ECN 275/375 – Natural resource and environmental economics
12:15-15:15 April 17, 2026

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

In case you find a question that is unclear or you are uncertain about what it means, state the clarifications you need to enable you to answer the question.

This test has been designed to limit the benefits of using artificial intelligence (AI). If AI use is detected beyond reasonable doubt, unreported use leads to a zero-score on that sub-question. Students may use AI if they self-report such use on specific sub-questions at a cost: A question with self-reported AI use reduces the given score by 40%.

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

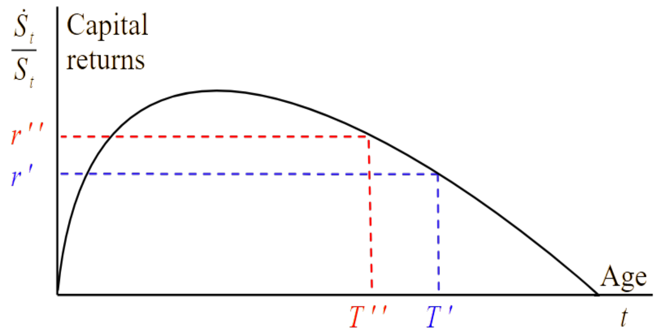
Your name: NN (+ ECN 275 or ECN 375)

Question 1 (30 points – 10 points for each sub-question a-c)

Even aged single rotation forest stand management with extensions.

(a) Suppose the interest rate, *r*, increases from r' to r''. How will that affect the expected optimal rotation age? Explain briefly.

Answer: Higher interest rates, $r''>r'$, implies that the optimal rotation age declines from T' to T''. Using a standard expression for the optimal rotation age for the interest rate, here r', gives $r'=\frac{\dot{S}(T')}{S(T')}$ at time T' and similarly for r''. The graph (right) illustrates the impact of an interest rate increase.



(b) Single rotation forestry with and without planting: Planting per hectare costs are K and takes place at time 0 if planting takes place. W and N are the respective optimal rotation ages with and without planting (natural regeneration of the forest) where $N>W$. $S(W)$ and $S(N)$ are the respective harvested timber volumes (quantities). Moreover, $\hat{P}_W$ and $\hat{P}_N$ are the expected net timber prices at times W and N. Finally, r is the interest rate. Based on this information, what is the net present value condition for it to be more profitable to plant than not to plant?

Answer: $\pi_W=\hat{P}_W S(W)e^{-rW}-K$ and $\pi_N=\hat{P}_N S(N)e^{-rN}$ are the respective expected profits with and without planting. The condition for planting to be more profitable than without is then given by $\hat{P}_W S(W)e^{-rW}-K>\hat{P}_N S(N)e^{-rN}$.

(c) Suppose there are yearly climate benefits, $B(t)>0$ for the lifetime of the forest stand, and that these benefits increase as the age of the stand grows, i.e. $\dot{B}(t)>0$.

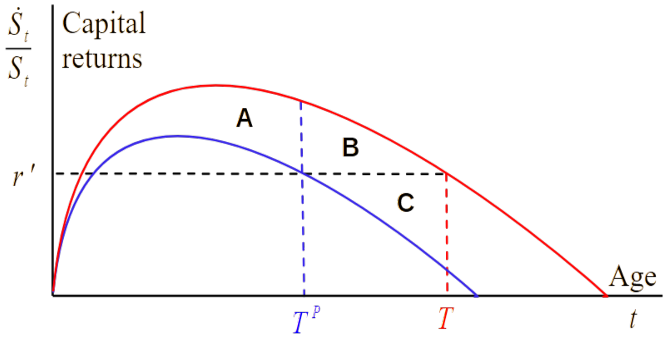
(i) Explain why this increases the optimal rotation age **under single rotation** from the private optimal rotation age T^P to the social optimal rotation age T . Draw a graph of the impact and write down the revised profit function (be careful to indicate the proper time indexes). Explain the reasoning behind your answer.

(ii) What is the size of the minimum payment for forest owners to increase the rotation age from T^P to T **under single rotation**, and why is this welfare enhancing from a societal perspective? Explain the reasoning behind your answer.

Answer (i): The optimal rotation age increases from T^P to T (the "private" optimal rotation age when only timber harvest (stumpage) values are included) to T (the "social" optimal rotation age when climate benefits values are included).

The revised profit function with climate benefits added can be written as:

$\pi_T = \hat{p}_T S_T e^{-rT} + \int_0^T B(t) e^{-rt} dt$ where the red portion is the additional terms due to the climate benefits.



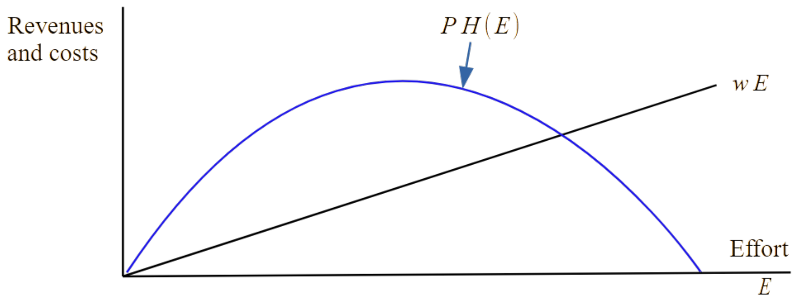
Answer (ii): Under single rotation the strictly necessary compensation equals area **C**. In practice a share of area **B** should also be included to ensure that the profits of harvesting at age T are greater than the profits of harvesting at age T^P . This payment is less than the climate benefits **B** + **C** of increasing the rotation age from T^P to T . Increasing the rotation age as suggested therefore has positive net benefits.

Remark: Under a multiple rotation setting, all of area **B** needs to be included in the payment to counter the effect of an even lower privately optimal rotation age than T^P .

Question 2 (30 points – 10 points for each sub-question a-c)

Fisheries – open access and regulation.

The graph to the right shows a standard picture of the harvest-effort model where:



- E is effort
- P is fish price per kilo
- w is real wage per effort
- $H(E)$ is harvest as a function of effort measured in kilo.

(a) (i) Use the figure above as a basis to identify the open access effort, E_{OA} . Explain.

(ii) Show why the open access effort, E_{OA} , cannot give the lowest costs per harvested kilo of fish.

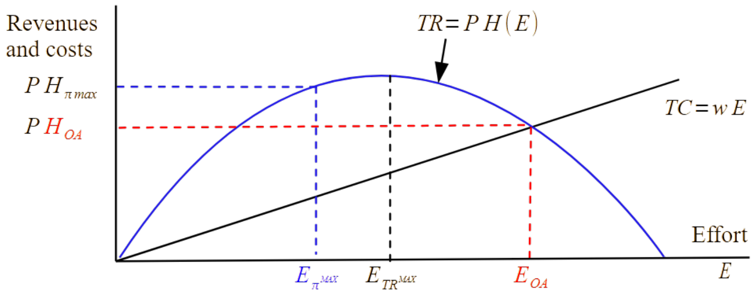
Answer (i): The open access equilibrium effort, E_{OA} , is where the total revenue curve crosses the total cost line; $TR(E)=TC(E)$, i.e. $PH(E)=wE$.

Answer (ii): E_{OA} cannot be the effort that gives the lowest costs per harvested kilo of fish because the exists at least one other effort, $E' < E_{OA}$, with less total costs $wE' < wE_{OA}$ as $w > 0$, that gives the same or higher harvest $H(E') \geq H(E_{OA})$.

(b) There are some direct regulatory implications given the premise in question (a) that E_{OA} cannot be a cost minimum effort. State what you deem the most direct regulation to reduce effort **without lowering total revenues per effort level**.

Answer: The direct regulatory implication is that effort needs to be reduced. The most direct way of doing this is an aggregate quota on effort, $\bar{E} < E_{OA}$. To deal with the second premise "without lowering total revenues per effort level" there are two clear approaches:

- The most elegant approach is to find the profit maximizing effort level, $E_{\pi^{MAX}}$ which we know is found by differentiating the profit function $\pi(E) = PH(E) - wE$ by effort and set this to zero (the first order condition for profit maximization) which gives $\pi_E(E) = PH_E(E) - w = 0 \Rightarrow H_E(E) = w/P$, i.e. $PH_E(E_{\pi^{MAX}}) = w$. For $E' > E_{\pi^{MAX}}$ we know that $PH_E(E') < PH_E(E_{\pi^{MAX}}) = w$ by the second order condition for the profit maximizing effort, i.e. $H_{EE}(E_{\pi^{MAX}}) < 0$. Alternatively (and still with full score on this sub-question) use a graph (like below) to add clarity to your reasoning).
- Another approach: look directly at a graph to see that for $E_{\pi^{MAX}} \leq E' < E_{OA}$ average revenues increase the closer E' is to $E_{\pi^{MAX}}$. (minus 1 point compared to the elegant solution).



Remark: Partial credit given for regulations on harvest because it is less direct than regulating effort.

(c) Explain how you would set initial aggregate quotas on effort, and how you would award these quotas to buyers. Mention possible challenges with your suggestion. These challenges may include undesirable effects on fish markets.

Answer: From (b) the aggregate quota on effort, $\bar{E}$, must satisfy $E_{\pi^{MAX}} \leq \bar{E} < E_{OA}$. It is tempting to set the starting aggregate quota to $E_{\pi^{MAX}}$, but depending on how the quotas are allocated to fishing firms, we may have consolidation in the fishing industry leading to lower harvesting costs, i.e. $w^{NEW} < w$ which causes a small increase in $E_{\pi^{MAX}}$. Hence, there is an argument for a gradual adjustment of the aggregate quota.

A natural starting point could be to set the aggregate quota for effort at $\bar{E} = E_{TR^{MAX}}$ (the revenue maximizing effort) for two reasons: First, because the loss in rents is quite small. Second, because it avoids having to increase the aggregate quota later.

Fisheries rents belong to a country's citizens represented by the state. One way to recapture these rents is to auction off the effort quotas. The empirical literature on auctions suggests using discriminatory (first price) price auctions but that opens for strategic bidding. A better approach is uniform price auctions because they provide true information about fishing firms' valuation of the effort quotas. Caps on how many quotas each buyer are allowed reduce market concentration, thereby lowering opportunities for fishing firms to manipulate prices in fish markets.

Question 3 (40 points – 10 points for each sub-question a-d)

Non-renewable resources and models. While these models share some common features, they come in many variants. Consider a non-renewable model with the following attributes:

- Utility originates from consumption.
- Production uses one non-renewable resource N_t from the natural resource base R_t, and man-made capital, K_t.
- There is a direct negative externality, $E(N_t)$, from consuming N_t.
- Immediate negative impacts of the negative externality $E(N_t)$ from consuming N_t and expenditures $V(E(N_t))$ to reduce these external impacts.

(a) Write down the objective function, the choice variables, and the capital and resource constraints that correspond to the problem description. Define terms that have not been previously defined. Briefly describe the reasoning behind your chosen formulations.

Answer: Objective function:

$$\underset{\{C_t, N_t, V_t\}}{\text{MAX}} \int_0^\infty U(C_t, E(N_t)) e^{-\delta t} dt \quad \text{where } \delta \text{ is society's discount rate}$$

The necessary constraints are:

Resource constraint: $\dot{R}_t = -N_t$

Capital change constraint: $\dot{K}_t = Q(K_t, N_t) - C_t - V(E(N_t))$

Remarks: Man-made capital, K_t ,is endogenous in this model through the formulation of the capital constraint (Solow-type formulation), where future production possibilities are reduced by less capital accumulation from consumption C_t and expenditures to reduce the immediate externality from consuming N_t .

(b) What is the economic interpretation of the change over time of the Lagrangian multiplier on the capital change constraint giving the co-state variable $\dot{\omega}_t = \delta \omega_t - Q_K \omega_t$? Explain briefly.

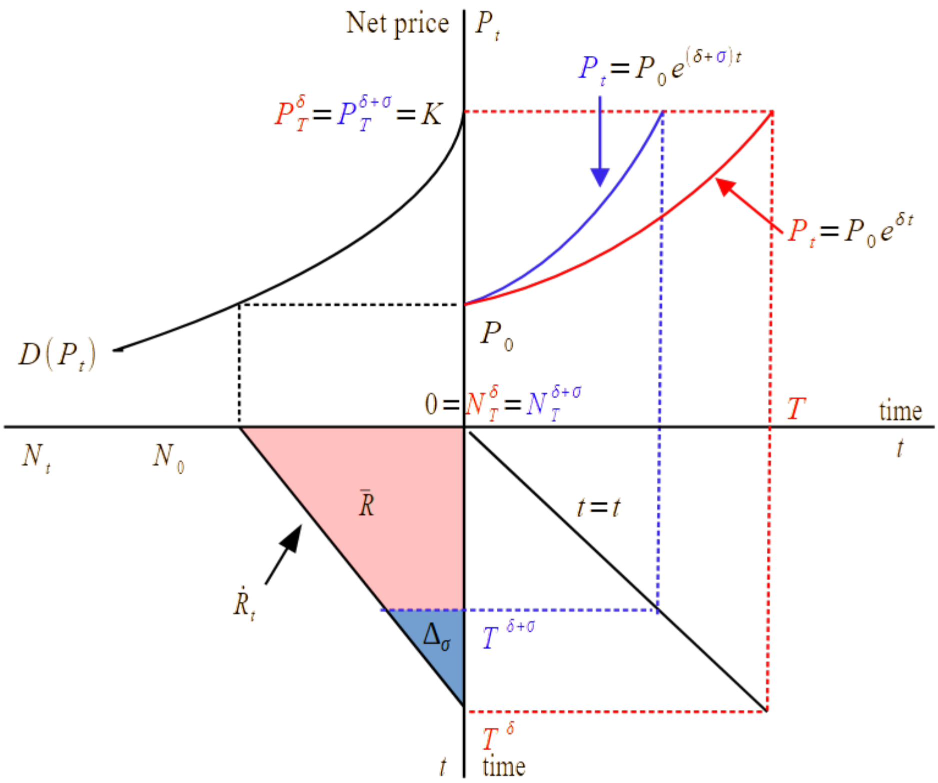
Answer: ω_t is the shadow value of the capital change constraint. $\dot{\omega}_t$ expresses how this value develops optimally over time when man made capital changes, affecting future discounted consumption. As consumption is part of the capital constraint, there is a trade-off between capital accumulation and consumption.

Reason: The decision maker is free to reallocate total resources into growing the capital stock or consumption. This means that in optimum the marginal value of increasing the size of the production capital must equal the marginal utility of consumption.

(c) The depletion of a resource with no apparent backstop solution implies that scarcity may become an issue.
(i) How is scarcity reflected in the equation for the Hotelling price path? It suffices to write the reformulated Hotelling price path equation.
(ii) Draw a four corners graph where you show the impact of a scarcity factor on the price path, then from prices onto quantity demanded, and finally for the stock of the resource or the time it takes for the resource to be fully utilized. Clearly mark the scarcity impacts.

Answer (i): This is captured by the scarcity factor σ which is added to the Hotelling price path equation as follows: $P_t = P_0 e^{(\delta+\sigma)t}$. This implies that the price path becomes steeper.

Answer (ii): In my version of the graph, I have introduced a choke price, *K*. Due to the steeper Hotelling price path the choke price is reached faster, i.e. $T^{\delta+\sigma} < T^{\delta}$ for the following condition to be met: $P_{T^{\delta+\sigma}} = P_{T^{\delta}} = K$. This means some of the natural resource is not extracted, shown in my graph as the small blue triangle Δ_{σ} .



Remark: For those choosing to use a demand curve without a choke price *K*, all of the resource will be utilized, but this will take longer. Reason: as the Hotelling price path with the scarcity factor is steeper, demanded quantities will become smaller earlier, which will extend the “life” of the resource.

(d) Suppose that the resource N_t is land with no previous commercial use that gradually is transformed for sites to build cabins in mountain areas. The loss of undeveloped area is of concern in the Norwegian public debate for two primary reasons. First, because it entails loss of wildlife habitat. Second, because it reduces the recreational value of Norwegian outbacks.

(i) How well suited is the above model for describing the welfare losses from the current expansion of areas used for mountain cabins? Explain briefly.

(ii) What kind of adjustments need to be made in the model for it to be fully compatible with this land use case?

Answer (i): The model captures the above situation when land is homogeneous with a consumption externality from using nature for cabin sites through the inclusion of a scarcity factor (that could be captured as an extra tax) leading to some available land is not developed for building cabins. In the figure in (c) this is captured by the blue triangle Δ_{σ} .

Answer (ii): Changes needed in the model: (1) The natural resource N_t in question is specified as not having any previous commercial use. Its use should therefore not be part of the production function, $Q(K_t, N_t)$ leading to a simplified version $Q(K_t)$ in the capital constraint. (2) The term $V(E(N_t))$ in the capital constraint to reduce the consumption externality, as the most likely measure that works would be a quota or a tax on land use conversion from outback to cabin sites does not belong in the capital constraint. A more direct and likely policy to work would be a direct cap on land use conversion to cabin sites.