14.42/14.420 Midterm 2011

Instructions:
The test begins at 2:38 and ends at 3:55 by the digital clock.
There are two sections: Quantitative and Short Answer.
There are 109 points in total, 53 points in the Quantitative section and 54 in the Short Answer section.
You may run out of time. Make sure to allocate your time appropriately between the two sections. We
expect that the most difficult question is at the end.

Part I: Short Answer Questions
Each of these questions has a number of points possible. Typically, a question worth one point will take
one sentence to answer, two points might take two sentences, etc.

1. Imagine a project that has benefits that accrue over a long period of time. When doing cost-
    benefit analysis, there are at least two ways to set the discount rate. Describe each and give a
    brief justification. (4 points).

The market discount rate
   *   *This reflects the return that we could expect for a dollar of investment today, so if an*
       environmental project returns less it is an inferior investment
   *   *We might need to risk adjust: some of the market discount rate reflects a risk premium, and*
       returns to environmental projects may not be correlated with the market return.
"Intergenerational social discount rate"
   *   *$r = \eta g + \delta$*
   *   *The market discount rate is "too high" – it gives implausibly low weight to benefits more*
       than a few years in the future.
   *   *This makes an investment look good if it raises the sum of utility discounted by the rate of*
       time preference δ.

2. What is the difference between cost-effectiveness and efficiency? If possible, give examples of
    outcomes that are efficient but not cost-effective, and outcomes that are cost-effective but not
    efficient. (4 points)

Cost-effectiveness refers to meeting some environmental goal at minimum cost. Efficiency refers to
setting that goal at the point that maximizes social welfare. An outcome that is efficient is also cost-
effective, so there are no examples of the former type. An outcome that is cost-effective but not efficient
might be an emissions trading program that achieves a given level of emissions at minimum cost to
industry, but that level of emissions is not the social optimum, i.e. not the point where marginal
abatement cost is equal to marginal benefit from abatement.

3. Give an example of a Pigouvian tax that has nothing to do with environmental issues. (2 points)

One example is congestion pricing on roads: when people drive, they impose congestion on others. The congestion price charges drivers for that externality.

4. Imagine a pollution cap-and-trade program where one firm is responsible for a relatively large share of emissions. Denote by τ* the marginal social cost of emission abatement at the emissions cap. Imagine further that this large firm is allocated more allowances than the amount of pollution it emits if the allowance price were at τ*.

Do we expect that the allowance price will be less than, equal to, or greater than τ*? Why? (2 points)

The allowance price will be higher than τ. This is because the firm is a net seller, and it exercises market power to keep the price relatively high. It withholds allowances and under-abates.*

5. Give three economic reasons why we should not have a cap-and-trade program imposed on automobile drivers for pollution from their cars. (3 points)

   Three example answers:
- *Each driver would incur administrative costs in complying with the program, and these costs would be high relative to the efficiency gains.*
- *The marginal damages vary substantially across time and space, so cap-and-trade program with undifferentiated allowances would not achieve the optimum.*
- *The margin on which consumers can most easily adjust is to drive less. This outcome can be achieved through setting optimal gasoline taxes.*

6. Give three factors that have determined SO2 allowance prices. Explain how they move allowances prices in one direction or another using economic logic. (6 points)

- *Natural gas prices: higher natural gas prices increase demand for coal-fired electricity, which pushes up demand for allowances and thus increases allowance prices.*
- *Additional environmental regulations: information that the cap would be reduced lowers the expected supply of allowance prices, which increases the future expected marginal abatement cost and thus increases allowance prices in the present.*
- *Economic growth: Economic growth increases demand for electricity, which increases demand for allowances and increases allowance prices.*

7. What is the difference between a normative statement and a positive statement? Give one example of each type of statement in the context of climate change. (3 points)

A normative statement is one that indicates what should be done, and a positive statement is one that simply describes the world around us. Positive analysis tends to require fewer value judgments by the analyst than normative economic analysis. A positive statement about climate change might be that higher temperatures are empirically associated with lower profits per acre on farmland. The statement that we must take immediate action is critical to prevent further damage is normative.

8. Precisely define *sustainability* using words. (1 point).

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. (This is the Brundtland Commission definition.)

9. Define *sustainability* mathematically. (1 point)

$\Sigma_{t=s'}^{\infty} \beta^t(U_t) \geq \Sigma_{t=s}^{\infty} \beta^t(U_t)$, all s'>s. The present discounted sum of future utility is weakly increasing over time s.

10. Give three arguments against using cost-benefit analysis as the only way of making social decisions. (3 points)

Three potential limitations of cost benefit analysis are:
1. *Measuring both damages (costs) and marginal willingness to pay (benefits) can be tricky, since these costs and benefits are often difficult to monetize.*
2. *Surplus is difficult to measure in the presence of other economic distortions, such as taxes or other regulations.*
3. *It may not be possible or desirable to quantify the value of certain types of things.*

11. Define Kaldor-Hicks Efficiency. (1 point)

*The Kaldor-Hicks compensation principle states that if state **a** is a potential Pareto improvement over state **b**, then **a** is also socially preferred to **b** even if no compensation occurs. A state is Kaldor-Hicks efficient if there is no other state that represents a potential Pareto improvement over that allocation.*

12. Define the Revenue Recycling Effect. (2 points)

One of the benefits of imposing a revenue-neutral tax on pollution is that the revenue gathered from the pollution tax can be used to reduce distortionary taxes on labor and thus the deadweight loss associated with those taxes. This is the Revenue Recycling Effect.

13. What does the Revenue Recycling Effect say about how the efficiency of the Acid Rain Program could have been improved? (1 point)

The Acid Rain Program could have been more efficient if the revenue generated from the auctions had been used to lower other distortionary taxes.

14. Define the Tax Interaction Effect (2 points)

A tax on pollution increases the price of the polluting good, which causes individuals to substitute toward more leisure if the good and leisure are substitutes. If labor is taxed, this shift in the demand curve for leisure generates an additional deadweight loss associated with the interaction between the two taxes. This is the Tax Interaction Effect.

15. Summarize Weitzman's (1974) argument about prices vs. quantities. Use a graph to do so (4 points).

Weitzman's argument is relevant to the problem of a regulator trying to determine whether to set a permit (quantity) regulation or a fee (price) regulation in the presence of uncertainty about the marginal cost of pollution abatement. If marginal damage is more steeply sloped than the marginal savings from pollution, tradable permits are preferred. Otherwise fees will tend to result in lower deadweight loss.
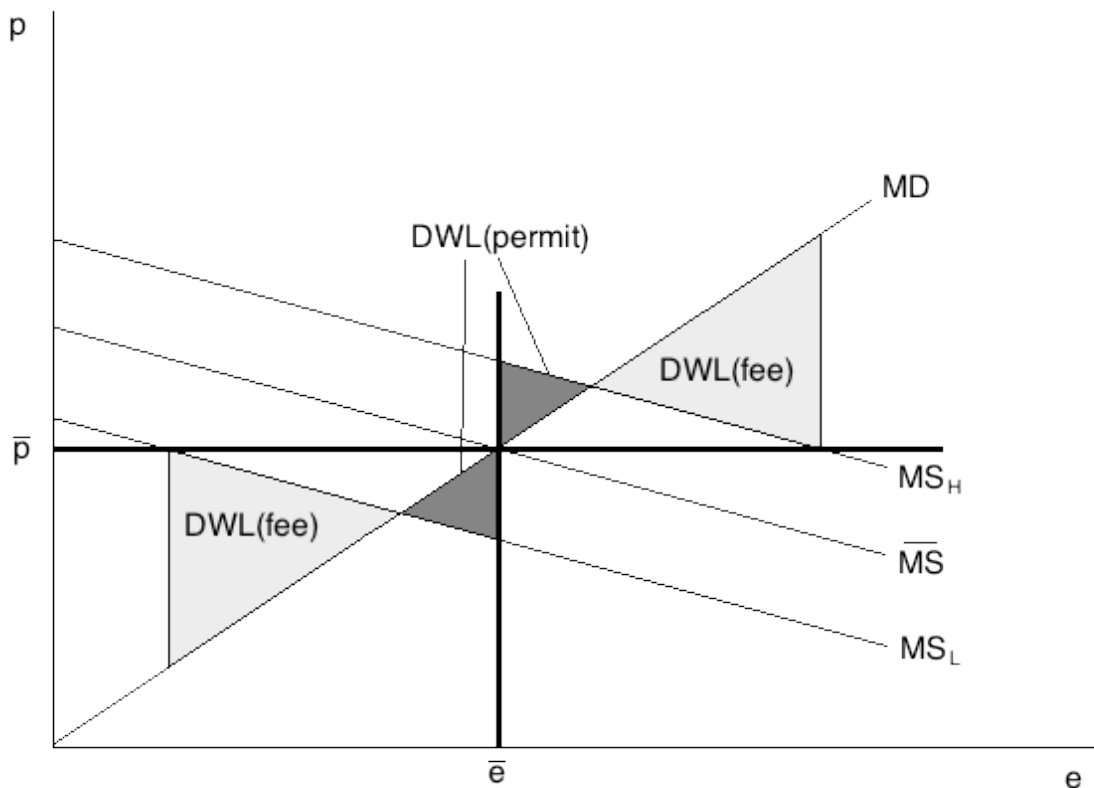
16. Define the Equimarginal Principle. Under what types of regulation does this typically hold or not hold? (2 points)

In controlling emissions from several polluters, all emitting the same pollutant, efficiency requires that the marginal cost of emission control be the same for all polluters.
This typically holds for emissions trading and Pigouvian taxes, but often not for command-and-control regulation.

17. The First Welfare Theorem says that a market equilibrium is Pareto Optimal. Under what conditions does this hold? (4 points)

- *Complete property rights*
- *Atomistic participants (no market power)*
- *Complete information*
- *No transactions costs*

18. An externality is when the consumption or production choices of one person or firm enter the utility or production function of another entity without that entity's permission or compensation. Much of our class has been about externalities, how they are problems, and how to design policy to control them.
    a. Recently, increased demand for oil in China and other fast-growing countries has raised the price of oil, thus lowering real incomes in the United States. Is this an externality? (1 point)

        Yes
    b. If so, what type of externality is this? If not, why not? (1 point)

        A pecuniary externality
    c. Is this inefficient? (1 point)

        No

19. Define a (pure) public good. (1 point)

A public good is a good that is non-rival and non-excludable.

20. Is a population of fish in a fishery a public good? Why or why not? (2 points)

Exploitation of fish is rival (unless the fishery is massive), although often not excludable. We would typically call a fishery an open-access resource.

21. Write a social welfare function that, at its optimum, necessarily generates equal levels of utility for all members of society (2 points).

Egalitarian with infinite weight on inequality:
W(U₁,...,Uₙ) = ΣᵢUᵢ - λ Σᵢ [Uᵢ-minᵢ [Uᵢ])
With λ=∞

22. Consider a firm that imposes risk of environmental damage and can reduce that risk through precautionary effort. Give three reasons why regulating only with liability may not give the efficient level of precautionary effort. (3 points)

Some problems with regulation through liability include:
1. *Limited liability constraints – a firm may not be sued for damages that exceed the net assets of the firm. The expected value of the payout is therefore lower than the expected value of the damages, causing firms to under-invest in precaution.*
2. *It may be prohibitively costly to the plaintiffs to bring legal action against the responsible party in the event of an accident. The expected payout here would again be lower than the expected damages.*
3. *If firms are risk-averse, they may over-invest in precautionary measures to avoid potential bankruptcy.*

Part II: Quantitative Questions
Part II.1: Heterogeneous Marginal Cost of Abatement
There are two firms in a polluting industry. Their profit functions are:

$\pi_1 = 5 + E_1 - E_1^2/2$

$\pi_2 = 10 + E_2 - E_2^2$

Pollution has local damages; the marginal damage functions for emissions from each firm are:

$MD_1 = E_1$

$MD_2 = E_2$

1. Let's say that the regulator has all of this information and can use command and control regulation to mandate the socially-optimal level of emissions from each plant. What levels of emissions does the regulator mandate from each plant? (4 points)

   MS(E*)=MD(E*)

   1-E₁=E₁
   E₁*=1/2

   1-2E₂=E₂
   E₂*=1/3

2. Instead of command and control, the regulator can also use a cap-and-trade program. Here, the total level of emissions by the two firms combined will equal the socially-optimal total level of emissions, but the regulator is letting firms trade emissions allowances to achieve that abatement at minimum cost.
   a. What are total emissions? (1 point)
      Total emissions are E₁* + E₂*= 5/6
   b. Assuming that neither firm has market power in the allowance market, what will be the equilibrium allowance price? (3 points)
   Two sets of equations needed:
   1. *Firms maximize profits:*
          E₁* = (1-τ)/2
          E₂* = (1-τ)

   2. *Total emissions constraint:*
      Total emissions = 5/6
             Total emissions = E₁* + E₂*= (1-τ)/2 + (1-τ) = 5/6
             τ=4/9

3. In this cap-and-trade program, the socially-optimal total level of emissions has been achieved at minimum cost to industry. Is this the social optimum? If so, explain why. Then draw the marginal damages and marginal savings from emissions and shade the deadweight losses from the command and control regulation in question 1 above. If not, explain why not, and draw the deadweight losses from the cap-and-trade program in question 2 just above. (5 points) (Don't

worry about getting the intercepts of the lines correct, but do worry about shading the correct triangles.)

The command-and-control regulation is the social optimum. Intuitively, what happens here is that the marginal damages at the optimum are not the same at the two different firms. If we impose an emissions trading program, the two firms will equate marginal costs. The first best thus cannot obtain: marginal costs are the same, but marginal damages are different. This differs from a uniformly-mixed pollutant, where the marginal damages would be the same across firms.

Part II.2: Consumers, Producers, and Equilibrium

This is a new quantitative question, so you can forget about all of the above.

1. There are N consumers, indexed by i, each with the following utility function:

   $U_i = x_i - kP^2/2$

   Consumers receive utility from consuming a composite good x, and their utility also depends on the pollution level P. Normalize the price of x to 1. This means that a one dollar increase in wealth generates a one unit increase in utility. Conversely, a one unit increase in utility is worth one dollar.

   a. What is an individual's marginal rate of substitution between pollution and the numeraire good? (1 point)

   $MRS = (dU_i/dP) / (dU_i/dx_i) = -kP$

   (also accept the inverse of this)

   b. What is the individual's marginal willingness to pay function for pollution? (1 point)

   $MWTP(P) = dU_i/dP = -kP$.

   c. Explain whether this function should be positive or negative. (1 point)

   Pollution is a bad, so the marginal willingness to pay is negative.

   d. Pollution is non-rival. What is the aggregate marginal willingness-to-pay function for pollution? (2 points)

   Aggregate $MWTP(P) = \Sigma_i MWTP_i (P) = -NkP$.

   e. For this sub-question (part (e)) only, temporarily assume that consumption of pollution is rival. If that were the case, what would be the aggregate marginal willingness-to-pay function? (2 points)

   In this case, we would sum "horizontally."

   Aggregate $MWTP(P) = -k/N \cdot \Sigma_i P_i$

   $\qquad = -k/N \cdot P_{Total}$

2. There are 2 firms in a polluting industry, indexed by j, each of which has the following profit function:

   $\pi_j = \pi_0 + AE_j - BE_j^2/2$

   E_j is the level of emissions for firm j in tons.

   a. If there is no environmental regulation, what level of emissions will each firm set? (1 point)

   $E^* = A/B$

   b. If there is a emissions cap-and-trade program where allowances cost price p per ton, what level of emissions will each firm set? (1 point)

   $E^* = (A-p)/B$

   c. If there is a emissions tax of amount τ per ton, what level of emissions will each firm set? (1 point)

   $E^* = (A-\tau)/B$

   d. Find the industry's aggregate marginal savings function from emissions. (2 points)

   $E_T = (A - MS_j)/B \cdot 2$

E_T is the total level of emissions.

$MS = A - E_T \cdot B/2$

3. The level of ambient pollution P (in parts per million, or "ppm") is determined by the following equation:

$P = a_1E_1 + a_2E_2$

   a. What are a_1 and a_2 called? (1 point)

   Transfer coefficients.

   b. What are the units on a_1 and a_2? (1 point)

   ppm per ton.

   c. Assume for the entire question that when we solve for the social optimum, it will involve firm 1 and firm 2 emitting the same amount. This implies a restriction on a_1 and a_2 in the above equation. What is this restriction mathematically? In words, what does this imply? (3 points)

   This would be the case if emissions from firm 1 generate the same amount of ambient pollution as emissions from firm 2. Mathematically, the condition is $a_1 = a_2$.

   d. Give a (true, real-world) example of a setting where this has NOT been the case. (2 points)

   Power plants very close to the Atlantic Coast have much of their pollution blow out over the ocean, while power plants in the Midwest have much of their pollution generating ambient pollution in population centers.

   e. Find the socially-optimal levels of emissions E_1^* and E_2^*. (6 points)

   $SW = \Sigma_i U_i + \pi_1 + \pi_2$

$$= N(x_i - kP^2/2) + \pi_0 + AE_1 - BE_1^2/2 + \pi_0 + AE_2 - BE_2^2/2$$
$$= N(x_i - k(a_1E_1 + a_2E_2)^2/2) + \pi_0 + AE_1 - BE_1^2/2 + \pi_0 + AE_2 - BE_2^2/2$$

   $dSW / dE_1 = -Nk \cdot (a_1E_1 + a_2E_2) \cdot a_1 + A - BE_1 = 0$

   Substitute in that $E_1^* = E_2^* =$

   $E_1^* = E_2^* = A/(B + Nka_1 \cdot (a_1 + a_2))$

   Substitute in that $a_1 = a_2$

   $E_1^* = E_2^* = A/(B + Nk2a^2)$

   f. Interpret each of the comparative statics in the above equation. E.g. How does the optimal level of emissions change with A, B, N, k, a_1, and a_2? Why does this make sense? (6 points).

- *A is the intercept of the marginal savings from pollution function. The higher it is, the more profits from emissions, and thus the more emissions in the optimum.*
- *B is the slope of the marginal savings from pollution function. Higher B means a steeper slope, meaning that the unregulated equilibrium level of emissions is lower, and thus that E^* is lower.*
- *$dE^*/dN < 0$. N is the number of people. More people breathing the air implies higher damages.*

- *dE*/dk < 0. k parameterizes the utility losses from one unit of pollution. More utility losses implies lower optimal emissions.*
- *a_1 and a_2 translate emissions into ambient pollution. If emissions translate into more pollution, the optimal level of emissions should be lower.*

g. Verify that your solution satisfies the Samuelson Condition for the optimal provision of public goods. (5 points)

The Samuelson Condition is:

$\Sigma_i MRS_i(P^*) = MRT(P^*)$

MRS can be thought of as the marginal rate of substitution between dollars of consumption of the numeraire good and units of pollution.

MRT is the transformation between dollars of profit and pollution.

$MRT(E) = A - E_T \cdot B/2$

$P = a_1 E_1 + a_2 E_2 = aE_T$

$MRT(P) = 1/a \cdot MRT(E_T)$

(This is from equation 14.4 in Kolstad.)

$MRT(P) = (A + PB/(2a)) / a$

Now plugging these values into the Samuelson Condition:

$NkP = (A + PB/(2a)) / a$

$P^* = A / (B/2a + Nka)$

Using that $P^* = 2aE_j^*$:

$E_j^* = A / (B+2Nka^2)$

This is the same as the socially-optimal level of emissions solved for above.

h. What level of Pigouvian tax would generate this social optimum? (2 points)

From above, the firm sets $E_j^* = (A-\tau)/B$

The socially optimal level is $E_j^* = A / (B+2Nka^2)$

Setting these equal, we have:

$E_j^* = A / (B+2Nka^2) = (A-\tau)/B$

$\tau^* = A - BA/(B+2Nka^2)$

i. Let's say we wanted to do a cost-benefit analysis of this Pigouvian tax, relative to no regulation at all. Draw a figure that shows marginal savings and marginal damages from emissions and shade the efficiency gain from the Pigouvian tax. (2 points) (Don't worry about getting the intercepts of the lines correct, but do worry about shading the correct triangles.)

The shaded region is the distance between the marginal savings and marginal damages curves between the quantity of emissions where they cross and the quantity at which MS=0.

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