Lecture # 21 –Energy Resources

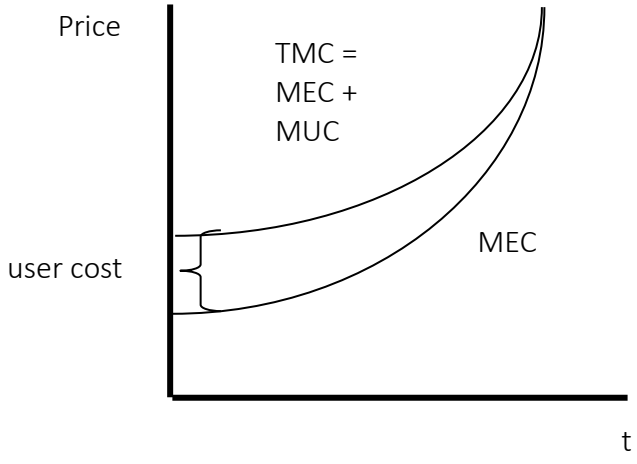
I. Optimal Extraction of an Exhaustible Resource

- Three classifications of exhaustible resources:
    1. current reserves -- known reserves that can be profitably extracted at current prices. Also known as proved reserves.
    2. potential reserves -- reserves that could be recovered at higher prices.
    3. resource endowment -- the entire geological supply of resources (including those not yet discovered).
- Decisions to use exhaustible resources are dynamic decisions, because future availability of the resource depends on what is used today.
- Thus, exhaustible resources should be treated as an asset.

A. The Costs of Extraction

- There are two costs to using a resource, such as oil, today:
    - Extraction cost
        - How much does it cost to obtain the resource?
        - Obviously, only sell if P >= MEC (marginal extraction cost).
    - User cost -- the opportunity cost of not having the resource to sell in the future
        - As a result, the price of the resource will be greater than the MEC.
- The owner of a resource, such as oil, has two options to make money for next year:
    - Sell all the oil now, and invest the profits at interest rate i.
    - Wait and sell the oil next year.
- Case A: Expected profit next year rises less than the rate of interest:
    - Present value of marginal profits next year is less than current value this year:
        - $P_1 - MEC > (P_2 - MEC)/(1+i)$
    - The owner of the oil is better off selling the oil now and investing it.
    - Leads to lower prices now (greater supply) and higher prices next year (lower supply).
- Case B: Expected profit next year rises faster than the rate of interest:
    - Present value of marginal profits next year is greater than current value this year:
        - $P_1 - MEC < (P_2 - MEC)/(1+i)$
    - The owner of the oil is better off waiting to sell the oil next year.
    - Leads to higher prices now (lower supply) and lower prices next year (higher supply).

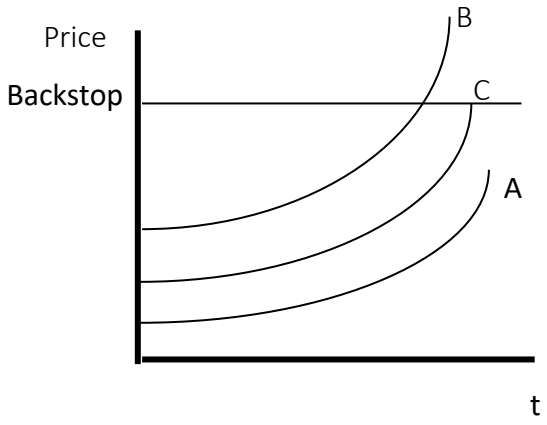
- Prices adjust whenever one option (case A or B) looks better. Thus, equilibrium is reached when the expected profit from the sale of the oil rises at the rate of interest.
    - P_1 - MEC = (P_2 - MEC)/(1+i), or
    - (1 + i)(P_1 - MEC) = (P_2 - MEC)
    - With a constant marginal extraction cost, this simplifies to:
        - $P_2 - P_1 = \Delta P = i(P_1 - MEC)$
        - *Intuition*: marginal profit received from extracting the resource rises at the rate of interest
- Marginal user cost (MUC) -- the present value of the opportunity cost of the last unit of oil used not being available in the next period.
    - P(t) = MUC(t) + MEC(t)
    - If marginal extraction costs are constant, the marginal user cost rises at the rate of interest.
    - This implies that the present value of marginal user cost remains the same!
        - The market is maximizing the present value of welfare (including consumer surplus) over time.
    - Note that the price of a resource is greater than the MEC. Thus, higher prices are not, by themselves, evidence of abuse of market power.
        - Rather, they simply represent economic rent due to scarcity.
        - The mathematical example shows how the marginal user cost increases as scarcity is more of a problem.
        - For those who would like more practice working with these concepts, you can download the spreadsheet I used in class by clicking here.
- Changes in the marginal extraction cost
    - Up to now, we have assumed the MEC is constant.
    - If marginal extraction costs rise over time, the marginal user cost will fall (represented by the narrowing gap between MEC and TMC below).



        - Intuition: MUC represents the opportunity cost of using the resource now. If it will be more costly to use the resource in the future, the opportunity cost is not as high.

B. Backstop Technologies

- This theory describes how the price should change over time. But what price should we start at?
    - We want to run out of the resource at the highest price that people are willing to pay. Consider the following example:



        - A: starts too low. As we approach the end, the price will jump, as people will hoard. Thus, should have started higher.
        - B: starts too high. Some of the resource remains in the ground at the backstop price, and must be sold at that price, which is lower than desired.
        - C: just right.
    - This is the backstop price. It is determined by a backstop technology.
    - A <u>backstop technology</u> is a technology that is available in vast quantities at the backstop price.
        - E.g.: solar energy
        - Note that the backstop price is constant, since the backstop technology is not exhaustible.
    - Note that, if several fuels are available, we will begin by using the one with the cheapest extraction cost, and continue, using up each fuel, until the backstop technology is reached.
        - Note that, if these prices do not account for negative externalities, such as pollution, all of the dirty fuel supplies are used up!
    - Technological innovation on the backstop technology could lower its price and speed the transition.
        - However, if the backstop won't be usable for many years, markets might not support this research.

II. Energy Prices Over Time

- Theory predicts that energy prices should rise over time. That has not happened.
- Factors leading to higher prices
    - Higher demand, particularly in emerging economies
    - Risk premium
        - Concerns over security and corruption in oil producing nations raise the risks of future shortages.
    - Lack of refining capacity
        - Even if more oil comes into the U.S., there isn't additional capacity to refine it into gasoline more quickly.
        - Price volatility reduces investment.
- Factors leading to lower prices
    - Demand for oil and gasoline in many richer countries is falling, as more consumers use hybrid and electric vehicles
    - Resource scarcity
        - If a resource is not scarce, the user cost is near zero, so the price is set at the marginal costs of extraction.
            - Scarcity rents become a factor as demand increases, leading to slowly rising prices.
        - Concerns about peak oil were first raised during World War I
            - US crude oil proved reserves grew from 22 billion barrels in 2000 to 36.3 billion in 2014
        - New discoveries have limited the importance of scarcity in oil prices.
            - Current reserves in our model at the beginning of class change with market conditions
            - Exploration increases when energy prices are higher
    - Competitive markets
        - Changes in the role of OPEC play a key role in oil prices. The supply of non-OPEC oil has increased
    - The quality of oil matters. This has caused complications for energy markets.
    - The model assumes constant marginal costs
        - Over time, technical progress has reduced the marginal cost of many resources.
        - Technological change has lowered extraction costs.
            - Lower extraction costs increase economic reserves => lower MUC as well.
        - Technological change changes expectations of future costs
        - Technological change lowers the cost of backstop technologies

- Hydraulic fracturing of shale oil is an example of technological change
    - Shale oil depends on three technological advances:
        - horizontal drilling
        - microseismic imaging
        - hydraulic fracturing
    - What is fracking?
        - Causes cracks and fissures in the rock formation that allow crude oil to escape
        - Fracking occurs at known resource sites. It isn't simply new resources, but rather resources becoming economical to access.
    - Possible costs of fracking
        - Water resource impacts
            - Water used could reduce flows of rivers and streams
                - Quantities of surface water used are small
                - But most water usage concentrated during the fracturing process
                    - If this occurs when water is scarcer (e.g. summer), may have an impact
            - Surface water pollution
                - These costs may be significant
            - Groundwater pollution
                - Determining causal effects often difficult.
            - Groundwater depletion not an issue in eastern U.S., but could be an issue in semi-arid areas
                - Little data on this yet
            - Increased seismic activity
    - Surge in fracking stimulated by high oil prices after 2003, which made the technology competitive
        - Since then, the cost of the technology has fallen.
        - Energy companies become more efficient as gain experience and drill more wells.
            - Advances include extending horizontal section farther:
    - Projected growth in US oil production comes entirely from shale oil
    - How has shale oil and gas affected prices?
        - Reduced US oil imports & increased US exports of refined products
        - Building infrastructure to export natural gas
            - More pipelines
            - Facilities for liquefied natural gas
        - Reduces volatility
            - Shale wells take longer to drill and reach production
            - But produces more per well with less variation in production
            - Thus shale oil and gas is more responsive to market prices
                - More so for natural gas, for which the market is primarily North America
                - Oil, in contrast, is a global market

III. Where Does Our Energy Currently Come From?

- Most energy used in the US is consumed by industry and transportation

- Of the 93.9 quads consumed in 2023, 77.0 were fossil fuels. Just 8.33 quads were renewable.
    - Of the renewables, most were biomass. 18% of renewables were wind, and 11% of renewables were solar.
    - Power generation is dominated by coal, nuclear and natural gas. In 2022:
        - 43% natural gas
        - 16% coal
        - 19% nuclear
    - The role of natural gas has been increasing over the past few years, which has reduced carbon emissions.
        - Natural gas surpassed coal as primary source for electricity in 2016

- Worldwide, renewables make up about 12% of total primary energy supply.
    - Most of this is biofuels and renewable waste, which makes up 8.8% of total primary energy supply.
        - Biomass is particularly important in developing countries. Thus, they have higher shares of renewable energy.
            - Highest in Africa: 47.4%
    - Hydro is another 2.5%.
    - The remainder is geothermal, solar, wind, and oceans.

IV Energy Transitions

- The climate change problem
    - Electricity generation is the main source of carbon emissions (25% of carbon emissions globally), followed by deforestation & land use (24%), industry (21%) and transportation (14%).
    - Significant reduction in emissions required to keep global temperature increases below 2^{o}C.

- Energy transitions have occurred throughout history.
    - Traditional biomass (wood, peat, and dung) was the main source of energy in the pre-industrial age
        - Wood became scarce in England during the 1500s and 1600s as the country grew
    - Use of coal emerged with steam engines. Coal surpassed biomass as the main source of energy in the early 1900s
        - Coal has three times the energy density of dry wood
    - Oil emerges next
        - Liquid fuel useful for transportation. It is very energy dense
    - Natural gas is cleaner, but requires special infrastructure
    - Electrification
        - Also emerged during the 20th century
        - Not a fuel, but a new way of delivering energy

- Previous energy transitions move towards fuels that are more energy dense and convenient to use. Moving to renewables adds new challenges
    - Solar energy is diffuse. It needs to be concentrated to provide energy
        - This is where technology comes in
        - Wind and solar energy sources concentrate power.
    - Renewable energy must be delivered to where it is needed.
        - Increased electrification is key to the renewable energy transition.

- The potential and problems of renewable energy sources
    - Wind
        - Global wind capacity has more than doubled since 2010
        - On-shore wind is now competitive in favorable locations.
        - Are there enough acceptable sites?
            - Good sites have sufficient wind or solar resources, are near where energy demanded (to avoid transmission losses) and are not ruled out politically.
            - Offshore sites take advantage of stronger, more consistent winds.
                - However, these are more expensive and require better technologies.
        - New transmission lines needed in some areas, because most productive sites aren't near population centers.
            - In 2022, the top ten states for wind production had 75% of generation, but only 32% of population
                - E.g. in New York, wind power mostly generated upstate
                - Congestion in transmission to New York City is an issue
            - Lines can over heat or shut down if too much power flows through them
            - Distance from center decreases intermittency, but increases transmission losses.
        - R&D needs include:
            - Continued cost reductions for offshore wind
                - Costs of installation are higher offshore
            - Understanding extreme wind conditions
            - Integrating wind turbines to the electric grid
            - Storage
        - Development of offshore wind turbines
            - Costs of installation are higher
            - But are becoming competitive in prime locations (e.g. U.K.)

- Solar
  - There are two types of solar
  - Solar photovoltaic
  - Concentrated solar (a/k/a solar thermal)
    - Concentrated solar uses mirrors to produce heat, which turns a turbine.
    - Can heat steam, allowing them to store power
    - Has fewer suitable sites
    - More expensive than solar PV
  - Solar has traditionally been the most expensive of currently used renewable sources, but PV costs have fallen
    - Primarily due to lower module costs
  - Solar thermal costs still high
  - Storage of solar energy remains a technical issue
  - As with wind, are there enough acceptable sites?
    - In 2022, the top ten states for solar production had 81% of generation, but only 42% of population
    - However, because high pressure areas have fewer clouds and less wind, solar is most abundant in places where wind energy is scarce.
    - Many of the best locations for concentrated solar are in developing countries.

- Challenges to a renewable energy transition
    - Transportation
        - Electric motors are more efficient and simpler mechanically
        - But gasoline or diesel fuel contains 40X as much energy as current batteries
            - Usable for vehicles carrying light loads and that can charge often (e.g. passenger cars)
            - Not yet viable for long-haul trucking, aviation, or maritime shipping
        - Consumers may not see EV as perfect substitutes for gasoline-powered vehicles
            - Charging infrastructure needed
        - Prices of raw materials needed for batteries growing
    - Industry
        - Not all processes can be electrified
        - Achieving very high heat for industrial processes such as steel, cement, and glass production is difficult without burning fuel
    - Electricity
        - Increased electrification is key to the renewable energy transition.
        - But solar and wind are intermittent
        - To understand the potential of renewable energy for electricity generation, it is important to understand how the electric grid works