Introduction to Environmental Economics (IKT3620)

Non-renewable natural resources and energy

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The extraction of a non-renewable resource

- How we, as economists, ought to think about using non-renewable resources, such as coal and oil?

Hoteling model

Hoteling model

- How much oil a producer should supply at each period of time?
- The present value of profit implies that delaying oil extraction has an opportunity cost in terms of the return (r) that money tied up in oil reserves could earl from alternative investments, such as
  - Money in interest earning deposits in a bank,
  - Money invested in stocks and investments
- So,

  why not empty the oil wells in the first year and live off these investments?

Hoteling (1931)

- Developed a model of how non-renewable natural resources extracted over time.
  - ***Hoteling's rule***
- We explain the idea in a simple two-period example.
- Define an equilibrium in which the producer is indifferent between
  - selling the last unit of oil in the current period or
  - in the next period
- The present value of a barrel of oil should be the same in both periods for this to hold

$$p_1 = \left(\frac{1}{1+r}\right) p_2$$

An introduction to Hotelling's rule

Suppose that r=0.1; that is, the discount rate is 10 per cent.

For the firm to be in equilibrium,

$$(1 + r)p_1 = p_2$$

Or

$$\frac{p_2 - p_1}{p_1} = r;$$

that is, oil price rise equals the discount rate.

Hotelling's rule predicts that the oil price will rise through time.

An introduction to Hotelling’s rule

What is the reason for the increase in the price?

“Market demand combined with a reduction in resource extraction in time.”

Firms extract in each period in such a way that equilibrium holds; that is,

$$\frac{p_2 - p_1}{p_1} = r$$

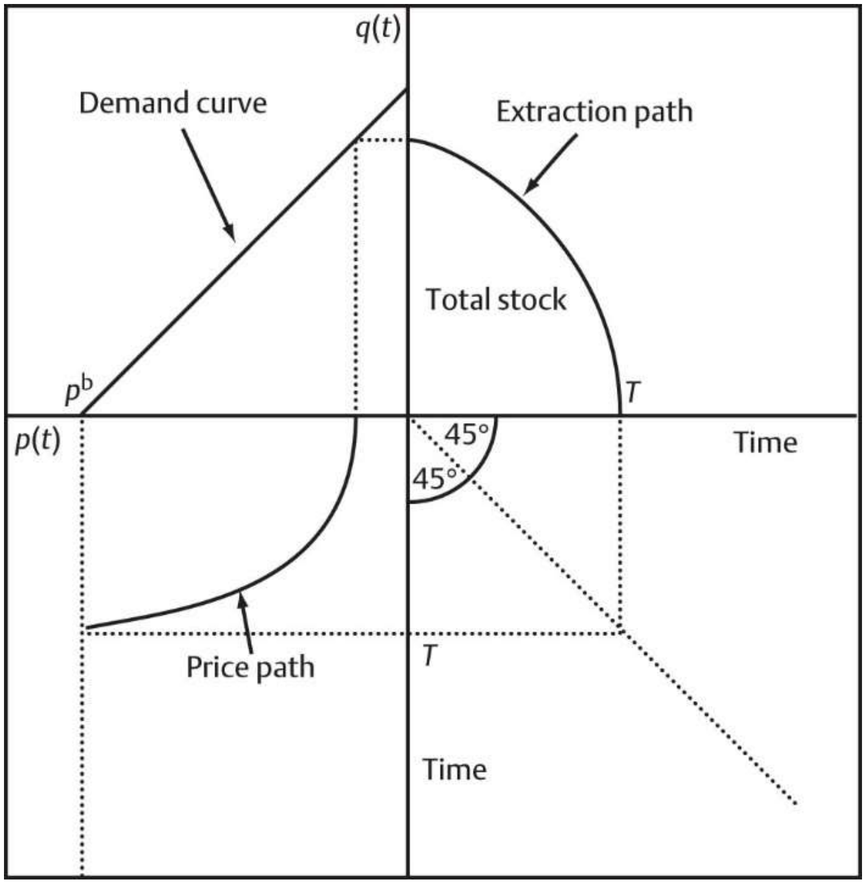
An introduction to Hotelling’s rule

To determine the life cycle of oil reserves, we need to know

- Initial oil reserve
- Price at which demand falls to zero: **Backstop price**
  - Price of a substitute for the non-renewable resource
  - E.g., the switch from oil to ethanol

- One we know the backstop price and the initial stock, we can calculate the price and quantity through time on the basis of Hotelling’s rule.

The Hotelling model of resource extraction



An introduction to Hotelling’s rule

- Is this resource extraction plan socially optimal?
- Remember that the discount rate reflects the current generation’s preferences for resource use through time
- So long as the discount rate is the social time preference rate, then the resource extraction path is efficient
- If firms face imperfect capital markets and interest rate, or returns on other assets are distorted, then firms can extract either too rapidly or too slowly.

An introduction to Hotelling's rule

- In many countries, the interest rate is higher than the social discount rate (markets are not perfect…)
  - Firms can be inclined to extract a resource too rapidly in this case
  - Predicted by Hotelling's rule:
    - High discount rates lead to
      - more rapid rise in the price and
      - a more rapid decline in the rate of extraction and
      - a shorter time to economic exhaustion of the resource

Resource extraction and the monopolist

Different than the competitive market example earlier, the structure of many non-renewable resource industries is highly concentrated

E.g., Organization of petroleum exporting countries - OPEC

How would a monopoly decide to extract a non-renewable resource?

Zero-cost, profit maximizing monopoly follows a similar version of Hotelling's rule.

Instead of equating the PV of price through time, the PV of MR is equated.

$$\frac{MR_2 - MR_1}{MR_1} = r$$

Including extraction costs

Hotelling's rule was given for a zero-cost firm

- unrealistic.

Hotelling's rule with costs ($M\pi$=p-MC):

$$\frac{M\pi_2 - M\pi_1}{M\pi_1} = r$$

The rate of increase in prices now depends partly on how costs change over time.

Measuring resource scarcity

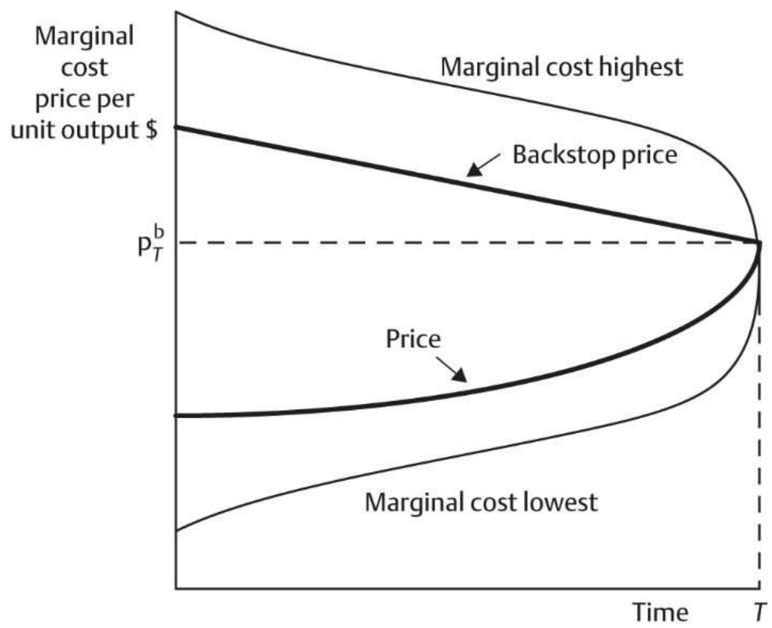
Are we running out of resources?

a positive rate of extraction means that the physical stock of the resource is reduced in size

1. Major problems in defining what the physical stock represents
2. The economic reserve size is not the same as the physical size
3. Value of the economic reserve changes over time
4. There are alternative measures for scarcity of the economic reserve

Resource extraction, technological innovation, and exploration through time

A more realistic representation of a non-renewable resource through time in terms of marginal costs and prices (modified version of the south quadrant of the previous figure)



Resource extraction, technological innovation, and exploration through time

- Upper and lower limits of the marginal costs change through time
- Lower MC rise due to extraction
- Rate of rise maybe reduced by new tech.
- The higher MC can fall due to new tech.
- Note that the most expensive reserves are not extracted until the end of the resource's life
- **The backstop** price generally falls due to new tech.
- Non-renewable resource owners can **anticipate** this and extract **more rapidly**

Resource extraction, technological innovation, and exploration through time

- **Economic reserves:** describes that portion of a deposit (or collection of deposits) profitable to extract, given current prices and costs.
  - Costs depend on tech. and cumulative extraction – they change over time
  - Prices also change in response to
    - decisions of extractors over extraction rates
    - Demand for the material
    - Government intervention on prices
- In the figure, the economic reserves are those with a MC less than the price and above the lowest MC

Resource extraction, technological innovation, and exploration through time

Resource lifetime: a frequently cited measure of scarcity. Usually expressed as the economic reserve of a resource divided by its current annual consumption rate, perhaps allowing for growth in its usage

As resource gets scarce its price will tend to rise (substitution). This will reduce consumption and increase production – this will change the lifetime measure

As price rises, producers are encouraged to engage in more exploration, increasing the resource base when there are discoveries

Resource extraction, technological innovation, and exploration through time

Unit cost measures: the earliest arguments about scarcity centered around costs of extraction.

As a mine is depleted, the miners have to travel further and further underground to recover ores or coal, causing labor costs per unit of output to rise → ***unit cost of production rises.***

Can we say that the unit cost rises when the resource base increases and vice versa

- ***Technological progress: reduced unit costs – also increases the size of economic reserves***
- ***We do not have perfect knowledge about the characteristics of all deposits/reserves***
- ***Some inputs may be substituted for others but a researcher can disregard the use of the additional inputs (energy, capital, labor)***
- ***Units costs are poor predictor of future scarcity because they are based entirely on past experience***
    - ***technological advances can increase economic reserves even if unit costs have risen***

Resource extraction, technological innovation, and exploration through time

Real prices: prices are indicators of scarcity

Many criticisms at the use of real price as a scarcity measure:

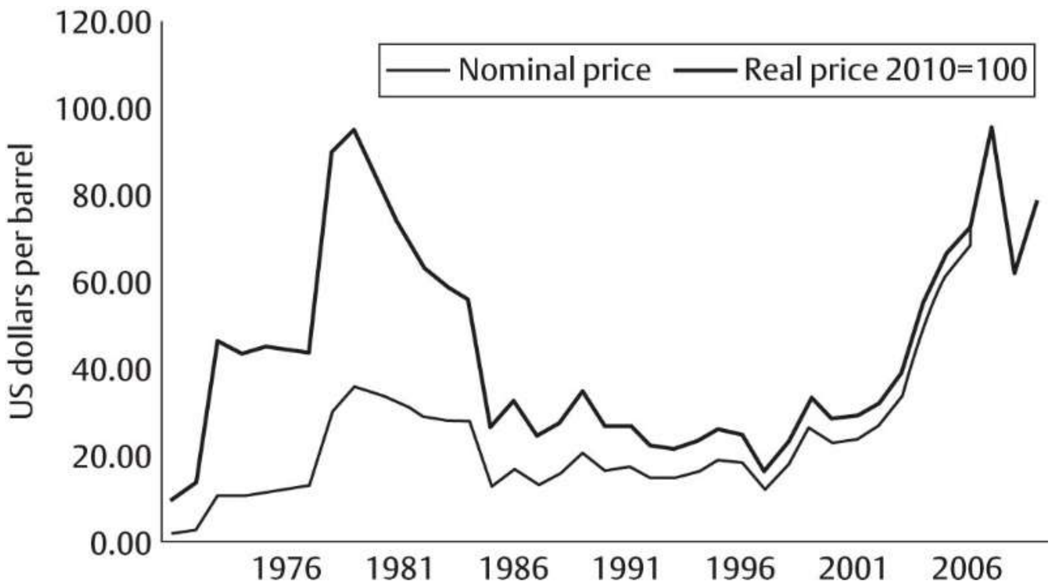
1. ***Producer cartels (OPEC, price hikes in the 1970s)***
2. ***Governments intervention (UK, 1980s; high gas prices to reduce loss in sales by the elec. companies)***
3. ***Natural resource prices do not measure social opportunity costs, partly because producers are not forced to pay for the env damage caused by the extraction and processing of these resources***

Resource extraction, technological innovation, and exploration through time

Economic rent: difference between price and marginal cost. Rising rents are an

Hotelling and the oil market

- Since 1972, the oil market has shown extreme price volatility that cannot be explained by a market price driven by resource scarcity



Global energy demand and supply

- Focus on natural scarcity in part because they are the source of the energy and material needed to drive modern economies
- Energy plays three key roles in our lives from an economic perspective:
    1. Energy is a consumer good
    2. Energy is a factor of production
    3. Energy is a strategic resource

Global energy demand and supply

- As the world economy grows, so does the demand for energy.
- World primary energy consumption (quadrillion Btu)
  - **Primary energy consumption** measures the total energy demand of a country. It covers consumption of the energy sector itself, losses during transformation (for example, from oil or gas into electricity) and distribution of energy, and the final consumption by end users. It excludes energy carriers used for non-energy purposes (such as petroleum not used not for combustion but for producing plastics).

Region	1980	1995	2008
North America	91.6	109.3	121.9
Central and South America	11.5	17.6	25.8
Europe	71.8	76.7	85.8
Eurasia	46.7	42.2	45.8
Middle East	5.8	13.8	25.5
Africa	6.8	10.7	16.1
Asia and Oceania	49.0	95.1	163.5[a]
World total	283.2	365.4	493.0

[a] Data for 2007

Source: US Energy Information Agency, http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=44&pid=44&aid=1&cid=ww,r1,r2,r3,r4,r5,r6,r7,&syid=2004&eyid=2008&unit=QBTU.

Global energy demand and supply

- World production of primary energy by energy type

Energy type/country group	1980	1990	2000	2006
Petroleum	133	136	156	168
Dry natural gas	55	76	91	107
Coal	71	91	90	129
Net hydroelectric power	18	22	26	30
Net nuclear electric power	8	20	26	28
Net geothermal, solar, wind, and wood and waste electric power	0.5	2	3	5
US production of biomass, geothermal and solar energy not used for electricity generation	2	2	2	3
Total energy	288	350	396	469

Source: Energy Information Administration, *International Energy Annual 2006*, http://www.eia.gov/emeu/international/energyproduction.html.

Global issues in energy policy

- Energy plays a crucial role in the modern world
- Policy makes want to control energy for national security reasons
  - They also have added environmental concerns as a justification for intervening in energy markets
  - Private markets can fail to provide the socially desired level of a G or S
    - Energy markets are no exception
  - Global climate change (CO_2), regional acid rain (SO_x,NO_x), local air pollution (smog and particulate matter)
    - All linked to fossil fuel use

Global issues in energy policy

- The question is whether governments should intervene in energy markets for environmental protection? If so, how?
- Three general ways:
  1. By changing economic incentives
  2. Expanding technological options
  3. Information programmes

Changing economic incentives

- Relative prices drive the mix of energy demand
- Governments that want to alter the energy mix can change the relative prices through economic incentives such as taxes and subsidies
- Another policy to change relative prices is to limit emissions or energy use and let people trade permits to pollute
- Changing the relative price of fossil fuels given incentives to reduce energy consumption
  - Drive less
  - Turn down the thermostat
  - More incentives to buy more energy-efficient equipment

Changing economic incentives

- Energy savings will however not be as high as predicted:
  - ***Rebound effect:*** people who drive cars with better fuel consumption drive more since they can get a longer drive with the same amount of fuel
  - The rebound effect works based on <u>substitution</u> and <u>income</u> effects:
    - Increased fuel efficiency reduces the cost of fuel consumption. Due to substitution effect, consumption of the fuel increases.
    - Since the fuel is cheaper, the consumer has more real income, allowing her to consume more other G&S that also use energy

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Expanding technological options

- Government can intervene in the energy market by promoting the R&D of new technologies that address the env problems associated with FF use
  - Government funded programmes
  - Subsidies for private R&D (private sector generally underinvests in this type of R&D – externalities…)

Information programmes

- Government can also try to alter the energy market by providing infor to people about different energy-efficient options