# Environment economics and policies

EC 506

# Chapter 4: Managing Natural Resources

# Economic scarcity

- ❑ *Are we running out of nonrenewable resources?*
- ❑ *How do prices for metals, minerals, and other nonrenewable resources change over time?*
- ❑ *What are the environmental costs of mining for mineral resources?*
- ❑ *How do economic incentives affect recycling of nonrenewable resources?*

# Economic scarcity

- *How their resource is used in daily life.*
- *What would happen if this resource became scarce.*
- *Ways to conserve or sustainably use this resource.*
- *If we only had one of these resources, which would be the most essential?*

# Economic scarcity

Nonrenewable resources do not regenerate through ecological processes, at least not on a human time scale, such as oil, coal, and mineral ores.

*Oil comes as a determining factor in production, transportation and consumption good. In 2007-2009, the most traded commodity was oil in world exports averaging about 1.8 trillion US dollars, which amounted to around 10 percent of world exports.*

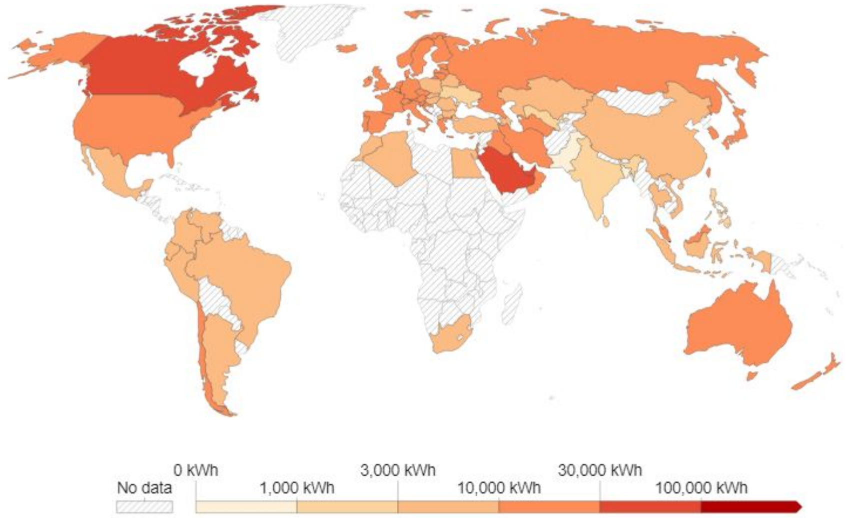
*The price of fuel in the Philippines goes up year after year. The most recent price of crude oil went above US$80 a barrel.*

*The key factor that leads to the rise in global oil prices is the rapid rise of demand compared to the supply which is more gradual, and this is due to the fact that the old oil fields on which the world relies for most of its oil have run out of oil and no new fields have been discovered that can match the amount of oil as compared to the older oilfields.*

# Economic scarcity

## Per capita oil consumption, 2023

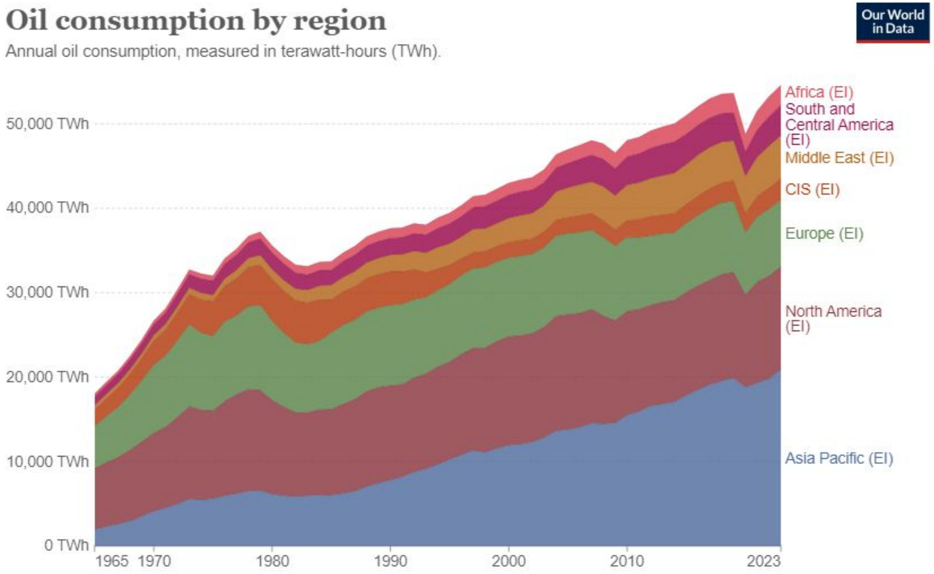
Average oil consumption per capita, measured in kilowatt-hours per person.




**Data source:** Energy Institute - Statistical Review of World Energy (2024); Population based on various sources (2023)


## Oil consumption by region

Annual oil consumption, measured in terawatt-hours (TWh).




**Data source:** Energy Institute - Statistical Review of World Energy (2024)


**Note:** CIS (Commonwealth of Independent States) is an organization of ten post-Soviet republics in Eurasia following break-up of the Soviet Union.

# Economic scarcity: physical supply and economic supply

Scarcity as an economic concept, which incorporates more than simply the limited availability of physical resource stocks.

Natural resource scarcity has economic and geologic dimensions.

The critical point in the economic analysis of resource management is this: the “stock” of a natural resource, like oil, depends not only on the physical availability of that resource within the earth’s crust, but also on its marginal extraction cost and the prices people are willing to pay to purchase it.

We differentiate between the **economic reserves** of a nonrenewable resource and its **physical reserves**.

# Economic scarcity: physical supply and economic supply

**The physical supply** (in the earth's crust) is the total amount available, which is finite but generally not precisely known.

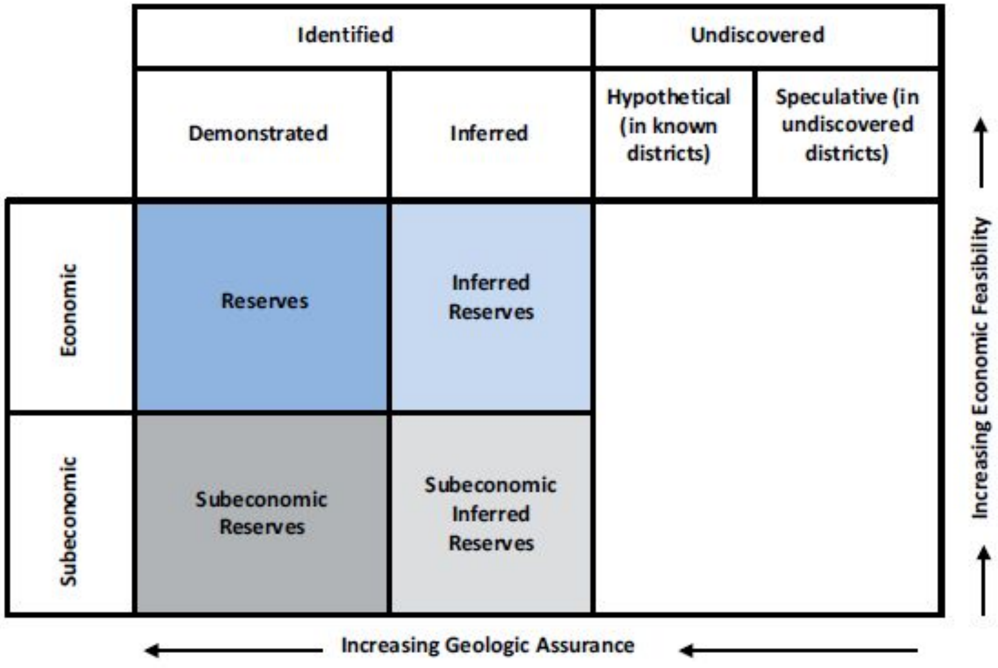
**The economic reserves** represent those known reserves that can be extracted profitably based on current prices and technology.

Economic reserves provide the measure most commonly used in, for example, calculations of how long a nonrenewable resource might last under assumptions about prices, technology, and depletion rates, referred to as the **resource lifetime**.

Economic reserves change over time for three main reasons:

- The resource is extracted and used over time, diminishing reserves.
- New resource deposits are discovered over time, increasing reserves.
- Changing price and technological conditions can make more (or less) of the known reserves economically viable. These factors make predictions of resource lifetimes an inexact science.

# Classification of non-renewable resources

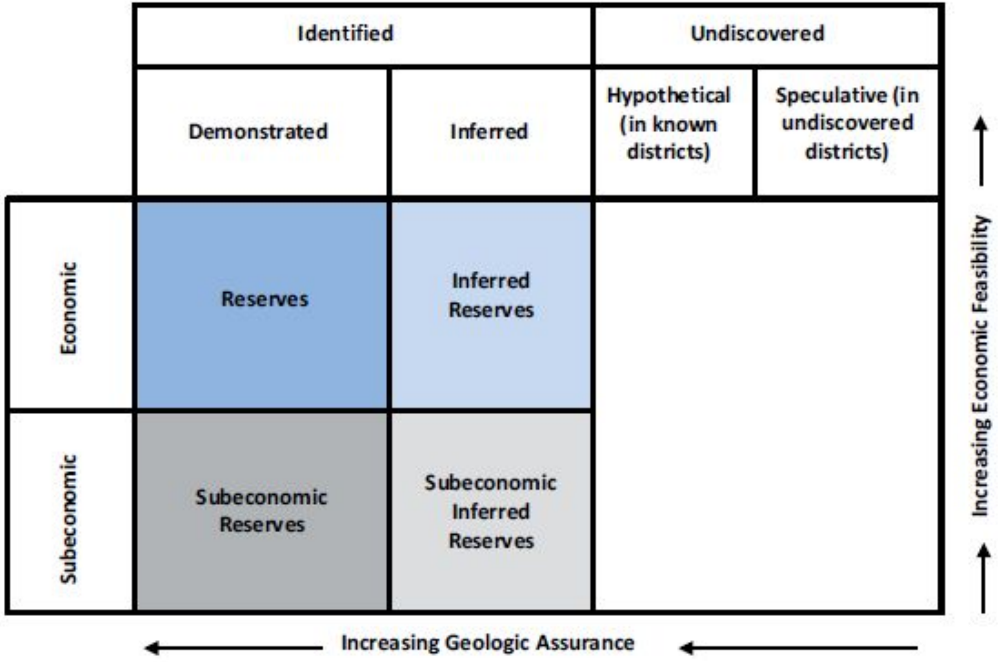



A mineral resource such as copper is classified through a combination of **geologic and economic measures**.

In geological terms, resources are classified in terms of **the degree of certainty about the availability of the resource**, shown as the horizontal dimension

Economic factors create another dimension to resource classification, shown vertically, with **the most economically profitable resources at the top**.

# Classification of non-renewable resources



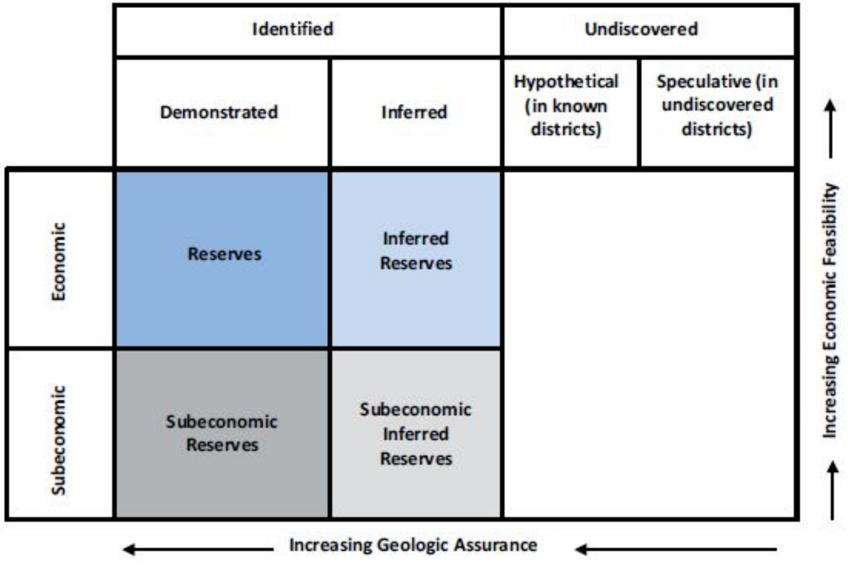

**Identified reserves** are those whose quantity and quality are already known, but with varying degrees of confidence.

Those identified with the highest degree of confidence are **demonstrated reserves**, meaning the quantity is generally known with a high degree of certainty.

A lower degree of confidence is assigned to **inferred reserves**, which are estimated based on geological principles but not accurately measured.

**Hypothetical and speculative reserves** are yet undiscovered, but are likely to exist in different geological regions.

# Classification of non-renewable resources




Resources of high-enough quality to be profitably extracted with current prices and technology are identified as **economic reserves**.

**Subeconomic resources** are those whose costs of extraction are too high to make production worthwhile with current prices and technology. However, if prices rise or extraction technologies improve, it may become profitable to exploit these deposits.

**Undiscovered reserves** are not counted toward economic reserves, as their existence is uncertain. Data on reserves normally reflect only the quantities that are demonstrated and economic.

# Measurement of non-renewable resources

One measure of the supply of nonrenewable resources is a **static reserve index**.

A static reserve index simply divides reserves (demonstrated and economic) by the current annual rate of use to get an estimate of resource lifetime:

$$\text{Expected Resource Lifetime} = \frac{\text{Economic Reserves}}{\text{Annual Consumption}}$$

The fact that resource reserves can be expanded in both geological and economic dimensions renders projections using a static reserve index unreliable. Also, current consumption is not necessarily a good indication of future use. Because of growing population and economic output, we can usually expect nonrenewable resource demand to grow—although substitution, changing consumption patterns, and recycling will affect rates of growth.

**An exponential reserve** index assumes that consumption will grow exponentially over time, leading to more rapid resource exhaustion.

# Measurement of non-renewable resources

The relevant question is how resource consumption, new technology, and discovery will interact to affect prices, which in turn will affect future patterns of resource demand and supply.

To gain a better understanding of these factors, we need a more sophisticated economic theory of nonrenewable resource use.

# Efficient extraction in two periods: static

Suppose we own an oil well, and we plan to pump oil from the well in two time periods—**“today” and “tomorrow.”, the goal of the model is to explore the balance between current and future use of a scarce resource.**

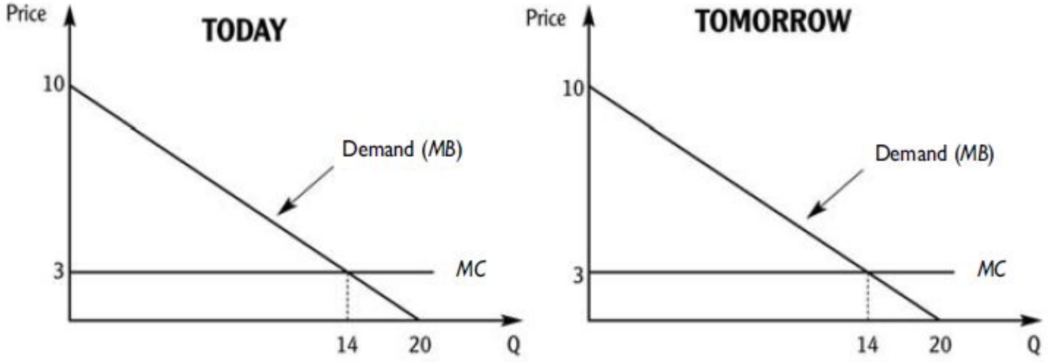
The demand for oil in each period is MB = 10 – .5q, where q is the quantity extracted; the marginal cost of extracting a barrel of oil (which might include labor and electricity, for example) is constant at MC = $3.

**let us assume that our oil supply is not limited, but infinite. What would be the efficient quantity of oil to extract today?**

We would set the marginal benefits of extracting oil today equal to the marginal costs.

**MB = MC**
**10–0.5q = $3**
**q*= 14 barrels**
**We would extract fourteen barrels of oil today.**

# Efficient extraction in two periods: static




*The problem we have just solved twice sequentially is* ***myopic****.We have intentionally ignored the limited oil supply (20 barrels) and acted as though extraction of oil today is independent of the quantity.* ***So, static efficiency rule failed us.***

Let’s introduce a limited stock—only twenty barrels are available. If we extract fourteen barrels today, as we would like to, what would that leave for tomorrow? We would be left with only six barrels of oil in the ground.

Given no change in demand and marginal cost between today and tomorrow, if we apply **the static efficiency rule** again tomorrow, we will want to pump another fourteen barrels. But our remaining six barrels will fall well short of this goal.

# Efficient extraction in two periods: static

***Does static efficiency rule explain/consider resource scarcity?***

We must consider-

- Marginal cost of extracting a barrel of oil: one cost of extracting a unit of that resource is the lost opportunity to extract that unit in the future.
- Marginal user cost or scarcity rent: the marginal cost of using up a barrel of oil, leaves one fewer to use in the future (when resources are scarce, greater current use diminishes future opportunities).
- Accounting for the marginal user cost associated with oil extraction, will reduce the amount of oil that we can efficiently extract today, leaving more in the ground for tomorrow
- Thus, the MARGINAL USER COST = Present Value of forgone opportunities at the margin

*Extraction of scarce resources, like oil in a finite well, imposes a cost above and beyond the marginal cost of extraction—a marginal user cost.*

# Efficient extraction in two periods: dynamic

The dynamic two-period problem we now solve differs from the static efficiency problem in three important respects.

First:

Because we are interested, today, in the value of extracting oil both today and tomorrow,we will need to **discount the returns to oil extraction tomorrow to reflect the time value of money**.

This will help us to account for the fact that **any oil left in the ground until tomorrow cannot be sold on the market today, and the proceeds from its sale cannot be invested to increase in value between the two periods.**

Thus **the marginal benefits and marginal costs of oil extraction will be expressed in terms of present value**—their value in today's dollars.

# Efficient extraction in two periods: dynamic

Second:

We will introduce the stock constraint directly into our efficiency problem.To do this, we will define **the quantity of oil available to extract tomorrow, q2, as the difference between the total stock (twenty barrels) and the amount extracted today, q1.**

Third,

Rather than setting the marginal benefits and marginal costs of extraction in a single period equal to each other, we will **equate the net marginal benefits (benefits, less costs) of oil extraction in each period**.That is, we will start from the presumption that, in order to maximize the net benefits of this oil well, we must **ensure that the net benefit of the last barrel pumped today is equal to the net benefit of the last barrel pumped tomorrow.**

# Efficient extraction in two periods: dynamic

Now, we solve for the efficient quantities of oil to extract today and tomorrow, assuming a discount rate of 10 percent. We have incorporated the limited stock into our problem,

***The rule of efficiency tell us to extract just over ten barrels of oil today, leaving the rest in the ground for tomorrow.***

Why is the specific extraction path we arrived at—10.19 today and 9.81 tomorrow—the efficient one? Why not split the well's contents exactly in half, extracting ten barrels today and ten tomorrow?

$$PV(MB_1 - MC_1) = PV(MB_2 - MC_2)$$

$$10 - 0.5q_1 - 3 = \frac{10 - 0.5q_2 - 3}{1 + .10}$$

$$7 - 0.5q_1 = \frac{7 - 0.5(20 - q_1)}{1.10}$$

$$7 - 0.5q_1 = \frac{0.5q_1 - 3}{1.10}$$

$$q_1^\star = 10.19 \ barrels$$

$$q_2^\star = 20 - q_1^\star = 9.81 \ barrels$$

# Efficient extraction in two periods: dynamic

This figure helps illustrate the intuition behind these numbers.

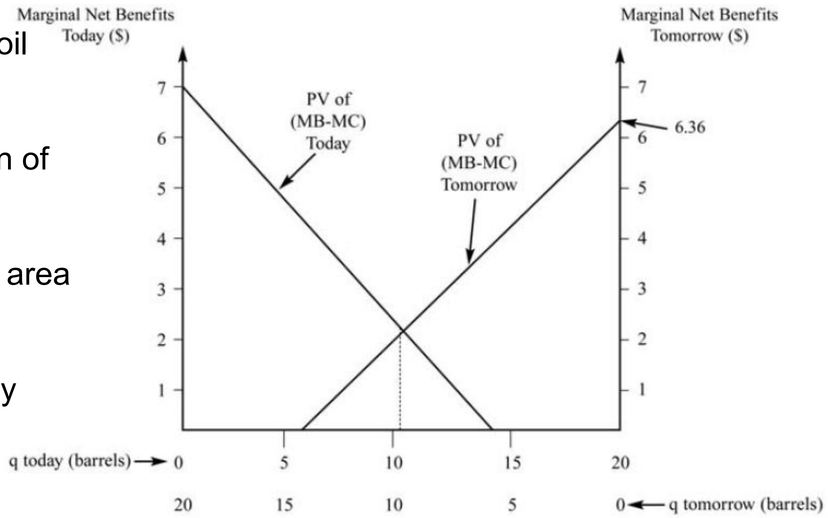
This figure plots the marginal net benefits, in present value terms, of oil extraction in each period.

The two marginal net benefit curves intersect at the efficient allocation of extraction over time.

The total net benefits of this resource to society are measured by the area under these curve.

If we move to the right of the efficient allocation, extracting more today and leaving less for tomorrow, the value of net benefits lost tomorrow would exceed today's gains.

If we move to the left of the efficient allocation, extracting less today and leaving more for tomorrow, the value of net benefits lost today would exceed those gained tomorrow.

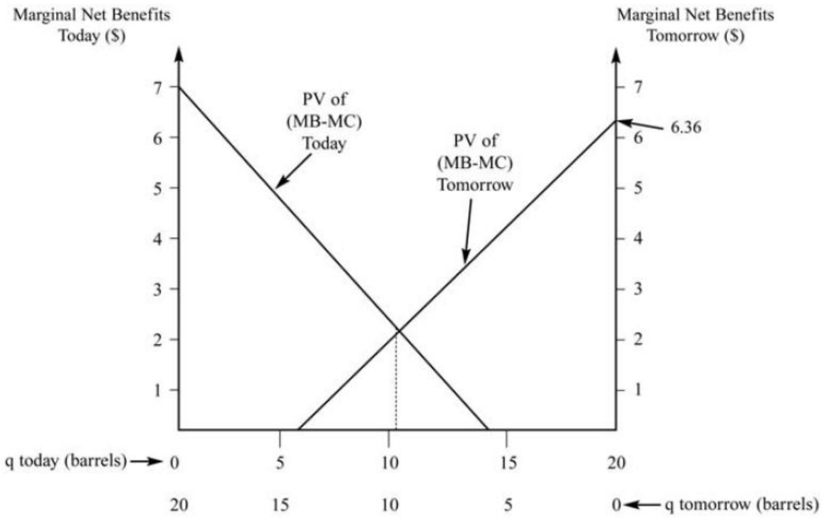



*Efficient Extraction Path*

# Efficient extraction in two periods: dynamic

The time value of money is the reason we extract just over half today and just under half tomorrow.

The value of the oil we extract today can earn interest in an alternative investment between today and tomorrow, it is efficient to extract a bit extra today.




*Efficient Extraction Path*

# Efficient extraction in two periods: special externality

Extraction of scarce resources, like oil in a finite well, imposes a cost above and beyond the marginal cost of extraction—a marginal user cost. **Is it possible to identify this extra cost, either in our algebra problem or in the diagram?**

We solve for the prices that we can expect to collect for a barrel of oil in each period, today and tomorrow:

$$p_1^{\star} = 10-0.5(q_1^{\star}) \approx \$4.905$$
$$p_2^{\star} = 10-0.5(q_2^{\star}) \approx \$5.095$$

P1 is the market price of a barrel … a barrel of oil tomorrow. Marginal extraction cost is $3 (it seems we violated profit maximizing condition, price=MC).

However, this difference between price and marginal cost in the case of scarce resources like oil is the marginal user cost (extra cost).

# Efficient extraction in two periods: special externality

Marginal user cost as a negative externality to current oil consumption. Extracting today, we impose an extra cost on tomorrow— diminished supplies.

if we own the oil well, by extracting oil, we impose a marginal user cost on ourselves, diminishing our own future supplies.Thus we have a strong incentive to account for that cost as we decide how much oil to extract! If we do not,we will not maximize the profits from our oil resource over time, and in a competitive market we will soon be out of business.

So when nonrenewable resources are privately owned and extracted in a competitive market, resource owners will account for scarcity in determining the optimal timing and quantity of extraction (the extraction “path”).They will treat oil resources, and other nonrenewable resources, like any other capital asset in their portfolio—as stocks that generate returns by the very nature of their scarcity.

A real-life example of oil extraction in a competitive market is the **U.S. shale oil industry**.

# Examples of competitive non-renewable resource markets

Coal Mining in Australia

Sand Mining in India

Copper Mining in Chile

# Renewable resource management: Forestry

In economic terms, standing trees are capital assets that increase in value as they increase in volume over time. But, allowing the trees to stand is also costly—we must consider the opportunity cost of alternative investments.

We seek to identify the length of time to wait between timber harvests that maximizes the difference between total benefits and total costs (in present value).

The economic analysis of forest management raises two issues:

***First****, oil and coal have value primarily as inputs to the production and consumption of other goods, like energy. In contrast, the value of a forest is more complex. In addition to their value as timber for potential harvest, standing trees offer other benefits, providing species habitat and carbon sink.*

***Second,*** *forested lands exhibit a wide variety of property rights regimes, ranging from private ownership to open access.*

# Renewable resource management: Forestry

- *We will start with the problem of commercial timber extraction, and*

- *We will consider a private landowner who makes rent-maximizing decisions about harvesting their trees.*

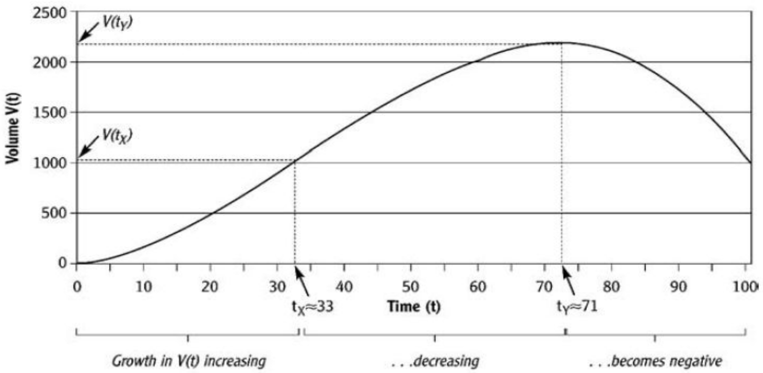
# Forest growth and biological rotation

Simple model of forest growth. We can model the volume of timber in a stand of homogeneous trees as a function of time. So, the volume function is-

$$V(t)=10t+t^2-0.01t^3$$

At first, the rate of growth is very fast. Over time the trees continue to grow, but the rate of growth begins to decline (in our model, after about thirty-three years).

At some point, depending on the species, climate, and a variety of other factors, the trees stop growing and begin to decay, resulting in declining volume (in our model, after about seventy-one years).



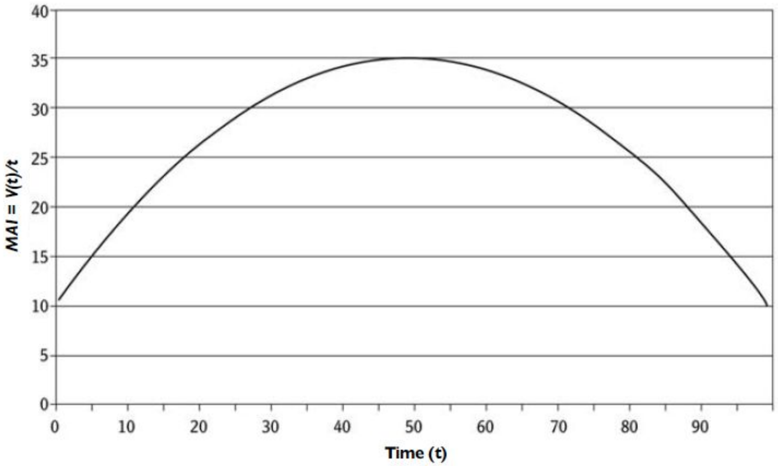

Timber volume in a forest as a function of time.

# Forest growth and biological rotation

The best interval at which to cut and replant these trees is the age that maximizes the mean annual increment (MAI),

The average volume of the stand, V (t)/t. If we divide volume by time, we obtain the MAI curve, which reaches its maximum after fifty years of stand growth.

This decision criterion makes some intuitive sense, because no other rotation yields a greater average volume of wood. For this reason, **the maximum MAI is often called the biological rotation.**




Mean annual increment ($V(t)/t$) in a forest, as a function of time.

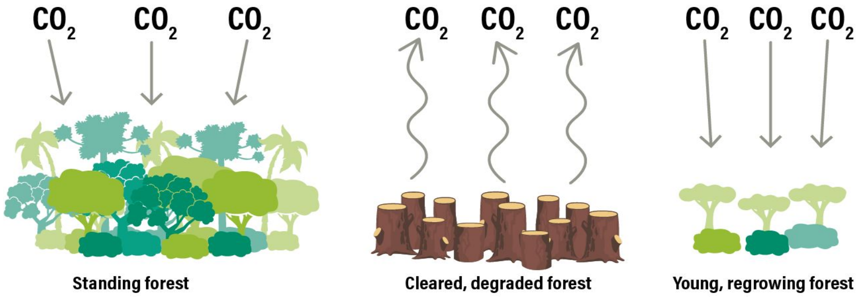
# Forest growth and biological rotation

If we were to cut the trees after forty years, instead of fifty, we would obtain fewer board feet of timber, but we would obtain the smaller cut ten years sooner.

***What is the economic consideration?***

***What is efficient rotation?***

***What is the optimal aging problem?***



# Optimal aging problem: The Wicksell Rotation

*“How long should I age a stand of hardwoods?”*

**Single rotation problem/optimal aging problem**- if we are interested in the returns to harvesting this stand of trees once, with no concern for what will happen to this currently forested land after we extract our timber.

The single rotation problem in forestry is a decision-making issue focused on determining the optimal time to harvest a single forest stand or tree plantation to maximize its economic value. This approach assumes a one-time harvest with no intention of replanting or managing the land for future rotations.

Think of the situation a private landowner would face each year. They would compare **the net returns to cutting their trees this year** to **the net returns to waiting for one more year**. As long as the net returns to cutting now were less than the net returns to waiting, they would prefer to keep her assets in standing trees.

**The net benefit-maximizing year** in which to cut the trees would occur just as **the net returns to waiting equaled the net returns to cutting.**

# Optimal aging problem: The Wicksell Rotation

We can represent this point in a simple equality, in which **the net returns to cutting now are on the left-hand side, and the net returns to waiting (in present value) are on the right**:

$$(p-c)\,V(T_0) = \frac{(p-c)\,V(T_1)}{(1+r)}$$

*where:*

$p$ = timber price
$c$ = unit harvesting cost
$V(T_0)$ = stand volume this year
$V(T_1)$ = stand volume next year
$r$ = discount rate

It is efficient to harvest the stand when the rate of growth in timber volume, the rate of return to our capital asset (standing trees), is equal to the interest rate. This is called **the Wicksell Rule, applied to any optimal aging problem.**

$$r = \frac{V(T_1)-V(T_0)}{V(T_0)}, \text{ or } r = \frac{\Delta V}{V(T_0)}$$

If we harvest the stand before this point, the lost value of the incremental growth we would expect between this year and next would exceed the value of the incremental gains we would earn by depositing our net harvest proceeds in the bank to earn interest for one year. If we wait to harvest the stand beyond this point, the opposite would be true.

# Optimal aging problem: The Wicksell Rotation

There is an inverse relationship between the Wicksell rotation and the rate of interest.

If the expected returns to alternative investments are very low, the Wicksell rotation is very long; a high interest rate implies a shorter rotation.

$$(p-c)\,V(T_0) = \frac{(p-c)\,V(T_1)}{(1+r)}$$

*where:*

$p$ = timber price
$c$ = unit harvesting cost
$V(T_0)$ = stand volume this year
$V(T_1)$ = stand volume next year
$r$ = discount rate

$$r = \frac{V(T_1)-V(T_0)}{V(T_0)}, \text{ or } r = \frac{\Delta V}{V(T_0)}$$

# Efficient forest management over time: The Faustmann Rotation

***"What is the value of the land on which our trees are growing?"***

A landowner deciding when to harvest a stand of trees is concerned not only with the growth rate in the value of alternative assets—that is, how much she might earn by cashing in her trees once and putting the money in the bank, but also with the value of her property as a whole.

The problem requires an understanding of ongoing returns to forestry on a tract of land over time, and a comparison of these returns to those from other potential land uses.

A variety of choices each year-

- cut timber and replant
- wait one more year, then cut and replant
- cut this year and convert the land to a new use (planting watermelons or building suburban tract housing)
- cut this year and sell the land to a new owner

# Efficient forest management over time: The Faustmann Rotation

***“What is the value of the land on which our trees are growing?”***

To solve the optimal rotation problem, which takes all of these options into account,we introduce the concept of site value.

**Site value**: is the value of a forested piece of land, assuming that the landowner will implement efficient forest rotation in perpetuity; or—if forestry is not the most profitable use of that land at any point in the future—convert the land to its most profitable use.


Site value allows us to **compare the present value of expected future rents (benefits less costs) from forestry to those from other potential land uses, like farming or residential development.**

**Land prices are equal to the present value of expected future rents from land in its most profitable use.**

# Efficient forest management over time: The Faustmann Rotation

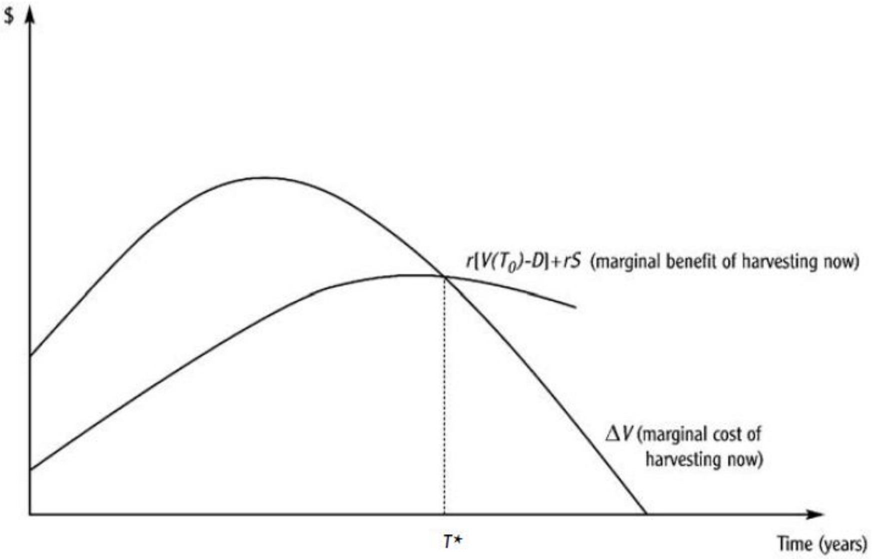
**Landowner will seek to cut timber and replant in the year in which the marginal net benefits of cutting are equal to the marginal net benefits of waiting one more year.**

We can represent this point in a simple equality, in which the net returns to cutting now are on the left-hand side, and the net returns to waiting one more period (in present value) are on the right. Everything is as before, but **we have added two additional terms, site value (S) and the cost of replanting trees after the timber harvest (D), S simply as the sale price of the land.**

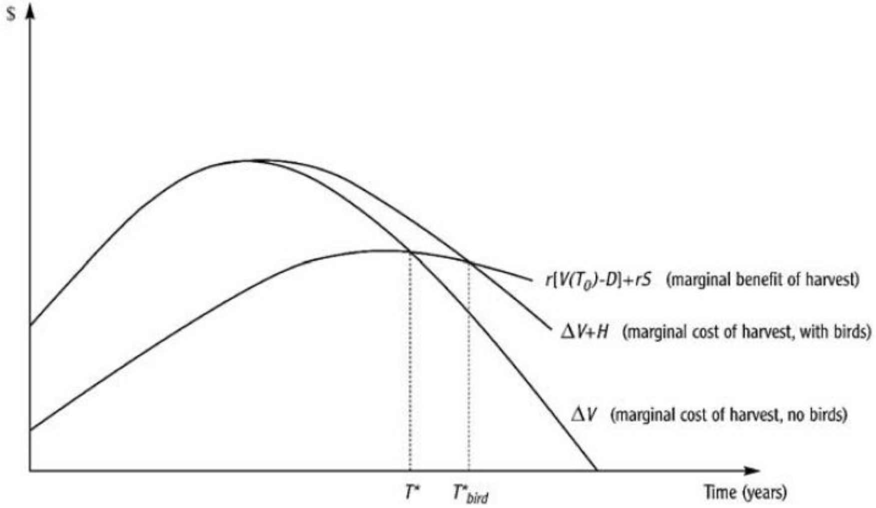
$$(p-c)\,V(T_0)-D+S = \frac{(p-c)[V(T_0)+\Delta V]-D+S}{(1+r)} \qquad r = \frac{\Delta V}{V(T_0)-D+S}$$

**The net returns to cutting in each period include not only the per unit returns from timber less the cost of replanting, but also the amount of money the landowner would make if she sold her land immediately after replanting.** Even if the landowner has no plans to sell this land, S still must be included in each year's potential returns, because it represents **the opportunity cost**, to her, of holding this land in forest, rather than doing something else with it.

# Efficient forest management over time: The Faustmann Rotation




**Efficient (Faustmann) forest rotation.** The efficient rotation length, T*, equates the marginal benefit of harvesting and the marginal cost

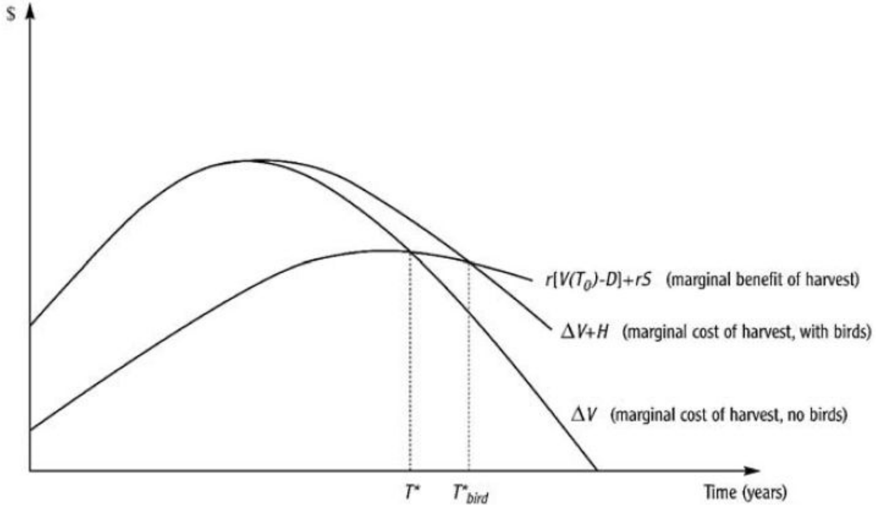



**The effect of non-timber benefits on the Faustmann rotation.** The value of bird habitat provided by old-growth forest represents an additional cost of harvesting timber. As a result, the efficient rotation length increases in this case, from T* to T* bird.

# Efficient forest management over time: The Faustmann Rotation

If the value of woodpecker habitat in old-growth forests is large enough, the social marginal cost of harvest curve may never intersect the curve that describes the marginal benefits of harvest. In other words, the optimal rotation may be infinite, meaning that it would be efficient to never harvest certain stands.

With respect to the value of water, carbon, and other factors, the particular forest should never be harvested.




**The effect of non-timber benefits on the Faustmann rotation.** The value of bird habitat provided by old-growth forest represents an additional cost of harvesting timber. As a result, the efficient rotation length increases in this case, from T* to T* bird.

# Public Goods, Property Rights, and Deforestation

There are two reasons that we cut down forests:

- **Forest resources:** we want the resources that they provide — the wood for fuel, building materials, or paper;
- **Land:** We want to use the land they occupy for something else, such as farmland to grow crops, pasture to raise livestock or land to build roads and cities.

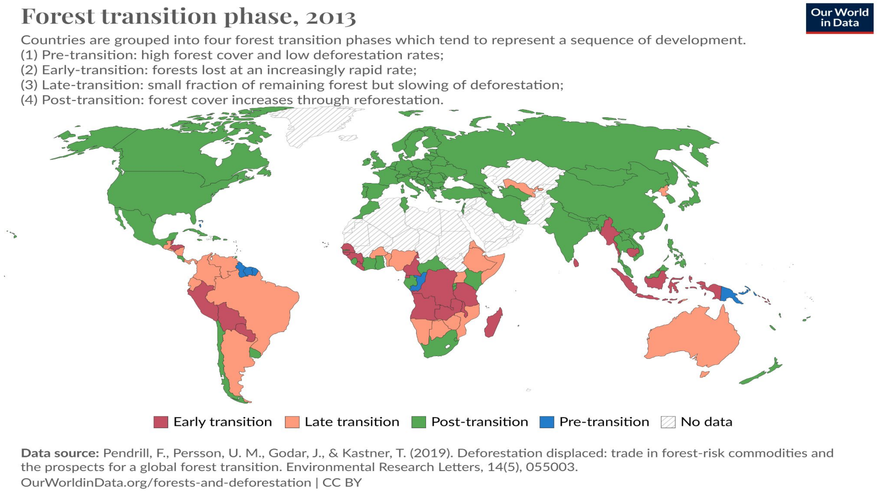
**In developing countries, more than 80 percent of forested lands are publicly owned. In addition, many non timber forest benefits are public goods.**

Private landowners, focused on maximizing their financial returns, are likely to harvest their trees sooner than would be optimal for providing ecosystem services, such as habitat for wildlife, watershed protection, and carbon sequestration. These services benefit society at large but often don't directly increase the landowner's financial gain. As a result, **the rotation period chosen by private landowners tends to be shorter than what would be ideal from an environmental or social perspective.**

# Public Goods, Property Rights, and Deforestation

Property rights and deforestation:

- Studies of the Amazon basin in Brazil have shown that **possession of land title leads to longer rotation periods** and increased efforts at reforestation and conservation by small landholders.
- In developing countries, there is a strong relationship between deforestation rates and factors (like **political instability**) that indicate uncertainty over property rights.
- if landowners are aware of the timing of neighbors' fires (for clearing land for farming), they can take preventative measures. Where such **coordination occurs, title-holders maintain longer rotations** and better conservation and reforestation practices.

# Efficient forest management over time: non-timber products

In the past two decades, a number of countries have begun to fine-tune and well-intentioned forest policies to reflect the socio-economic, ecological and cultural realities of NTFP use, e.g., poverty reduction, biodiversity conservation.

It has been proposed that long-term economic benefits from sustainable NTFP extraction might be significant enough to prevent forests from being put to more destructive land uses such as logging, mining or ranching and help lower rates of tropical deforestation.


*Save resources!*