ECN 275/375 – Natural resource and environmental economics
12:15-15:15 April 6, 2021

All help aids allowed except assistance from others.
This test consists of 3 questions, for a total score of 100 points.
All questions are to be answered. You may answer in English or Norwegian.

In the case that you find a question unclear, or you are uncertain about what is meant, state your extra assumptions needed to be able to answer the question.

When I submit my answers on this exam, I confirm that I have worked alone on my answers and not cooperated with others. I am aware that cooperation with others is to be considered an attempt or a contribution to cheat.
I am aware of the consequences of cheating (Ch. 39, Academic regulations for NMBU).

Your name: NN

Question 1 (30 points)

Forestry and forest conservation.

(a) Consider a forest operation where the only source of income are timber harvest sales. Formulate a single rotation even aged stand equation that reflects the *expected income stream per hectare* of a forest operation when planting takes place once an area is clear cut (think of this as the rotation has already started). Assume planting is profitable. Explain the terms entering your equation and the reason for your choice of formulation. **(10 points)**

Answer: $\begin{Bmatrix} MAX \\ T \end{Bmatrix} \pi(T) = \begin{Bmatrix} MAX \\ T \end{Bmatrix} \left(\hat{p}_T S_T e^{-rT} - \hat{k}_T e^{-rT} \right) = \begin{Bmatrix} MAX \\ T \end{Bmatrix} \left(\hat{p}_T S_T - \hat{k}_T \right) e^{-rT}$

T: The length of the optimal single rotation, also known as the harvest time.
$\hat{P}_T$: The expected net timber price at time T.
S_T: The timber harvest volume per hectare at time T.
$\hat{k}_T$: The expected replanting costs per hectare at time T.
r: The risk free interest rate.
e^{-rT}: The discount factor with interest r at time T.

The chosen formulation is a slight modification of the basic single rotation problem from lecture 17 with the following changes: (1) Actual timber prices and planting costs are replaced by their expected values as harvest and planting occurs some time into the future when the actual values are not known with certainty (this detail not needed for full score). (2) As planting is assumed profitable in the question, planting takes place at time T, and planting costs are therefore discounted at time T with the factor e^{-rT}.

From the environmental economics part of this course we know that in a uniform price conservation procurement auction, optimal bids in the auction equal net present foregone profits (opportunity values) of the forest operation.

(b) Take a single rotation perspective and assume that $0 < t < T$, where T is already determined. Explain why the size of the optimal bid decreases with decreasing t. A formula may help you to clarify your argument. **(10 points)**

Answer: The larger the distance $T-t$, the further into the future timber revenues will take place, i.e., stronger is the effect of discounting. Mathematically: $\left(\hat{p}_T S_T - \hat{k}_T\right)e^{-r(T-t)}$.

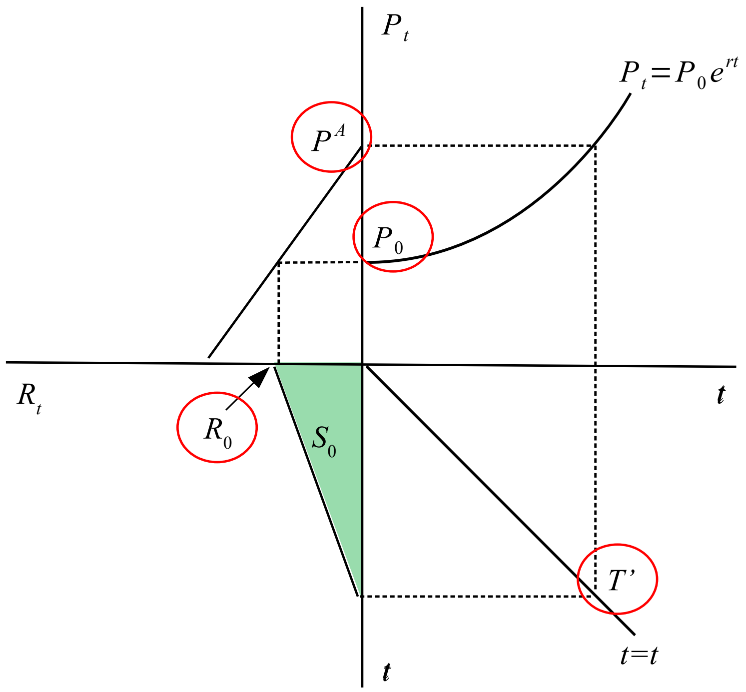
Remark: Conservation contracts are unlikely to be awarded to younger forest as their conservation values are perceived lower than for older forests. Such criteria should be part of the call (tender) for conservation contracts to avoid low bids due to this discounting effect to enter the auction.

(c) Suppose conservation contracts are awarded for eternity. Assume that conservation contracts are only awarded to forests equal to or older than the optimal rotation age, T. Explain why the necessary size of the lump sum compensation then needs to equal $\pi_T + \pi_{2T}e^{-rT} + \pi_{3T}e^{-2rT} + \ldots = \sum_{x=1}^{\infty} \pi_{xT}e^{-(x-1)rT}$, where π_t is profits at time t. **(10 points)** (Clarifying comment: You only need to explain reasons for left side formulation of the equal sign, but understanding the right hand side may make it easier for you to explain the compensation scheme).

Answer: The conservation payment needs to fully compensate forest owners for the forgone net timber values (profits). As compensation only applies to forest stands equal to or older than T, the compensation starts with T as the starting point. This implies that the first rotation is fully compensated without discounting. Constant optimal rotation times, i.e., T does not change, implies that future timber harvests that occur every T years are discounted. The right hand side of the above equation captures this regularity.

Question 2 (30 points)

The graph below illustrates a standard mining problem of a non-renewable resource in a fully competitive market. Assume that demand does not change over time until a perfect substitute is in place and demand is determined by the price of the substitute. Also assume mining costs are so small that we can disregard those.



(a) (i) Explain the meaning of the terms within the red circles. (ii) Explain why the mining profile in the graph is optimal. **(10 points).**

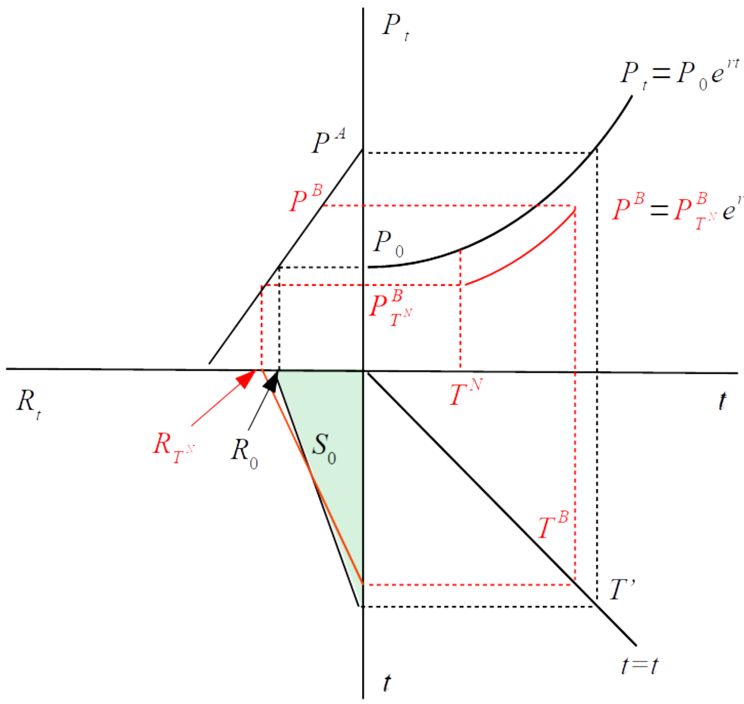
Answer:

(i) P_0 : The gross price (recall mining costs are assumed away).
R_0 : The amount of resources mined at time t=0.
T': The time when all of the resources are mined, i.e., no more resources left.
P^A : The price charged for the last unit of the resource mined in period T', and the choke price for the resource (at this price, there is no more demand).

(ii) This mining profile is optimal because mining of the resource has been timed so that when the resource is fully exploited, there is no more demand. Hence, neither consumers nor producers could benefit from a different mining profile over time as the price path $P_t = P_0 e^{rt}$ gives indifference on mined quantities over time, i.e., absence of arbitrage.

(b) Assume that at time $T^B < T'$ a backstop technology that is a perfect substitute for the resource will be available with a market price $P^B < P^A$. This is known with certainty at time $T^N : 0 < T^N < T^B$. Explain verbally what happens, draw the new price path, and make other adjustments in the graph to make it approximately consistent. Clearly indicate when any adjustments take place. **(10 points)**

Answer: At time T^N, the arrival time T^B and the backstop price P^B are known with full certainty. In a fully competitive market with this knowledge, resource use will increase such that by the time the backstop technology is available, all of the resource has been mined. Note that as the backstop technology is a perfect substitute for the resource, the resource has no value once the backstop technology is available. As the market is fully competitive, mining firms have no better option than to price the resource following a Hotelling price path starting in $P^B_{T^N}$ and ending in $P^B = P^B_{T^N} e^{rt}$.



(c) Suppose that in stead of the full certainty case in (b), the arrival time, $T^B \geq T'$, of the backstop technology is uncertain, where T' is the earliest estimate for the arrival of the backstop technology. Also, assume that as the arrival time gets closer, mining firms gain more precise information about the true arrival time, T^B. Briefly explain how that would affect mining firms' mining profile. **(10 points)**

Answer: Less resources extracted at T^N → the starting price $P^B_{T^N}$ of the resource at T^N becomes somewhat higher to avoid the situation of having no resources left if resource prices get really high. As uncertainty is gradually resolved this would lead to a flatter price path if the true arrival time is sooner than expected (mining increases), and a steeper path (mining decreases) if the true arrival time is later than expected.

Question 3 (40 points)

Harvest-effort models are frequently used to analyze the profitability properties of fisheries.

(a) (i) Formulate a profit maximizing harvest-effort model with harvest as a function of effort and a linear cost for effort. Specify the terms in your model. (ii) Derive the condition for the open-access equilibrium from your formula in general terms, and explain the reasoning behind and implications from your mathematical formulation of the open-access equilibrium. **(10 points)**

Answer: (i) $\begin{Bmatrix} MAX \\ E \end{Bmatrix} p\,H(E) - w\,E$, where $p > 0$ is the price per harvested kilo of fish, $w > 0$ is the per unit cost of effort, E, and $H(E)$ is the harvest function from effort, E.

(ii) The open access equilibrium is given where the profits are zero (additional entrants into the fishery cannot make profits > 0 if costs including wages are to be covered). This corresponds to setting the profit equation to zero for the open access equilibrium to give the following generic solution: $p\,H(E_{OA}) - w\,E_{OA} = 0 \Rightarrow H(E_{OA}) = (w/p)\,E_{OA}$. At E_{OA} total revenues equal total costs.

(b) (i) Derive the profit maximizing effort and ensuing harvest level from your model in (a), and provide a brief verbal explanation for the solution. (ii) Draw the open-access equilibrium from (a) and the profit maximizing equilibrium you have just found in the same harvest-effort graph. **(10 points)**

Answer: (i) Differentiating the profit function in (a) by effort, E, setting this derivative equal to zero, and solving for the profit maximizing effort gives:

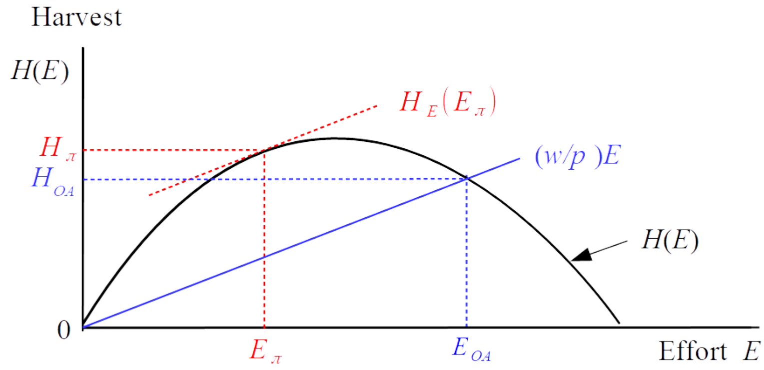
$$\pi_E = p\,H_E(E) - w = 0 \Rightarrow$$
$$H_E(E_\pi) = (w/p) > 0$$

This implies that at the profit maximizing effort level, E_π, the derivative of the harvest function equals the slope of the relative price line *w/p*, which corresponds to the effort level where marginal revenues equal marginal costs of effort.

(ii) A harvest-effort graph with effort, E, as the independent (choice) variable gives harvest, $H(E)$, on the vertical axis and effort, E, on the horizontal axis. Mark the equilibria:

Profit max.: $\{ H_\pi, E_\pi \}$

Open access: $\{ H_{OA}, E_{OA} \}$

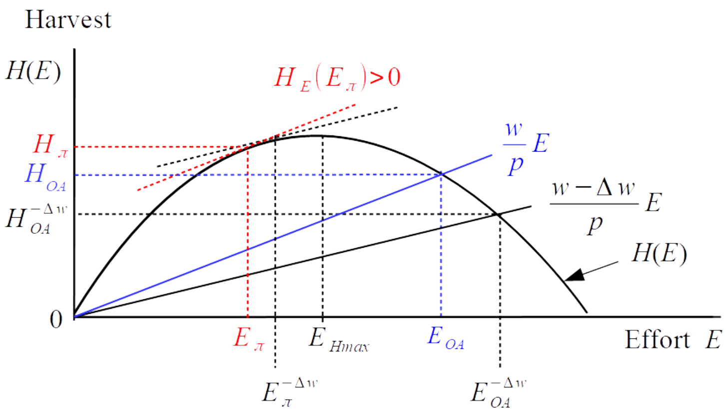


Suppose a new harvest technology becomes available that lowers the per unit costs of effort.

(c) (i) Explain why a large cost savings technology leads to higher effort and less harvest for the open access fishery regime. (ii) Explain that any cost saving technology leads to both increased effort and harvest for a profit maximizing fishery regime. **(10 points)**

Answer: The new technology with reduced per unit effort costs, *w*, implies that the slope of line $(w/p)\,E$ declines. (i) For the open access fishery this implies that the zero profits condition occurs at a higher effort level, $E_{OA}^{-\Delta w}$. For efforts less than the maximum harvest effort, E_{Hmax}, harvests increase. Once efforts are greater than E_{Hmax}, harvests decline (see graph below where the new equilibrium harvest is marked $H_{OA}^{-\Delta w}$) as efforts increase. To see this, recall that $H(E)$ defines the steady state harvest level from effort, i.e, as efforts increase, harvests must decline.

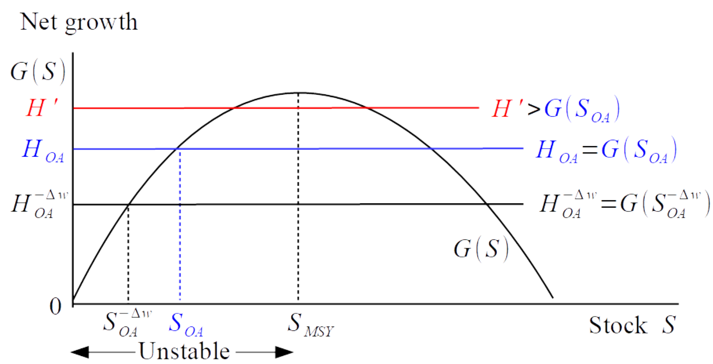
(ii) Profit maximizing efforts are less than E_{Hmax} for any positive unit effort costs. To see this, recall the solution from (b), $H_E(E_\pi)=(w/p)>0$, and that $H_E(E_{Hmax})=0$. Consequently, both effort $E_\pi^{-\Delta w}$ and harvests increase (not marked on vertical axis in figure as the increase is so small) when per unit effort costs decrease.



(d) In open access fishery regimes like in (c), increased efforts due to lower per unit effort costs reduce long run harvests. What insights does this provide for the sustainability of open access fisheries? **(10 points)**

Answer: The effort-harvest graph in this question and the stock-net growth graph needed to analyze the sustainability of open access fisheries adhere to steady states. Changes due to lower per unit effort costs therefore represent changes from one equilibrium to another.

Free entry associated with open-access fisheries entail that the stock is less than the maximum sustainable stock size, i.e., $S_{OA}<S_{MSY}$. This renders the initial equilibrium unstable for $H_{OA}<H_{MSY}$. Reduced harvests, $H_{OA}^{-\Delta w}$ in my notation, is therefore caused by temporary harvests above the net growth, for ex. $H'>G(S_{OA})$ due to reduced costs, which cause stocks to decline. The resulting harvest-stock equilibrium { $H_{OA}^{-\Delta w}, S_{OA}^{-\Delta w}$ }, is then characterized by $S_{OA}^{-\Delta w}<S_{OA}$ and $H_{OA}^{-\Delta w}=G(S_{OA}^{-\Delta w})$ which is unstable.



The case $H>G(S_{OA}^{-\Delta w})$ is of particular concern in terms of maintaining stocks. Failure to limit entry entails that $H>G(S_{OA}^{-\Delta w})$, which further reduces stocks and the net-growth. In worst case settings this could lead to extinction of the fish species.

Remark: Open access fisheries have repeatedly contributed to depleted stocks. In most cases successful restoration of previous stock levels have taken place after entry to the fisheries has been restricted, i.e., the fishery is no longer open access.