Lecture 11

Storable, Renewable Resources: Forests

Storable, Renewable Resources: Forests

- Introduction
- Characterizing Forest Harvesting Decisions
- Sources of Inefficiency
- Poverty and Debt
- Sustainable Forestry
- Public Policy

Introduction

- Chapter 12 covers forests, forest management and sustainable forestry.
- Efficient allocations of the forest resource are defined and examples of how economic incentives can be used to protect biodiversity are presented.
- The calculation of optimal rotations is presented. Timber values as well as biodiversity values of the forest are highlighted.
- The problem of deforestation and potential solutions are also emphasized.

Characteristics of Forests

- Forests directly provide timber, fuel wood, food, water for drinking and irrigation, stocks of genetic resources, and other forest products.
- Moreover, as ecosystems, forests also provide a wide variety of services, including removal of air pollution, regulation of atmospheric quality, nutrient cycling, soil creation, habitats for humans and wildlife, watershed maintenance, recreational facilities and aesthetic and other amenities.
- Because of the wide variety of functions that forests perform, timber managed for any single purpose generates a large number of important external effects.
- We would expect that the management of woodland resources is often economically inefficient because of the presence of these external effects.
- A tree may take more than a century to reach its maximum size. The length of time between planting and harvesting is usually at least 25 years, and can be as large as 100 years.

Forest Harvesting Decisions

Special Attributes of the Timber Resource

- Timber is both an output (flow) and a capital good.
- The harvest decision involves
  - how much timber to harvest,
  - how often to harvest it
  - and whether to replant after harvesting.

- Standing trees are a capital asset. Tree growth increases the harvestable volume and standing trees provide watershed protection and wildlife habitat.
- Existence of externalities make it difficult to define the efficient allocation.

Forest Harvesting Decisions

Main problems with Deforestation:

- intensified climate change,
- decreased biodiversity,
- caused agricultural productivity to decline,
- increased soil erosion and desertification,
- and precipitated the decline of traditional cultures of people indigenous to the forests.

Forest Harvesting Decisions

The Biological Dimension

- Tree growth is measured on a volume basis (typically cubic feet).

- Young trees will grow tall quickly, but volume growth is slow. Medium aged trees increase in volume quite rapidly while mature trees grow very slowly and eventually stop growing or reverse growth.

- Growth will also be affected by weather, soil fertility, disease, forest fires, etc.

Modeling tree growth (Douglas Fir)

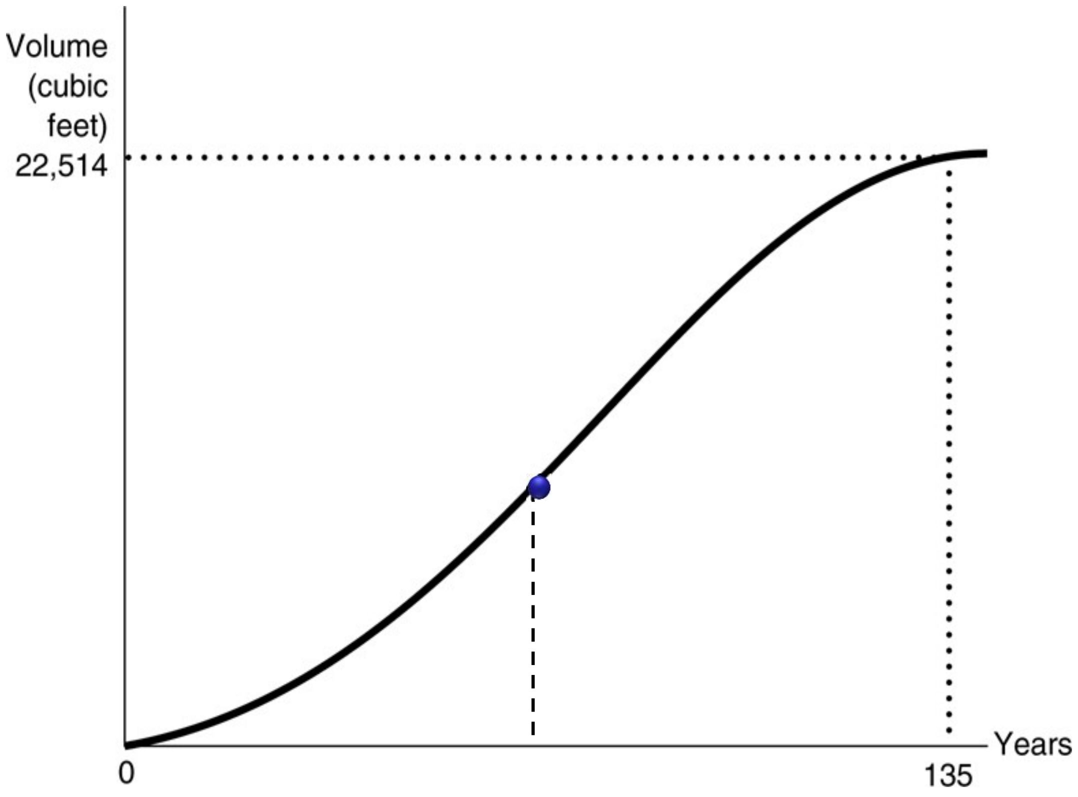
We use data reported in Clawson (1977) referring to the volume of timber in a stand of US Northwest Pacific region Douglas firs. Let **S** denote the volume, in cubic feet, of standing timber and **t** the age in years of the stand since planting. The age–volume relationship estimated by Clawson for a typical single stand is the cubic function of time,

$$S = 40t + 3.1t^2 - 0.016t^3$$

The next Figure plots the volume of timber over a period up to 145 years after planting. It is evident from the diagram that an early phase of slow growth in volume is followed by a period of rapid volume growth, after which a third phase of slow growth takes place as the stand moves towards maturity. The stand becomes biologically mature (reaches maximum volume with zero net growth) at approximately 135 years.

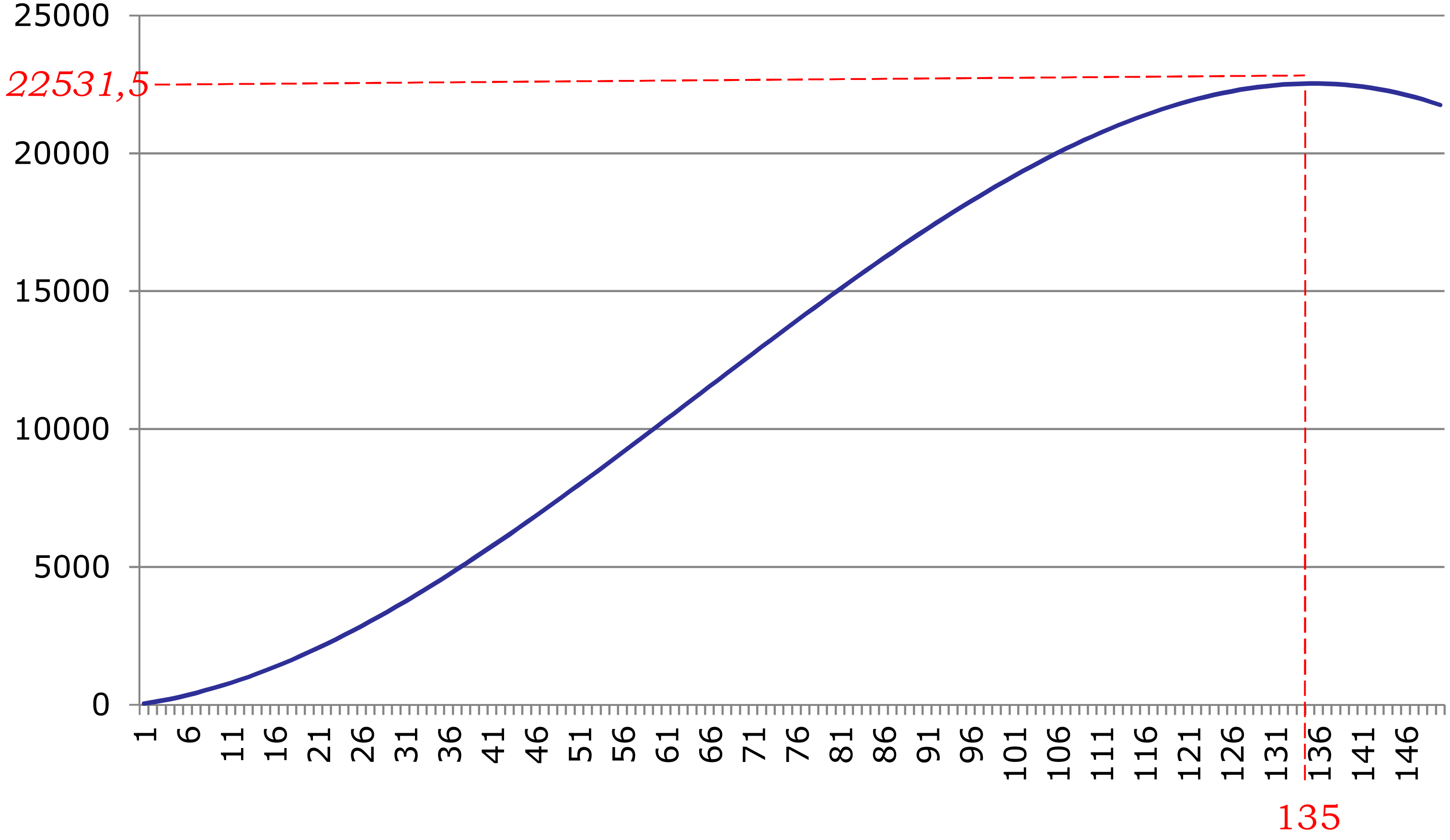
Inspection of Clawson's estimated timber growth equation shows that growth becomes negative after (approximately) 135 years. The equation should be regarded as being a valid representation of the growth process only over the domain $t = 0$ to $t = 135$.

Modeling tree growth (Douglas Fir)



Notice that the figure is consistent with the growth phases listed above, following an early period of limited growth in its middle ages, with growth ceasing after 135 years.

Modeling tree growth (Douglas Fir)



A more precise representation of the age – volume Clawson's function:

$$S = 40t + 3.1t^2 - 0.016t^3$$

Forest Harvesting Decisions

The Economics of Forest Harvesting

- The optimal time to harvest from a profit maximization perspective would be the age that maximizes the present value of net benefits from the wood (max PVNB).
  - Benefits are measured using the potential volume of wood given the growth rate and the price of the lumber. The annual incremental growth represents the marginal growth.
  - Planting costs are immediate and thus are not discounted while harvesting costs are discounted because they are paid in the future.

- Net benefits are calculated by subtracting the present value of costs from the present value of the timber at harvest age.

- The discount rate will affect the harvest decision.

Economic Harvesting Decision (douglas fir)

Age (years)	10	20	30	40	50	60	68	70	80	90	100	110	120	130	135
Volume (cubic feet)	694	1,912	3,558	5,536	7,750	10,104	12,023	12,502	14,848	17,046	19,000	20,614	21,792	22,438	22,514
Undiscounted (r = 0.0)															
Value of Timber ($)	694	1,912	3,558	5,536	7,750	10,104	12,023	12,502	14,848	17,046	19,000	20,614	21,792	22,438	22,514
Cost ($)	1,208	1,574	2,067	2,661	3,325	4,031	4,607	4,751	5,454	6,114	6,700	7,184	7,538	7,731	7,754
Net Benefits ($)	−514	338	1,491	2,875	4,425	6,073	7,416	7,751	9,394	10,932	12,300	13,430	14,254	14,707	14,760
Discounted (r = 0.01)															
Value of Timber ($)	628	1,567	2,640	3,718	4,712	5,562	6,112	6,230	6,698	6,961	7,025	6,899	6,603	6,155	5,876
Cost ($)	1,188	1,470	1,792	2,115	2,414	2,669	2,833	2,869	3,009	3,088	3,107	3,070	2,981	2,846	2,763
Net Benefits ($)	−560	97	848	1,603	2,299	2,893	3,278	3,361	3,689	3,873	3,917	3,830	3,622	3,308	3,113
Discounted (r = 0.02)															
Value of Timber ($)	567	1,288	1,964	2,507	2,879	3,080	3,128	3,126	3,046	2,868	2,623	2,334	2,024	1,710	1,449
Cost ($)	1,170	1,386	1,589	1,752	1,864	1,924	1,938	1,938	1,914	1,860	1,787	1,700	1,607	1,513	1,435
Net Benefits ($)	−603	−98	375	755	1,015	1,156	1,190	1,188	1,132	1,008	836	634	417	197	14
Discounted (r = 0.04)															
Value of Timber ($)	469	873	1,097	1,153	1,091	960	835	803	644	500	376	276	197	137	113
Cost ($)	1,141	1,262	1,329	1,346	1,327	1,288	1,251	1,241	1,193	1,150	1,113	1,083	1,059	1,041	1,034
Net Benefits ($)	−672	−389	−232	−193	−237	−328	−415	−438	−549	−650	−737	−807	−862	−904	−921

Value of timber = price × volume/$(1 + r)^t$

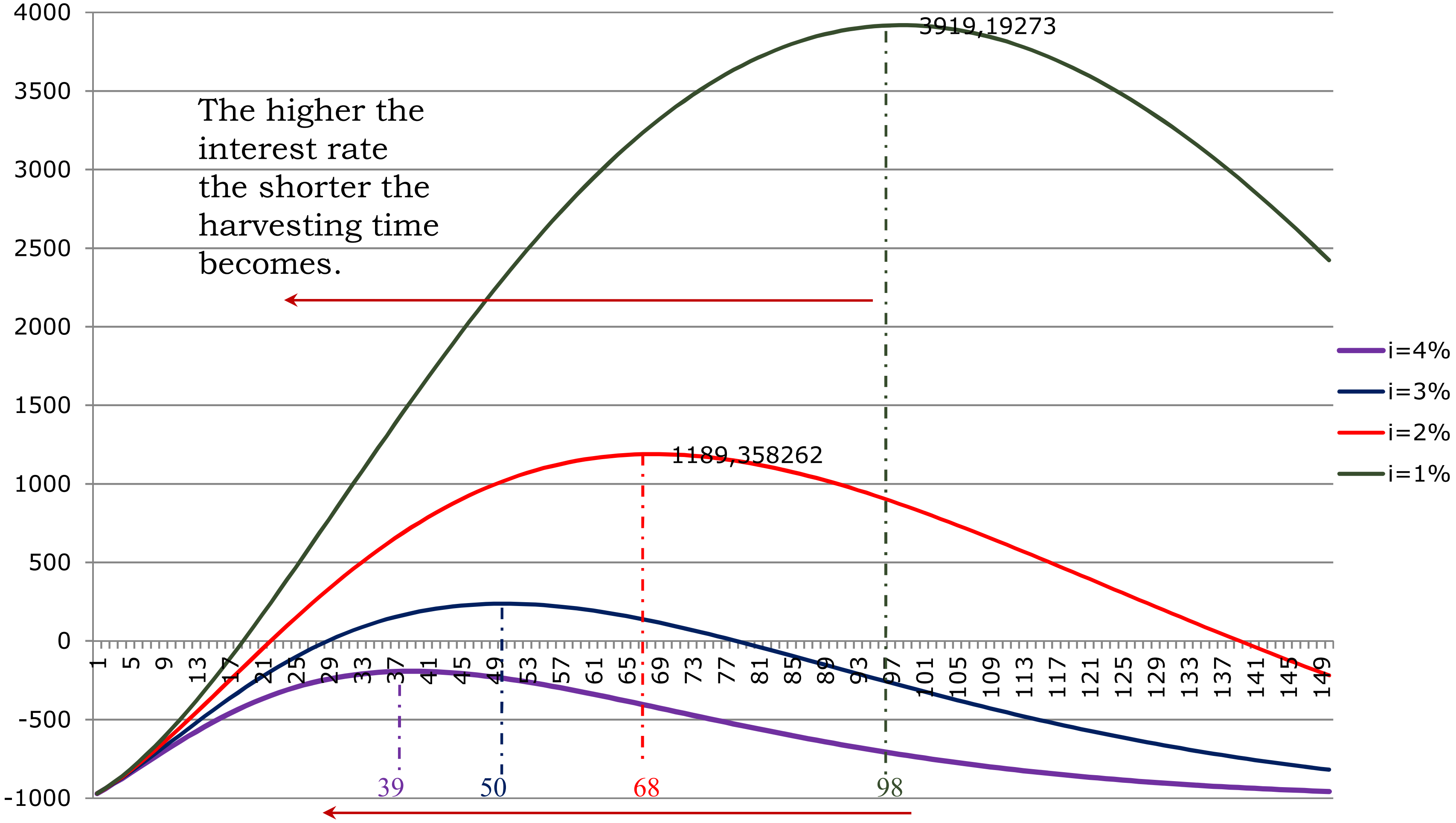
Cost = \$1,000 + (\$0.30 × volume)/$(1 + r)^t$

Net benefits = value of timber − cost

Price = \$1

We assume that the stand is harvested once. We also shall assume that neither the price (assumed to be \$1) nor the harvesting costs per cubic meter (\$0.30) vary with time. The cost of planting this forest is assumed to be \$1,000.

Economic Harvesting Decision (douglas fir)



The higher the interest rate the shorter the harvesting time becomes.

Assume the stand is harvested once and that neither the price (assumed to be \$1) nor the harvesting costs (\$0.30) /m^3 vary with time. The cost of planting this forest is assumed to be \$1,000.

Economic Harvesting Decision (douglas fir)

To find the optimal harvesting time we choose the time at which the present value of profits from the stand of timber is maximized.

Profits are given by the value less the planting and harvesting costs.

Because we are assuming the land has no other uses, the opportunity cost of the land is zero and so does not enter this calculation.

If the forest is clear-cut at time t, then the present value of profit is

$$PV(NB) = (P - c)V(t)e^{-it} - k = pV(t)e^{-it} - k$$

where:

- $V(t)$ denotes the volume of timber available for harvest at time t
- P is the price and c is the cost per volume
- $p=P-c$ is the net price of the harvested timber
- k is the planting cost incurred at the initial period
- i is the private discount rate (opportunity cost of capital to the firm).

Economic Harvesting Decision (douglas fir)

~~To maximize the PV(NB) we take the derivative and set it equal to zero:~~

$$\xcancel{\frac{dPV(NB)}{dt}=0 \Rightarrow \frac{d\left(pV(t)e^{-it}-k\right)}{dt}=0 \Rightarrow p\frac{\partial V(t)}{\partial t}e^{-it}+(-i)pV(t)e^{-it}=0}$$

$$\Rightarrow \frac{\partial V(t)}{\partial t}=iV(t) \Rightarrow \boxed{i=\frac{\frac{dV(t)}{dt}}{V(t)}}$$

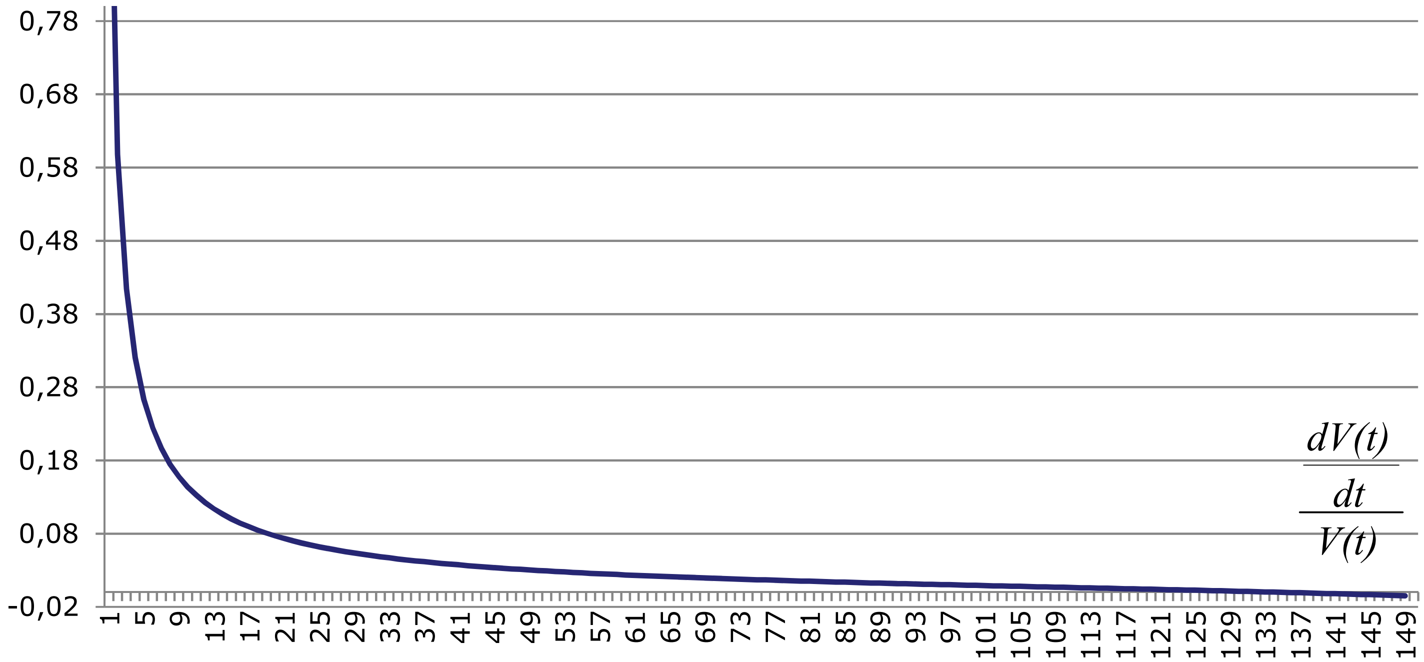
No Questions on calculations but definitely you should be able to interpret the formulas

The above equation states that the present value of profits is maximized when the rate of growth of the (undiscounted) net value of the resource stock is equal to the private discount rate.

Note that with the timber price and harvesting cost constant, this can also be expressed as an equality between the proportionate rate of growth of the volume of timber and the discount rate.

Economic Harvesting Decision (douglas fir)

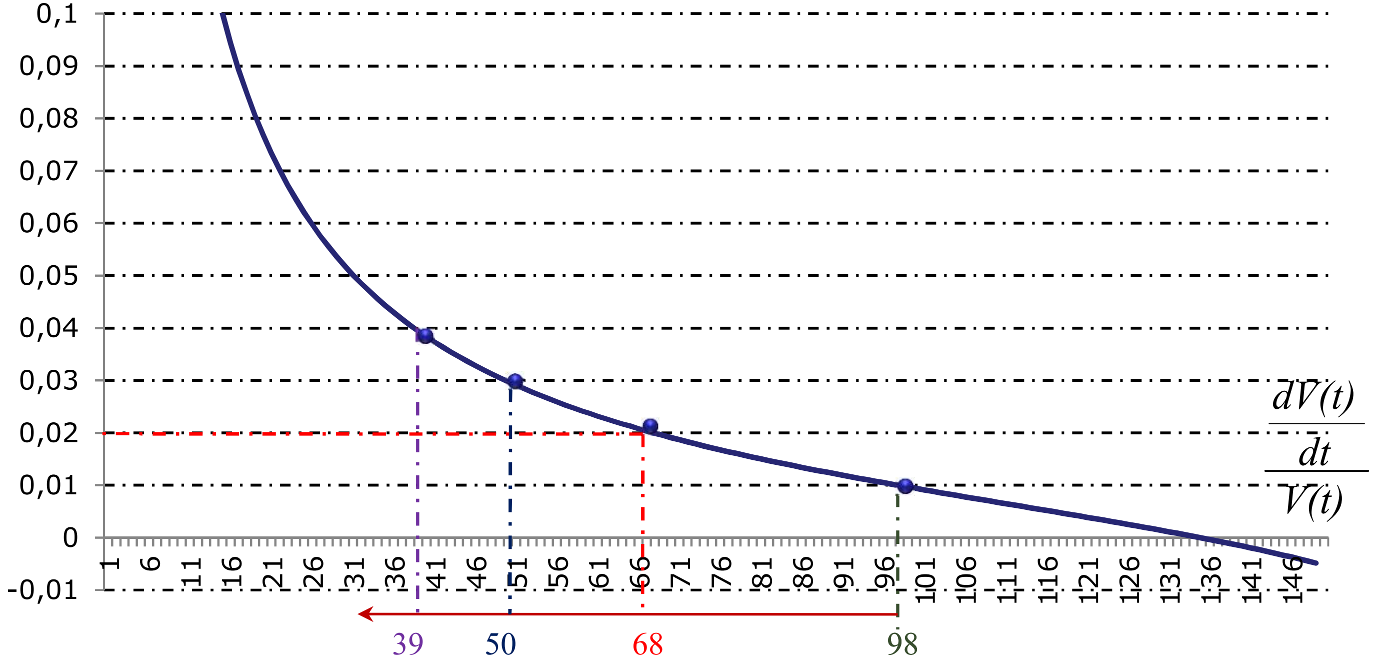
The graph presents the percentage growth in NB (undiscounted). That is, we calculated the V(t), then its time derivative and then we divide it by V(t).



Initially, with zero and low NB the growth of the value (M(NB)) is more than 100% of the NB, thus the curve starts high, and drops as the NB increases (as the volume increases). Eventually, the growth of NB will become zero. Actually (and not surprisingly) it becomes zero at $t=135$ at which we get the maximum (undiscounted) NB. This is exactly the optimal harvesting time if interest rate is zero ($i=0$).

Economic Harvesting Decision (douglas fir)

We focus on the interesting part of the graph, that is, for interest rates between 0 and 10%. It is apparent that, we get exactly the same results as those we got by maximizing the discounted NB.



We cut the trees at the time that the growth of NB becomes less than the interest rate. There is no point of growing the trees if their value increases slower than the (constant) interest rate. We can cut the trees, sell them and put the money in the Bank to earn a higher return. So, *(dV(t)/dt)/V(t)* is the (annual) rate at which the value of the tree is growing and in some sense is an interest rate.

Economic Harvesting Decision (douglas fir)

It should be noticed that for a discount rate of zero ($i = 0$), the level of the present value of NB over time is identical to undiscounted values. Net benefits are maximized at 135 years, the point at which the biological growth of the stand ($dV(t)/dt$) becomes zero.

With no discounting and fixed timber prices, the profile of net value growth of the timber is identical to the profile of net volume growth of the timber.

It is also useful to look at this problem in another way.
The interest rate to a forest owner is the opportunity cost of the capital tied up in the growing timber stand. When the interest rate is zero, that opportunity cost is zero. It will, therefore, be in the interests of the owner to not harvest the stand as long as the volume (and value) growth is positive, which it is up to an age of 135 years.

Indeed, inspection of the previous equation confirms this; given that V(t) is positive, when $i = 0$, $dV(t)/dt$ must be zero to satisfy the first-order maximizing condition.

Economic Harvesting Decision (douglas fir)

- Harvesting costs are discounted and are proportional to the amount of timber harvested.
- The net benefit of a unit of wood harvested at any age is the price of the wood minus the marginal cost of that unit.

- Conclusions:
  - discounting shortens the age of the efficient harvest
  - the optimal harvest age is insensitive to the planting and harvesting costs
  - with high discount rates, replanting may not be efficient.

- A tax levied on each cubic foot of wood harvested would simply raise the marginal cost of harvesting by the amount of the tax.

Forest Management: Infinite Rotation (Faustmann)

Forest Harvesting Decisions

Extending the Basic Model

- The single-rotation model assumes the forest is harvested only once
- This is not realistic if:
  - The land has no alternative use
  - Forestry remains profitable

- A rational landowner will:
  - Harvest
  - Replant
  - Continue production over time

☞ We therefore move to a model with repeated (infinite) rotations

- Key difference from single rotation: Delaying harvest now affects:
  - The current stand
  - All future rotations

- Waiting becomes more costly than in the single-rotation case

Site (Land) Value

- Land generates repeated timber profits over time

- Thus land itself is a capital asset

- Site value (Π): present value of all future rotations
  - Not just the current trees → the entire stream of forests

- Important: delaying harvest delays returns on land value

- Think of the land like a machine that keeps producing forests every T years.”

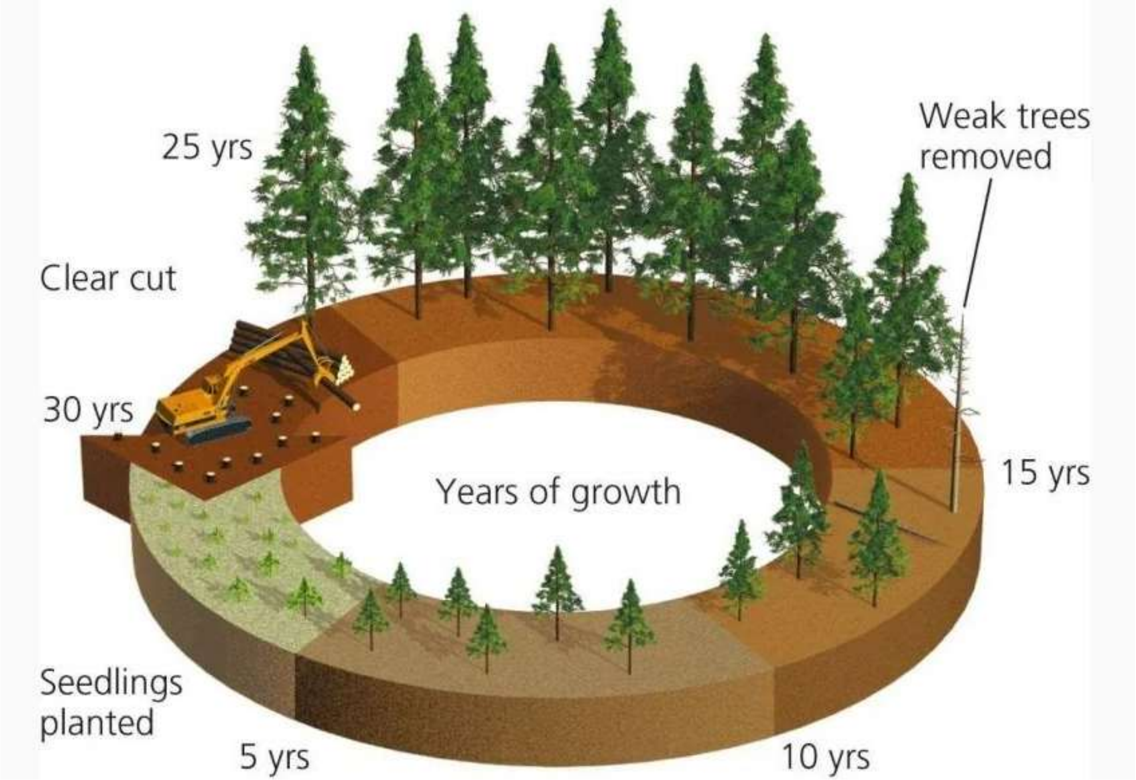
Infinite-planning model

- The single-rotation model is limited and not very realistic

- If the land has no alternative use and forestry is profitable:
- A rational owner will not stop after one harvest
- Instead, they will replant and continue production

- Therefore, it is more appropriate to consider multiple rotations

- In forestry economics, this is modeled as an infinite time horizon, where the forest is harvested and replanted repeatedly



Infinite-planning model

- When the harvesting of one stand of timber is to be followed by the establishment of another, an additional element enters into the calculations.
- In choosing an optimal rotation period, a decision to defer harvesting incurs an additional cost over the costs we included in the previous model.
- We have already taken account of the fact that a delay in harvesting has an opportunity cost in the form of interest forgone on the (delayed) revenues from harvesting.
- But a second kind of opportunity cost now enters into the calculus.
  - This arises from the delay in establishing the next and all subsequent planting cycles.
  - Timber that would have been growing in subsequent cycles will be planted later.

- So an optimal harvesting and replanting programme must equate the benefits of deferring harvesting – the rate of growth of the undiscounted net benefit of the present timber stand – with the costs of deferring that planting – the interest that could have been earned from timber revenues and the return lost from the delay in establishing subsequent plantings.

From Single Rotation to Infinite Rotations

- Single rotation: decision affects only current stand
- Infinite rotations: decision affects current AND all future stands
- Key implication: delaying harvest delays the entire sequence of future rotations
  - Higher opportunity cost of waiting
  - Leads to earlier (shorter) optimal rotation compared to single rotation

Two Costs of Delaying Harvest

- 1. Lost interest on current timber revenue (as before)

- 2. Lost opportunity to start the next rotation (NEW)
  - Future trees start growing later
  - All future revenues are delayed

- Conclusion: marginal cost of waiting is higher than in single-rotation model

Infinite-planning model

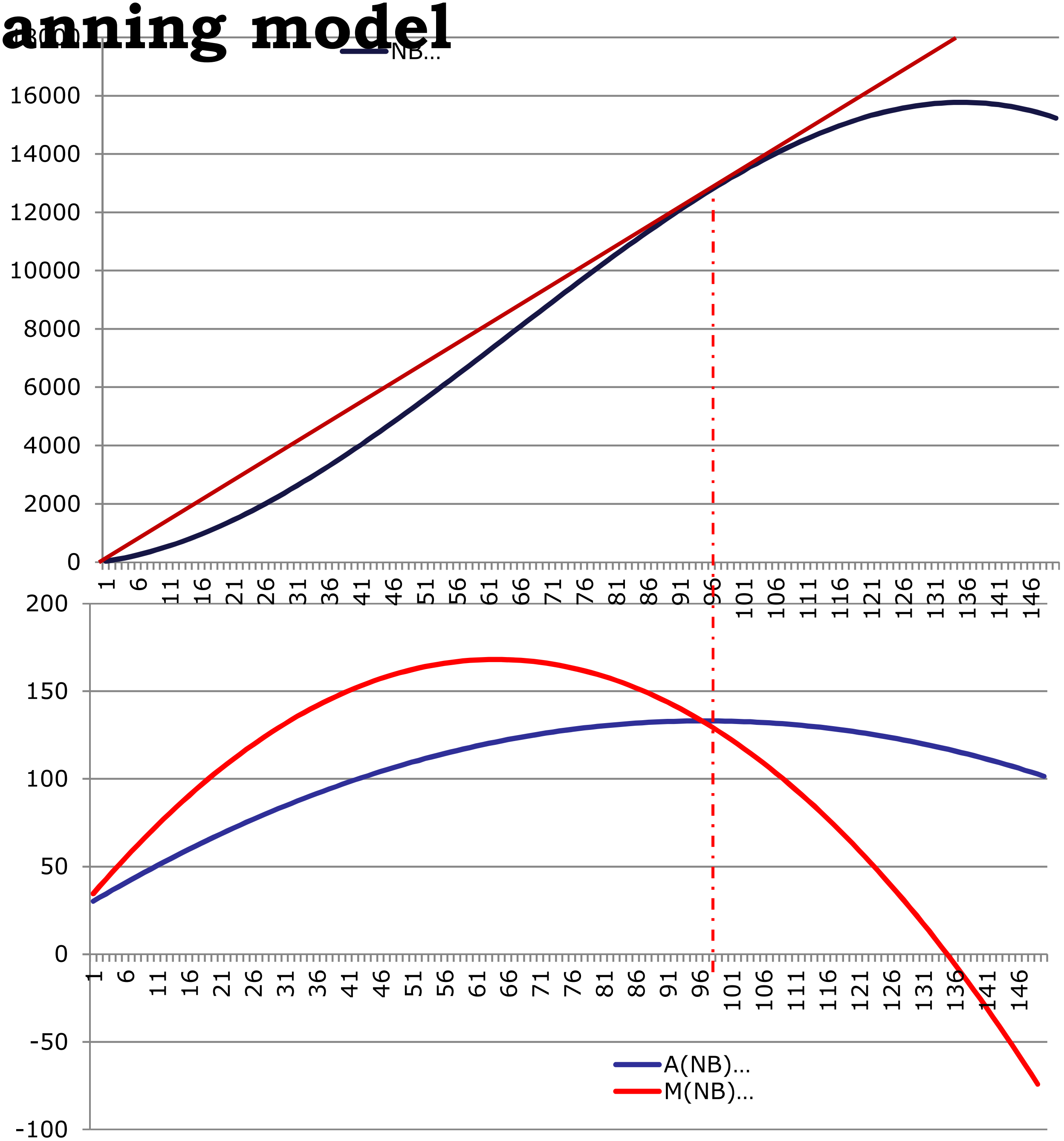
Optimal rotation time

If we do not take into account discounting, but we can replant (reuse the land) then we should cut the trees when

M(NB) = A(NB),

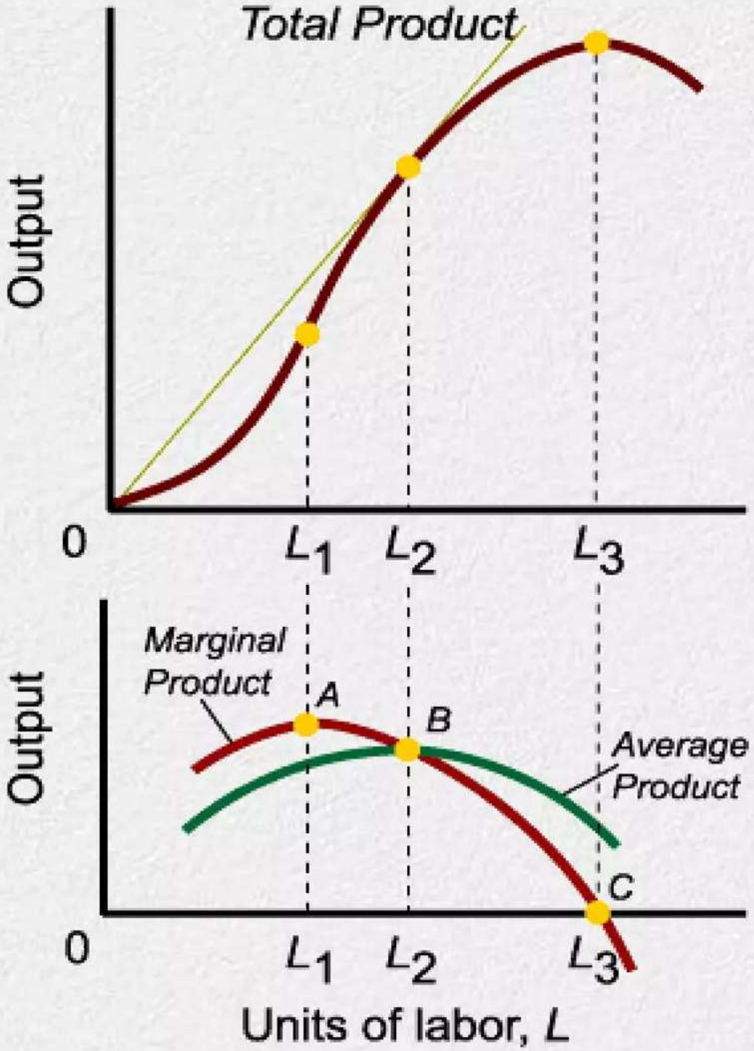
where the average growth of the NB (the value of the forest) is maximized.
Then this is the optimal rotation time with zero interest rate.

Recall that if replanting was not an option, the optimal harvesting time was at the max of NB.



Compare with classic production function

Total, average, and marginal product

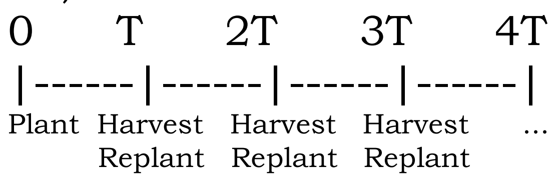


- The average product at any point is equal to the slope of the ray from the origin to the total product curve at that point
- When a ray drawn from the origin falls tangent to the total product function, average product is maximum and equal to marginal product at that point

Infinite-planning model

- First, construct the PV(NB) function for the infinite-rotation model.
- Step 1: AssumptionsPrices and costs are constant over time:
  - total planting cost (in each planting period): k,
  - price of timber: P,
  - harvesting cost/per unit of timber: c,
  - *Net price:* $p = P - c$.

- Step 2: Structure of rotations.
  - The forest is: Planted (on bare land at time t_0) → Grows → Harvested → Replanted (T: rotation length. Each rotation is identical)
  - This cycle repeats forever



0 T 2T 3T 4T

|------|------|------|------|

Plant | Harvest Replant | Harvest Replant | Harvest Replant | …

- Step 3: Cash flow from one rotation
  - Net benefit from one rotation (at harvest time T): $pV(T) - k$
  - Discounted to present: $(pV(T)e^{-iT} - k)$

- Step 4: Infinite sequence of rotations
  - After the first rotation, the same cycle repeats:

$$PV(NB) = (pV(T)e^{-iT} - k) + e^{-iT}(pV(T)e^{-iT} - k) + e^{-2iT}(pV(T)e^{-iT} - k) +$$

$$e^{-3iT}(pV(T)e^{-iT} - k) + e^{-4iT}(pV(T)e^{-iT} - k) + \ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

Infinite-planning model

- If we factor out the term e^{-iT} from all periods after the first one, we get:

$$PV(NB) = (pV(T)e^{-iT} - k) + e^{-iT}\{(pV(T)e^{-iT} - k) + e^{-iT}(pV(T)e^{-iT} - k) + e^{-2iT}(pV(T)e^{-iT} - k) + e^{-3iT}(pV(T)e^{-iT} - k) + \ldots\ldots\ldots\ldots\}$$

$$= (pV(T)e^{-iT} - k) + e^{-iT}\{PV(NB)\} \text{ ❾}$$

$$\text{❾ } (1 - e^{-iT})\, PV(NB) = (pV(T)e^{-iT} - k) \text{ ❾}$$

$$\text{❾ } PV(NB) = \frac{\left(pV(T)e^{-iT} - k\right)}{1 - e^{-iT}}$$

- The above equation gives the present value of profits for any rotation length, T, given values of p, k, i and the timber growth function $V = V(t)$.

- The wealth-maximizing forest owner selects that value of T which maximizes the present value of profits.

Infinite-planning model

- The optimal value of *T* will be that which maximises the present value of the forest over an infinite sequence of planting cycles.
- To find the optimal value of *T*, we obtain the first derivative of PV(NB) with respect to *T*, set this derivative equal to zero, and solve the resulting equation for the optimal rotation length.
- The algebra is simple but tedious. The German forester Martin Faustmann solved the rotation problem, maximizing the present value of the income stream for forest rotation.
- The optimal solution is expressed by:

$$pV'(T) = ipV(T) - iPV(NB)$$

$$i = \frac{pV'(T)}{pV(T) - PV(NB)}$$

No Questions on calculations but definitely you should be able to interpret the formulas

Infinite-planning model

To derive the first-order-condition, it is useful to first rewrite PV(NB):

$$PV(NB) = \frac{pV(T)e^{-iT} - k}{1 - e^{-iT}} = \frac{pV(T) - ke^{iT}}{e^{iT} - 1} = \frac{pV(T) - ke^{iT}}{e^{iT} - 1} + k\frac{e^{iT} - 1}{e^{iT} - 1} - k = \frac{pV(T) - k}{e^{iT} - 1} - k$$

which upon differentiating and setting equal to zero yields:

$$\frac{\partial PV(NB)}{\partial T} = \frac{pV'(T)\left(e^{iT} - 1\right) - ie^{iT}\left(pV(T) - k\right)}{\left(e^{iT} - 1\right)^2} = 0 \Rightarrow$$

$$pV'(T) = \frac{ie^{iT}\left(pV(T) - k\right)}{e^{iT} - 1} \Rightarrow \frac{pV'(T)}{pV(T) - k} = \frac{ie^{iT}}{e^{iT} - 1} = \frac{i}{1 - e^{-iT}}$$

which, after rearranging becomes:

$$pV'(T) = ipV(T) + i\,PV(NB)$$

or:

$$i = \frac{pV'(T)}{pV(T) - PV(NB)}$$

Infinite-planning model

Results: Determinants of Optimal Rotation T

1. In the infinite-rotation model (Faustmann): The optimal rotation depends on: Interest rate, Planting cost, Timber prices.
   Unlike the single-rotation case, all economic parameters matter
2. Comparative Statics
   - *$dT/di < 0$:*
     Higher interest rate → higher opportunity cost of waiting
     Forest owner prefers to harvest earlier.
     Result: $i\uparrow \Rightarrow T\downarrow$
   - *$dT/dk>0$:*
     Higher planting cost → future rotations less profitable
     Lower incentive to replant quickly
     Result: $k\uparrow \Rightarrow T\uparrow$.
   - *$dT/dp < 0$:*
     Higher timber price → future rotations more valuable
     Higher opportunity cost of delaying harvest
     Result: $p\uparrow \Rightarrow T\downarrow$

Rule of thumb:
Anything that increases the value of future rotations → leads to earlier harvesting

Infinite-planning model

$dT/di < 0$:
Waiting longer generates additional timber growth (marginal benefit)
But it also has two opportunity costs:

- Forgone interest on timber value
- Forgone return on land (site value)

When the interest rate increases: Both opportunity costs become larger
Waiting becomes more expensive
☞ Result: Harvest earlier → T↓

$dT/dk > 0$:
Lower planting costs → future rotations become more profitable
Site value of land increases
Delaying harvest now means:
Giving up more valuable future rotations
☞ Result: Harvest sooner when k↓,or equivalently: k↑⇒T↑

$dT/dp < 0$:
Higher timber prices increase the value of harvesting
Future rotations become more valuable
Delaying harvest becomes more costly
☞ Result: Harvest earlier → T↓

QUESTIONS:

“If forests are cut faster when prices rise… is that good or bad for sustainability?”

Higher prices lead to economically efficient but potentially ecologically suboptimal outcomes unless environmental values are internalized.Key trade-off

Profit maximization ≠ ecological sustainability

- Market decisions ignore:
    - biodiversity value
    - carbon storage
    - ecosystem services

“A government introduces a subsidy that reduces planting costs. How does this affect:

- Site value
- Opportunity cost of waiting
- Rotation length”

Site value: ↑ increases
Opportunity cost of waiting: ↑ increases
Rotation length: ↓ decreases (harvest earlier)
When replanting becomes cheaper, future forests become more valuable—so you don’t want to “waste time” waiting with the current one.

Infinite-planning model

Harvest when the gain from growth equals the opportunity cost of capital tied up in:

- the trees, and
- the land

Results:

3. Economic Interpretation

The optimal rotation length T is chosen such that:
Marginal benefit of waiting = Marginal cost of waiting

3a. The Faustmann rule as written in $pV'(T) = ipV(T) + i\,PV(NB)$

The length of the optimal rotation period is chosen such that the gain from letting the timber grow for one additional instant ($pV'(T)$, the left-hand-side) exactly equals the cost of doing so. These cost consist both of the money lost from not harvesting the timber and putting the money in the bank ($ipV(T)$, the first term on the right-hand-side) and the money lost from not starting a new growing cycle, $i\,PV(NB)$ (or selling the land at its current site value).

3b. The Faustmann rule as written in $i = \dfrac{pV'(T)}{pV(T) - PV(NB)}$ takes the form of an Hotelling rule, where the marginal return on the resource is adjusted by the land value.

In Hotelling:Return = interest rate
In forestry (Faustmann):Return must also cover land value

Infinite-planning model

Results:

The expression $pV'(T) = ipV(T) + i\,PV(NB)$ can also be written as:

3c. $$\frac{pV'(T)}{pV(T)} = i + i\,\frac{PV(NB)}{pV(T)}$$

in order to be interpreted in the following way:

Right-hand side (RHS):

- Interest rate *i* (Return on financial capital)

Land value component $\frac{PV(NB)}{pV(T)}$

- •Opportunity cost of holding land in the current rotation
- •Expressed relative to the value of standing timber

Left-hand side (LHS): $\frac{pV'(T)}{pV(T)}$

Proportionate growth rate of timber

"Rate at which the value of the forest is growing"

The forest should be harvested when:

The growth rate of timber value equals the total opportunity cost of capital, where capital includes: (1)the value of the trees (2) the value of the land

Single Vs infinite rotations

1. Single period: $\dfrac{pV'(T)}{pV(T)} = i$

2. Infinite periods: $\dfrac{pV'(T)}{pV(T)} = i + i\,\dfrac{PV(NB)}{pV(T)}$

- Where the site value is zero, an optimal rotation interval is one in which the rate of growth of the value of the growing timber is equal to the interest rate on capital alone.

- It is clear from inspection of the one period equation that for any given value of *i*, a positive site value will mean that (dV/dT)/V will have to be larger than when the site value is zero if the equality is to be satisfied.

- This requires a shorter rotation length, in order that the rate of timber growth is larger at the time of felling.

Single Vs infinite rotations

1. Single period: $\frac{pV'(T)}{pV(T)} = i$

2. Infinite periods: $\frac{pV'(T)}{pV(T)} = i + i\,\frac{PV(NB)}{pV(T)}$

- Intuitively, the opportunity cost of the land on which the timber is growing requires a compensating increase in the return being earned by the growing timber.

- With fixed timber prices, this return can only be achieved by harvesting at a point in time at which its biological growth is higher, which in turn requires that trees be felled at a younger age.

- The larger is the site value, the shorter will be the optimal rotation.

Sources of Inefficiency

- Our discussions of multiple-use forestry have assumed that the forest owner either directly receives all the forest benefits or is able to appropriate the values of these benefits (presumably through market prices).

- But it not plausible that forest owners can appropriate all forest benefits. Many of these are public goods; even if exclusion could be enforced and markets brought into existence, market prices would undervalue the marginal social benefits of those public goods. In many circumstances, exclusion will not be possible and open-access conditions will prevail.

- Where there is a divergence between private and social benefits, the analysis of multiple-use forestry we have just been through is best viewed as providing information about the socially optimal rotation length.

- In the absence of efficient bargaining, to achieve such outcomes would involve **public intervention**. This might consist of public ownership and management, regulation of private behaviour, or the use of fiscal incentives to bring social and private objectives into line.

Sources of Inefficiency

Perverse Incentives for the Landowner

- Perverse incentives create inefficient and unsustainable outcomes especially with respect to privately owned forests.

- The value of a standing forest as wildlife habitat or ecosystem function is an **external cost**. Failure to recognize social values will result in inefficiencies.

- External costs of timber harvesting may not be adequately considered by the private landowner.

- Government policies can also create perverse incentives

Sources of Inefficiency

- Government resettlement programs have also encouraged deforestation by facilitating the movement of migrants into agriculture.

- Concession agreements are another source of inefficiency. Concession agreements define the terms under which public forests can be harvested.

Sources of Inefficiency

Perverse Incentives for Nations

- Deforestation involves transboundary or global externalities.
-
  - Biodiversity: Deforestation is a major source of species loss. Many benefits of species preservation are external to the country with the forest.
  - Climate change: Deforestation contributes to climate change, but the benefits of leaving the trees standing are largely external. The costs, however, are largely internal.

Integrating non-timber values

- Let non-timber benefits, such as recreation, biodiversity, landscape beauty, or carbon storage, generate a flow of value over time.
- The present value of those benefits during one rotation is:

$$N(T) = \int_0^T n(T)\ e^{-iT} dt$$

- So the total present value from forestry plus non-timber benefits becomes:

$$PV(NB)^* = \frac{pV(T)e^{-iT} - k + N(T)}{1 - e^{-iT}}$$

- If non-timber benefits are fully internalized, the first-order-condition for the optimal rotation period is changed to:

No Questions on calculations but you should be able to interpret the formulas

$$pV'(T) + n(T) = ipV(T) + i\ PV(NB)^*$$

Integrating non-timber values

- **Intuition**
- The optimal harvest age changes because waiting one more year now gives an extra non-timber benefit, $\eta(T)$, in addition to extra timber growth, $pV'(T)$.
- So the landowner compares:

  Benefit of waiting: $PV'(T)+n(T)$

  (extra timber growth plus extra non-timber value)

  Cost of waiting: $ipV(T) + i\,PV(NB)^*$

  (the interest cost of delaying timber revenue and delaying the whole land value cycle)

- **Main takeaway**
- Non-timber benefits affect the rotation age depending on how they change with forest age.
- If non-timber benefits are roughly constant over time, the optimal rotation may not change much.
- If non-timber benefits rise with forest age, for example old-growth habitat, recreation, or landscape value, the optimal rotation becomes longer.
- If non-timber benefits are higher in younger forests, for example some carbon-sequestration cases, the optimal rotation becomes shorter.

Integrating non-timber values

- Non-timber benefits affect harvest timing in two opposite ways.

  1. **They make waiting more attractive**

     If an older forest provides more non-timber value, then delaying harvest gives an extra benefit.
     Examples: recreation, habitat, biodiversity, scenic beauty, old-growth value.
     This tends to lengthen the rotation.

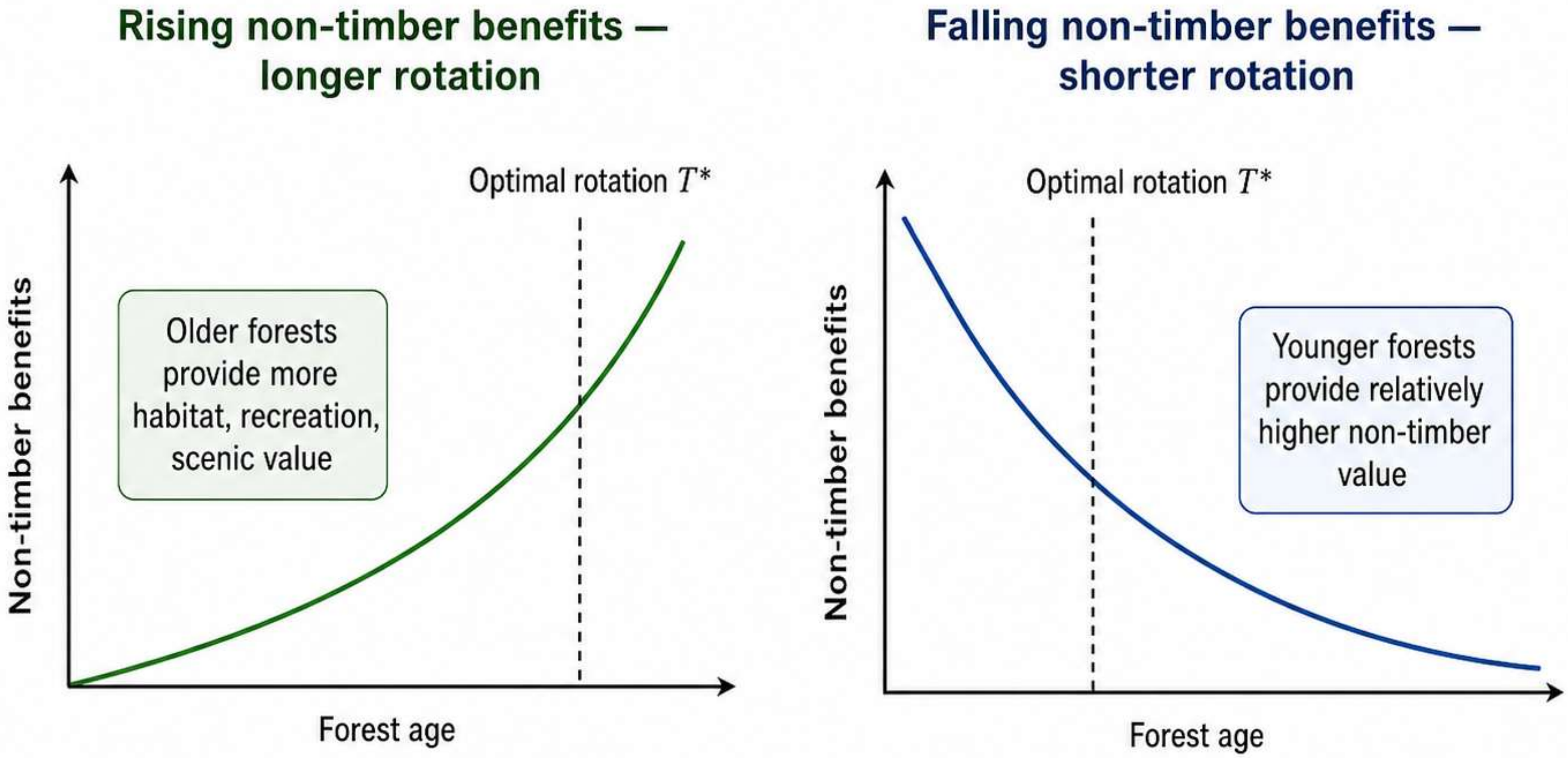
  2. **They raise the opportunity cost of land**

     Non-timber benefits also increase total land value.
     A higher land value means there is a larger cost to keeping land tied up in the current rotation instead of starting the next one.
     This tends to shorten the rotation.

- **Main intuition**
- The final effect depends on which force is stronger: extra benefit from waiting vs. higher opportunity cost of land.
  So non-timber values do not automatically lengthen rotations.
- **Key takeaway**
  If non-timber values rise strongly with forest age, the optimal rotation is usually longer. If non-timber values are constant or fall with forest age, the optimal rotation may stay the same or become shorter.

Integrating non-timber values

How non-timber benefits affect optimal rotation



Rising non-timber benefits — longer rotation

Older forests provide more habitat, recreation, scenic value

When non-timber value rises with age, waiting becomes more attractive.

Falling non-timber benefits — shorter rotation

Younger forests provide relatively higher non-timber value

When non-timber value falls with age, earlier harvest becomes more attractive.

Key idea: the shape of non-timber benefits over forest age determines whether rotation lengthens or shortens.

Integrating non-timber values

- As the PV of the flows of non-timber benefits over any one rotation ($N(T^*)$) enters the last equation in the previous slide directly, then other things being equal, a positive value for $N(T^*)$ implies a reduced value of $\mathrm{d}V/\mathrm{d}T$, which means that the rotation interval is lengthened.

- As positive non-timber benefits increase the value of land (from *PV(NB)* to *PV(NB)**) and so increase the opportunity cost of maintaining timber on the land, this will tend to reduce the rotation interval.

- Which of these two opposing effects dominates depends on the nature of the functions $V(\mathrm{T})$ and $N(\mathrm{T})$. Therefore, for infinite-rotation forests it is not possible to say *a priori* whether the inclusion of non-timber benefits shortens or lengthens rotations.

- If non-timber values are greater in old than in young forests (are rising with stand age) then non-timber values have a positive annual increment, generating a longer optimal rotation. An equivalent, but opposite, argument shows that falling non-timber benefits will shorten the optimal rotation.

Integrating non-timber values

- Only if the flow of non-timber benefits is constant over the forest cycle will the optimal rotation interval be unaffected. Hence it is variation over the cycle in non-timber benefits, rather than their existence as such, that causes the rotation age to change.

- It is often assumed that N(T) (the annual magnitude of undiscounted non-timber benefits) increases with the age of the forest.

- While this may happen, it need not always be the case. Studies by Calish *et al*. (1978) and Bowes and Krutilla (1989) suggest that some kinds of non-timber values rise strongly with forest age (for example, the aesthetic benefits of forests), others decline (including water values) and yet others have no simple relationship with forest age.

- All that can be said in general is that it is most unlikely that total non-timber benefits will be independent of the age of forests, and so the inclusion of these benefits into rotation calculations will make some difference.

Integrating non-timber values

- In extreme cases the magnitude and timing of non-timber benefits may be so significant as to result in no felling being justified.
- Where this occurs, we have an example of what is called ‘dominant-use’ forestry.
- It suggests that the woodland in question should be put aside from any further commercial forest use, perhaps being maintained as a national park or the like.

- As a matter of interest at a time when reducing the growth of carbon dioxide atmospheric concentration is so central to international environmental policy, we note that CO_2 sequestration varies with the growth rate and so favours shorter rotations, given that growth slows right down with old age.
- This is not good news for mature natural forests; if CO_2 sequestration were our sole concern, then the best thing would be to chop down mature forests and plant new ones.
- There are some qualifications to this kind of reasoning; for example, we might need to ensure that the felled mature timber would be locked up in new built houses or furniture.
- But this is suggestive of a case where there could be a trade-off between climate change mitigation and biodiversity conservation.

Poverty and Debt

- Un-owned or publically owned forests are sometimes seen as a means of providing land to peasants.

- Poverty and deforestation can reinforce each other through positive feedback loops.

- At the national level, large debts in many developing countries encourage the overexploitation of resources in order to raise foreign exchange to finance the debt.

Sustainable Forestry

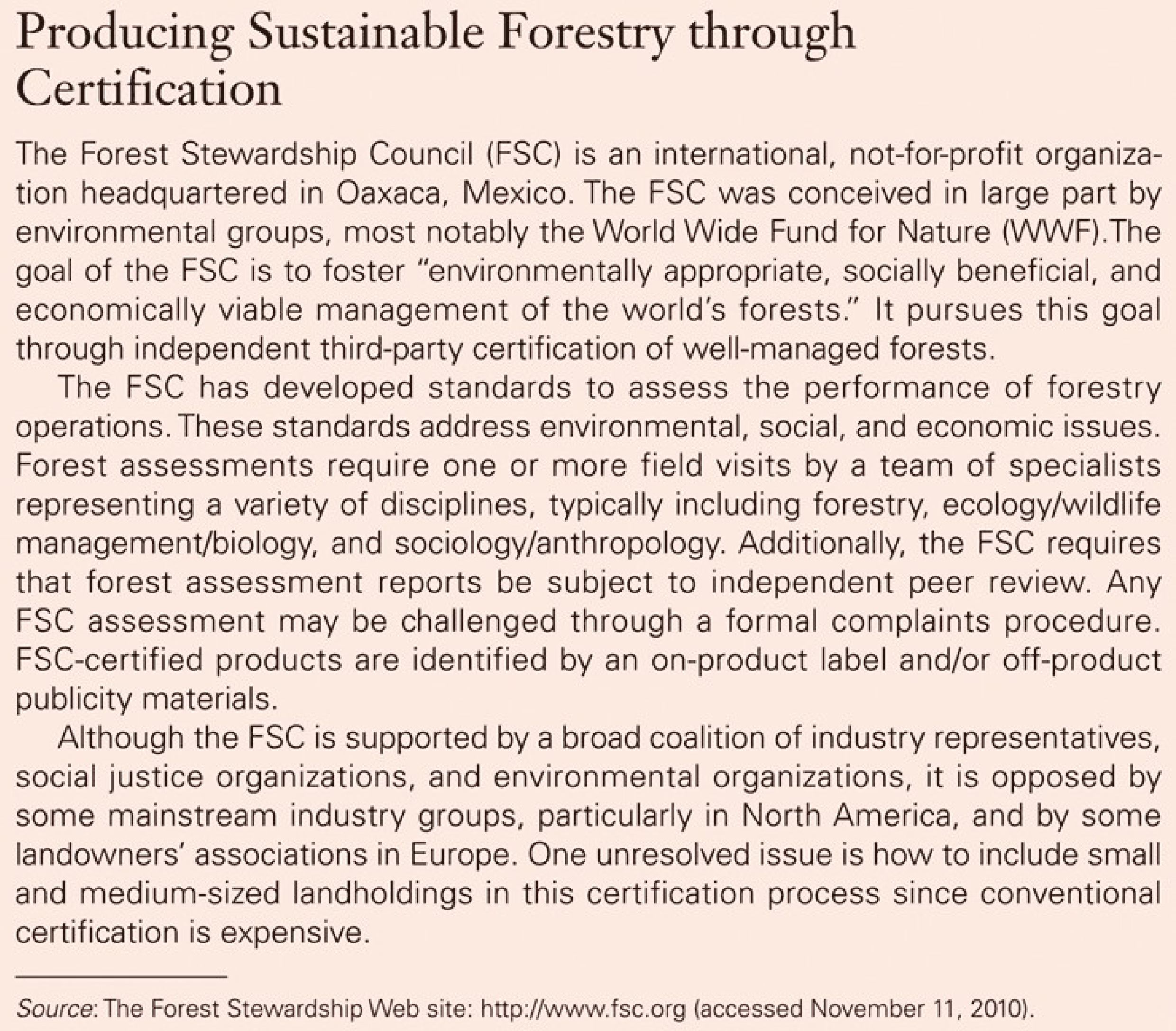
- Profit-maximizing decisions may not be efficient due to externalities.

- Efficiency and sustainable forestry are not necessarily compatible.

- Practices aimed at sustainable forestry that is also economically sustainable had led to a focus on rapidly growing trees and plantation forestry.

- Plantation forestry is controversial.

EXAMPLE



Producing Sustainable Forestry through Certification

The Forest Stewardship Council (FSC) is an international, not-for-profit organization headquartered in Oaxaca, Mexico. The FSC was conceived in large part by environmental groups, most notably the World Wide Fund for Nature (WWF). The goal of the FSC is to foster "environmentally appropriate, socially beneficial, and economically viable management of the world's forests." It pursues this goal through independent third-party certification of well-managed forests.

The FSC has developed standards to assess the performance of forestry operations. These standards address environmental, social, and economic issues. Forest assessments require one or more field visits by a team of specialists representing a variety of disciplines, typically including forestry, ecology/wildlife management/biology, and sociology/anthropology. Additionally, the FSC requires that forest assessment reports be subject to independent peer review. Any FSC assessment may be challenged through a formal complaints procedure. FSC-certified products are identified by an on-product label and/or off-product publicity materials.

Although the FSC is supported by a broad coalition of industry representatives, social justice organizations, and environmental organizations, it is opposed by some mainstream industry groups, particularly in North America, and by some landowners' associations in Europe. One unresolved issue is how to include small and medium-sized landholdings in this certification process since conventional certification is expensive.

Source: The Forest Stewardship Web site: http://www.fsc.org (accessed November 11, 2010).

Public Policy

- Debt-for-nature swaps
  - An agency, usually a non-governmental organization, purchases developing country debt, typically at a discount if repayment by the developing country is unlikely.
  - The non-governmental organization then “trades” (cancels) the debt back to the developing country in exchange for an environmental action such as the protection of a tropical forest.

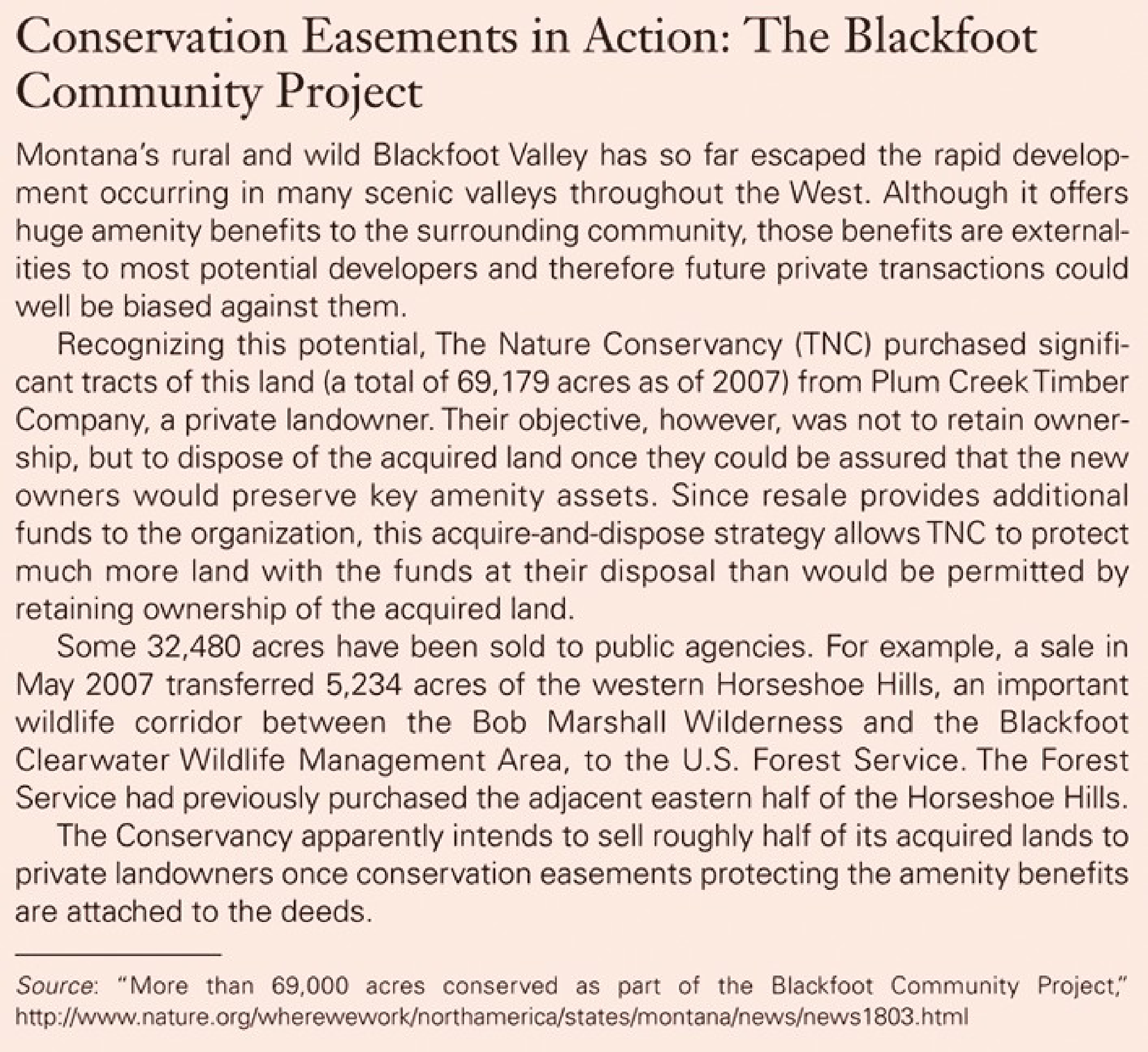
- Extractive reserves
  - Areas reserved for indigenous peoples to engage in traditional hunting and gathering activities

- Conservation easements and land trusts.
  - A conservation easement is a legal agreement between a land owner and a land trust or a government agency. Conservation easements can be sold or donated.

Public Policy

- The **World Heritage Convention** requires 1% of contributions to UNESCO to be put into a World Heritage Fund. The fund is used to protect cultural and natural environments of "outstanding universal value."
  - Ratifying countries can have their natural properties of outstanding value added to the **World Heritage List** and apply for funds to help protect these sites.

EXAMPLE



Conservation Easements in Action: The Blackfoot Community Project

Montana's rural and wild Blackfoot Valley has so far escaped the rapid development occurring in many scenic valleys throughout the West. Although it offers huge amenity benefits to the surrounding community, those benefits are externalities to most potential developers and therefore future private transactions could well be biased against them.

Recognizing this potential, The Nature Conservancy (TNC) purchased significant tracts of this land (a total of 69,179 acres as of 2007) from Plum Creek Timber Company, a private landowner. Their objective, however, was not to retain ownership, but to dispose of the acquired land once they could be assured that the new owners would preserve key amenity assets. Since resale provides additional funds to the organization, this acquire-and-dispose strategy allows TNC to protect much more land with the funds at their disposal than would be permitted by retaining ownership of the acquired land.

Some 32,480 acres have been sold to public agencies. For example, a sale in May 2007 transferred 5,234 acres of the western Horseshoe Hills, an important wildlife corridor between the Bob Marshall Wilderness and the Blackfoot Clearwater Wildlife Management Area, to the U.S. Forest Service. The Forest Service had previously purchased the adjacent eastern half of the Horseshoe Hills.

The Conservancy apparently intends to sell roughly half of its acquired lands to private landowners once conservation easements protecting the amenity benefits are attached to the deeds.

Source: "More than 69,000 acres conserved as part of the Blackfoot Community Project," http://www.nature.org/wherewework/northamerica/states/montana/news/news1803.html

Public Policy

- **Royalty payments** grant payments to biologically rich countries for all products developed from species in those countries.
  - These royalties are incentives for countries to preserve their biological diversity. Pharmaceutical companies have been making payments based on shared profits.

- Carbon sequestration credits
  - This approach attempts to internalize the carbon-absorption benefit externality by giving forest owners credit for the additional carbon they remove from the atmosphere. This credit is tradable.