EC371 – Environmental Economics, Spring 2010, Boston University

Instructor: Jeremy Smith

Final Exam

Wednesday, May 5, 2010

This is a 100-minute exam, but you will have 120 minutes to complete it. There is a total of 100 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. [2 parts, 22 points total] Florida is considering implementing a clean-up effort of its coastal mangrove habitats. The goal of the proposed clean-up is to protect several species of game fish that rely on the mangrove ecosystem. For the specific proposal under consideration, initial clean-up costs as of year 0 would be $1,400. Annual benefits derived from the clean-up effort would be $180 per year for years 1 through 14 inclusive. The clean-up would happen once, so there would be no recurring annual costs. The proposal includes an agreement with an out-of-state private company to take over maintenance of the habitats after year 14. Therefore, at the beginning of year 15, the government would derive a one-time benefit of $1,520 (representing all future benefits from protection of the species); but it would also have to pay a one-time fee to the private company of $540 at that time.

a) [12 points] Calculate the net present value to the government of Florida of this proposal, first using a discount rate of 10% and again using a discount rate of 5%. Explain briefly and intuitively why you would expect one of these NPVs to be greater than the other. Do your calculations correspond with what you would intuitively expect? (For 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. Your work can continue onto the next page.)

answer:

$r = 10\%$:

$\delta = 1/1.1 = 0.9091$

$$\text{NPV} = -C_0 + \frac{\delta - \delta^{15}}{1 - \delta}B_{1\text{-}14} + \delta^{15}NB_{15}$$

$= -1400 + 7.3667*(180) + 0.2394*(1520 - 540)$

$= \$160.61$.

$r = 5\%$:

$\delta = 1/1.05 = 0.9524$

$$\text{NPV} = -C_0 + \frac{\delta - \delta^{15}}{1 - \delta}B_{1\text{-}14} + \delta^{15}NB_{15}$$

$= -1400 + 9.8986*(180) + 0.481*(1520 - 540)$

$= \$853.15$.

The higher the discount rate we use to evaluate a project, the less weight we are placing on benefits to be received or costs to be borne in the future relative to the present. This project has up-front costs followed by positive net benefits received into the future. Thus, with a higher discount rate, these future net benefits are weighted less in relation to the up-front costs, and we would hence expect NPV with the higher discount rate (10%) to be less than NPV with the lower discount rate.

Some people let their response concerning the effect of a higher discount rate get clouded by some points that were made in discussions we had in class about the appropriate choice of discount rates. I was asking a question of a "positive" nature (what *does* happen if we choose a certain rate), but the discussion of appropriateness of discount rates is a "normative" issue (what rate *should* be chosen). For example, some responses got side-tracked talking about impatience and outside options and so on, which were fair points, but ultimately had to have been tied back to the effect on the outcome of NPV calculations to receive full credit.

b) [10 points] The annual benefit measure of $180 was estimated by applying the contingent valuation method. In considering the results of your cost-benefit analysis, some government analysts question where this estimate came from. Briefly describe the general aspects of the contingent valuation method, including an explanation of the term “contingent” in the name. One of the government analysts suggests that, since the protected species are fished by several private companies and individuals, a more reliable estimate of the benefits of protection could be derived by looking at price data from the game fishing industry and market. Explain why you agree or disagree.

answer:

In a nutshell, contingent valuation estimates willingness to pay for an environmental good – equivalently, the total benefits of that good – by asking people how much they would be willing to pay to protect it. It’s that simple. Some additional salient characteristics: this is achieved through a survey, which also provides a lot of information about the good in question and collects a lot of data on “control” variables; the data collected through the survey is subjected to econometric analysis to estimate WTP for an “average” person (WTP directly, NOT a demand curve); the survey design issues are many and complex, and ultimately the technique is either very expensive to perform in a way that provides meaningful and reliable results, or very useless if not performed according to a set of guidelines that were developed by a panel of eminent economists for the National Oceanic and Atmospheric Administration in relation to the Exxon Valdez legal proceedings (due to many types of biases that can be present in responses to a poorly-designed survey, which have been studied by economic psychologists); and this is basically the only method we have for estimating value comprehensively, i.e. encompassing use, option and existence values.

The word “contingent” in the name refers to the hypothetical scenario that the survey constructs. Ideally, the survey will simulate a market setting, so that the punch-line question about willingness to pay resembles as much as possible being in a store and deciding whether or not to purchase any ordinary commodity. Responses are thus *contingent* on the scenario constructed and information provided by the survey. We would expect responses to change as the underlying hypothetical situation changes, just as we’d expect people to buy different groceries today than they did last week if the prices and availability of various products have changed substantially from the previous week.

An important point that I tried to underline is that valuation of environmental goods is only a challenge because these goods are typically non-marketed. When we calculate total benefits in a textbook setting, we just calculate an area under a demand curve or some small variation on this. So if we have a demand curve, there’s no problem. How do we get a demand curve in real life? We just gather price and quantity data on the good in question – which is easy to do for normal goods, because stores and companies typically collect this data automatically at points of sale – and do some econometrics, and then we have a demand curve to calculate areas with. The problem is that, in most cases where environmental issues and concerns are present, the “goods” that we are interested in estimating a value for are never transacted in markets. So we never see people buying (or not) at some posted price, and sometimes it’s even difficult to interpret what we mean by quantity. We therefore need to be more clever by using data that we can acquire as best as we can. Contingent valuation is one of these clever techniques that economists have developed.

So, on the face of it, the government analyst makes a good point. In this case, the ultimate resources we're interested in valuating – the various species of fish that depend on the mangrove ecosystem – are in fact marketed, in contrast to most environmental goods. Some species are harvested for human consumption, while others are exploited by sport fishing companies, which earn revenue by selling boat trips and guides to tourists who catch (and often release) fish for recreation. Either way, we should be able to collect enough price and quantity data to estimate demand curves for various species. (Some people suggested that companies would withhold or purposely misreport such data; I consider the latter as having no credible basis whatsoever, and the former to be a mere practicality that in reality is rarely a show-stopper.) So, given the uneasiness some people feel about contingent valuation – especially and deservedly so if the survey design is sloppy, but even by some, likely less deservingly, if the survey design meets the NOAA guidelines – perhaps we could develop an estimate that is at least perceived as being more "reliable" by going the more conventional market demand curve route.

The problem is that the market purchases probably only reflect the use value that purchasers place on the species. This is likely less true of the recreational catch-and-release fishers than it is of large-scale commercial fishing species for food consumption, but still, it's a bit difficult to believe that everyone who cares to some degree about the basic existence of these species expresses this by purchasing recreational fishing trips. Further, it seems reasonable that the existence value, which on this argument is not captured by market transactions, is an important aspect of overall value when at-risk species are in question in general. This may be reinforced by noting that there are "several" individual harvesters, which is an indication that the mangrove fisheries are characterized by open access. As we discussed in our fishing unit, conservation concerns are typically at center stage in such cases, as open access often leads to over-exploitation. So market price data will almost certainly lead to a significant under-estimation of benefit. However, it might be a good idea to also collect market data, and use it to get an estimate of use value that can be used as something of a reality check for the comprehensive CV estimate of value: if the CV estimate is "too high" relative to the market-price-based estimate and it's difficult to justify existence value being large enough to make up the difference, it's an indication that there could be some bias in the application of the CV procedure, and that we might therefore want to do some sensitivity analysis using a lower benefit estimate in the NPV calculation.

Some suggested that the market price approach would be preferable to CV – and a few thought this even despite the overlooking of existence value – because CV is so expensive to do well. That's a fair point about CV, but the argument doesn't really hold in this case, because the CV analysis has already been performed in the make-believe world of the question. Some assumed that the CV in the question had been done poorly, and used this to argue that the market price approach would be better; this was slightly penalized if it was not accompanied by a recognition that the technique can provide reliable estimates in principle if employed properly. Some argued that we would want to get a market-price-based estimate and add it to the CV estimate because this would make

NPV higher, which, it was suggested, would be especially important if we had found a negative NPV in the previous part. This makes two important mistakes. First, it's essentially suggesting that we double count the use value portion of total benefit, which we wouldn't actually want to do. And second, it implies that a positive NPV is something that we somehow *want* to find. As good cost-benefit analysts, it's not our job to aim for a specific outcome: what CBA is all about is doing our best to provide an accurate and unbiased estimate of NPV to inform decision making. Trying to play a game of purposely pushing the estimate one way or the other dilutes the value of the information we're seeking to provide, and renders the whole exercise fairly pointless.

2. [30 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. The marginal cost relations faced by each firm for abating a given amount are $MC_1 = 4q_1$ and $MC_2 = 9q_2$ (in dollars) where q_1 and q_2 are the units of abatement undertaken by firm 1 and firm 2 respectively. The government has set an aggregate abatement target for this pollutant of 91 units.

a) [12 points] Calculate the cost-effective allocation of individual abatement requirements that meets the aggregate abatement target. Calculate the appropriate per-unit uniform emissions fee that the government would have to implement to achieve this allocation. If this fee were implemented and raised \$28,728 in total revenue, how much must be economy-wide baseline emissions?

answer:

For cost effectiveness, $MC_1 = MC_2$

and, of course

$q_1 + q_2 = 91$

$\rightarrow$

$4q_1 = 9(91 - q_1)$

$q_1^{ce} = 63$, $q_2^{ce} = 91 - 63 = 28$.

To find the appropriate fee:

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

$f^{ce} = 4*63 = \$252/\text{unit}$.

To find economy-wide baseline emissions, first note that total fee revenue is given in symbols by $f^{ce}*Z^{ce}$, where Z^{ce} is economy-wide emissions associated with the cost-effective abatement allocation. Then, apply the familiar formula, emissions equals baseline emissions minus abatement (the latter, of course being 91, since the cost-effective allocation meets the abatement target by definition).

$f^{ce}*Z^{ce} = 28728$

$\rightarrow Z^{ce} = 28728/252 = 114$;

$114 = \text{baseline emissions} - 91$

$\rightarrow \text{baseline emissions} = 114 + 91 = 205$.

b) [10 points] Suppose that the government decides to impose a uniform per-unit emissions fee at the level you found in the previous part. (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 adopts a new abatement technology that shifts its marginal cost relation from $MC_2 = 9q_2$ to $MC_2' = 3q_2$. Assuming that the fee stays fixed, what would firm 2's total cost savings in a given period be from having the new technology? Describe the two sources of the total savings.

answer:

See the graph, appropriately modified, from the solutions to the second mid-term or the third set of practice problems if you want to supplement these calculations. With the old technology, firm 2 will choose to abate 28 units (from setting $9q_2 = 252$, which is the firm's cost-minimizing condition, but also from the cost-effective allocation, since the fee of 252/unit was chosen precisely to achieve the cost-effective allocation). With the new technology, firm 2 will choose to abate 84 units (again from applying the cost-minimizing condition, but now with the new marginal abatement cost curve). Remember from class that the total cost savings from adopting the technology can be broken into two sources, which are labeled as A and B in the graphs referred to above. In this case, area A comes out to 1/2*(252 – 84)*28 = $2,352; and area B is 1/2*(84 – 28)*(252 – 84) = $4,704; and so the total cost savings is 2352 + 4704 = $7,056. (It was also fine if you calculated total abatement costs plus total fee payments with the old technology and then again with the new, and subtracted the latter total from the former; but this was a bit trickier than usual without knowing firm 2's baseline emissions for sure.)

Area A represents the savings from lower marginal abatement costs on the first 28 units abated. Area B represents the savings from re-minimizing costs by choosing to abate a further 56 units rather than pay fees for emitting them.

(When checking these calculations and perhaps drawing a graph, note that, in this specific example, 84 happens to be both the abatement level chosen by firm 2 with the new technology and the height of the new marginal abatement cost curve at the old level of abatement. This might be a bit confusing if you just look at the calculations above, and is not a general occurrence in this type of problem. A couple of people still made the mistake of calculating the new cost-effective allocation that hits the aggregate abatement target of 91 and trying to relate it to the question that was actually asked. This misses the crucial point that imposing a fee fixes the "price" dimension only, and as firms adjust their abatement decisions according to their private incentives, the aggregate abatement target can be missed if the fee is not at the appropriate level. As soon as firm 2 adopts the new technology, 252 is no longer the appropriate fee level to hit the target of 91, and the private outcome will hence diverge from the desired target as long as the fee stays fixed at 252.)

c) [8 points] Suppose that the aggregate marginal damage costs (in dollars) from emissions of the pollutant in question are given by $MD = 2 + 3Z$, where Z is the aggregate level of emissions of the pollutant. The economy-wide marginal control costs (in dollars) are given by $MC = 1.3 + 1.7Q$, where Q is the aggregate amount of emissions abated. Calculate the efficiency loss associated with the fee staying fixed at the same level as in the previous parts. (Firm 2 has definitely adopted the new technology, and the economy-wide marginal control cost function given here reflects this.)

answer:

The general procedure is to figure out how much is emitted under the fee policy and what the efficient emissions level is, then to calculate the efficiency loss of being at the former rather than the latter. Abatement under the fee policy is 63 + 84 = 147. (As discussed in the previous part, 84 is firm 2's cost-minimizing choice with the new technology. Nothing has changed for firm 1, so it continues to abate 63, which is its cost-minimizing choice but is also its part of the old cost-effective allocation, since the fee of 252 was chosen to reach that allocation.) Using baseline emissions as calculated in the first part, emissions = 205 – 147 = 58.

Efficiency is defined as the choice of emissions that minimizes total damage costs plus total control costs, which is found by setting $MC = MD$ subject to the fact that $Z = 205 - Q$. (This latter equation is of course just the general guise of the statement that emissions have to equal baseline emissions minus abatement.) Performing these calculations, you should get that $MC = 349.8 - 1.7Z$ when converted to depend on emissions rather than abatement, and $Z^{**} = 74$ (and $Q^{**} = 205 - Z^{**} = 131$).

(Note that what we just found as efficient abatement is not the same as the target of 91 that the government was shooting for in the previous two parts. That is fine, and does not affect anything that has been done so far. It just means that the government was not aiming for the efficient target. Neither efficiency nor actual abatement chosen by the firms with the fee have anything to do with the target in this case, nor do they have to in general.)

For efficiency, this economy should be emitting 74 units, but with the fee of $252/unit in place and with firm 2 having adopted the new technology, only 58 units will be emitted (from above). Thus, relative to efficiency, this policy would cause too much to be borne in terms of control costs and too little to be borne in terms of damage costs. On a graph (upward-sloping marginal damage curve, downward-sloping marginal control cost curve, emissions on the horizontal axis), this would be represented by a triangular loss between MC and MD and between a quantity of emissions of 58 and the quantity of 74 corresponding to the intersection of the two curves. The area of this triangle – and so the value of the loss – is $601.60.

There is an unfortunate little technical issue with this part. The economy-wide marginal control cost function is a slightly imprecise estimate of what it should be based on the two underlying firm-level marginal abatement cost functions. If it were estimated exactly, we would be able to plug in abatement of 147 (or equivalently, emissions of 58 after transforming the function) and get a height of the function of 252 at that point, corresponding to the fee level. Conversely, one should be able to set the precisely-estimated economy-wide marginal control cost function to the fee level of 252, and find economy-wide abatement to be 147 (or emissions to be 58 if working with the transformed function). This isn't something we discussed in class, but both of these relations should be mathematically true. However, because of the estimation error, neither of these calculations comes out precisely. The calculation of the efficiency loss above uses emissions of 58 exactly (which I find to be the most natural way to proceed, since we can calculate aggregate emissions as above from individual firm abatement behavior, which we have lots of practice working with) and finds the height of the function to be 251.2 rather than 252. Some alternatively set the height to 252 precisely and found abatement of 147.471… rather than 147 precisely; this gives a slightly different outcome of the efficiency loss calculation compared to the one above, but was perfectly acceptable. I was generous with partial credit if people seemed to be confused by this. In general, though, the people who did well on this question did not appear to have any trouble with this issue, while this issue appeared to be moot for most people, who seemed overwhelmed by and unprepared for the question more broadly. It should not have been so unfamiliar, having appeared in similar form previously in the third set of practice problems and again on the set of additional practice exam questions posted before the second mid-term.

3. [2 parts, 20 points total] Suppose that a tannery is situated on the outskirts of a small town. The private marginal cost (MC) of producing tanned hides (in thousands of dollars per shipment) is given by MC = 3 + 2.25Q where Q is shipments. In addition to the private marginal cost, an external cost is incurred. Tanning causes the discharge of toxic chemicals which, through contamination of the town's water supply, cause damage valued at MD = 1.8Q (also in thousands of dollars per shipment). Even though we are concerned with a single firm, it behaves perfectly competitively. The aggregate inverse demand curve for tanned hides (in thousands of dollars per shipment), representing both the private and social marginal benefits (MB), is given by MB = 27 – 0.75Q.

a) [12 points] Find both the market equilibrium and socially efficient quantities of shipments of tanned hides. Calculate the Pigouvian per-unit tax, to be collected from the tannery, that would exactly achieve the socially efficient output level in this market.

answer:

market: MB = MC
$27 - 0.75Q = 3 + 2.25Q$
$3Q = 24$
$Q^* = 24/3 = 8.$

efficient: MB = MSC
MB = (MC + MD)
$27 - 0.75Q = [(3 + 2.25Q) + (1.8Q)]$
$4.8Q = 24$
$Q^{**} = 24/4.8 = 5.$

tax: $t^{**} = \text{MSC}(Q^{**}) - \text{MC}(Q^{**})$ [or using MB for MSC is fine too, or MD directly or other methods discussed, but at Q^{**}, *not* at Q^*]
$= 3 + 4.05 \times Q^{**} - (3 + 2.25 \times Q^{**})$
$= 1.8 \times Q^{**}$
$= 1.8 \times 5 =$ \$9 (thousand per shipment).

b) [8 points] Describe what is meant by the “double dividend”. Suppose that the town council implements the Pigouvian tax from the previous part. Suggest two additional measures that the town council might take in an attempt to realize a double dividend. For each, explain why the effect of the additional measure might be desirable.

answer:

The double dividend hypothesis states that there is an extra return from correcting externalities with revenue-raising instruments: in the first place, the externality is corrected and social efficiency is obtained in the market being focused on (the first “dividend”); but secondly, the tax revenue can be used to pursue efficiency in other areas (yielding further “dividend(s)”).

Two very important points need to be stressed. First, note that what is said above is that the tax revenue *can* be used for other purposes. It’s crucial for the revenue to *actually* be used for the second dividend to actually be realized: there’s no intrinsic benefit to the government just holding onto money. Second, the revenue can’t just be used for any old thing for us to be able to assume that an additional benefit will be realized. The additional measures must have efficiency-enhancing or market-correcting effects, or otherwise be used to obtain some valued end.

One strong example of an additional measure that would almost certainly yield a further efficiency improvement would be investing the revenue in research and development, which is generally recognized as being an area in which positive externalities are large. This could be done by the government directly, or by giving firms tax credits or subsidies to do research themselves. It could be targeted at development of new tannery technology or something else.

Another good example that some people mentioned is using the revenue to invest in health improvements of the population, perhaps specifically those caused by tainted water. There are certainly arguments to be made that there are inefficiencies in private health insurance provision, and also in terms of healthier workers being more productive.

The classic double dividend scenario is an exercise in “revenue neutrality”, whereby the government hypothetically uses all of the tax revenue from externality correction to reduce tax receipts from other sources by an exactly offsetting amount. Since other forms of taxation are generally distortionary to some degree, this is hypothesized to improve overall efficiency in addition to correcting the externalities, though there has been great debate on how strongly and certainly we can support this hypothesis in the general case. Similarly, the revenue could be used to pay down the national debt, but there would have to be some argument made that current debt levels are dynamically inefficient or something similar. Again related to public finances, the revenue could be distributed to consumers in a manner that is designed to achieve redistributive goals, with an argument to the effect that existing redistributional instruments are not adequate on their own to achieve equity objectives.

I accepted a lot of different responses as long as they were well supported. One frequent kind of suggestion that I didn’t accept was that further measures be taken directly related to the tannery externality. Lots of people suggested implementing a permit system or various subsidy and fee policies in this regard, which could have been incorrect for a variety of potential reasons. If these other policies were offered as *alternatives* to the tax, it's just not what the question was asking. If the suggestion was (or appeared to be) to put these policies in place *along with* the tax, there was either a failure to recognize the redundancy of this (since the tax achieves efficiency perfectly well on its own if set at the correct level, and it's not clear why we'd want to purposely set it at an inappropriate level and then use an additional instrument to correct for this) or a fallacious implication that it would be desirable on some unstated or unsupported basis to use these additional instruments to move output below the efficient level (which may have been an indication of a fundamental misunderstanding of the concept of economic efficiency – and in any case, also failed to recognize that this could just as easily be accomplished by raising the tax rate). Additionally, these suggestions were often unable to make a connection back to the tax revenue, which is the crucial tie-in with the double dividend that I was looking for.

Another kind of response that only got partial credit was vague statements about the tax revenue being used to "boost the economy" or "protect jobs" or something like that. I know this is the kind of journalistic tripe we're bombarded with every day, but as economists, we need to think more critically about whether any efficiency improvements are actually there. We don't know that unemployment, particularly in specific industries, is inefficiently high unless we carefully examine the labor markets, we don't know if growth of a given industry is good on net if it's coming at the expense of other industries or involves additional environmental harm, etc.

Finally, only partial credit was given for suggestions of returning the revenue to consumers (who of course bear part of the burden of taxation through higher prices) or the firm without specific descriptions of why these private actors could use the funds for more efficient uses than the government might (or why it might otherwise be desirable). But almost full credit was given if the proposed reimbursement to the firm was mentioned as being designed to be de-linked from the firm's marginal decisions: sometimes reimbursement or concessions of some kind are necessary for political cooperation of businesses, so if they must be made, they should be done in a way that does not undo the externality-correcting nature of the tax; the political cooperation is not an additional benefit, though, but rather just a necessary means to realizing the primary benefit of externality correction.

4. [28 points total, 3 parts] The biological relationship between the growth of the tarpon population in the Florida mangroves and the population size can be expressed as $g = 300x - 5x^2$, 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) [12 points] Find all of the biological equilibria of this fishery, and state which of these are stable and which are unstable. Find the maximum sustainable yield for this fishery.

answer:

The two biological equilibria are where $g = 0$, i.e. $x = 0$ and where $300x = 5x^2$, which is $x = 60$. The latter (60) is stable (and is called the carrying capacity), and the former (0) is unstable.

By taking the derivative of $g = 300x - 5x^2$ with respect to x and setting it to zero, we will be able to solve for x^*, the population level corresponding to the maximum sustainable yield (and to the highest point on the graph of the g function).

$g' = 300 - 10x = 0 \rightarrow 10x = 300 \rightarrow x^* = 30$ thousand fish.

This is NOT the *MSY* itself, nor is it a biological equilibrium! (Only a couple of people made the former mistake. Nobody made the latter mistake on this part, but some people did use 30 as the starting population in the next part for some reason.) The maximum sustainable yield will be the number of fish by which the population is growing at population x^*:

$MSY = g^* = 300x^* - 5(x^*)^2 = 300*30 - 5*900 = 4{,}500$ fish.

b) [8 points] Suppose that the tarpon population is in stable biological equilibrium. In a given period, the pinfish population, which is a major source of food for tarpon, is temporarily depressed, causing the tarpon population to fall instantaneously by 5 thousand fish. In all subsequent periods, the pinfish population is at its normal size and condition. Describe briefly how the tarpon population will evolve following this negative shock. To support your description, calculate the stock size in the two periods following the shock.

answer:

This was just meant as an example of a simple one-time negative shock to the tarpon population. The idea is that population has been running along smoothly from period to period maintaining its stable biological equilibrium population level of 60 thousand fish. Then, a big chunk of the food supply suddenly disappears, and 5,000 more tarpon than usual consequently die in the same period. The next period, the food supply has returned to normal, so the biological relationship will be operative as usual, but the tarpon population finds itself below its stable equilibrium, at a level associated with more births than deaths (i.e. positive net natural growth). So the population will be a bit higher at the beginning of the next period, but still at a level associated with positive net growth, albeit slightly lower net growth than was experienced in the previous period. This process of gradually diminishing net natural growth from period to period will continue until the stable biological equilibrium is re-obtained – which is exactly what is to be expected given the stability of the equilibrium.

Following are the calculations for the stock size in the two periods after the shock. In period 0, the population is in equilibrium. Think of the shock as occurring at the end of period 0 and the pinfish population being fully recovered by the beginning of period 1, so that the starting tarpon population in period 1 is 55 thousand but the growth dynamics throughout period 1 correspond to the normal biological relationship. We want to find the tarpon population level in periods 2 and 3.

$x_0 = 60$

$x_1 = 55$

$x_2 = x_1 + g_1/1000$
$= 55 + (300\times55 - 5\times55^2))/1000$
$= 56.375$

$x_3 = x_2 + g_2/1000$
$= 56.375 + (300\times56.375 - 5\times56.375^2))/1000$
$= 57.396797\ldots$

There were a couple of small recurring errors that were slightly penalized. One was to say that *growth* would increase until the stable biological equilibrium was re-obtained. I think this was in most cases just a slip in word usage where the intended meaning was that the *population level* would increase, but it's an important difference: as noted above and as discussed when talking about the biological model in general, growth *diminishes* as the population level gets closer to the carrying capacity (though I guess in this case growth does increase from zero to something positive once, following the shock, before starting to diminish as the population regenerates). Second, some described the growth mechanics broadly correctly, but either implied or stated that growth would continue indefinitely, as opposed to the population re-obtaining its stable biological equilibrium at a population level of 60 thousand fish with zero net natural growth. Finally, as mentioned in the solution to the previous part, a few people were confused about the starting population level, even if the stable biological equilibrium had been correctly identified.

c) [8 points] The Florida government decides to clean up its mangrove habitats. After the clean-up, the tarpon population begins to display the rather unusual biological relationship $g = 1000$ for any population level below 80 thousand fish. The tarpon is a very popular game fish, and tourists are willing to pay $p = 20 - 0.25x$ to sport fishing companies per fish they catch (where p is the price per fish caught, in dollars). That is, the price increases as the species becomes scarcer. There are several sport fishing companies, all with a marginal cost of fishing effort of \$300 and no fixed costs. The number of fish caught depends on both effort and the population size: $h = ex$, where h is the number of fish caught and e is fishing effort, measured in fishing trips per week. Before the mangrove clean-up, the tarpon population was in bionomic equilibrium, with 25 fishing trips being made per week and a population level of 40 thousand fish. Find the new bionomic equilibrium effort level. Calculate the change in the welfare of tarpon-fishing tourists following the clean-up.

answer:

<u>new bionomic equilibrium</u>

$g = h$
$1000 = ex$
$x = 1000/e$

$h = ex$
$= e \times 1000/e$
$= 1000$ (always, regardless of effort, which is strange, but makes sense given the new biological relationship and the definition of bionomic equilibrium)

$p = 20 - 0.25x$
$= 20 - 0.25(1000/e)$
$= 20 - 250/e$

$TR = ph$
$= (20 - 250/e) \times 1000$

$TC = 300e$

With open access (which the description of the sport fishing industry indicates),

$TR = TC$
$20 - 250/e = 0.3e$ (divided both sides by 1000)
$0.3e^2 - 20e + 250 = 0$ (multiplied by e and rearranged)

$e^{OA} = 50$ and 16.666… (applied the quadratic formula)

At the initial conditions (25 trips, stock size of 40 thousand fish) the industry was making positive profits. An industry characterized by open access that experiences a positive profit at a point in time will see firms respond by entering/increasing effort. So we can assume that the number of trips will *increase* to 50, not decrease to 16.67. Therefore, the new bionomic equilibrium will be characterized by

$e^{OA} = 50$,

$x^{OA} = 1000/e^{OA} = 1000/50 = 20$,

$h^{OA} = 1000$ (always), and

$p^{OA} = 20 - 250/e^{OA}$
$= 20 - 250/50$
$= 15$.

<u>change in tourist welfare</u>

This part of the question ended up being more boring than I was intending. What I was getting at was calculating consumer surplus associated with the harvest before then after the clean-up, and taking the difference. But the price specification is a funny kind of demand curve: it says that the price of each individual fish *caught* depends on the size of the *total population in existence*, not on the number of fish caught The upshot is that the price equation, as given, cannot be interpreted directly as a demand/marginal benefit function for catches. The correct way to interpret the demand function for catches is as a flat line (in harvest-price space), just like the fish examples we did in class except that the height of this flat line now depends on the stock size rather than just being a given fixed number (i.e. x shifts the position of the flat demand function, such that the given price specification determines its height). So, what is consumer surplus with a perfectly elastic demand curve? It's zero, regardless of the quantity consumed or the height of the line. Therefore, net tourist welfare is zero before the clean-up and zero after the clean-up, and so changes by zero. Like I said: boring!

I was generous with giving partial credit for attempts to calculate a welfare change of any kind, and in general was interested to see how "welfare" was interpreted with the information given. The thing that got the least partial credit was calculating profit under various scenarios. Maximized profit is how we defined efficiency in the simple fish examples in class, so it feels natural to look at profit differences when thinking about welfare. But efficiency is, in principle, broader than just profits, and should encompass consumer and producer welfare at the societal level. It is only because consumer surplus is zero by virtue of the perfectly elastic demand curve (and because we explicitly ignore ecological concerns and so on) that we can define efficiency as just profit maximization in the simple fish examples. So profit is actually fairly far removed from what I was going for, even though what I was going for – tourist surplus – is trivially zero and thus not a meaningful component of efficiency in practice in this case.

There are a couple of other things that were eligible for partial credit. Total (gross) consumer benefits is the area under the demand curve up to the given quantity, as usual, which corresponds to just price times harvest, or total revenue, in this case. So we can easily calculate a change in total benefits, but this does not fully correspond with what we typically conceive of as "welfare". (Substituting the relevant effort and stock size into the harvest and price functions and then taking the product of harvest and price gives total benefits of \$10,000 before and \$15,000 after, for a change of +\$5,000.) We could also calculate the triangular area (in stock-price space) below the price function and above the equilibrium price up to the equilibrium stock in each case and then take the difference, but unlike consumer surplus from a usual demand curve that this resembles geometrically, this has no meaningful welfare interpretation. (The change comes to –\$150.)

<u>further comments</u>

This entire problem was originally a lot more complicated. There was a story about how species like shrimp and pinfish would be affected by the clean-up and how inter-species competition amongst tarpon, snook and other large species that rely on the first set of species for food would change. There was a demand curve for tarpon catches depending on both the harvest and the stock size of tarpon, which made the welfare calculation more interesting but everything messier. There was even a division of the tarpon harvest into a proportion that is caught and dies, and the remaining proportion that is released live after being caught, which was meant to capture the catch-and-release nature of much game fishing.

What I was aiming for overall was an example of how even a very well-intentioned policy that is beneficial on average – the mangrove clean-up, in this case – might actually lead, through various biological and economic interactions, to certain species becoming substantially less abundant (and, by extension, to a decrease in the welfare of specific consumers of those species). But, as I mentioned in class, the disadvantage of adding more and more layers of realism to these models is that they quickly become intractable, which proved true with the early version of this problem. So I simplified it, especially by making sure that the first two parts were straightforward and familiar, then by working this last part down to something that I thought was manageable and not entirely unfamiliar on one hand yet retaining some of the novelty and interest of the original story I had in mind on the other. I'm not sure how successful I ended up being relative to any of my goals with this last part.

It turns out that, with the eventual price specification I settled on, the open access solution with a quadratic biological relationship isn't overly arduous: even though the revenue function is cubic, the zero-profit condition simplifies to a quadratic at most. But I thought that the solution with the simplified (though somewhat odd) biological relationship would be even cleaner because it avoids cubes altogether. Though perhaps lacking some of the intuitive clarity of a quadratic formulation and not as carefully specified as it might have been, this kind of reduced-form biological relationship (which is a flat line on the stock-growth graph) is analytically sound for a lot of purposes, and is in principle simpler to work with than a quadratic. The idea was to make one aspect a bit more complicated and realistic than in the simplest examples (the price specification) and offset this by making another aspect a bit simpler but not altogether unrealistic (the biological relationship). Unfortunately, the loss in intuition and familiarity with the new biological relationship seemed to overshadow the intended simplification. Additionally, the price specification did not end up allowing for interesting welfare calculations. As can be seen in the solutions above, though, what I was going for is not all that strange or formidable.

A lot of people focused almost exclusively on doing some kind of manipulation with the "old" biological relationship given in the first part. What I had intended was for you to forget all about that function, and to work just with the given "before" values for effort and stock size in trying to calculate tourist welfare before the clean-up. Indeed, the pre-clean-up situation is only relevant for calculating previous welfare in order to compare it to welfare after the clean-up, not for determining anything to do with the after-clean-up situation; and the given effort and stock values are sufficient for that without further reference to the biological relationship. (In fact, the given initial conditions don't correspond with a bionomic equilibrium under that biological relationship from the first part, because the resulting harvest level would be less than natural net growth at that stock size. The initial conditions actually came from an intermediate result with yet a different biological relationship in the earlier version of the problem. I didn't bother changing them because it doesn't matter for the problem, but I guess I could have changed the wording near the end of the question from "was in bionomic equilibrium, with" to "was in a situation with" to have been strictly proper, and/or explicitly stated that the biological relationship from the first part was no longer relevant.)

Another common mistake was to impose the bionomic equilibrium condition, but then fail to follow through as above and instead just substitute in various values for effort and/or the stock size. This misses the point that all of these variables are determined endogenously within the joint biological and economic model, and all are subject to change after the clean-up. I purposely avoided asking for the open access outcome directly because I wanted you to decide on open access as an appropriate modeling choice through interpretation; but it seems that most people needed to be led further down the path that was taken in class and in the practice problems, i.e. finding the revenue and cost functions and then imposing economic equilibrium.

Anyway, this part was certainly meant to be challenging, but not to have given quite as much difficulty as it seems to have. Looking back, there are a couple of subtle changes I might make to the way the information and specific questions are presented, and some accompanying modifications to the functional forms, all to make things a little clearer. But on the whole I regard it as a reasonable and well-formed problem in its existing state. I'm thus a little surprised that there wasn't a bit more success within the class as a whole, at least at deriving the revenue function.

As a final point, and to sort of bring the exam full circle, note that the people doing the cost-benefit analysis from the first problem would need to think about interactions between one species and another and between specific species and economic actors in order to inform the estimation of the benefits associated with the mangrove clean-up. The type of modeling this problem is getting at would be a useful tool in that regard. I mention this as a reminder, first of all of how complex it can be to do cost-benefit analysis well, but also of the wide applicability of the tools you've been introduced to this semester.

BONUS QUESTION [6 points maximum – no penalty for guessing]: Name past winners of the Nobel Prize in Economics who have made significant contributions to environmental economics.

answer:

Arrow and Solow have made major contributions in many fields within economics, and specific to environmental economics, have each done important work on sustainability, intergenerational issues, resource use and other topics. They were both on the panel of economists who drew up guidelines for the application of contingent valuation for the NOAA. Some of the most important work on biases in contingent valuation studies before these guidelines were constructed was done by a more recent laureate, Kahneman.

Coase's influence has also been extensive in economics broadly, with obvious specific contributions to work and thought in environmental economics. One of the most recent laureates, Ostrom, has also done work related to property rights and institutions.

There are some important laureates who have made at least moderate contributions to the field but were never mentioned in class. Schelling is prolific within economics generally, including within environmental and energy economics. Tobin was a pioneer in "green" national accounting. Stigler on the effects of regulation and Buchanan on governance and political decision-making could also be mentioned here, though related less to environmental economics specifically.

There are other laureates who have done some work on environmental, resource or related issues, but without this necessarily being important in the field or in their personal bodies of work: Stiglitz, Spence, Mirrlees, Vernon Smith, Koopmans. Schultz did much important work in agricultural economics, though mostly from a development rather than an environmental perspective. I wouldn't be surprised if a case could be made for others (Samuelson, Becker, Lucas, Klein, Sen, Lewis, Heckman, Krugman, more?) to have done something at least vaguely related to the environment or influencing environmental economic thought at some point in their careers.

Kuznets is an interesting case. His name has been applied to an important theory in the study of development and the environment (the Environmental Kuznets Curve), but based on work he had done much earlier in quite a separate area (income inequality). He did not make any contributions to environmental economics himself that I'm aware of. I suppose Nash deserves a mention too. The Nash equilibrium concept is foundational to so much of economic analysis and many other fields. But again, I'm not aware of any specific and direct contributions to environmental economics that he has made.

Any from the first five was worth a point each without further explanation. In general, I was surprised that there wasn't a point or so more scored on average on this basis. The rest from above had to have been either accompanied by an explanation of some kind or mentioned in sufficient number to earn a point.

There are a few notables who perhaps "should" have a Nobel Prize in Economics but do not. Hotelling made myriad original and important contributions in all areas of economics, including his work on resource use. He died just a few years after the prize in economics was established, and the rules are that the prize cannot be awarded posthumously. Pigou died over a decade before the prize was established. Kahneman's long-time co-author Tversky died years before Kahneman was awarded the prize. Some argue that Tullock and Olson should receive the prize for the same kinds of contributions that Buchanan was awarded the prize for; Olson died a decade ago, but Tullock is still alive and might therefore win in the future. A few people guessed Nordhaus, who was mentioned a lot in class; he doesn't have one yet, but wouldn't be a bad bet to receive it eventually.

The point is that the field is rich in contributions from some of the most important economic thinkers of the past century, perhaps more so than any other field within the discipline.

Stern had been knighted a few years before the *Stern Review* and received a life peerage as an Earl in the British system of nobility afterwards, but has not (yet) been awarded any Nobel Prize. Also, there has been an argument made that the review is as much a political document as any kind of a contribution to economic analysis, although it should be mentioned that he has long been a well-regarded economist.

Levitt, the author of *Freakonomics*, won the John Bates Clark medal, but is not a Nobel laureate – though Krugman and others have noted that winning the former is an excellent predictor of eventually becoming the latter. It's not clear that he has yet made anything that could be construed as a contribution to environmental economics. Feldstein, Boulding and Nerlove are other Clark medalists without a Nobel who come closest to having made any kind of a contribution related to environmental issues.

Muhammad Yunus, though an economist, won the Nobel Peace Prize, not the Prize in Economics. His contributions are much more to the practical development and application of micro-credit than to its theoretical analysis, and in any case are not directly or specifically related to the environment.

Al Gore (with the IPCC) and Barack Obama also were awarded the peace prize as opposed to the economics prize. I'll withhold my personal opinion on what either has contributed to environmental economics or anything else.