NONRENEWABLE (DEPLETABLE) RESOURCES

LESSON OBJECTIVES

01

Define and categorize resources

02

Analyze optimal extraction of nonrenewable resources

03

Explain and analyze sources of market failure for nonrenewable resources

QUESTION OF THE DAY

Will we run out of oil?

Independent

Warning: Oil supplies are running out fast

Warning: Oil supplies are running out fast. Catastrophic shortfalls threaten economic recovery, says world's top energy economist. Science Editor ...

Aug 3, 2009

The Week Magazine

Is Saudi Arabia running out of oil?

Diplomatic cables released by Wikileaks suggest that Saudi Arabia, the world's largest crude oil exporter, may have 40 percent less oil than ...

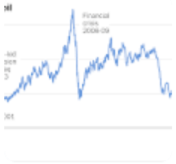
Feb 10, 2011

The New York Times

Too Much Oil: How a Barrel Came to Be Worth Less Than Nothing

The price of the main U.S. oil benchmark fell more than $50 a barrel to end the day about $30 below zero, the first time oil prices have ever turned negative. ... the world is running out of places to put all the oil the industry

1 month ago



01

HOW DO ECONOMISTS CATEGORIZE RESOURCES?

LET'S LOOK AT A COUPLE EXAMPLES…

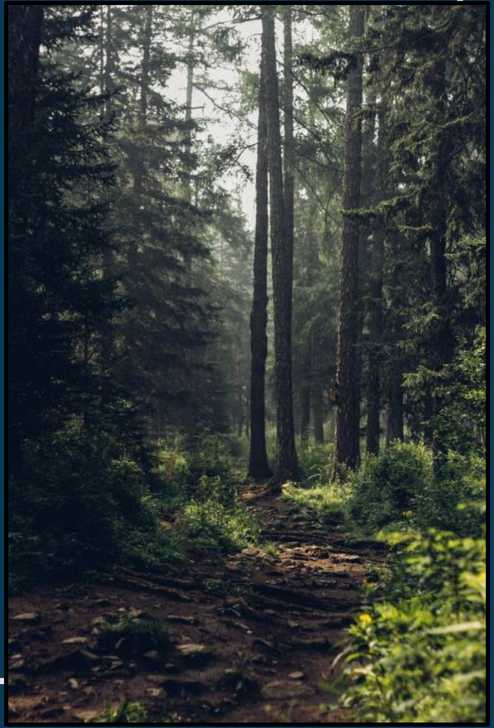
RENEWABLE RESOURCES

Example: Forests

What happens when you cut down part of a forest?
Is it gone forever?

Forests are an example of a *renewable resource*.

Stock replenishes from period to period.



DEPLETABLE RESOURCES

Example: Diamonds

What happens when you mine diamonds?
Will they replenish?

Diamonds are an example of a *depletable/exhaustible resource*.

Stock decreases with use and does not replenish from period to period.

EXPENDABLE RESOURCES

Example: Corn

What happens when you harvest corn?
Will it replenish?
How quickly will it replenish?

Corn is an example of an *Expendable resource*.

- Stock replenishes so quickly consumption in one period has no effect in subsequent periods.

TAXONOMY OF RESOURCES

Examples of natural resources

Availability	Physical properties			
	Biological	Non-energy, Mineral	Energy	Environmental
Expendable	Most agricultural products, e.g., corn, grains	Salt	Solar radiation; Hydropower; Ethanol	Noise pollution; Non-persistent, e.g., air pollution (NO_x, SO_x, particulates), water pollution
Renewable	Forest products; Fish; Livestock; Harvested wild animals; Wood; Whales; Flowers; Insects		Wood for burning; Hydropower; Geothermal	Ground Water; Air; Persistent, e.g., air pollution, water pollution (CO_2, toxics); Animal populations; Forests
Depletable	Endangered species	Most minerals, e.g., gold, iron ore, bauxite, salt; Top soil	Petroleum; Natural gas; Coal; Uranium; Oil shale	Virgin wilderness; Ozone layer; Water in some aquifers

Source: Handbook of Natural Resource and Energy (Kneese and Sweeney, 1993)

NONRENEWABLE RESOURCE

Finite in quantity. Stock decreases with use and does not replenish.

Examples: oil, natural gas, minerals

RENEWABLE RESOURCE

Sufficient rate of generation or regeneration.

Examples: water, living species, forests

ATTENDANCE ACTIVITY

Categorize the following as expendable, depletable, or renewable. Explain why.

1. Rubies
2. Solar energy
3. Honey Bees
4. Cows
5. Soy beans

ATTENDANCE ACTIVITY

Categorize the following as expendable, depletable, or renewable. Explain why.

1. Rubies
   Depletable, if consumed does not replenish
2. Solar energy
   Expendable, consumption doesn’t affect future periods
3. Honey Bees
   Renewable, consumption affects future periods consumption but replenishes
4. Cows
   Renewable, consumption affects future periods consumption but replenishes
5. Soy beans
   Expendable, consumption doesn’t affect future periods

Are exhaustible resources actually exhaustible?

Are inexhaustible resources actually inexhaustible?

IS THIS TAXONOMY APPROPRIATE?

ARE RENEWABLE RESOURCES INEXHAUSTIBLE?

Example: Passenger pigeon

Estimated population of 3-5 billion when Europeans discovered America

Extinct by 1914.

What happened?

Are Nonrenewable Resources Exhausted?

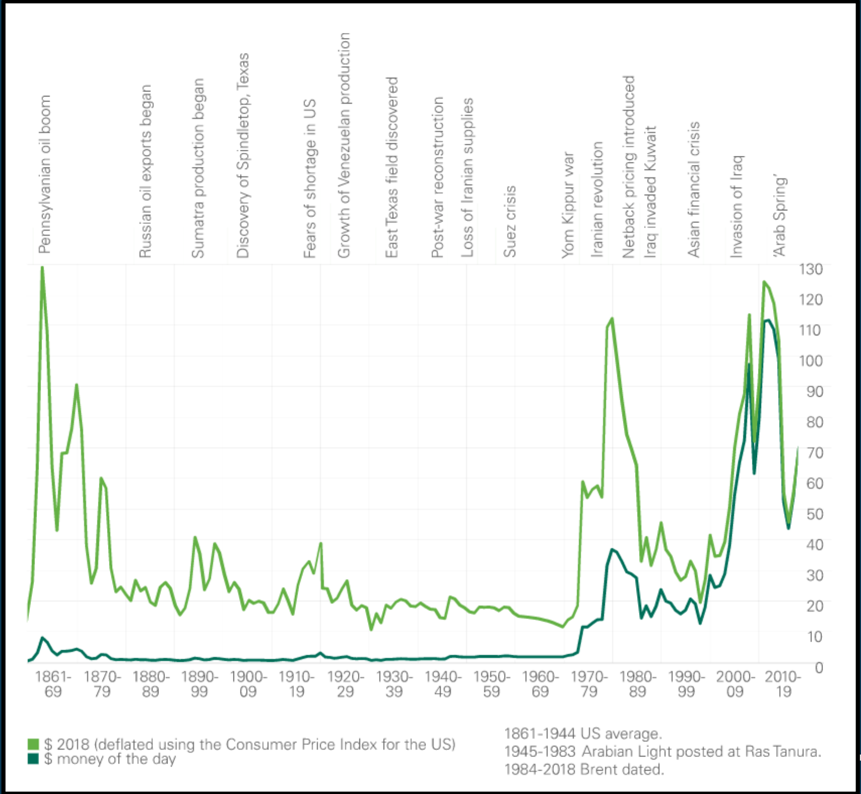
Example: Coal

Stanley Jevons – English Economist

- In 1865, predicted coal would be exhausted in under 100 yrs
- What happened?

Transition to using petroleum just like a shift from peat to coal before it

ARE NONRENEWABLE RESOURCES EXHAUSTED?



Example: Oil

US Energy Crisis

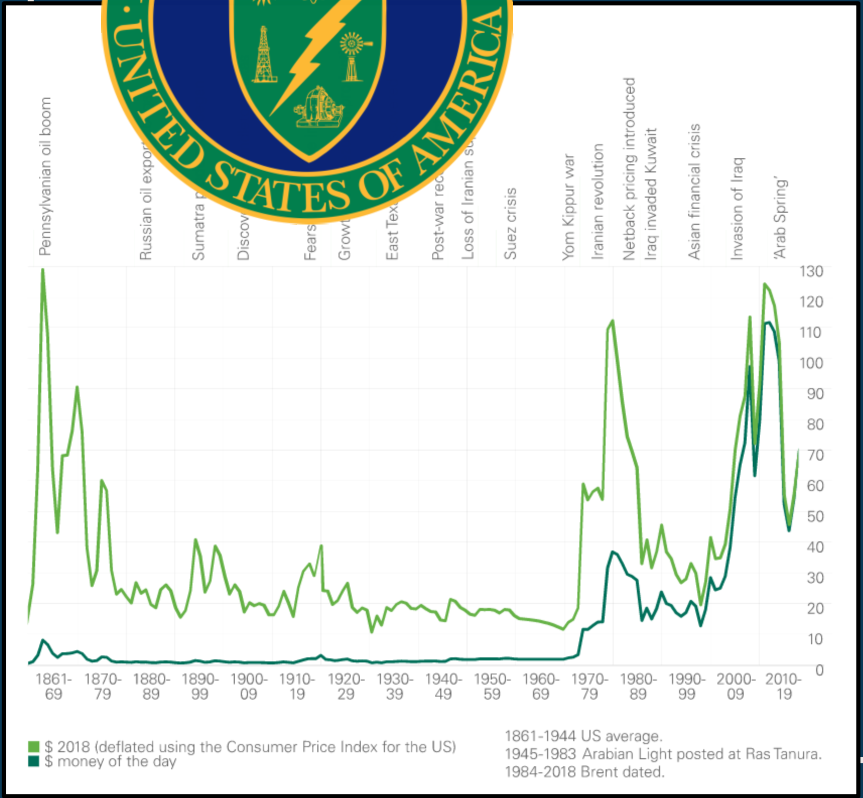
- 1973 Arab Oil Embargo

Are Nonrenewable Resources Exhausted?

Example: Oil
US Energy Crisis

- 1973 Arab Oil Embargo
- 1977 President Carter predicts demand for oil will be greater than it can produce by 1980s

ARE NONRENEWABLE RESOURCES EXHAUSTED?



<u>Example</u>: Oil

US Energy Crisis

- 1973 Arab Oil Embargo
- 1977 President Carter predicts demand for oil will be greater than it can produce by 1980s
- What happened?

ARE NONRENEWABLE RESOURCES EXHAUSTED?

History shows that nonrenewable resources are not exhausted!

Why?

Because of the economics of scarcity.

Independent

Warning: Oil supplies are running out fast

Warning: Oil supplies are running out fast. Catastrophic shortfalls threaten economic recovery, says world's top energy economist. Science Editor ...

Aug 3, 2009

The Week Magazine

Is Saudi Arabia running out of oil?

Diplomatic cables released by Wikileaks suggest that Saudi Arabia, the world's largest crude oil exporter, may have 40 percent less oil than ...

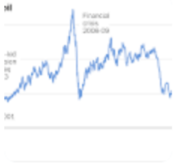
Feb 10, 2011

The New York Times

Too Much Oil: How a Barrel Came to Be Worth Less Than Nothing

The price of the main U.S. oil benchmark fell more than $50 a barrel to end the day about $30 below zero, the first time oil prices have ever turned negative. ... the world is running out of places to put all the oil the industry

1 month ago



QUESTION OF THE DAY

Will we run out of oil?

NONRENEWABLE RESOURCES

Economists treat nonrenewable resources as assets (a subset of society's capital assets)

How do we manage these assets?

- How much should we extract now/later
- What is the optimal extraction rate?

What are market outcomes?

- What is the market extraction rate?
- How does it compare to the optimal rate?

WHAT IS THE EFFICIENT RATE OF EXTRACTION OF A DEPLETABLE RESOURCE?

Economists treat depletable resources as assets

How do we manage this asset in an efficient manner?
How much should we extract now vs. later?

- Cost of extraction
- Value of asset

How do we value depletable resources?

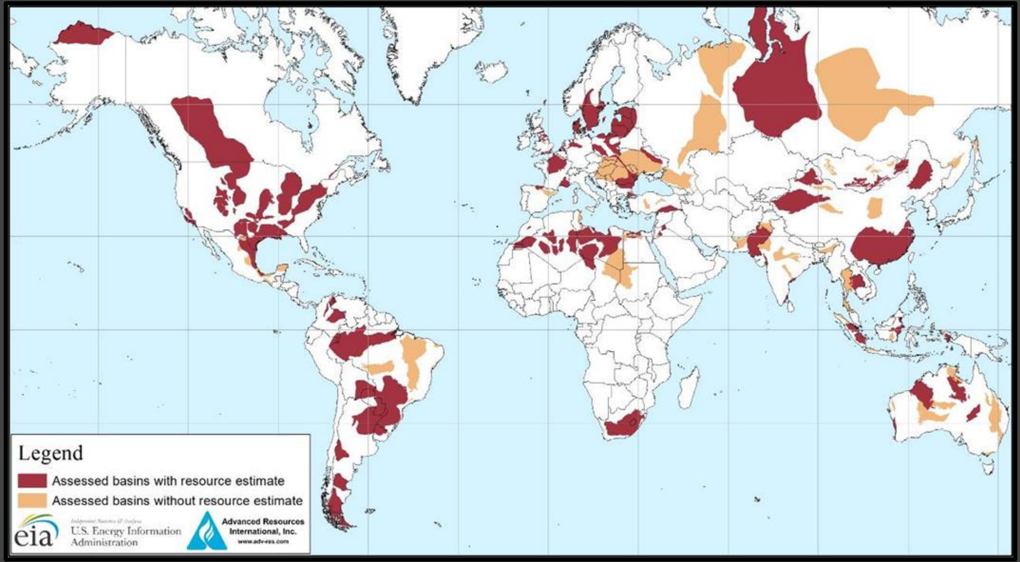
Scarcity!

SCARCITY OF NONRENEWABLE RESOURCES

Scarcity will depend on two factors:

1. Geology (physical scarcity)
2. Economics

GEOLOGY



Natural resources are good provided by nature

In some cases there is a limited quantity of these resources available (at least in a reasonable time span)

ECONOMICS

Natural resources that are *physically* available are not always *economically* available.

There is a cost to extraction.

If price<cost, is it worth extracting?
Is it “available”?

HOW TO MEASURE SCARCITY?

A commonly used metric of scarcity is the Reserves-to-use-ratio

- Commonly cited in press and reports

Defined as known reserves/current annual consumption

Example:
Known reserves = 45,000,000 tons
Current annual consumption = 1,000,000 tons/yr

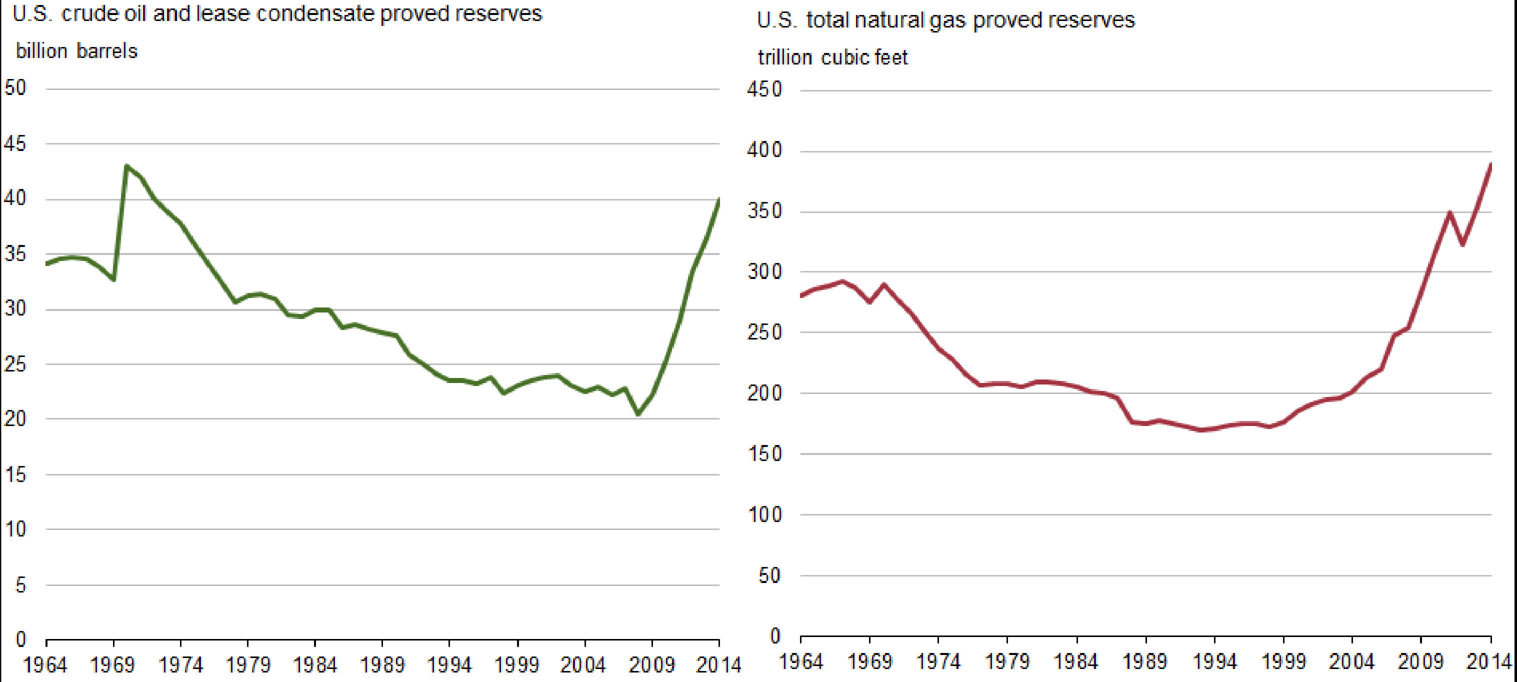
$$\text{Reserves-to-use-ratio} = \frac{45{,}000{,}000 \text{ tons}}{1{,}000{,}000 \text{ tons/yr}} = 45 \text{ yrs}$$

PROVED RESERVES DEFINITION (EIA, 2015)

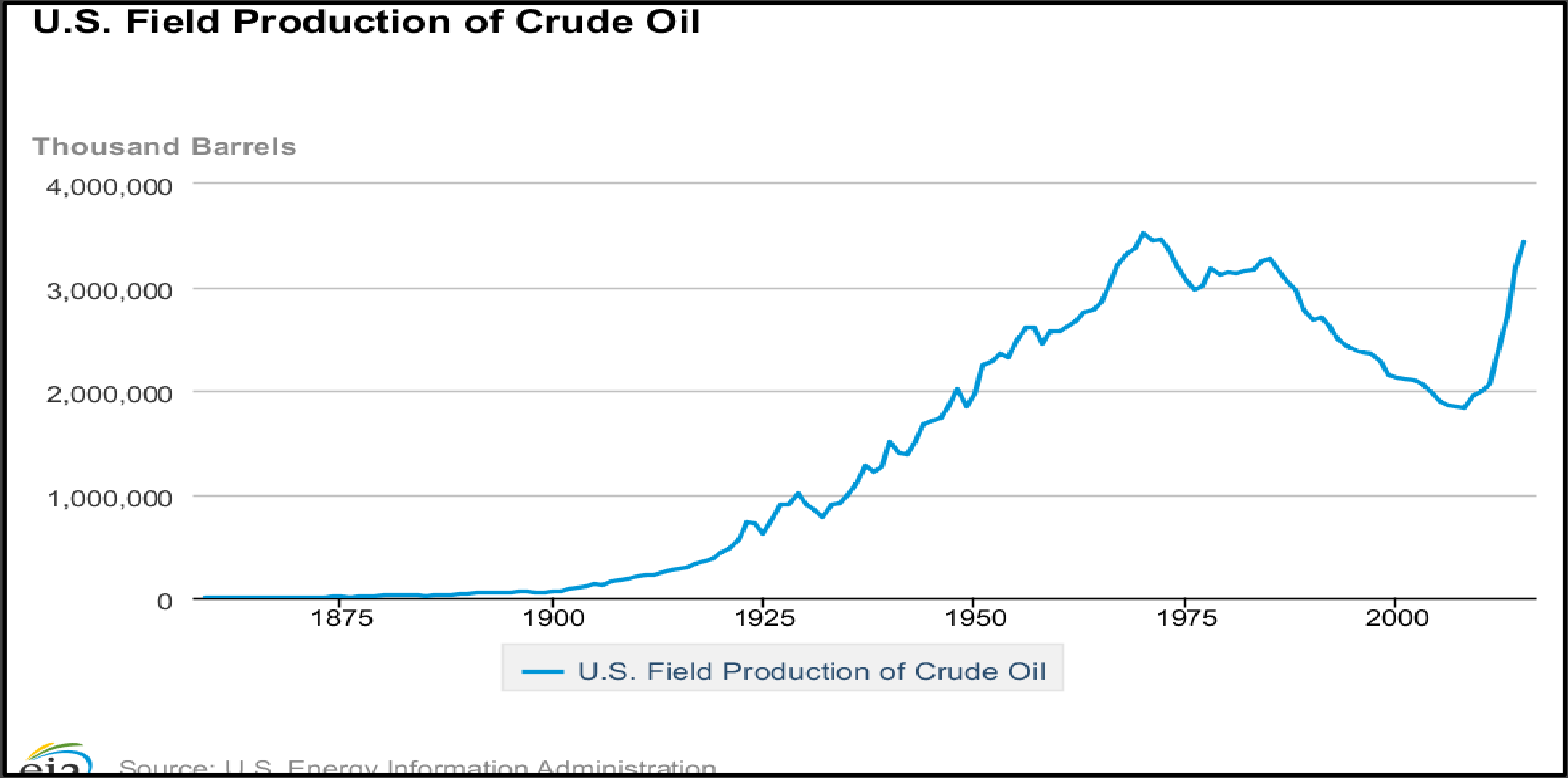
Proved reserves

Estimated volumes of hydrocarbon resources that analysis of geologic and engineering data demonstrates with reasonable certainty are ***recoverable under existing economic and operating conditions****. Reserves estimates change from year to year as new discoveries are made, as existing fields are more thoroughly appraised, as existing reserves are produced, and as prices and technologies change.*

Figure 1. U.S. oil and natural gas proved reserves, 1964-2014



Sources: U.S. Energy Information Administration, Form EIA-23L, Annual Survey of Domestic Oil and Gas Reserves, 1977-2014, American Petroleum Institute, 1964-76


U.S. Field Production of Crude Oil
Thousand Barrels
4,000,000
3,000,000
2,000,000
1,000,000
0
1875
1900
1925
1950
1975
2000
U.S. Field Production of Crude Oil
eia
Source: U.S. Energy Information Administration

HOW TO MEASURE SCARCITY?

Reserves-to-use-ratio

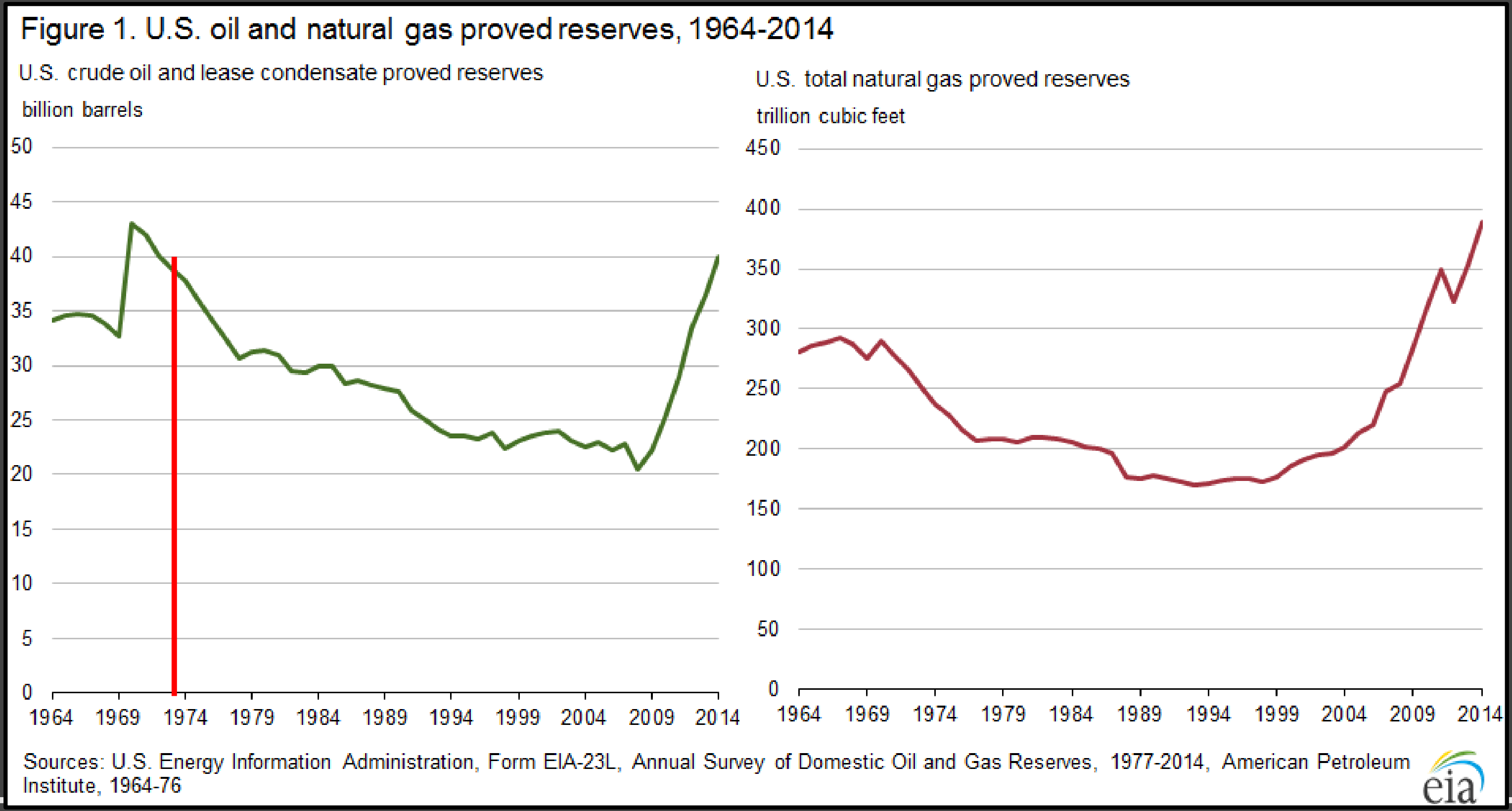
US Reserves 2015 = 40B barrels

US Annual Production 2015 = 3.5B barrels

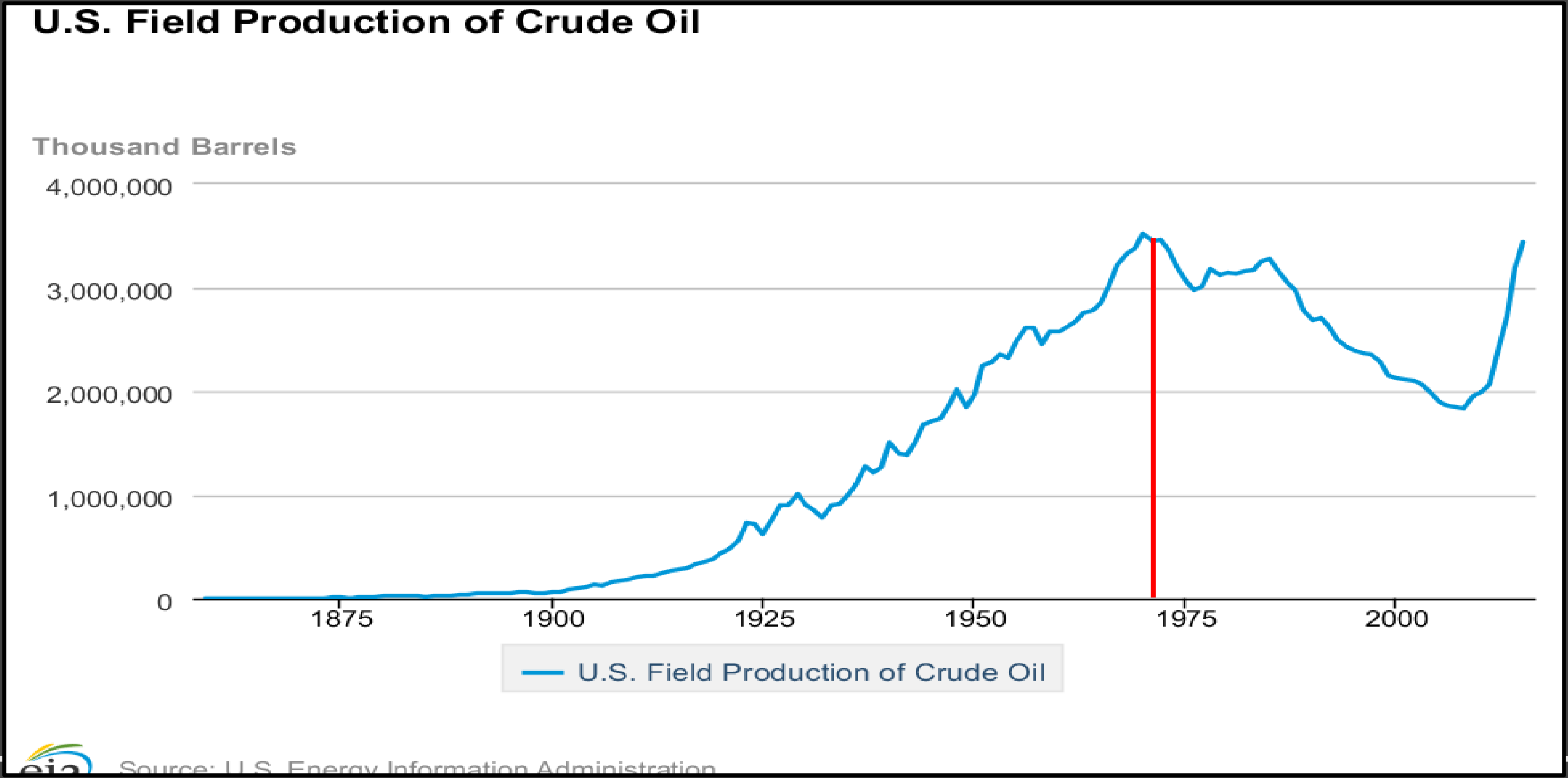
$$\text{Reserves-to-use-ratio} = \frac{40\ \text{Bbl}}{3.5\text{Bbl/yr}} = 11.5\ \text{yrs}$$

Do you think we will run out of oil in 2026?

IN 1973 WE HAD AROUND 40 BBL OF OIL RESERVES



WE PRODUCED 3.5B BARRELS IN 1973 TOO!



HOW TO MEASURE SCARCITY?

Reserves-to-use-ratio

US Reserves 1973 = 40B barrels

US Annual Production 1973 = 3.5B barrels

$$\text{Reserves-to-use-ratio} = \frac{40\ \text{Bbl}}{3.5\text{Bbl/yr}} = 11.5\ \text{yrs}$$

Did we run out of oil in the 1980s like the energy crisis predicted?

RESERVES-TO-USE-RATIO

Clearly not a great measure

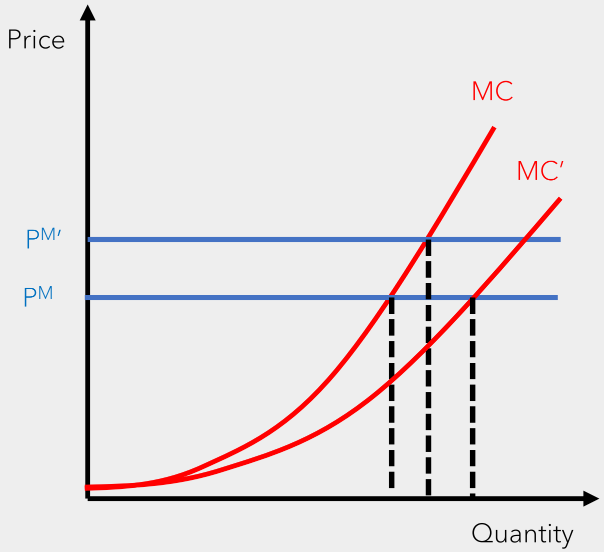
- Very simplistic

What is it missing?

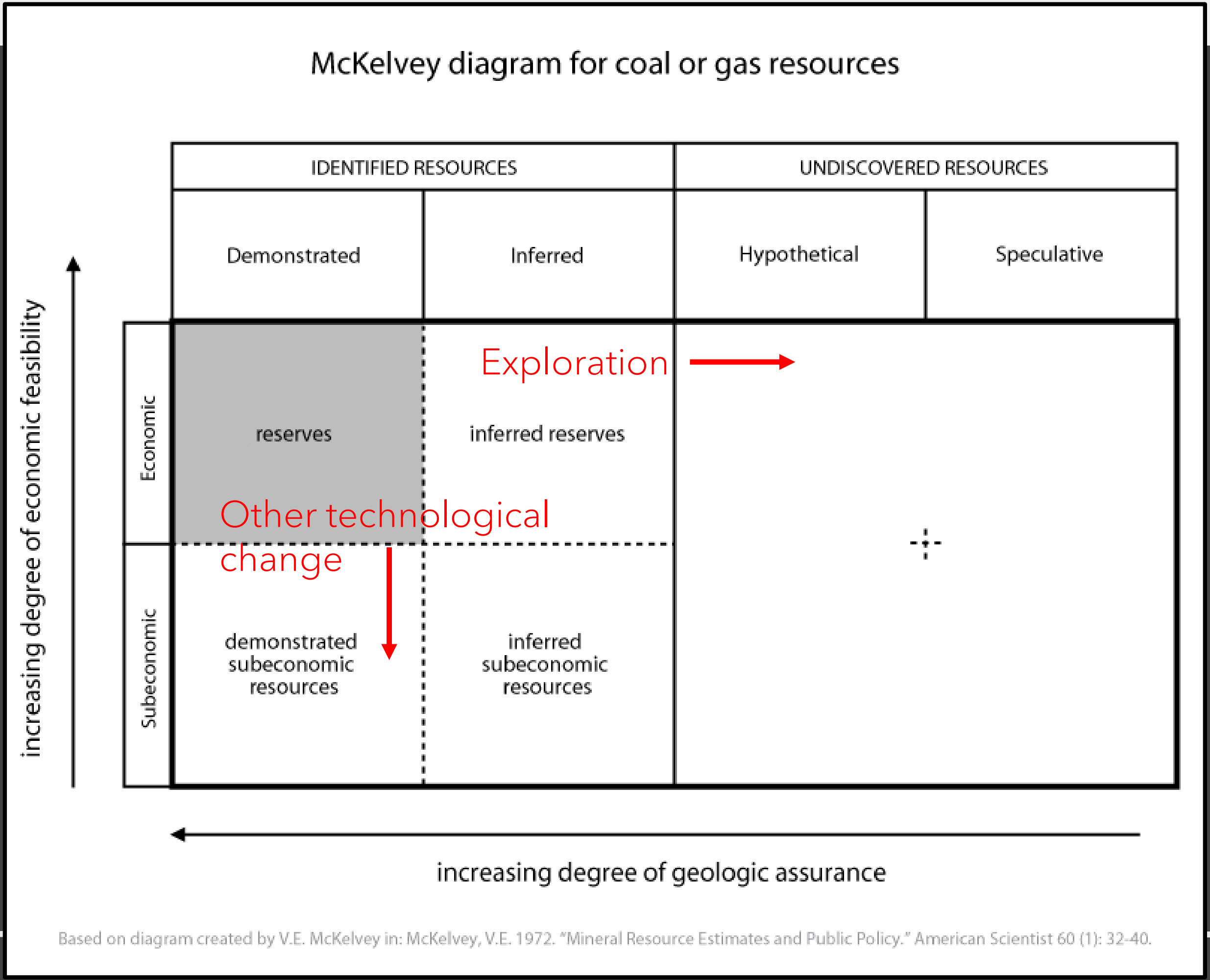
- Assumes no new discoveries
- No change in cost
- No change in technology
- No change in demand

RESERVES DEPEND ON PRICE AND TECHNOLOGY

"Sustained low prices for oil and natural gas are anticipated to reduce the reserves in EIA's next report (for year-end 2015). Lower prices have curtailed drilling and made recovery economics more challenging. Although resource estimates are not necessarily reduced by lower prices, the calculation of proved reserves is sensitive to price." (EIA, 2015)



HOW MUCH IS THERE?



02

EFFICIENT EXTRACTION OF DEPLETABLE RESOURCES

HOW FAST SHOULD WE EXTRACT NONRENEWABLE RESOURCES

Apply our concept of efficiency!

Efficient extraction depends on:

1. How much of the resource there is
   a) Talked about this above
2. The cost (full cost!) of extracting the resource
   a) This includes opportunity cost (if you use the resource today, don't have it tomorrow)
3. The price society is WTP for the resource (the demand)

EFFICIENT NONRENEWABLE RESOURCE EXTRACTION

Efficiency says:

$$MB = MC$$

- MB comes from WTP
- MC comes from costs (including opportunity cost)

Dynamic problem, so we apply *dynamic equimarginal principle*

- Maximize net present value of net benefits

TWO-PERIOD EXAMPLE

Setup:

Two periods: Today and tomorrow

Demand for oil: $P = 10 - 0.5Q$

MC of oil extraction: MC= \$3

- For now, ignore externalities and other sources of market failures

Let's solve using our equimarginal principle MB=MC…

TWO-PERIOD EXAMPLE (TODAY)

Setup:

Two periods: Today and tomorrow

Demand for oil: P = 10 – 0.5Q

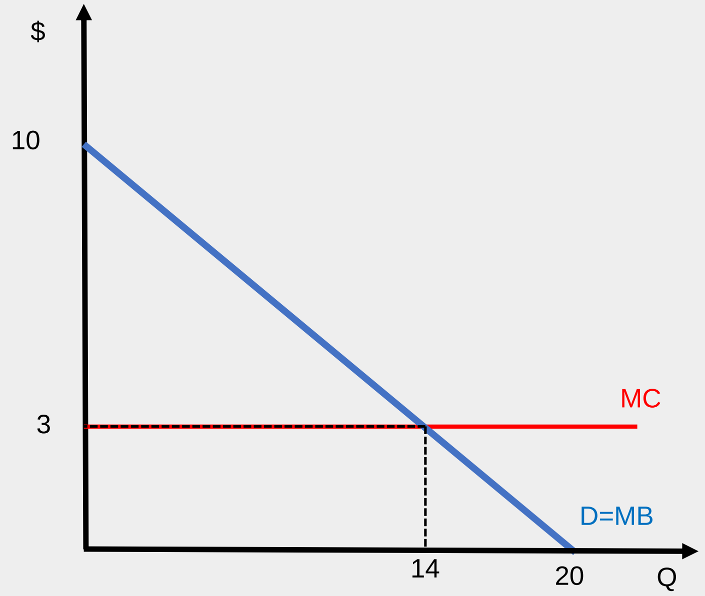
MC of oil extraction: MC= $3

Solution:

MC=MB

Q^*=14

P^*=$3



TWO-PERIOD EXAMPLE (TOMORROW)

Setup:

Two periods: Today and tomorrow

Demand for oil: P = 10 – 0.5Q

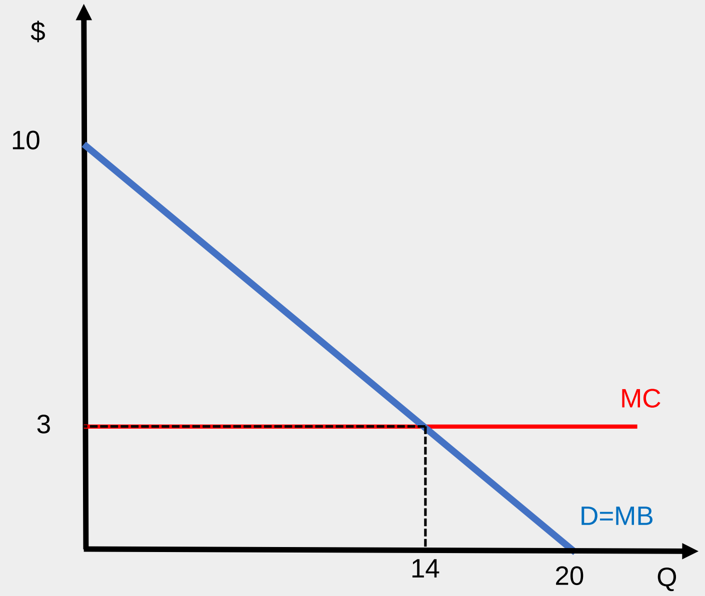
MC of oil extraction: MC= $3

Solution:

MC=MB

Q^*=14

P^*=$3



So, in both periods we extract 14 barrels

Let's introduce a limited stock. Let's say…20 barrels.

Period 1: extract 14 barrels
Period 2: only 6 barrels left?

Are net benefits maximized?

WHAT HAPPENED?

WHAT DID WE MISS…?

1. Didn't discount second period
2. We acted myopically

We must recognize there is a cost of using the resource today equal to the lost opportunity to use the resource in the future.

This lost opportunity cost is called the "**marginal user cost**" or "**scarcity rent**" or "**scarcity cost**".

WHAT CAN WE DO TO FIX IT?

1. Discount second period
   a) Incorporates time value of money
2. Introduce stock constraint directly into the period
   a) Incorporates scarcity cost
3. Equate net marginal benefits in each period
   a) Incorporates dynamic equimarginal principle

TWO-PERIOD EXAMPLE (REVISITED)

Setup:
- Two periods: Today and tomorrow
- Demand for oil: P = 10 - 0.5Q
- MC of oil extraction: MC= $3
- Discount rate = 10%

Solution:

$q_1^* = 10.19$ barrels

$q_2^* = 9.81$ barrels

$$\mathrm{PV}(\mathrm{MB}_1 - \mathrm{MC}_1) = \mathrm{PV}(\mathrm{MB}_2 - \mathrm{MC}_2)$$

$$10 - 0.5\mathrm{q}_1 - 3 = \frac{1}{1+\mathrm{r}}(10 - 0.5\mathrm{q}_2 - 3)$$

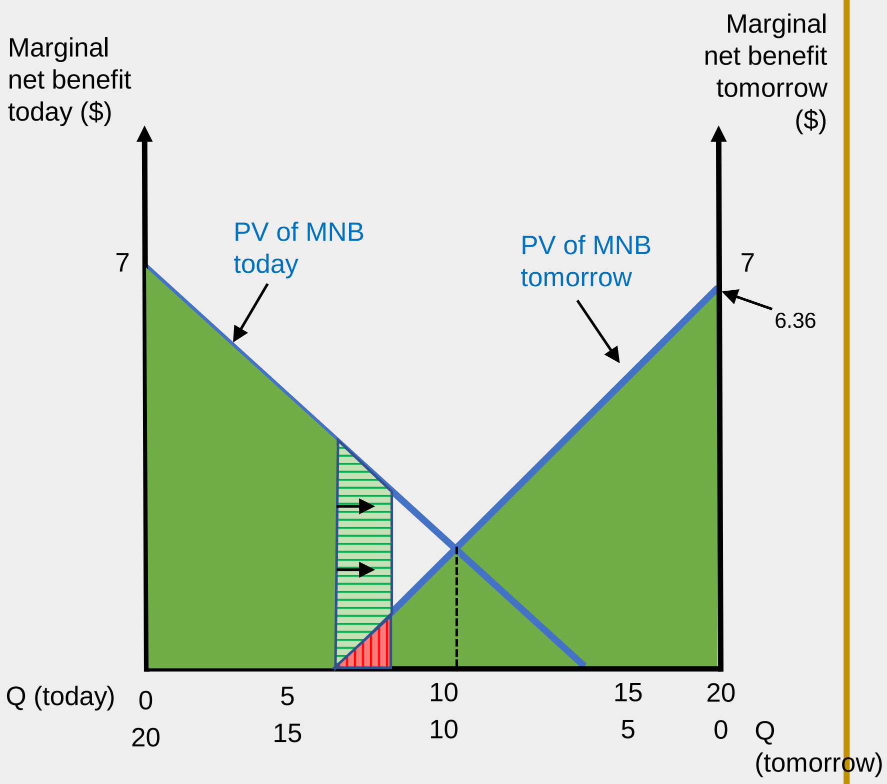
$$10 - 0.5\mathrm{q}_1 - 3 = \frac{(10 - 0.5(20 - \mathrm{q}_1) - 3)}{1+\mathrm{r}}$$

$$7 - 0.5\mathrm{q}_1 = \frac{0.5\mathrm{q}_1 - 3}{1 + 0.1}$$

Why don’t we just split it 10 barrels today/10 barrels tomorrow?

We know there is a time value of money.

So how do we know 10.19 barrels today/9.81 barrels tomorrow is the efficient extraction path?



WHY DOES P≠MC?

$q_1^* = 10.19$ barrels, $q_2^* = 9.81$ barrels

What about price? P = 10 – 0.5Q

$p_1^* = \$4.905$, $p_2^* = \$5.095$

But MC=$3? What happened?

When resources are limited, consumption today comes at a cost of forgone consumption tomorrow

The present value of those costs give us the marginal user cost (MUC), or scarcity rents

The difference between P and MC measures the scarcity rents

- In period 1 the MUC = $1.905
- In period 2 the MUC = $2.095

Scarcity rent rises over time as resource becomes scarcer

HOTELLING RULE

Firms treat nonrenewable resources like any other capital asset

Must generate returns at the market rate

- If gaining faster, extract at slower rate
- If gaining slower, extract at faster rate

Rate of change of MUC…

$$\frac{MUC_2 - MUC_1}{MUC_1} = \frac{(P_2 - MC_2) - (P_1 - MC_1)}{P_1 - MC_1}$$

$$= \frac{(5.095 - 3) - (4.905 - 3)}{4.905 - 3}$$

$$\approx 0.10 = r$$

This shows the **Hotelling rule**

Marginal user rate increases at the rate of interest

03

WHEN IS THE MARKET EXTRACTION RATE NOT THE OPTIMAL RATE?

TWO-PERIOD EXAMPLE

Setup:

Two periods: Today and tomorrow

Demand for oil: P = 10 – 0.5Q

MC of oil extraction: MC= $3

Discount rate = 10%

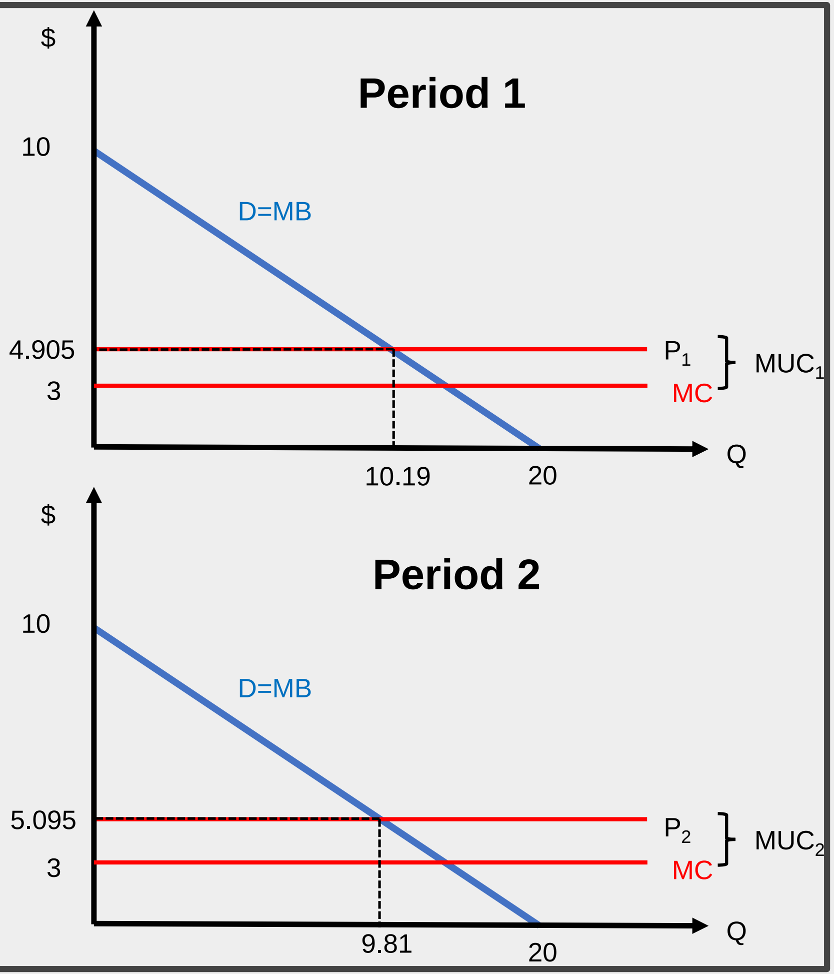
Solution:

$p_1^* = \$4.905$

$p_2^* = \$5.095$

$\mathrm{MUC}_1^* = \$1.905$

$\mathrm{MUC}_2^* = \$2.095$



WHEN DOES PRICE FULL CAPTURE SCARCITY RENTS?

What happens when price only reflects marginal cost?

- Overconsumption in early periods
- Inefficient extraction path

When will markets reflect the *true* cost of extraction by incorporating MUC?

PRIVATE OIL FIELD

Imagine a single firm owns an oil field

Will the firm consider the impact of <u>their</u> extraction on <u>their</u> future extraction?

SHARED WATER SOURCE

Imagine multiple consumers share a common water source

- Eg. Aquifer

Will consumers consider the effect of <u>their</u> consumption on <u>their</u> future consumption?

Will consumers consider the impact of <u>their</u> consumption on <u>others'</u> future consumption?

WHEN DOES PRICE FULL CAPTURE SCARCITY RENTS?

What happens when price only reflects marginal cost?

- Overconsumption in early periods
- Inefficient extraction path

When will markets reflect the *true* cost of extraction by incorporating MUC?

This depends on the assignment of *property rights*

When a depletable resource is privately owned, markets will account for scarcity.

ATTENDANCE ACTIVITY

What is the optimal extraction rate for two periods:

Setup:

Two periods: Today and tomorrow

Demand for oil: $P_i = 10 - 0.5Q_i$

20 bbls of oil

MC of oil extraction: MC= $3

Discount rate = 10%

Negative externality in production of $1/bbl

ATTENDANCE ACTIVITY

What is the optimal extraction rate for two periods:

Setup:

Two periods: Today and tomorrow
Demand for oil: $P_i = 10 - 0.5Q_i$
20 bbls of oil
MC of oil extraction: MC= $3
Discount rate = 10%
Negative externality in production of $1/bbl

$$\mathrm{PV}(\mathrm{SMB}_1 - \mathrm{SMC}_1) = \mathrm{PV}(\mathrm{SMB}_2 - \mathrm{SMC}_2)$$

$$10 - 0.5q_1 - 4 = \frac{1}{1+r}(10 - 0.5q_2 - 4)$$

$$10 - 0.5q_1 - 4 = \frac{(10 - 0.5(20 - q_1) - 4)}{1+r}$$

$$6 - 0.5q_1 = \frac{0.5q_1 - 4}{1 + 0.1}$$

Solution:

$q_1^* = 10.1$ barrels

$q_2^* = 9.9$ barrels

WHAT IF THERE ARE NEGATIVE EXTERNALITIES IN PRODUCTION?

We know that if there is a negative externality in production, markets will provide too much of a good relative to the optimum.

In other words, if there is a negative externality in production, The efficient (optimal) rate of extraction decreases (leave more in the ground).

We can think of the marginal user cost as an externality.

If the resource is privately owned, the externality will be internalized.

PRIVATE OIL FIELD

Imagine a single firm owns an oil field

Will the firm consider the impact of their extraction on their future extraction?

SHARED WATER SOURCE

Imagine multiple consumers share a common water source

- Eg. Aquifer

Will consumers consider the effect of their consumption on their future consumption?

Will consumers consider the impact of their consumption on others' future consumption?

WHAT HAPPENS TO EXTRACTION WHEN THERE ARE MONOPOLIES?

? =

What happens when firms extracting depletable resources have market power?

What happens to output when there is market power?
How does output of a monopolist compare to perfect competition?

- Incentive to raise price and decrease output

Thus, monopolies have incentives to decrease extraction rates and further increase price over the marginal user cost!

Conservationist!
But not efficient – they will maximize firm profits, but not net benefits to society).

LESSON OBJECTIVES

01

Define and categorize nonrenewable and renewable resources

02

Analyze optimal extraction of nonrenewable resources

03

Explain and analyze sources of market failure for nonrenewable resources