

# **EC371 – Environmental Economics, Fall 2011, Boston University**

Instructor: Jeremy Smith

## **First Mid-term Exam**

Wednesday, October 19, 2011

This is a 46-minute exam, but you will have 51 minutes to complete it. There is a total of 46 points allocated across two 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. [18 points total, 2 parts] Consider a mining company that has discovered a new coal seam and is deciding whether it should extract the coal. If it does, extraction will start in year 1, and will end in year 12 when all of the feasible reserves of coal are exhausted. The company always uses a discount rate of 8% in the evaluation of projects (which appropriately captures its opportunity cost of funds). You can use formulas from class without deriving them for this problem, but be careful to write them down clearly and to show your calculations.

a) [10 points] If the company decides to extract the coal, it must first pay royalties and start-up costs equal to 1,000 dollars, in year 0. When extraction begins, the company must pay 200 dollars per year in wages to its employees. It will also earn 600 dollars per year for the coal that it sells. At the end of operation, the mine will simply be abandoned. In year 20, the government will conduct a site analysis, and will assess a fine of 5,000 dollars on the firm if there is environmental harm from the tailings. The company believes that there is a 75% chance that no environmental harm will be found, and hence no fine levied. However, there is a 25% chance that they will have to pay the fine in year 20. Would you recommend that the company extract the coal?

answer:

$$\delta = 1/1.08 = 0.9259$$

$$NB = B - C = 600 - 200 = 400$$

$$EV(C_{20}) = 0.75*0 + 0.25*5000 = 1250 \text{ [3 points]}$$

$$NPV_1 = -C_0 + \frac{\delta - \delta^{13}}{1 - \delta} NB - \delta^{20} * EV(C_{20})$$

$$= -1000 + 7.5344*(400) - 0.2144*1250 \text{ [5 points]}$$

$$= \$1745.76. \text{ [1 point]}$$

I would recommend the project, because  $NPV > 0$ . [1 point]

This means that extracting the coal is better for the company than doing nothing (where “doing nothing” means keeping its money invested in other investments/projects with returns of about 8%, i.e. the status quo). Moreover, NPV is very large, so its sign is not likely to be sensitive to small changes in the numbers we’ve used.

There is nothing particularly unusual about the structure of this project, even if it doesn’t fit exactly into one of the specific formulas we’ve used. The period of operation is followed by seven years in which the mine site lies abandoned and nothing of relevance to the company happens, then, finally, there’s a year in which they may or may not have to pay a fine. This can all be made to fit neatly into the general net present value framework, as has been done here.

b) [8 points] Now suppose that, before the company decides what to do, it learns that there is a new extraction technology available. The technology will allow the company to hire fewer workers, so that the annual wage cost will only be 100 dollars each year of operation. It will also allow more coal to be extracted, so that the annual earnings from selling coal will be 700 dollars each year of operation. (The feasible reserves of coal will still be exhausted in year 12, though.) Finally, the new technology will guarantee clean operations, and reduce the probability that the company will have to pay a fine in year 20 to zero. However, the technology is expensive: adopting it would raise total costs in year 0 to 2,750 dollars altogether. What recommendation would you make to the company?

answer:

$$NB = B - C = 700 - 100 = 600$$

$$EV(C_{20}) = 1.0 * 0 = 0$$

$$NPV_2 = -C_0 + \frac{\delta - \delta^{13}}{1 - \delta} NB$$

$$= -2750 + 7.5344 * (600) \text{ [4 points]}$$

$$= \$1770.64. \text{ [1 point]}$$

The recommendation, though I didn't ask for this specifically, should be multi-faceted. One thing that we can say for sure is that the company should definitely extract the coal: whether it uses the new technology or not, the NPV is well above zero, thus indicating an efficient use of its funds. [1 point] The choice of whether to use the new technology or not is a little less clear cut. It's true that  $NPV_2 > NPV_1$ , which suggests on face value that using the new technology is the better choice. [1 point] However, these NPV estimates are not very different from one another. It's probably therefore in the company's interests to have its cost-benefit analysts do some sensitivity analysis before they decide what to do. [1 point]

Two areas seem like good places to look for sensitivity. One is the probability of having to pay the fine in year 20 in the first part. If that is just a bit smaller, the new technology looks less good (though of course it's still close). The other is the start-up costs associated with the new technology. Costs in time and learning associated with new equipment are often under-estimated, and if the 2,750 were just a bit higher, the new technology would again look less good. Firms are reticent to adopt new technologies unless it can be demonstrated that there is a very clear net benefit from doing so. After seeing the results of the sensitivity analysis, the company might decide that the risk of the new technology not turning out as well as hoped is too high. It might instead opt for a third "compromise" project, such as sticking with the old technology but hiring an additional site manager, thus trading off higher annual labor costs for a lower probability of having to pay the fine.

2. [28 points total, 3 parts] Consider a beekeeper who is deciding how much honey to produce. The beekeeper gains a benefit from producing honey, represented by the marginal benefit relation  $MB = 300 - 6Q$ , where  $Q$  is barrels of honey and  $MB$  is measured in dollars. The beekeeper's marginal costs of production are given by  $MC = 40 + 4Q$ , in dollars. In addition to the private benefit accruing to the beekeeper, there is also a marginal external benefit given by  $MEB = 100 - 2Q$ , in dollars. This external benefit arises because the more honey the beekeeper produces, the more bees there are to pollenate a neighboring apple orchard.

a) [8 points] Find an expression for marginal social benefits (MSB) in this case, defined as you think appropriate. Calculate the level of honey production that will arise if the beekeeper acts in self interest only. Calculate the socially efficient level of honey production as well.

answer:

$$MSB = MB + MEB = 300 - 6Q + 100 - 2Q = 400 - 8Q$$

[2 points]

self-interest:  $MB = MC$

$$300 - 6Q = 40 + 4Q$$

$$10Q = 260$$

$$Q^* = 26. \text{ [3 points]}$$

socially efficient:  $MSB = MC$

$$400 - 8Q = 40 + 4Q$$

$$12Q = 360$$

$$Q^{**} = 30. \text{ [3 points]}$$

b) [12 points] Suppose that the beekeeper and the owner of the apple orchard enter into negotiations. The orchard owner wants to bribe the beekeeper to change honey production from the self-interest level to the socially efficient level (all at once). (If you were unable to find these quantities in the previous part, you can assume numbers for them here, as long as you state your assumption clearly.)

- i. What is the maximum total bribe that the orchard owner would be willing to pay for this overall change?
- ii. What is the minimum total bribe that the beekeeper would require before making this overall change?
- iii. Assume that, if a deal is reached, each party must pay \$35 in legal fees to finalize it. If there are no further transaction costs, will the socially efficient quantity be reached? Explain.

(You need to do the calculations to get full credit, but if you are unable to, you can earn partial credit by explaining each party's incentives in words.)

answer:

This is the Coase Theorem, but with a positive externality and without having to worry about property rights explicitly. The “pre-bargaining outcome” is the self-interest outcome (i.e. a quantity of 26), and we're assuming that the two parties are negotiating over a single jump to the efficient quantity (30).

i. The orchard owner benefits from more honey because the resulting greater number of bees pollenate his trees. This benefit from pollination is captured by MEB. The total external benefit of the four units between the self-interest and efficient quantities represents the total improvement in the orchard owner's welfare, and therefore the maximum that the orchard owner would pay to effect the increase. The total external benefits for these four units are given by the area under MEB between the two quantities. This will be an area of a triangle plus a rectangle, and should come out to  $(48 - 40) \cdot 4/2 + 40 \cdot 4 = \$176$ . [4 points]

ii. The beekeeper suffers decreasing net benefits (think of net private benefits as profit in this case if it helps) if the quantity of honey goes above the self-interest quantity. For each additional unit in this range, there are additional private benefits, but these are more than offset by the associated additional private costs. The total drop in private net benefits represents the “damage” to the beekeeper's welfare of the increased quantity, and therefore the minimum amount that would be necessary to convince the beekeeper to increase the quantity of honey produced to 30. The (negative of) total private net benefits between 26 and 30 are given by the area of a triangle, and should come out to  $(160 - 120) \cdot 4/2 = \$80$ . [4 points]

iii. If the orchard owner is willing to pay a maximum of \$176 to effect the change but \$35 must go as a legal fee, the maximum left-over amount remaining to be paid as a bribe is  $(176 - 35) = \$141$ . If the beekeeper would be harmed by \$80 by increasing quantity and

then by an additional \$35 by having to pay a legal fee, the overall minimum amount required to compensate for these harms is  $(80 + 35) = \$115$ . The bargaining range for the bribe is therefore between \$115 and \$141. This is a large enough range – and the situation is simple enough that other complications and impediments to bargaining can be ruled out – that it is reasonable to expect that a mutually beneficial bribe will be worked out between the two parties, and the efficient quantity obtained. [4 points]

If the two parties were bargaining over unit-by-unit changes and there were legal fees to pay at each stage, the efficient quantity would not be reached. But that's not the situation that this part is asking about. Calculating the bargaining range correctly but then arguing that the socially efficient quantity would not be reached was possible, but the argument had to be persuasive and to refer convincingly to factors not mentioned in the question.

c) [8 points] Regardless of your answer to the previous part, assume that the beekeeper and the orchard owner come to a private agreement to set honey production at the socially efficient quantity. However, now suppose that a policy maker reads somewhere that honey production entails a positive externality on apple orchards, and decides that the beekeeper should therefore be subsidized. With the subsidy in place, the beekeeper decides to increase production by an additional 5 barrels. Calculate the associated efficiency loss. If honey is good to eat and bees are good for trees, why is there such a thing as too much honey?

answer:

The question asks you to assume that the socially efficient quantity is obtained. We could technically model the agreement between the orchard owner and the beekeeper as causing the beekeeper to “internalize the externality”. But the details and implications of this are not necessary. All that matters is that, after the agreement, honey production is 30, and then a subsidy is put in place that induces – through channels we don’t need to worry about – production of 5 more barrels, for total honey production of 35 barrels.

Since honey production with both the agreement and the subsidy in place is higher than the socially efficient quantity, there will be an efficiency loss relative to being at the efficient quantity. On a graph, we could see this by drawing just the MSB and the MC. They intersect at a quantity of 30, but actual production is further right, at 35. The efficiency loss is the area of the triangle between MC and MSB, and between the quantities of 30 and 35. This should come out to  $(180 - 120) * 5 / 2 = \$150$ . [5 points]

The simple answer to why there is such a thing as too much honey is that, regardless of all of the different benefits of honey, there are also costs to producing it. This is implicit in our calculation of the efficiency loss. Each unit above the socially efficient quantity of 30 is associated with higher costs of production than the additional social benefits it entails.

This is related to a point we made in the context of negative externalities in class: the efficient level of pollution is not zero. Why not? We can eliminate pollution by eliminating all production, at the same time saving ourselves all production costs. The problem is that, when a product is scarce, we value additional units of it very highly, while when pollution and production are low, costs of these sorts are small for additional units.

The same logic applies here, but in the opposite direction. The efficient quantity of honey is not infinity. Why not? We can produce massive quantities of it by devoting all of the world’s resources to its production, making beekeepers and orchard owners very happy. The problem is that, when a product is hugely abundant, we do not value additional units of it very much. At the same time, the more resources we devote to producing one thing, the less we have to produce other things, so that the cost of additional units is very high. So we can use subsidies to make it in the beekeeper’s

private interests to produce more and more honey, but from a social perspective, we're not getting good "bang for our buck" by doing so. [3 points]

One might wonder why the orchard owner wouldn't take legal action. There is a signed contract specifying that 30 units of honey will be produced, but then the subsidy induces the beekeeper to breach the terms of that contract and produce 35 instead. One response to this observation is that the breach of contract "goes in the right direction" for the "injured" party in this case. The orchard owner gets additional benefits from additional production of honey all the way up to 50 units, so when getting a better deal than bargained for, is unlikely to want to go to court. A clever attorney might find a way to get part of the bribe returned in any case (which might then cause the beekeeper to reduce honey production somewhat), but this would entail further transaction costs. We just don't have enough information on the contract and legal system to speculate very productively about this kind of thing.

BONUS QUESTION [3 points maximum – no penalty for guessing]: Give the title of each author’s most notable contribution to environmental economics.

Ronald H. Coase      “The Problem of Social Cost”

Garret Hardin      “The Tragedy of the Commons”

William Cline      *The Economics of Global Warming*