

EC371 – Environmental Economics, Fall 2011, Boston University

Instructor: Jeremy Smith

Final Exam

Tuesday, December 20, 2011

This is a 108-minute exam, but you will have 120 minutes to complete it. There is a total of 108 points allocated across four questions. In addition, there is one bonus question at the end. Use the number of points allocated to each part as a rough guide to how long to spend on that part. I recommend that you use one minute per point *at most* until you have gotten through each question, then use your extra time to revisit parts you may have missed the first time through and to check your work.

Please read the questions carefully and write your answers in the space provided. You can use the backs of the sheets for scrap paper, but to get full credit you must show all relevant work in the space provided.

Please follow my instructions at all times.

Concentrate and think carefully, but try to relax too!

Student Number: Solutions

(Please do not include your name.)

1. [3 parts, 32 points total] Consider an economy with two firms that emit an environmentally harmful uniformly mixed fund pollutant as a by-product of their production processes. These emissions are perfectly and costlessly monitored by the government. Suppose it has been decided that an aggregate abatement target of 155 units must be met. The marginal cost relations faced by each firm for abating a given amount are $MC_1 = 14q_1$ and $MC_2 = 17q_2$ (in dollars) where q_1 and q_2 are the units of abatement undertaken by Firm 1 and Firm 2 respectively. Each firm has baseline emissions of 300 units.

a) [8 points] Calculate the cost-effective allocation of individual abatement requirements that satisfies the aggregate abatement target. Calculate the appropriate per-unit uniform emissions fee that the government would have to implement to achieve this allocation.

answer:

For cost effectiveness, $MC_1 = MC_2$

and, of course

$$q_1 + q_2 = 155$$

→

$$14q_1 = 17(155 - q_1)$$

$$q_1^{ce} = 85, q_2^{ce} = 155 - 85 = 70.$$

To find the appropriate fee:

$$f^{ce} = MC_1(q_1^{ce}) \text{ (or, equivalently, } f^{ce} = MC_2(q_2^{ce}))$$

$$f^{ce} = 17 * 85 = \$1,190/\text{unit.}$$

b) [16 points] Suppose that the government decides to impose a uniform per-unit emissions fee at the level you found in the previous part, and commits to keeping the fee at this level permanently. (If you were not able to complete the previous part, assume a value for the per-unit fee, and state this assumption explicitly.) Firm 2 is considering adopting a new abatement technology that would shift its marginal cost relation from $MC_2 = 17q_2$ to $MC_2' = 5q_2$. Assuming that the fee stays fixed at its permanent level, what would Firm 2's total cost savings in a given period be if it adopted the new technology? What would aggregate emissions be if the fee were in place at its permanent level and Firm 2 had adopted the new technology?

answer:

With the old technology, firm 2 will choose to abate 70 units (from setting $17q_2 = 1190$, which is the firm's cost-minimizing condition, but also from the cost-effective allocation, since the fee of 1190/unit was chosen precisely to achieve cost effectiveness). With the new technology, firm 2 will choose to abate 238 units (again from applying the cost-minimizing condition, but now with the new marginal abatement cost curve). Remember that the total cost savings from adopting the technology can be broken into two sources. In this case, the savings from lower marginal abatement costs on the first 70 units abated comes out to $1/2 * (1190 - 350) * 70 = \$29,400$; and the savings from re-minimizing costs by choosing to abate a further 168 units rather than pay fees for emitting them is $1/2 * (238 - 70) * (1190 - 350) = \$70,560$; and so the total cost savings is $29400 + 70560 = \$99,960$.

As already mentioned, with the new technology in place, firm 2 will abate 238 units. To know how much will be emitted in the aggregate, we need to find the associated level of emissions for firm 2, and we also need to know how much firm 1 will abate and hence emit. By the familiar formula, emissions equal baseline emissions minus abatement. So firm 2's emissions with the fee and new technology in place will be $300 - 238 = 62$. Firm 1 will try to minimize its costs when faced with the fee, just like firm 2, and again, since the specific fee level was chosen to achieve the cost-effective allocation from part a), it will choose to abate 85 units, since nothing has changed for firm 1. Using the same familiar formula, firm 1's emissions will hence be $300 - 85 = 215$. In the aggregate, then, there will be $215 + 62 = 277$ units emitted with the fee in place and assuming firm 2 has the new technology.

c) [8 points] Now consider whether it is worthwhile for Firm 2 to adopt the new technology. Suppose the technology costs \$1.1 million, including all material, installation and learning expenditures associated with it. This is paid in period 0 (today), and once it is paid, the firm will receive an annual net benefit equal to the per-period total cost saving you calculated in the previous part. (Assume a value for this if you were not able to complete the previous part.) This annual net benefit will be received once per period, starting in period 1 and continuing for every period thereafter. The firm uses the market interest rate of 8% to evaluate long-term projects like this, and has an infinite planning horizon. The technology never wears out once it is installed. Calculate the net present value to the firm of adopting the technology today. Explain why the firm should adopt the technology or not. (You can use formulas given in class without deriving them, but please be clear about writing the formulas down and showing your calculations.)

answer:

$$NPV = -C_0 + 1/r(B)$$

$$= -1100000 + (99960)/0.08$$

$$= -1100000 + 1249500$$

$$= \$149,500.$$

The net present value is positive, indicating that installing the technology will yield a better return than investing \$1.1 million at the market interest rate. Therefore, the firm should adopt the technology, since doing so is better than its outside option.

2. [2 parts, 24 points total] Consider a non-renewable and non-recyclable natural resource that has no substitutes. Society only places value on this resource for the present period and the immediately following period (called periods 0 and 1 respectively). Marginal benefits to society are represented by the inverse demand function $P_i = 80 - 2Q_i$ for each period $i = 0, 1$ (where Q_i is the quantity of the resource that would be extracted/consumed in period i at price P_i dollars per unit) and marginal extraction costs are \$20 per unit in each period. The stock of the resource is fixed at 40 units.

a) [12 points] Using a discount rate of 20% where necessary, calculate the dynamically efficient allocation of the resource across the two periods. Verify that the Hotelling Rule holds.

answer:

$$MNB_0 = 80 - 2Q_0 - 20 = 60 - 2Q_0$$

$$PV(MNB_1) = 1/(1.2) * (60 - 2Q_1)$$

$$\text{For efficiency, } MNB_0 = PV(MNB_1)$$

and, of course

$$Q_0 + Q_1 = 40$$

→

$$60 - 2Q_0 = 1/(1.2) * [60 - 2(40 - Q_0)]$$

$$Q_0^{**} = 20.9090\dots, Q_1^{**} = 40 - 20.9090\dots = 19.0909\dots$$

In words, the Hotelling Rule states that the marginal user cost associated with the efficient extraction plan will rise over time at a growth rate equal to the discount rate. This implies that $MUC_1 = (1.2) * MUC_0$, so this is what we need to check.

$$P_0^{**} = 80 - 2(20.9090\dots) = 38.1818\dots$$

$$P_1^{**} = 80 - 2(19.0909\dots) = 41.8181\dots$$

$$MUC_0 = P_0^{**} - MEC = 38.1818\dots - 20 = 18.1818\dots$$

$$MUC_1 = P_1^{**} - MEC = 41.8181\dots - 20 = 21.8181\dots$$

$$MUC_1 / MUC_0 = 21.8181\dots / 18.1818\dots = 1.2, \text{ as required.}$$

b) [12 points] Suppose that the government is unable to implement a policy that achieves the dynamically efficient allocation. Instead, it decides to let private markets operate, but to tax extraction of the resource in period 0, and use the revenue raised from the tax to fund exploration for additional units of the resource. Extraction is performed by a private mining company that behaves perfectly competitively. The extraction tax is set at \$10 per unit of the resource extracted, which is collected from the mining company and is imposed in period 0 only. New units of the resource that are discovered as a result of the exploration will be available to period 1 only, *in addition to* the units left over from the original stock that were not consumed in period 0, and can be obtained at the same marginal extraction cost. The total number of new units of the resource discovered will be $x = 0.032R$, where x is the number of *additional* units of the resource available to period 1 and R is the total tax revenue raised in period 0, in dollars. Calculate the consumer surplus that will be enjoyed in period 1 if this policy is implemented. Calculate the consumer surplus that would arise in period 1 if, alternatively, there were no policy in place at any time. (There is no need to discount.)

answer:

$$MEC_t = MEC + t = 20 + 10 = 30.$$

Consumption in period 0 will be determined by market equilibrium with the tax in place:

$$\begin{aligned} P_0 &= MEC_t \\ 80 - 2Q_0 &= 30 \\ Q_0 &= 50/2 = 25. \end{aligned}$$

Tax revenue will therefore be $25 \cdot 10 = \$250$. This revenue will fund enough exploration to discover $x = 0.032R = 0.032 \cdot 250 = 8$ new units. So, in period 1, there will be $(40 - Q_0) + 8 = 23$ units available to be extracted. The resource is hence still scarce in period 1 (because $P = MEC$ requires 30 units to be extracted and consumed), so all 23 units will be consumed. Due to the scarcity of the resource, the market price will be bid up above the marginal extraction cost, providing profit to the mining company. Consumer surplus is the area between the demand curve and the market price, up to the quantity of 23, and should come out to $CS = 1/2 \cdot (80 - 34) \cdot 23 = \529 . With no policy in place, the market will operate freely in period 0, leading to 30 units being consumed, thus leaving only 10 for period 1 (with zero tax revenue and therefore zero new units discovered). In this case, $CS = 1/2 \cdot (80 - 60) \cdot 10 = \100 .

So, consumers are a lot better off with the tax-and-explore policy than with no policy. The tax has a double benefit from the perspective of period 1: it leads to less consumption in period 0 than there otherwise would be; and it leads to additions to the stock through the funding of exploration. (This part has nothing to do with the efficient allocation calculated in the previous part, which is NOT AN EQUILIBRIUM. The question of what is efficient – i.e. how big the tax should be – with the possibility of exploration is more complicated. Also, more structure would be necessary to examine the private incentives of the mining company to perform exploration on its own.)

3. [2 parts, 20 points total] Consider a pure public good, the quantity of which is referred to as Q . Society consists of two people, named A and B, with demand curves for the good given by $q^A = 8 - 2p$ and $q^B = 8 - 0.5p$, where q^i is the quantity that person i would want to consume if the price were p dollars per unit.

a) [8 points] Calculate the total social benefits that would be gained due to an increase in the availability of this good from $Q = 2$ to $Q = 6$. (This is equivalent to the total willingness to pay of society in the aggregate for this change.)

answer:

Since this is a public good, we first need to invert the individual demand curves so that we can sum individual marginal willingnesses to pay for a given quantity (i.e. vertical summation):

$$q^A = 8 - 2p \rightarrow 2p = 8 - q^A \rightarrow p = 4 - 0.5q^A;$$

$$q^B = 8 - 0.5p \rightarrow 0.5p = 8 - q^B \rightarrow p = 16 - 2q^B.$$

Now, re-label p as the individuals' MWTPs and the q 's as Q , and sum.

$$\text{MWTP} = \text{MWTP}^A + \text{MWTP}^B = 4 - 0.5Q + 16 - 2Q = 20 - 2.5Q.$$

This gives society's marginal willingness to pay relation, or equivalently and perhaps more familiarly, aggregate marginal social benefits. A total value is, as usual, calculated as an area under the corresponding marginal function. Since the question asks for total social benefits, the appropriate marginal function is the societal MWTP function we just found. So, we want to calculate the area under this function, between a quantity of 2 and a quantity of 6. This involves summing the area of a triangle and the area of a rectangle; you should get \$40 for the total.

(Some people were tempted to calculate a change in consumer surplus rather than an increase in total benefit. This could be useful in some circumstances, but it is not what the question asked for. Total benefit is typically a more useful measure with public goods, since consumers of such goods do not often pay a price for using them, rendering the concept of consumer surplus inapplicable.)

b) [12 points] Suppose that the government is considering permanently increasing the availability of this good as per the previous part, and would like to commission a cost-benefit analysis before it makes its decision. If the policy were implemented, the initial cost would be \$1,400, to be paid immediately (in year 0). There would also be a recurring cost of \$10 that would have to be paid each year starting in year 1. The annual benefit of this policy would be the total social benefits calculated in the previous part, which would be enjoyed each year starting in year 1. (If you were not able to calculate this in the previous part, you can assume a value for it for this part as long as you explicitly state your assumption.) The government requires all cost-benefit analyses to use a 100-year time horizon and a discount rate of 1%. Calculate the net present value of implementing the policy. Why might the government require the use of such a low discount rate? State whether the use of a higher discount rate would make the policy appear more or less attractive, and briefly explain why. (You can use formulas given in class without deriving them, but please be clear about writing the formulas down and showing your calculations.)

answer:

$$\delta = 1/1.01 = 0.9901$$

$$NPV = -C_0 + \frac{\delta - \delta^{101}}{1 - \delta} NB$$

$$= -1400 + 63.0289*(40 - 10)$$

$$= \$490.87.$$

The government most likely requires the use of such a low discount rate because it is concerned about the ethical implications that a higher discount rate would have in terms of the treatment of future generations. The Axiom of Anonymity states roughly that the welfare of all generations should be considered with equal weight, which justifies – because consumption tends to grow across generations – only slight discounting of dollars received by future generations. It is also possible that the government considers its opportunity cost of funds to be only 1%, but this would be a very optimistic estimate. (This part was about the *normative* question of how a discount rate *should* be chosen.)

A higher discount rate would make the policy look less attractive, because it would cause net present value to be lower. A higher discount rate means that dollars received in the future are being given less weight than dollars received in the present. This policy would force a large cost to be borne in the present, with benefits only realized in the future. So a higher discount rate would give more consideration to the cost (i.e. the part of the policy affecting the present) and less to the benefits (i.e. the part of the policy affecting the future), thus leading to a lower calculated net present value and hence a lower estimate of the net benefit of the policy. (This part was about the *positive* question of how a given discount rate actually affects the calculation of NPV and why.)

4. [3 parts, 32 points total] The biological relationship between the growth of a given fish population and the population size can be expressed as $g = 360x - 4.5x^2$, where g is the net addition to the stock in number of fish and x is the size of the stock in thousands of fish.

a) [6 points] Find all of the biological equilibria of this fishery, and state which of these are stable and which are unstable.

answer:

The two biological equilibria are where $g = 0$, i.e. $x = 0$ and where $360x = 4.5x^2$, or $x = 80$. The latter (80) is stable (and is called the carrying capacity), and the former (0) is unstable.

b) [12 points] Consider how this population would evolve if it were being harvested at a fixed rate of 4,000 fish per period. Specifically, with harvesting of 4,000 fish per period and starting from an initial population of $x_0 = 70$ (thousand) fish at the end of period 0, calculate what the population level would be at the end of each of the next two periods (i.e. calculate x_1 and x_2). Regardless of what your calculations show for this specific case, if we observe declining population levels across consecutive periods in general, does this indicate that the species is being driven to extinction? Explain briefly.

answer:

$$\begin{aligned} x_1 &= x_0 + (g(x_0) - h)/1000 \\ &= 70 + ([360*70 - 4.5(70)^2] - 4000)/1000 \\ &= 69.15 \end{aligned}$$

$$\begin{aligned} x_2 &= x_1 + (g(x_1) - h)/1000 \\ &= 69.15 + ([360*69.15 - 4.5(69.15)^2] - 4000)/1000 \\ &= 68.5262. \end{aligned}$$

Declining populations over time *could* indicate that the species is on an unsustainable path and will be driven to extinction in the absence of some action (e.g. reducing harvesting) to put the population on a different path. But not necessarily. As in this example, the population could be above its stable bionomic equilibrium level at some point in time, in which case, negative population growth is simply associated with a convergence of the species to a constant and sustainable population level. (It is also possible that negative population growth over consecutive periods results from a series of temporary but repeated negative shocks. This would not cause the population to become extinct as long as, when the shocks stop occurring, the population is still above the unstable bionomic equilibrium level, at which point it will start to converge to the stable bionomic equilibrium level.)

c) [14 points] Suppose that, in contrast to the hypothetical scenario of the previous part, this species has been harvested at a very high rate for the past several years. The government decides to reduce harvesting, and limit it to 7,200 fish per period. This would correspond with a bionomic equilibrium at the current actual stock size of 40 (thousand). An Individual Transferable Quota system is put in place. This system caps the total annual harvest at 7,200 fish, and allocates this aggregate quota across all fishing companies. Specifically, suppose that there are two fishing companies, and that the government initially gives the first company sole rights to harvest the entire allowance of 7,200 fish, while leaving it free to transfer any part of this allowance according to private agreements with any other party. Using your knowledge of tradable permits to control air pollution and related topics, explain how you would expect firms to react to this policy and why. Also, discuss what might make this policy desirable from a social perspective. (You should explicitly state any assumptions you are making about the objectives and motivations of the firms. This might be a useful thing to think about at the outset.)

answer:

It makes sense in this case to assume that firms are profit maximizers (with cost minimization implicitly a component of profit maximization). Each firm must bear costs in order to go fishing, and each can gain benefits from using or selling the fish it catches. We could in principle estimate marginal net benefit functions – or marginal profit functions – for each firm individually if we wanted to undertake a mathematical analysis. We would expect some heterogeneity across firms on both the cost and benefit side – though, if we think of fish as being sold to a competitive market at a fixed price, then each firm will have identical marginal revenue. Presumably, since the species has been harvested at a high rate recently, unconstrained individual profit maximization would lead these firms to want to harvest far more than 7,200 fish in the aggregate. Thus, the cap part of this policy is a binding constraint on firms.

If firm 1 were to make use of its entire initial quota, it would be facing high marginal costs and potentially diminishing marginal revenue/benefit. It may still be below the number of fish it would want to catch relative to its unconstrained optimum, but this does not matter. What matters is that firm 2 would love to be able to catch just one fish, because its marginal revenue from doing so would be great compared to its marginal cost for the first unit caught. (Both firms are assumed to be incumbents that have already borne fixed investments associated with entering the industry.) So there is scope for firm 2 to offer a slice of the profit it stands to gain from catching one fish as compensation to firm 1 for the profit it would lose by reducing its catch by one fish and so freeing up one unit of quota for transfer. And so on for several more units.

The point at which the firms will run out of bargaining range is associated with a division of the aggregate quota that ends up maximizing the aggregate profits of the industry subject to the constraint that only 7,200 fish are caught each period. Given the heterogeneity in benefits and especially costs, this is unlikely to be an equal division or some other allocation that would be easy to guess at the outset. But the policy doesn't require anyone to know what this allocation is: the firms have the incentives to find their

way there themselves. (Another implicit assumption, by the way, is that the firms behave perfectly competitively. If firms have market power, the initial allocation of quota can matter. In this example, the benefits to firm 1 of keeping the entire quota and hence cornering the market could outweigh any bribe that firm 2 could hope to make. This can be gotten around by assuming that there is an international market for fish of this and many substitute species, so that any attempt for a domestic firm to raise prices will lead to a loss of all of its customers to foreign competitors. Also, we would want to be sure that there are no transaction costs or other frictions restraining firms from bargaining over the transfer of quota.)

The primary benefit of the policy is that the long-term viability of the species is ensured: the harvest of 7,200 fish will be available year after year while the population of fish remains constant at 40 thousand (at least in the absence of severe negative shocks that policymakers are not able to respond adequately to). This is good from the perspective of the use we make of the species and of the value we place on its continued existence. And it is good from the perspective of the firms because the profits of the industry as a whole are maximized given the aggregate harvest cap. Other policies achieving the same cap could lead to a higher cost burden, which may also end up being passed onto consumers in the form of higher prices. And some policies could moreover be much less effective at achieving the main goal of limiting harvesting. It is also possible that the ITQ policy will give firms incentives to innovate, hence driving down the cost of compliance further in the long run. Many other possibilities could be mentioned and delved into further.

BONUS QUESTION [6 points maximum – no penalty for guessing]: Identify the first and last names of the authors of the following articles from the optional readings, in the corresponding space provided.

“Environmental Policy Since Earth Day I: What Have We Gained?”

A. Myrick Freeman III

“The Problem of Social Cost”

Ronald H. Coase

“The Tragedy of the Commons”

Garrett J. Hardin

“Prices vs. Quantities”

Martin L. Weitzman

“Economic Growth and Climate: The Carbon Dioxide Problem”

William D. Nordhaus

“The Effect of Driving Restrictions on Air Quality in Mexico City”

Lucas W. Davis
