid supply function is everywhere increasing in the domain of choice variable, here *Z*, and is also non-negative for the domain of the choice variable. Everywhere increasing supply implies that the second order derivative of the total cost function, 2*c* is positive, i.e., $c>0$. For the marginal costs to be non-negative in the domain of *Z*:

$$MC(Z)\geq b+2cZ>0\Rightarrow Z\geq\frac{-b}{2c}$$

With $c>0$, the domain of *Z* is non-negative if $b<0$. Finally, for a valid supply function marginal costs need to exceed average costs, which also holds for all $Z>0$ as

$$AC(Z)=\frac{TC(Z)}{Z}=\frac{bZ+cZ^2}{Z}=b+cZ<MC(Z)=b+2cZ\;\forall\;Z>0 \quad \text{as } c>0.$$

(b) (i) Write down the profit function for producing *Z*, and (ii) solve for the profit maximizing quantity of *Z*.

Answer: (i) The profit function: $\pi(Z)=TR(Z)-TC(Z)=sZ-(bZ+cZ^2)$ where $s>0$ is the per unit subsidy (payment financed through taxes as endogenous market prices are ill-defined for public goods).

(ii) Differentiate the profit function with *Z* to get the first-order condition for profit maximization: $s-b-2cZ=0$, which gives:

$$Z=\frac{b-s}{-2c}>0$$

as $(b-s)<0$ and $-2c<0$ from the preceding analysis.

(c) Citizens have a utility function that reflects that welfare is obtained from consumption of a private good, Q, and the public good Z. (i) Formulate the social welfare maximization problem for a representative citizen, define terms you add, and explain your reasoning behind your formulation. Note that you are not asked to formulate a specific functional form for the utility function.

(ii) Write down the Lagrangian that corresponds to your formulation in (i), and use the first-order conditions to characterize the solution. **(10 points)**

Answer: (i) The welfare maximization problem is:

$$\underset{\{Q,Z\}}{MAX}\, U(Q,Z) \text{ subject to } M - pQ - T = M - pQ - sZ = 0$$

where M is total income in society, p is the price for the market good Q, and s is the per unit subsidy for paying from the production of Z. Note that the subsidy requires increases in taxes $T = sZ$.

(ii) The Lagrangian: $\mathscr{L} = U(Q,Z) + \lambda(M - pQ - sZ)$

The first-order conditions + first transformations for easier analysis:

(1) $\frac{\partial \mathscr{L}}{\partial Q} = U_Q(Q,Z) - \lambda p = 0 \Rightarrow \frac{U_Q(\cdot)}{p} = \lambda$

(2) $\frac{\partial \mathscr{L}}{\partial Z} = U_Z(Q,Z) - \lambda s = 0 \Rightarrow \frac{U_Z(\cdot)}{s} = \lambda$

(3) $\frac{\partial \mathscr{L}}{\partial \lambda} = M - pQ - sZ = 0$

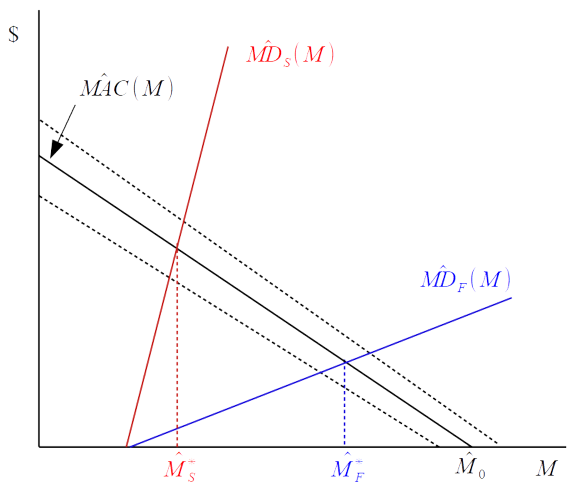
Equate the transformed versions of (1) and (2) to get $\frac{U_Q(\cdot)}{p} = \lambda = \frac{U_Z(\cdot)}{s}$ which gives room for the following interpretations:

- In the optimal allocation between the consumption of the private and public good, the marginal utility of the private good consumption divided by its price equals the marginal utility of consumption of the public good divided by its income impact (the subsidy)
- These marginal utilities equals the marginal utility of income, captured by λ .

Question 2 (30 points)

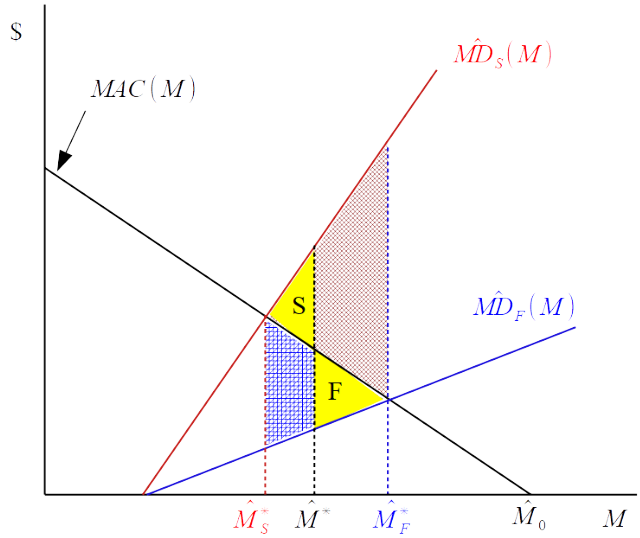
Consider marginal abatement costs and marginal damages as functions of emissions, M, as illustrated in the graph to the right where:

- $\hat{MAC}(M)$, the expected marginal abatement costs are uncertain. This uncrtainty is captured by an upper and lower bound around the expected MAC-curve.
- $\hat{MD}_i(M)$ are the expected marginal damages (marginal economic costs), where i captures two mutually exclusive states, flat, $\hat{MD}_F(M)$, or steep, $\hat{MD}_S(M)$.



(a) Assume that the marginal abatement cost curve, $MAC(M)$, is known with certainty, while it is uncertain which of the two marginal damage curves, $\hat{MD}_F(M)$ or $\hat{MD}_S(M)$, that best represents the true marginal damage curve. Explain why the expected optimal emission level, $\hat{M}^*$, is located between $\hat{M}_S^*$ and $\hat{M}_F^*$ before the true marginal damage curve is known. **(10 points)**

Answer: Assume that one of the two possible state dependent optimal emission levels is chosen, for example $\hat{M}_F^*$ when the true optimum is $\hat{M}_S^*$. This gives a welfare loss equal to the yellow triangle S plus the red hatched trapezoid. With the other choice for the perceived optimum, the welfare loss equals the yellow triangle F plus the blue hatched area. The total welfare loss will be a probability weighted sum of yellow and hatched areas.



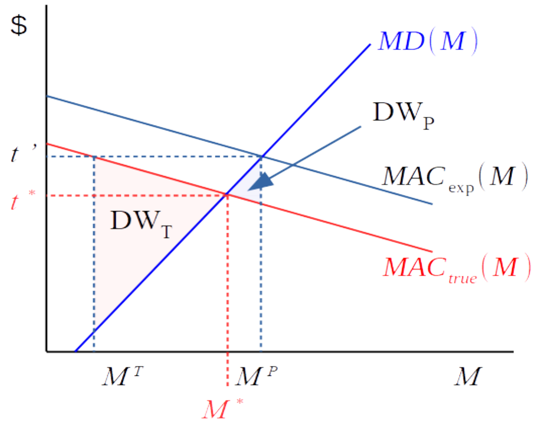
The in-between emission level $\hat{M}^*$, gives a welfare loss equal to the sum of the two yellow triangles S and F, which is smaller than the probability weighted areas described.

An alternative way of explaining this is that as one moves further away from an optimum, the dead weight losses grow more because it is the "fat end" og the triangle that expands.

(b) Suppose that the uncertainty about marginal damages have been sufficiently resolved to conclude that marginal damages are adequatly represented by $\hat{MD}_S(M)$. Now, introduce uncertainty about the location of the marginal cost function, $MAC(M)$, which is definitely not as steep as the marginal damage function. What are the implications of this uncertainty for the choice of policy instrument? Show graphically, and if possible add further justifications for your choice. **(10 points)**

Answer: The graph illustrates the essence with the MAC-curve less steep than the MD-curve:

Incorrect expectations about the MAC-curve, here where $MD(M)$ crosses $MAC_{exp}(M)$, lead to: (i) an incorrect tax is set at t', which gives the corresponding emission level M^T and the welfare loss DW_T. (ii) The perceived correct permit is set at M^P, which gives the welfare loss DW_P. The true optimum $\{t^*, M^*\}$, marks the reference point for calculating the welfare losses. Policy advice: When the MD-curve is steeper than the MAC-curve, use (tradable) permits.



The graph illustrates the first part of the Weitzman "prices vs. quantity" proposition:

When marginal damages are steeper than marginal abatement costs, and there uncertainty about marginal abatement costs, use quantity based instruments (permits). In the converse situation, use price based instruments (taxes).

(c) Which of the two uncertainties, uncertainty on the benefit side or uncertainty on the cost side, is usually most difficult to resolve? Briefly justify your answer. **(10 points)**

Answer: Uncertainty on the benefit side is most difficult to resolve. Main reason: Regulator errors the cost side from incorrect assumptions on costs will more quickly be revealed from the responses of agents to the regulations that will be inconsistent with the regulator's expectations.

Conversely, errors from incorrect assumptions on the benefit side are often revealed after much longer time delays, which implies corrections in policy are also likely to be more delayed.

Question 3 (40 points)

The use of genetically modified organisms (GMOs) is a controversial issues in today's policy debate, with strong proponents for allowing more wide spread use, and opponents for the opposite.

Proponents for GMOs argue that with reduced growth in food production, GMOs are among the most promising ways of maintaining or increasing growth in global food supplies. They also point to GMOs contributing to less demand for pesticides. Reduced pesticide use may have beneficial environmental effects in addition to reducing consumer's and farm worker's exposure to pesticides or pesticide residues.

Skeptics towards GMOs argue that the long term health effects from consuming genetically modified (GM) foods are still not sufficiently investigated, and that GMOs may pose severe biological risks if not properly contained, for example if traits of the GMO spread to wild plants and animals.

(a) (i) Define the term externality and explain what internalization means. (ii) Which of the **above listed effects in the lead text** could be termed *externalities*? **(10 points)**

Answer: (i) An externality is an unintended positive or negative effect on the production or consumption possibilities of other agents that is not compensated for. The modern definition of externality includes impacts on the environment where effects are uncertain, like biodiversity. When full compensation takes place, the externality is fully internalized. Note that compensation may lead to changes in the extent of an externality.

(ii) Externalities from the use of GMOs are: beneficial environmental effects and reduced farm worker exposure to pesticides or pesticide residues. Possible externalities are biological risks and health effects on consumers.. Note that increased food production is not an externality as it is part of the calculations agricultural enterprises normally undertake when deciding to allow using GMOs or not. As such, increased food production borders on being a *pecuniary externality*.

(b) What are the economic approaches available for dealing with the possible externalities from GMOs? Briefly discuss the advantages of the various proposals. **(10 points)**

Answer: One should only seek to internalize positive externalities if that would increase their supply towards what is optimal. A tricky issue in that regard is that using public funds to finance internalization (subsidies) reduces funds available for other purposes, i.e., opportunity cost considerations need to be performed.

For negative externalities several principal approaches exists: Coasean bargaining, the use of (Pigouvian) taxes (that do not have the same adverse effects on public funds as subsidies), legal instruments (a negative externality can be seen as an infringement on the right of others). With a large number of agents in the supply chain, Coasean bargaining may not be a welfare enhancing option as negotiation costs (transaction costs) are likely to be high. Taxing the use of GMOs entails lower transaction costs, but may be difficult to implement/justify given the uncertainty surrounding the severity of these effects.

For both positive and negative externalities one needs to conduct analysis to check for what level of a (partially) uncorrected externality is Pareto-irrelevant (marginal correction cost exceed marginal benefits), i.e., correction beyond that level is not optimal.

(c) With large uncertainties surrounding more widespread adoption of GMOs, some argue that allowing for an increase in the use of GMOs could have irreversible impacts, particularly related to effects on ecosystems with uncontrolled spread of GMO attributes to other plants or insects. Name what you deem the most relevant economic tool for analyzing such potentially irreversible outcomes. Justify your choice, and briefly formulate verbally how such an analysis could be structured, and how an optimal decision is made. **(10 points)**

Answer: Given the large uncertainty of GMOs and advances in reducing those uncertainties, the most relevant economic analytical concept is the quasi-option value. The main reason for this is that the quasi-option value framework enables a comparison of the value of deciding now (expand the use of GMOs or to limit their use), and the value of waiting for more information to become available. Waiting enables making a more informed decision, but at a possible cost: Current benefits of using GMOs are lost.

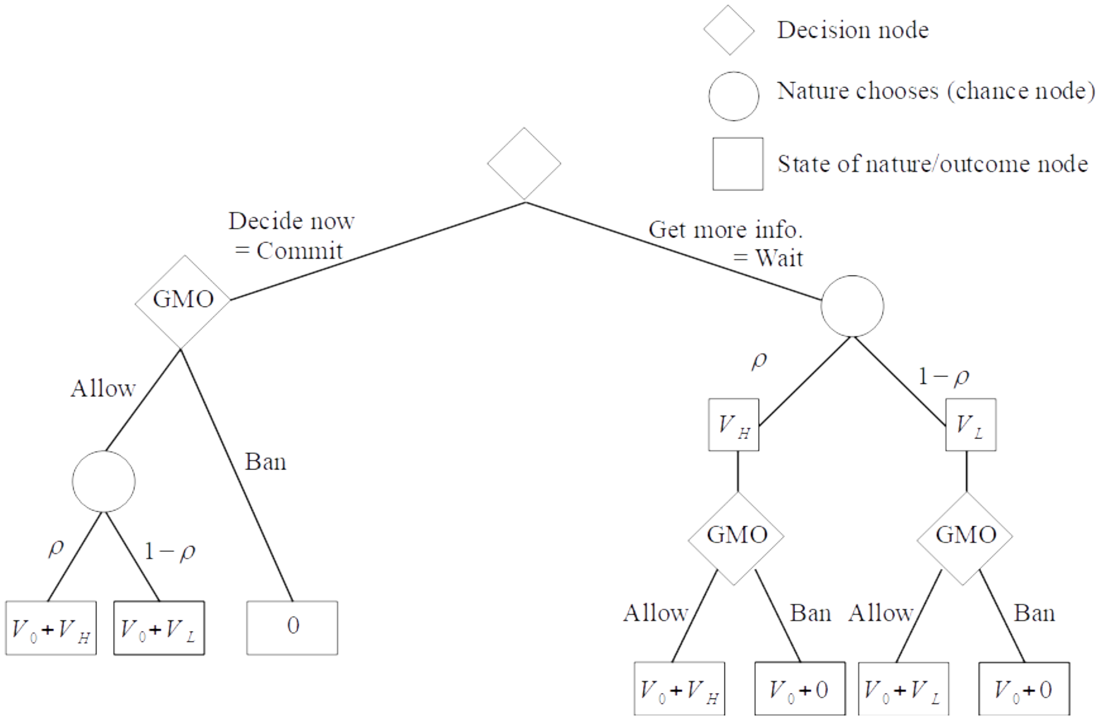
The optimal decision is the maximum of the following two decisions:

- The value of committing today equals the expected maximum value of allowing expanded GMO use or banning its use.
- The value of delaying the decision is the expected value of reduced uncertainty (less uncertainty on whether it is the high or low net benefit scenario that is revealed by waiting, upon which a decision is made to allow or not allow (ban).

(d) (i) Provide a graphical illustration that captures the essence of your answer in (c) where the decision alternatives are expand the use of GMOs or ban GMOs. Clearly define the terms that you are using. (ii) Provide a mathematical formulation that matches your graphical illustration. **(10 points)**

Answer on next page

Answer: (i) Graphical illustration (my suggestion, reasonable variants of this suggestion will also give full score). Explanation of the terms I use: V_0 = current net benefit of committing to GMO use today. For simplicity I assume that net benefit of not allowing GMO use today or in the future equals 0 (zero). V_H = future state dependent discounted high net benefit. V_L = future state dependent discounted low net benefit. V_H and V_L occurs with the respective probabilities ρ and ($1-\rho$).



(ii) Mathematical formulation that represents the decision tree in (i).

Value of commit, D_C = $MAX\left[\rho(V_0+V_H)+(1-\rho)(V_0+V_L), 0\right]$ (allow, ban)

Value of waiting, D_W = $\rho\, MAX\left[(V_0+V_H),(V_0+0)\right]+(1-\rho)\, MAX\left[(V_0+V_L),(V_0+0)\right]$