WRITTEN PRELIMINARY Ph.D. EXAMINATION

Department of Applied Economics

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Natural Resource and Environmental Economics

Instructions:

• Identify yourself by your code letter, not your name, on each question.
• Start each question’s answer at the top of a new page.
• Answer two of the first three questions I–III: Natural Resource Economics.
• Answer two of the last three questions IV–VI: Environmental Economics.
• You have four hours to complete this examination.
Natural Resource Economics

Answer two of questions I–III

I. 1. A renewable resource has a natural growth function \( G(X_t) \). Assume that \( G(X_t) \) is a concave function and \( G(X_t) > 0 \) for \( 0 < X_t < K \), where \( K \) is the natural carrying capacity of the resource. Suppose that resource harvest for any individual harvester \( i \) at time \( t \) is equal to

\[
h_{it} = F(E_{it}, X_t) = E_{it}f(X_t),
\]

where \( E_{it} \) is the harvesting effort for harvester \( i \), \( i = 1, 2, \ldots, N \), and \( f(0) = 0 \), \( f(X_t) > 0 \), for \( X_t > 0 \), \( f'(X_t) > 0 \) for \( X_t \geq 0 \). Suppose that the cost per unit effort is \( C \) and that the harvest can be sold at a unit price of \( P \). Let \( \delta \) be the discount rate.

A. Solve for the dynamic harvest path that maximizes the present value of profits from harvest for the case where \( N = 1 \). Solve for the conditions that characterize steady state.

B. Now suppose that \( N \to \infty \). Solve for the “open access” harvest path and steady state. How does the steady state here compare to the steady state in part (A) in terms of harvest, stock size and rents generated?

C. Describe at least two ways that the resource could be managed that overcome the “tragedy of open access” and increase the present value of rents derived from resource harvest.

D. Solve for the conditions that characterize maximum sustainable yield. Is the stock size at maximum sustainable yield greater than, less than, equal to, or indeterminate (could be larger, equal, or smaller) compared to the steady state stock level found in part (A)? How does steady state harvest found in part (A) compare to maximum sustained yield (greater than, less than, equal to, or indeterminate)? Explain why these comparisons turn out as they do.

II. Initially there are \( S_0 \) units of an exhaustible resource that can be extracted at zero cost. The utility from consumption of the flow of extraction at time \( t \) is given by:

\[
U(q_t) = aq_t - q_t^2/2,
\]

with \( a > 0 \). The discount rate is \( r \). There is a fixed time horizon over which the resource may be consumed: \( t \in [0, T] \).

A. a. Write down the dynamic optimization problem to maximize discounted utility from consumption of the exhaustible resource. Write down the Hamiltonian for this problem and solve for the necessary conditions for an optimal consumption path.

B. Solve for the shadow value of a unit of stock, \( \lambda \), and for the time path of consumption.

C. How are the shadow value of a unit of stock and the time path of consumption affected by: i) a change in the discount rate \( (r) \), ii) a change in the time horizon \( (T) \), iii) a change in initial stock level? Explain the intuition for each of these results.

D. Consumption of exhaustible resource causes pollution (think oil and climate change). The government decides to institute a tax of \( t \) per unit of consumption of the resource. Write down a model with a per unit tax of \( t \) on the resource and solve for the necessary conditions for an optimal consumption path. How does the tax change the shadow value of a unit of stock and the time path of consumption?
III. Consider a discrete-time two-period renewable resource model. Suppose that the initial stock of the resource at the beginning of period 1 is $X_1 = 1$. The evolution of the stock between period 1 and period 2 is given by: $X_2 = (X_1 - H_1)^\alpha$, where $H_1$ is the harvest in period 1, and $0 < \alpha < 1$. There are two harvesters of the resource, firms $i$ and $j$. Let harvest of firms $i$ and $j$ in period $t$ be given by $h_{it}$ and $h_{jt}$ respectively, $h_{it} + h_{jt} = H_t$, $t = 1, 2$, where $H_t$ is the total harvest in period $t$. In the second period, assume that the two firms each harvest half of the period 2 stock: $h_{i2} = h_{j2} = H_2/2$. The goal of each harvester is to maximize the present value of profits. Assume that profit for harvester $i$ and $j$ in time period $t$ is given by:

$$\pi_{it} = \ln(h_{it}); \quad \pi_{jt} = \ln(h_{jt}).$$

The discount factor between periods is $\delta$.

A. Solve for the (subgame perfect) Nash equilibrium amount of harvest for each harvester in period 1.

B. Suppose that the firms could cooperate and maximize joint profits. Solve for the joint profit-maximizing amount of harvest in period 1 for each firm. How does this compare to the solution found in part (A)? Explain the economic intuition for the results of this comparison.

C. Now suppose that there is the potential for a natural disaster prior to period 2. If this natural disaster happens it would eliminate any potential for harvest in period 2. Suppose the probability of this disaster is $\sigma > 0$. Solve for the (subgame perfect) Nash equilibrium amount of harvest for each harvester in period 1 with this positive probability of disaster. How does your answer here compare with part (A)? Explain the economic intuition for your result.

D. Finally, suppose that there is the potential for a natural disaster prior to period 2 but that its probability is a decreasing function of stock size in period 2: $\sigma(X_2)$, with $\sigma'(X_t) < 0$. Solve for the (subgame perfect) Nash equilibrium amount of harvest for each harvester in period 1 in this case. How does your answer here compare with part (A)? Explain the economic intuition for your result.
Environmental Economics

Answer two of questions IV–VI

IV. Two firms are the only sources of smog-creating ozone emissions in a localized airshed. Before controls are imposed, the firms emit \( e_1 = 250 \) and \( e_2 = 150 \) units of ozone respectively. The firms’ abatement cost functions are

\[
AC_1(q_1) = 20q_1 + q_1^2 \quad \text{and} \\
AC_2(q_2) = 20q_2 + \frac{q_2^2}{2},
\]

where \( q_i \) is abatement by firm \( i \). A regulator has decided that emissions are too high. The regulator knows with certainty that the marginal benefits from aggregate abatement are \( MB(q) = 200 - q \), where \( q = q_1 + q_2 \) is aggregate abatement.

A. Find the socially optimal level of abatement.

B. Suppose that the regulator has decided to employ a permit-trading scheme. The firms behave competitively in the permit market. How many permits should the regulator issue in order to achieve the optimal level of emissions? What will be the equilibrium permit price and the trading outcome? How should the permits be distributed among the two firms to achieve the social optimum?

C. Now suppose that firm 2 has market power in the permit market and can choose both the price and quantity of the permits it buys or sells. The initial allocation of permits is proportional to initial emissions. That is, if the optimal level of emissions is \( e^* \), then firm 1 is given \( 5e^*/8 \) permits and firm 2 is given \( 3e^*/8 \) permits. Discuss how the equilibrium outcome in this situation will differ from the solution you found in part b. Will market power lead to a loss in social welfare?

D. Finally, suppose the regulator’s assessment of marginal benefits is uncertain: \( MB(q) = 200 - q + \varepsilon \), where \( \varepsilon \) is a random variable with mean zero and finite support. Return to the competitive setup in part B. and discuss how the uncertainty would (or would not) lead to a change in the optimal regulatory approach.

V. A consumer obtains utility from two goods, a private market good \( x \) and a fixed environmental good \( q \). Her utility for these two goods is described by the function \( U(x, q) = \ln x + \ln q \).

A. The consumer has income of \( M = 250 \) and the initial level of \( q \) is \( q^0 = 30 \). If the price of \( x \) is \( p = 10 \) and the price of \( q \) is \( r = 0 \), determine her willingness to pay (define this term carefully) for a change in \( q \) to \( q^1 = 40 \).

B. Now suppose that \( q^1 = 40 \) is the initial or status quo level of the public good and determine the consumer’s willingness to accept for a change back to \( q^0 = 30 \). Discuss the relationship between WTP and WTA.

C. Suppose that, instead of \( r = 0 \), the price of \( q \) is \( r = 2 \). Solve the problem given in part A. using this price and keeping \( p = 10 \), \( q^0 = 30 \), and \( M = 250 \).

D. Discuss why, in a nonmarket valuation exercise (CVM for example), it is recommended that the question be of the WTP form, not the WTA form.
VI. Two identical firms are the only source of a given pollutant. Each currently emits $E_i = 80$ units of the pollutant, and initial abatement costs for each firm are $C_i^0(q^i) = (q^i)^2$. The firms have available an improved abatement technology, at a cost of $F_i = 112.5$, that reduces abatement costs to $C_i^I(q^i) = (2/3)(q^i)^2$. Marginal benefits to abatement, experienced by society at large, are $MB(q) = 80 - q$, where $q = q^1 + q^2$.

A. A regulator enters the picture and decides to apply a Pigouvian tax $t$ to each unit of emissions. If the regulator knows that the low-cost abatement technology is available, determine the tax level at which the firms are indifferent between adopting the new technology and not adopting it.

B. Suppose now that the regulator is unaware of the opportunity firms face to purchase the low-cost abatement technology, believing (mistakenly) that the only technology available is the high-cost technology. Determine the tax that such a regulator would impose in order to maximize perceived social welfare, given by the difference between aggregate abatement costs and aggregate benefits. How much will firms abate and what is actual social welfare under this scenario?

C. What would be the gain in social welfare if the regulator was aware of the firms' opportunity to adopt the low-cost technology? Compute the optimal tax, abatement levels, the technology-adoption decision, and the welfare gain relative to your result in part B.