Resource Economics
Lecture 5

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Research & Development
Substitutes
Exploration
Sustainability

Research & Development

- We'll analyze two main types of R&D in the Hotelling model:
    1. Making our resource use more efficient
    2. Making us more efficient at extracting the resource.

Misunderstanding 1

- When we become better at using a resource we need less of it, hence demand falls and so do prices.
- This can explain why prices fall over time.
- Or?

Efficiency in resource use

- Add to the Hotelling model a term making $F_{t+1} > F_t$ for the same amount of resource input E.

Results – Efficiency in resource use

- **Price will increase at the rate of interst.** (Exactly the same prediction as without technological change).
- Cause of misunderstanding: forgetting that the market is forward looking. The market foresees the technical change and hence the price has to rise for resource owners to be indifferent between selling the resource today or tomorrow. With rational expectations the market will ”on average” guess correctly the future technical change.
- Extraction may be increasing in the short run, but has to be decreasing in the long run.

Improving extraction technology

- Add to the Hotelling model with extraction costs an assumption that a given amount of extraction becomes cheaper over time.
- Holding E fixed, M_{t+1} (E)< M_t(E).

Results – extraction cost technology

- Extraction initially increases but will eventually fall.

- The price contains two components:
  - The scarcity rent which increases exponentially. (large if S is small)
  - The extraction costs which fall over time. (small if S is small)

- For sufficiently rapid technical change and/or sufficiently large initial stock the price will fall initially.
- Eventually the price will start rising as the extraction costs play less of a role (go to zero) and scarcity rents increase.

- **New prediction: There should be a correlation between the price *growth* and the *level* of the interest.**

Testing the prediction and the condition

- Is there a correlation between price growth and interest rate level? Not supported by most empirical papers (see later lecture).

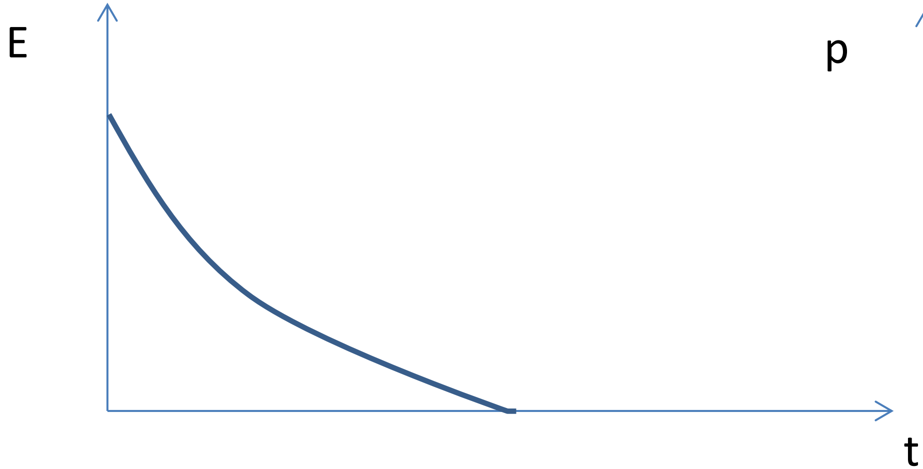
- Do the costs of extraction fall over time?
  - Two sources affect the costs: 1) technology lowers costs while 2) extracting deeper/more remotly increases costs.
  - Costs have remained more or less constant (Lin & Wagener, 2007). The condition leading to falling prices does not have empirical support.

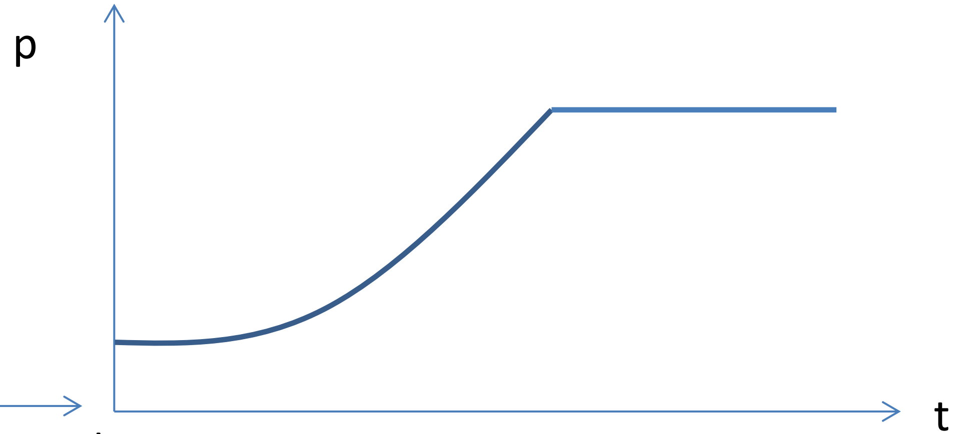
Renewable substitute

- Add a renewable substitute, R, to the basic Hotelling model.
- E.g. Wind instead of coal power, wood instead of concrete houses...

Results: Renewable substitute

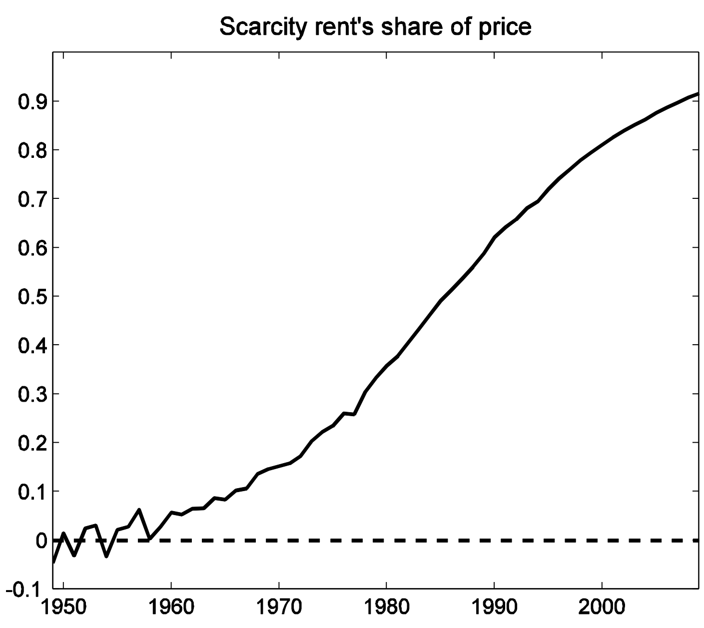
- Extraction falls over time, goes to zero in finite time at which point the renewable substitute is alone in production.
- Price increases over time, goes to a finite value (when S=0) and then stays flat.
- Same prediction: correlation between price growth and interest level.

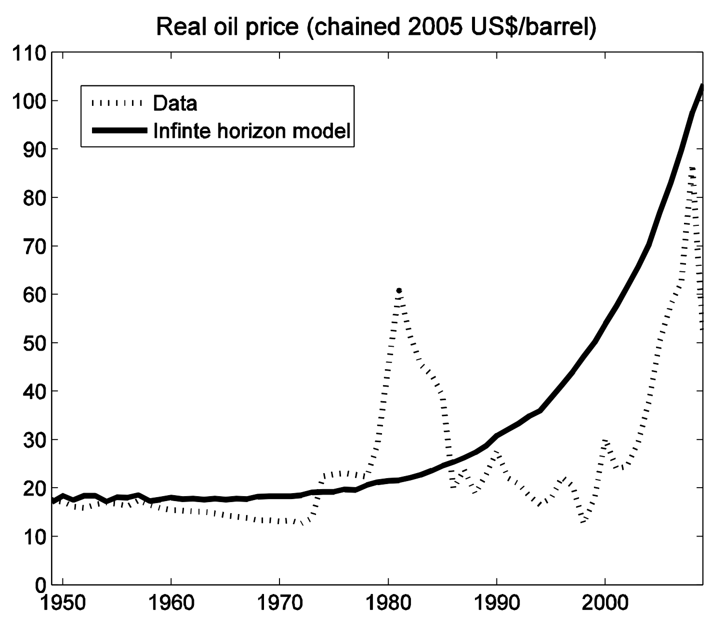




Calibration - Hotelling

- Can a combination of technology, labor, substitutes, capital etc explain the observed oil price?
- Spiro (2014)
- Build a large model, let the model's (Hotelling) agent determine their extraction of oil taking data of technology, labor, capital, extraction costs, total stock, other energy sources as given.





Inventing a substitute

- Kamien & Schwartz (1978)
- At every time period there is a probability, q, that a backstop technology will be invented. I.e. also a sort of technological change.
- Backstop technology roughly means a substitute that exists in sufficient amounts to make the initial resource worthless.
  - Cold fusion based on water.
  - Solar power.
- The resource owner faces a risk that the resource will have no value in the future.

Results – Inventing a substitute

- Extraction falls faster than in the Hotelling model since the owner fears to have too much of the resources once the backstop hits.

- The backstop risk works as an additional component of discounting.

- To be indifferent between extracting today and tomorrow the price needs to rise faster than at the (risk free) rate of interest.

- This continues until the backstop is actually invented.

Backstop exists at higher cost

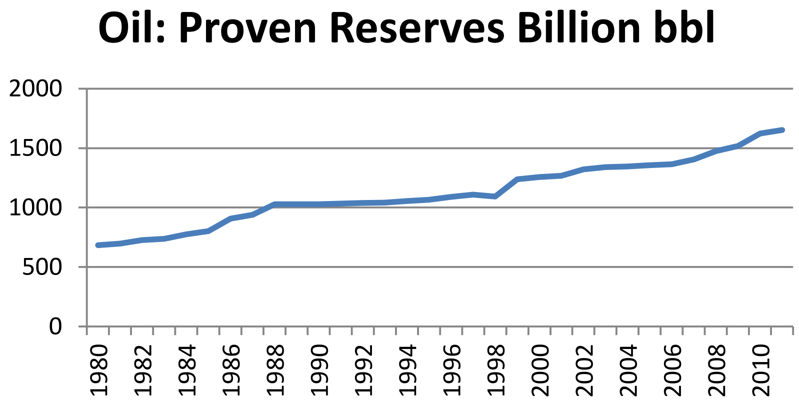
- Heal (1976)
- Suppose there exists a backstop (in endless amounts) but it is too costly to use today.
- Costs of extraction of the exhaustible resource rise as one digs deeper.
- Result:
  - There is no scarcity, only the ”externality” (see Farzin model in previous lecture)
  - Externality rent is large initially (since backstop is far in time) but falls as we approach the backstop. The profitability of the resource market falls.
  - The extraction cost rises.
  - Price approaches the backstop cost of extraction from below
  - In total the price rises or is flat.
  - Why? Roughly: If the price would fall an owner would extract more early in time. This pushes up costs later and hence the price increases.

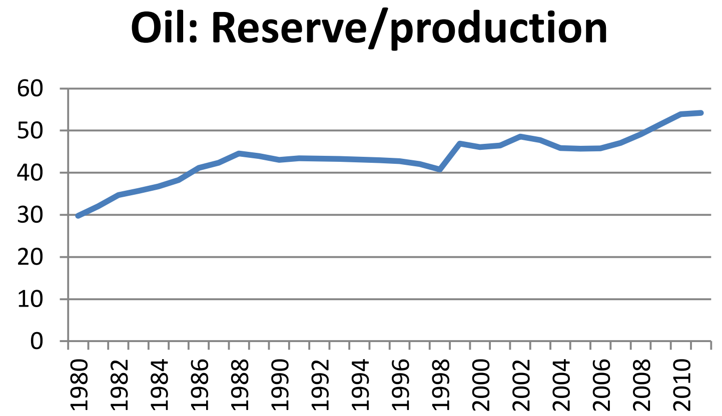
Backstop exists only in the future

- The backstop arrives at a future date which is *known with certainty*.
- Result: the price may rise throughout or first rise and then fall. Counterfactual.
- Is it realistic to assume that the backstop technology is known? E.g. Cold fusion.

Misunderstanding 2 - exploration

- When the world finds new stocks of the resource then the scarcity falls. Hence also the extraction should rise and the price should fall.
- This can explain the empirical observations.
- Or?





Adding exploration

- Arrow & Chang (1982), see Cairns for overview (1990).
- If market participants are forward looking they will expect future findings to arrive.
- Hence, the future findings will be incorporated in the planning already today.
- When a finding is made the price falls momentarily but rises in between findings.
- If the market is ”positivelly surprised” many times the price may fall over long time periods.
- But if the market is ”negativelly surprised” the price will increase.
- With rational expectations positive and negative surprises should occur equally often. Hard to explain falling/constant prices for 57 resources over 100 years.
- The overall price path looks like a sea-saw but has a rising trend.
- Note also: positive surprises still imply a link between price growth and the interest ”between” the surprises. Not supported by data.

A clarification

- If the models with extraction costs, technology, backstop substitutes and exploration cannot explain the broad patters of resource market, does that mean that these things do not affect resource markets?

- No, these are all important activities that indeed take place in practice and surely influence the price. But the conclussion, this far, is that such market mechanisms cannot explain the long run patterns and hence that something has been overlooked. Next lecture will be about non-market mechanisms.

- But it shows, that the scarcity mechanism (Hotelling) has not played an important role in determining the price historically.

Sustainability

- A central question in resource economics is whether we are using our resources in a sustainable manner.
- Sustainability is often defined as “non-decreasing consumption”.
- Note that the Hotelling model with most of its extensions imply falling extraction (and consumption) over time. Such resource use is ***efficient but not sustainable***.
- Why? Discounting (which is what lowers consumption over time) reflects the preferences of the currently living, who (at least when acting on markets) attach a lower value to future consumption. Hence it is efficient from their point of view. But sustainability is requirement on outcomes rather than underlying assumptions.

The Hartwick rule

- If we want to maintain the consumption level while using an exhaustible resource, Hartwick (1977) says we should reinvest all our resource profits in capital (i.e. build machines) that substitutes for the resource.

- Example: Cobb Douglas production, invest αF in capital

$$F = AE^{\alpha}K^{\beta}L^{1-\alpha-\beta}$$

$$C_t + K_{t+1} = F_t + K_t = w_t L + p_t E_t + r_t K_t + K_t$$

$$Resource\ share\ of\ output = \frac{pE}{F} = \frac{F'E}{F} = \frac{\alpha AE^{\alpha-1}K^{\beta}L^{1-\alpha-\beta}E}{AE^{\alpha}K^{\beta}L^{1-\alpha-\beta}} = \alpha$$

- **National interpretation**: Put all resource income in the bank; consume labor income and returns from bank account.

- **Global interpretation**: Saving rate should be α.

Hartwick prerequisites

- If Cobb-Douglas production then it works only if $\alpha<\beta$. Calibration yields that in reality $\alpha \approx$5-10% and $\beta \approx$30%. OK.

- But suppose a more general production function of substitutability (Constant Elasticity of Substitution, CES):

$$F = \left[\gamma\left(AK^{\beta}L^{1-\beta}\right)^{\frac{\sigma-1}{\sigma}} + (1-\gamma)(A_E E)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}$$

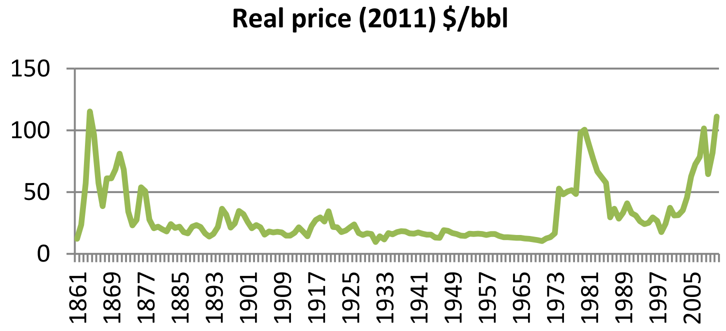
- $\sigma < 1$ high complementarity between resources and labor/machines. $\sigma > 1$ high substitutability. $\sigma = 1$ Cobb-Douglas.

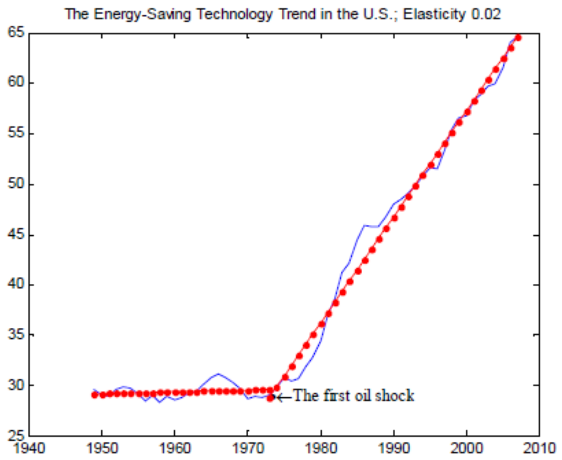
- For Hartwick's rule to work we need $\sigma \geq 1$. Research shows that $\sigma \ll 1$.

- Interpretation: The rule may work on national level but not global level.

Sustainability and technology

- Instead of investing in capital we can improve our technology ←→
- When prices go up there are incentives to become more efficient at using a resource, to find more deposits and to find substitutes.
- This indeed seems to happen (Hassler et al, 2012).





Problems with technology

1. Endogenous growth theory shows that markets generally supply too little investments in technology (because technology is a non-rivalrous good).

2. The market itself needs to be functioning efficiently so that the price signals scarcity. In this light our previous learning is very worrying since it shows than none of the market based models comes close to explaining the long run price and extraction dynamics, suggesting that the market is not efficient (more next lecture). E.g., we needed to assume non-rational expectations for technology or exploration to be a consistent explanation.

3. Laws of thermodynamics…

Technology, sustainability and the laws of thermodynamics

- Smulders (1995) for overview
- The laws of thermodynamics say
  1. Energy and matter cannot be destroyed, only be transferred to alternative states.
  2. Entropy (roughly: disorder) is increasing unless new energy is added, in particular as a consequence of (economic) activity.
- Second law implies:
  - The economic activity in terms of mass is limited by the solar energy reaching the earth.
  - There is a non-zero lower limit to how little matter you can use in producing something.
  - There is a non-zero lower bound for how much that can be recycled.
  - **In terms of consuming resources there is a limit to growth**.

Technology, sustainability and the laws of thermodynamics

- In terms of ***value*** there ***may*** not be a limit.
  - E.g. increase in service production.
  - But people need food (min calories and nutrients) which is irrespective of “value”. This makes population growth problematic.
  - We need efficient markets.
- Will the second law bind any time soon to be relevant?
  - Unknown.
- Will technology be able to offset resource scarcity in the long run?
  - Depends on beliefs about the far future.
- How to deal with such uncertainty from a fairness point of view is a normative question.