EC371 – Environmental Economics, Fall 2011, Boston University

Instructor: Jeremy Smith

Second Mid-term Exam

Wednesday, November 30, 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 non-renewable and non-recyclable natural resource that currently 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), and there will be no exploration for this resource over this time. Marginal benefits to society are represented by the inverse demand function $P_i = 17 - 0.8Q_i$ 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 $6.00 per unit in each period. The stock of the resource is fixed at 12 units.

a) [10 points] Using a discount rate of 10% where necessary, calculate the dynamically efficient allocation of the resource across the two periods. Calculate the marginal user cost in period 0 associated with the efficient extraction plan, and interpret in words what it means.

answer:

$PV(MNB_0) = 17 - 0.8Q_0 - 6 = 11 - 0.8Q_0$
$PV(MNB_1) = 1/(1.1)*(11 - 0.8Q_1)$

For efficiency, $PV(MNB_0) = PV(MNB_1)$

and, of course

$Q_0 + Q_1 = 12$

$\rightarrow$

$11 - 0.8Q_0 = 1/(1.1)*[11 - 0.8(12 - Q_0)]$

$Q_0^{**} = 6.369$, $Q_1^{**} = 12 - 6.369 = 5.631$.

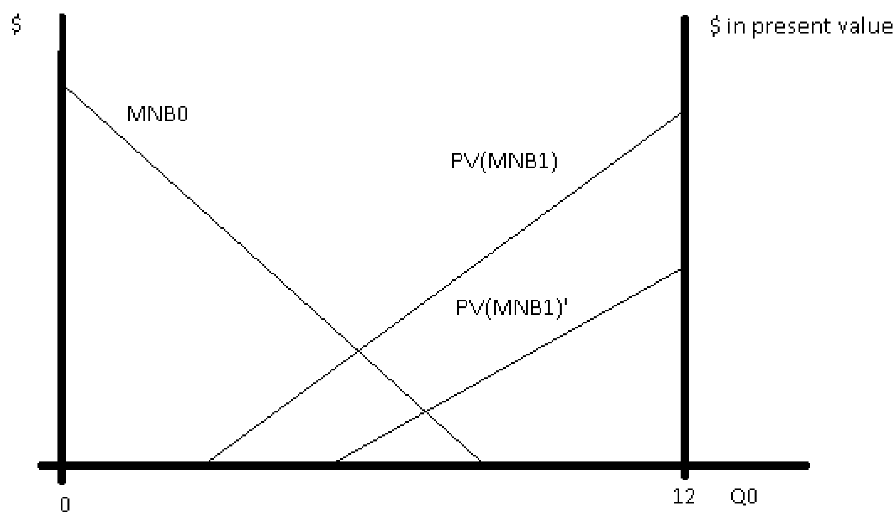
To find the marginal user cost in the first period associated with the efficient extraction plan,

$P_0^{**} = 17 - 0.8(6.369) = 11.9048$
$MUC_0 = P_0^{**} - MC_0 = 11.9048 - 6 = 5.9048$.

The marginal user cost in year 0 represents the value of forgone consumption imposed on the second period if one additional unit of the resource were consumed in period 0, starting from the efficient quantity. It is a measure of the cost that society bears due to the scarcity of the resource when this cost has been spread efficiently across the two periods.

b) [8 points] Now suppose that policymakers realize that marginal extraction costs will be $c > 6$ in period 1 (but remain at 6 in period 0). Further, society decides that a discount rate of $r > 10\%$ should be used where necessary. Sketch a graph – showing the present value of marginal net benefits in each period and accounting for the constraint imposed by the scarcity of the resource – that illustrates how this new situation will differ from that in the previous part. (Be careful to label your curves and axes clearly.) How will the efficient allocation change relative to that in part a)? Explain briefly why this makes sense.

answer:



$PV(MNB_1)$ should have a flatter slope (in absolute value) than $PV(MNB_0)$ because of the 10% discount rate (and, consequently, a lower vertical intercept). $PV(MNB_1)'$ (i.e. the present value of marginal net benefits in period 1 under the assumptions of this part rather than the previous part) should have yet a flatter slope, due to the discount rate that is greater than 10%. Further, $PV(MNB_1)'$ should be shifted downwards relative to $PV(MNB_1)$, due to the marginal extraction costs greater than $6.00/unit extracted.

The intersection between $PV(MNB_1)'$ and $PV(MNB_0)$ is to the right of the intersection between $PV(MNB_1)$ and $PV(MNB_0)$. That is, under the new assumptions, the efficient quantity consumed in the first period (period 0) will be higher than that found in the previous part.

Higher extraction costs mean that the resource is more costly to obtain. A higher discount rate means that the planners in period 0 value the welfare of the future generation less. Therefore, with an increase in both of these values in period 1, consumption of the resource in the second period becomes more costly from an extraction perspective and less worthwhile from the perspective of the planners in the first period. It is thus not surprising that efficiency requires consumption of the resource to be biased more towards the earlier period (when extraction is cheaper and consumption provides relatively more value) under these alternative assumptions.

2. [28 points total, 3 parts] 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 110 units must be met. The marginal cost relations faced by each firm for abating a given amount are $MC_1 = 8 + 4q_1$ and $MC_2 = 4 + 2q_2$ (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 200 units.

a) [10 points] Calculate the cost-effective allocation of individual abatement requirements that satisfies the aggregate abatement target. If the government were to impose a uniform emissions fee of $192/unit emitted, would this allocation be achieved?

answer:

For cost effectiveness, $MC_1 = MC_2$

and, of course

$q_1 + q_2 = 110$

$\rightarrow$

$8 + 4q_1 = 4 + 2(110 – q_1)$

$q_1^{ce} = 36$, $q_2^{ce} = 110 – 36 = 74$.

Cost-minimizing firms respond to a per-unit emissions fee by abating up to the point that marginal abatement costs equal the fee level. So,

$MC_1 = f$
$8 + 4q_1 = 192$
$q_1^m = 184/4 = 46$
(and likewise, $q_2^m = 94$, following the same steps with MC_2).

A fee of $192/unit therefore achieves the abatement allocation (46, 94), which is not the cost-effective abatement allocation associated with the aggregate abatement target of 110, which we found to be (36, 74). So, no, this fee does not achieve the allocation we would like it to. (You could also just have checked that the height of both marginal abatement cost curves at the cost-effective allocation is not equal to 192.) This particular fee level is too high compared to the one that would achieve the desired allocation.

b) [8 points] Suppose that, without any fee in place, a fully-enforced command-and-control policy is implemented to achieve the aggregate abatement target. Under this policy, an emissions limit of 145 units emitted is imposed on each firm. Calculate the excess costs that will be suffered in the aggregate with this policy in place compared to a case in which the cost-effective abatement allocation is reached. (You can make a reasonable assumption about what the cost-effective allocation is if you were unable to find it in the previous part.)

answer:

Each firm would like to emit 200 units in the absence of regulation, because this is what their baseline emissions are. But now the government is telling them that they can emit at most 145 units each. The firms will respond to this mandate by emitting as much as they can up to the limit. In other words, each firm will abate 55 units (200 – 145 = 55). They will not choose to abate more, because this would entail bearing higher abatement costs than the regulation requires. So this policy achieves the aggregate abatement target (55 + 55 = 110) by effectively dividing it equally across the two firms.

It is clear that the policy forces Firm 1 to abate too much relative to what is cost effective (because q_1^{ce} = 36 from the previous part, which is less than 55), and allows Firm 2 to abate too little (because q_2^{ce} = 74 from the previous part, which is greater than 55). The associated loss will be the total abatement costs that Firm 1 is forced to bear by the policy over and above the cost-effective amount, minus the total abatement costs that Firm 2 is spared by the policy relative to what is required for cost effectiveness. On a graph (upward-sloping marginal abatement cost curve for Firm 1, downward-sloping marginal abatement cost curve for Firm 2, Firm 1's abatement level on the horizontal axis), this would be shown by the triangle between MC_1 and MC_2 and between the abatement level of 36 units for Firm 1 associated with the intersection of the two lines and the abatement level of 55 units for Firm 1 induced by the regulation. The area of this triangle – and so the value of the loss – is ((8 + 4*55) – (4 + 2*55))*(55 – 36)/2 = $1,083. Draw this on a graph, and make sure you understand why 55 is being plugged into both marginal abatement cost curves here but that this is specific to this example.

There are other equivalent ways to calculate this. One notable example is to calculate total abatement costs for Firm 1 at 55 and again at 36, and take the difference; and total abatement costs for Firm 2 at 74 and again at 55, and take the difference; and finally, to subtract Firm 2's difference from Firm 1's difference.

The hypothetical "case in which the cost-effective abatement allocation is reached" is just that – hypothetical. It is not relevant *how* the cost-effective allocation might be reached. If it were reached by fee, the fee payments would just be a transfer at the societal level, and therefore not an "excess cost" to society as a whole. If it were reached by anything else besides pure mandates, it would require all kinds of additional assumptions about what "excess costs" might entail. This would have been acceptable if such assumptions were stated explicitly in your answer, but strays well beyond the scope of the question. The intended focus was abatement costs.

c) [10 points] Now suppose that the command-and-control policy is removed, and is replaced with a tradable permits system, with the same aggregate abatement target in place. The government initially gives all of the permits to Firm 1 for free. In addition, the government forces Firm 1 to purchase and adopt the same set of technologies used by Firm 2, so that Firm 1's marginal abatement cost relation becomes $MC_1' = 4 + 2q_1$ (while Firm 2's marginal abatement cost relation remains $MC_2 = 4 + 2q_2$). The total costs associated with acquiring and adopting the technology for Firm 1 are $15,000. Under what conditions will Firm 1 be better off with the permit policy compared to the command-and-control policy? (Explain in words all of the ways in which Firm 1 is affected, then support your answer with calculations. Assume that the technology cost must be paid all at once, and that there are no future periods to consider.)

answer:

Firm 1 is affected in three ways. First, the technology must be purchased. Second, the new technology allows abatement to be done more cheaply. Third, Firm 1 will have far more permits than it can use and Firm 2 won't have any, so Firm 1 can earn revenue by selling permits to Firm 2.

Let's work backwards to try to find dollar values for these three categories. To know how much Firm 1 will earn by selling permits, we need to know how many will be sold. We know that, with permits, firms will bargain with one another until the cost-effective allocation is reached. What is the cost-effective allocation? It's different than it was in part a) because Firm 1's marginal abatement cost curve is different. In fact, it's the same as Firm 2's now. When firms are completely symmetric, the cost-effective allocation will just be an even split of the aggregate abatement target (which can be verified by imposing the equimarginal condition if you want to). So, when all the bargaining is done, each firm will be abating 55 units (i.e. half of the 110 aggregate abatement target, which has remained constant throughout the problem), which will require them each to be holding 145 permits to cover the 145 units that each will be emitting. (There must be 290 permits in total, because economy-wide baseline emissions are 200 + 200 = 400, the aggregate abatement target is 110, and 400 – 110 = 290.) So Firm 1 will end up selling 145 permits to Firm 2. How much will it earn as a result? We don't know, because we don't know the price per permit that the firms will reach through bargaining.

How much does Firm 1 save by using the new abatement technology? When we did this sort of a calculation for a firm facing an emissions fee, the cost savings could be broken down into two convenient areas with meaningful interpretations. That's not really the case here. First, the calculation is a bit tricky because the old marginal abatement cost curve has a different vertical intercept than the new one, so it doesn't fall out naturally into triangles. Second, we have to be careful identifying how the firm adjusts its abatement level. With the command-and-control policy, Firm 1 was forced to abate 55 units. With the permit policy and new technology, Firm 1 will end up abating 55 units as the firms bargain with one another, as just argued above. So the abatement level ends up staying constant across the two cases, at 55. The most straightforward approach is to calculate Firm 1's total abatement costs at an abatement level of 55 with the old technology and again with the new technology, and take the difference. Each time involves calculating the area of a triangle and a rectangle. Total cost savings should come out to ((8*55) + (8 + 4*55 – 8)*55/2) – ((4*55) + (4 + 2*55 – 4)*55/2) = 6490 – 3245 = $3,245.

And finally, Firm 1 must pay $15,000 for the new technology.

On net, then, Firm 1 is better off by permit revenue + abatement cost savings – technology cost = permit revenue + 3245 – 15000. For this to be greater than zero, permit revenue > $11,755 (= 15000 – 3245).

So, for Firm 1 to be better off with the permit policy than the command-and-control policy, it must be able to raise at least $11,755 by selling permits to Firm 2. Since it will sell 145 permits, this is equivalent to an average permit price of just over $81/permit. This is substantially less than the height of the marginal abatement cost curves where they are equalized at the cost-effective allocation, which is $114. Also, $11,755 is much less than the maximum that Firm 2 would be willing to pay to acquire 145 permits in one chunk (which would be given by the difference in total abatement costs if all 200 baseline emissions were abated and at 55 units abated, which I think comes out to $37,555).

BONUS QUESTION [3 points maximum – no penalty for guessing]: Return to the set-up of the first part of the first problem. With all other aspects the same, now let there be three periods, i = 0, 1 and 2. Calculate the dynamically efficient allocation.

answer:

The present value of marginal net benefits must be equalized across all three periods, and the scarcity constraint must hold. Mathematically, this gives three equations in three unknowns:

$MNB_0 = \delta MNB_1$,

$\delta MNB_1 = \delta^2 MNB_2$, and

$Q_0 + Q_1 + Q_2 = 12$.

Using the discount rate of 10% (and hence $\delta = 1/1.1$), along with $P_i = 17 - 0.8Q_i$ and $MEC_i = 6 \ \forall \ i$ gives, after much messy algebra,

$Q_0^{**} = 4.913$, $Q_1^{**} = 4.03$, $Q_2^{**} = 3.057$.

[0 points for nonsense or pure guessing; 1 point for getting the majority of the efficiency conditions written down in words or in math, or for roughly characterizing the expected solution in words; 2 points for the conditions along with some algebraic manipulation, or for the conditions along with a rough characterization of the expected solution in words; 3 points for the conditions, all work and the correct answer]