

## EC371 – Environmental Economics, Spring 2010, Boston University

Instructor: Jeremy Smith

### First Mid-term Exam – Solutions

Tuesday, March 2, 2010

This is a 50-minute exam, but you will have 60 minutes to complete it. There is a total of 50 points allocated across two questions. In addition, there is one bonus question at the end. Each part of each question is worth 10 points. 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. Concentrate and think carefully, but try to relax too!

#### Student Number: Solutions

1. [2 parts] A book collector is considering buying a signed first edition of *The Catcher in the Rye* by J. D. Salinger. The current buying price is \$30,000 (which is very high due to the recent death of the author). If the book is purchased now (year 0), there will be benefits obtained for the next fifty years (years 1 through 50) equivalent to \$1,000 per year. In year 51, the book will be sold to a museum at an agreed-upon price of \$35,000. In answering this question you can use formulas given in class without deriving them, but please be clear about writing the formulas down and showing your calculations.

a) What (conceptually) would the collector want to use for a discount rate for evaluating this purchase? Explain why in one sentence. Assuming that a discount rate of 3% is chosen, calculate the net present value of this purchase. (Your response can continue onto the next page.)

answer:

A market interest rate should be used as the discount rate. (More specifically, the interest rate on a financial market instrument comparable to the project, like a 50-year secure bond in this case, should be used.) [2 points]

Private, individual investors, like this book collector, should use a market interest rate as a discount rate because this reflects the appropriate outside option, or opportunity cost of funds. (And this itself is desirable because then  $NPV > 0$  implies that the project is unambiguously better than the outside option.) [2 points]

$$\delta = 1/(1 + r) = 1/(1.03) = 0.9709$$

$$\begin{aligned} \text{NPV} &= -C_0 + \frac{\delta - \delta^{51}}{1 - \delta} B_{1-50} + \delta^{51} B_{51} \\ &= -30000 + \frac{0.9709 - 0.9709^{51}}{1 - 0.9709} (1000) + 0.9709^{51} (35000) \\ &= -30000 + 25.7298(1000) + 0.2215(35000) \\ &= \$3,480.98. \text{ [6 points]} \end{aligned}$$

b) Now consider a cultural group that is deciding whether or not to purchase the same book at the same buying price. Unlike the individual collector, the cultural group uses a discount rate of 7%, and takes an infinite planning horizon (intending to permanently protect the book rather than eventually sell it). In addition to the baseline annual benefits of \$1,000 per year, the group believes that there is a further annual benefit associated with the cultural heritage of the work itself, which their purchase of the book will secure for posterity. However, the precise value of this additional annual benefit is not known. Calculate the net present value of the book to the group without accounting for this additional annual benefit [4 points]. The group is also considering the purchase of another rare book, but it can only purchase one of the two books. The net present value of the purchase of the alternative book has been calculated as \$5,800. Find the minimum value that the additional annual benefit would have to be to make the purchase of the Salinger book more attractive than the purchase of the alternative book [6 points].

answer:

without additional annual benefit

$$\begin{aligned} NPV_A &= -C_0 + (1/r)B_A \\ &= -30000 + (1/0.07)1000 \\ &= -\$15,714.29. \end{aligned}$$

with additional annual benefit

$$\begin{aligned} NPV_B &= -C_0 + (1/r)(B_A + B_B) \\ &= -30000 + (1/0.07)(1000 + B_B) \\ &= -15,714.29 + B_B/0.07. \end{aligned}$$

For the purchase of this book to be preferred to the purchase of the alternative book,

$$\begin{aligned} NPV_B &> NPV_C \\ -15,714.29 + B_B/0.07 &> 5,800 \\ B_B/0.07 &> 5,800 + 15,714.29 \\ B_B &> \$1,506. \end{aligned}$$

2. [3 parts] Consider the owner of a forested area who is choosing how much pesticide to spray on the land. The more pesticide that is sprayed, the less likely that a destructive species of insect will flourish and thereby cause damage to the trees, which would reduce revenue to the owner. The owner therefore gains a benefit from spraying pesticide, represented by the marginal benefit relation  $MB = 20 - 0.5Q$ , where  $Q$  is the number of gallons of pesticide spread per season and  $MB$  is measured in dollars. The owner can buy pesticide for a fixed price of \$10 per gallon, and this flat marginal cost represents the only expense faced by the owner. In addition to the private benefit accruing to the owner, there is also a marginal external benefit given by  $MEB = 5 - 0.125Q$  in dollars. This external benefit arises because the more pesticide the owner sprays, the less likely that the insects will thrive on surrounding lands owned by other foresters.

a) Find an expression for marginal social benefits (MSB) in this case, defined as you think appropriate. Calculate the level of pesticide use that will arise if the owner acts in self interest only. Calculate the socially efficient level of pesticide use as well.

answer:

$$MSB = MB + MEB = 20 - 0.5Q + 5 - 0.125Q = 25 - 0.625Q$$

[2 points]

self-interest:  $MB = MC$

$$20 - 0.5Q = 10$$

$$0.5Q = 10$$

$$Q^* = 20. \text{ [4 points]}$$

socially efficient:  $MSB = MC$

$$25 - 0.625Q = 10$$

$$0.625Q = 15$$

$$Q^{**} = 24. \text{ [4 points]}$$

Note that  $MC = 10$ , not  $10Q$ . Very similar language was used to describe marginal costs in this problem as was used in the third problem from the first set of practice problems. (Indeed, the first two parts of the present problem are virtually identical to the latter parts of that problem.) This issue was raised in the solutions to that problem, as well as earlier in the semester in class. An upward-sloping marginal cost curve very simply does not fit the description given. If you made this mistake, you will lose 2 points on this part, but none on further parts if you carry the mistake through.

b) Suppose that the government considers addressing this situation by giving the owner a per-unit subsidy for each gallon of pesticide sprayed. Calculate the appropriate per-unit subsidy that would achieve the socially efficient level of pesticide use. If there is a 60% chance that the government puts this subsidy in place and a 40% chance that it does nothing, calculate the expected value of the total subsidy amount that the government would disburse to the owner.

answer:

$$\begin{aligned} \text{appropriate subsidy} &= s^{**} = \text{MSB}(Q^{**}) - \text{MB}(Q^{**}) \\ &= 25 - 0.625(24) - 20 + 0.5(24) \\ &= 10 - 8 \\ &= 2. \text{ [4 points]} \end{aligned}$$

$$\begin{aligned} \text{total subsidy payments with this per-unit subsidy in place} &= s^{**} \times Q^{**} \\ &= 2 \times 24 \\ &= \$48. \text{ [3 points]} \end{aligned}$$

The expected value bit was partly thrown in to keep people who might have been on auto-pilot with this question on their toes. But it also gives an opportunity to demonstrate how we can add a bit of policy-making reality to the story. Basically, this little short-cut approach we introduced to deal with various sorts of uncertainty in a cost-benefit analysis scenario can also be used to take a short-cut to modeling uncertainty in outcomes of the political process. Picture a piece of legislation that is wending its way through various congressional sub-committees. There is some chance it will eventually get stamped by the president and passed into law, in which case the per-unit subsidy will be put in place, the socially-efficient quantity will be obtained and the total subsidy payment as calculated above will be disbursed. There is also a chance – cynics would say much the greater, but the set-up here is a bit more optimistic – that the legislation “dies on the table” – through filibuster, veto, partisan stalemate, whatever. In that case, no subsidy will be put in place, so there will be zero total subsidy payments disbursed (also implying that the self-interest outcome will prevail). We just have to attach the appropriate probabilities to these outcomes and calculate it out.

$$\begin{aligned} \text{EV}(\text{total subsidy payments}) &= 0.6*48 + 0.4*0 \\ &= \$28.8. \text{ [3 points]} \end{aligned}$$

(It is also fine if you calculated everything in one shot, or if you calculated the expected per-unit subsidy first and then multiplied this by the socially efficient quantity.)

c) Now suppose that there is no subsidy in place, and the owner is hence acting in self interest only. A sport-fishing company opens in the same region. Now, in addition to the marginal external benefit to other foresters, there is also a marginal external cost, or marginal damage, associated with pesticide use because run-off enters a nearby river, affecting the fishing firm. Specifically, assume that  $MD = 0.3125Q$  in dollars. Calculate the new socially efficient level of pesticide use. Calculate the efficiency loss that would be suffered if the self-interest rather than the new socially efficient level of pesticide were used.

answer:

First we need to define  $MSC = MC + MD$ , as usual. The new socially efficient outcome will now be the one that correctly balances the owner's private costs and benefits, the external benefits to the other foresters and the external cost to the fishing firm. We find this by maximizing total net benefits from a social perspective, which is appropriately interpreted in this case as total social benefits minus total social costs. This will be found at the intersection of MSB and MSC.

new socially efficient outcome:  $MSB = MSC$

$$25 - 0.625Q = 10 + 0.3125Q$$

$$15 = 0.9375Q$$

$$Q^{***} = 15/0.9375 = 16. \text{ [5 points]}$$

To think about the efficiency loss, it probably helps a lot to draw a graph. But in this case, drawing a graph might do more harm than good if you try to include too much on it. The graph that I think makes this the most clear has just two lines: the MSB and the MSC. Their intersection gives the efficient quantity, and the only other piece of information we need is the self-interest quantity. We of course need other lines to find this, but we already found it in an earlier part, so we can leave off the lines now.

So, we are comparing the quantities 20 and 16, and are looking for the efficiency loss. Starting at 16 and moving rightward, we note that MSC begins to exceed MSB, so an incremental move in this direction is efficiency-deteriorating. Summing up all of the incremental moves from 16 to 20, we see that the total deterioration – the efficiency loss we are seeking – is the area of a triangle, with “height” given by the difference in quantities (20 – 16) and “base” given by the height of MSC minus the height of MSB at the self-interest quantity.

$$\begin{aligned} \text{efficiency loss} &= (Q^* - Q^{***}) \times ([10 + 0.3125 \times Q^*] - [25 - 0.625 \times Q^*]) / 2 \\ &= (20 - 16) \times (16.25 - 12.5) / 2 \\ &= \$7.5. \text{ [5 points]} \end{aligned}$$

(It would also be fine to find this area using integration. A graph was not asked for, but you will not lose any points for drawing one if the rest of your response is correct. There are no points just for drawing a graph either, although you may receive partial credit if you correctly showed the efficiency loss visually on a clearly-labeled graph.)

BONUS QUESTION [3 points maximum – no penalty for guessing]: Continuing on from the last part of the second problem, suppose that the owner of the forested area is granted fully-enforced property rights. Calculate the minimum bribe that the owner would be willing to accept to move directly from the self-interest level of pesticide use to the socially efficient level of pesticide use.

answer?

This question is harder than it might look, and I'm not sure that I really know what the right answer is. The problem is that there are two parties that would like to bribe the owner once property rights are assigned, but these parties have competing objectives: the other foresters want more pesticide use while the fishing firm wants less pesticide use. In moving from 20 to 16, it will be the fishing firm shelling out a bribe to the owner. The other foresters will be hurt by this move, but they don't have property rights, so are in no position to be seeking compensation. However, they can offer a bribe of their own – to the owner for *not* reducing pesticide use. In bargaining with the fishing firm over the amount of that bribe, the owner will also have to consider the bribe from the other foresters that will have to be forgone.

To be a bit more concrete, we can calculate a few areas and see if we can wring any meaning out of them. First, let's find the area under MEB between 16 and 20. This is the area of a triangle and a rectangle, and should come out to \$11. This represents the *maximum* that the other foresters would be willing to pay to the owner to *prevent* the move from 20 to 16. Now, let's find the owner's private total net benefits between 16 and 20. This should come to \$4. This would be the minimum bribe that the owner would accept if it were just the owner and the fishing company bargaining over this quantity change in isolation. (But note that, if they were in isolation, their own bargaining incentives would actually lead them to a quantity less than the socially efficient one. On a graph, the MNB function and the MD function intersect around 12.) Finally, let's find the area under MD between 16 and 20. This should come to \$22.5, and represents the maximum that the fishing firm would pay to effect the change from 20 to 16.

With these in hand, here's an illustration of what could possibly happen. Let's say the other foresters get together and decide to offer the owner \$6 for keeping pesticide use at 20. (If the owner accepts, this will leave them better off, because they will have spent just \$6 to avoid a damage of \$11.) The owner replies "I'll think about it" and then goes to a meeting with the fishing firm. The fishing firm says "I know damned well that the net cost to you of lowering your pesticide use to 16 is only \$4, so that's all I'm going to offer you." The owner replies, "if that's the best you've got to offer, I'll be much happier keeping my pesticide use right where it is and taking the \$6 from these other foresters, thank you very much." "Playing hardball, are you?" retorts the fishing firm. "Ok then, I'll give you \$12, but not a penny more." "Jolly good," says the owner, and they shake hands and sign their contract over a nice cigar. And everybody lives happily ever after.

Or do they? Collectively, everyone is certainly better off because, by the terms of the contract, the owner will start using just 16 gallons of pesticide, which is the socially

efficient quantity and maximizes total net benefits for society as a whole by definition. But on an individual level, let's take it group by group. The fishing firm is better off, because it has paid just \$12 to rid itself of \$22.5-worth of damage. The owner is better off because the \$12 received is enough to compensate for lower private net benefits, the forgone bribe from the other foresters and then some. The other foresters, however, are clear losers. They bear a loss of \$11. (Correctly totting up all of these net gains and losses, by the way, leads to the recouping of the \$7.50 efficiency loss found in the previous part.) So society is better off as a whole, but there are some underlying distributional issues.

The real moral of the story, though, is that, while no bribe ever changed hands between the owner and the other foresters in the example above, the very offer of such a bribe is integral to the attainment of social efficiency in general. It would be possible, for example, for the other foresters to put together a bribe to block a contract that would further move pesticide use from 16 to 15 (which would be socially undesirable, but which would be in the interests of the owner and the fishing company if they were acting in isolation).

Somewhere in there is an answer to the question, but I claim neither that it's the one precise answer nor that such a thing exists. An even more complicated issue is the question of how Coasean bargaining might work in general in this situation. That is, without focusing specifically on a change from 20 to 16, how might private bargaining proceed in general starting from the pre-bargaining outcome of 20? Perhaps the other foresters will strike a deal that induces the owner to *increase* pesticide use before the fish company can apprise its lawyer of all the details and put together its own offer. This could lead to a sequence of nullified and re-written contracts as a whole series of incremental offers are made by each side, and, if the legal system is not flexible enough to deal with this, to a serious impediment to the attainment of the socially efficient quantity. It doesn't seem unreasonable to suppose that, even with the small number of participants involved, there might be a failure of private bargaining to reach the efficient outcome.

In terms of grading, if you found the \$4 bribe or were going for something similar considering the owner and the fishing company in isolation, that's worth a point. If you showed signs of thinking about all three parties involved, that's worth one or two points depending on how far you got. Three points would require something like the numerical example I went through above and/or other indications of having thought really thoroughly about it. Anything that appears to be pure guessing is worth zero, although playing around with graphs and plugging things into marginal functions could be worth a point even if you did not come to any conclusions, as long as it looks like you were on a reasonable track.