

# Econ 366

Fall 2012

Production (Supply) of Exhaustible  
Energy Resources

# I have a deposit of oil. What should I do with it?

- Beverley Hillbillies scenario:
- Jed (with zero exploration costs) discovers that he has an oil deposit. (And since he isn't in Alberta, doesn't need to bid against others for a lease or permit.)
- This deposit is an “asset” that can either be left in the ground (*in situ*) or extracted and sold.
- Jed can make period-by-period extraction decisions himself or sell the entire operation to somebody else (perhaps the OK Oil Company)

# Oil (or natural gas or coal or ...) as an asset

- The exhaustible resource deposit is a 'physical' asset.
  - It can be (partially or entirely) converted into a 'financial' asset by:
    - Selling units of the physical asset (barrels of oil, for example)
    - Investing the proceeds in a financial asset (bond, for example)
  - Consider a simple case
    - 2 assets : oil and bonds; bonds earn  $r$  % per annum
    - 2 periods:  $t=1$ ,  $t=2$
    - All agents are price takers (**competitive\***)
    - Prices are known (or knowable by an understanding of supply and demand)
- \* The assumption of competitive producers will be maintained until we consider monopolies and cartels

# Possible Strategies for Simple Case

- Strategy A

At  $t=1$ : sell a barrel of oil, receive  $\$P_1$ , invest proceeds in bonds

At  $t=2$ : value of bonds is now  $\$P_1(1+r)$  (initial investment plus interest payment)

- Strategy B

At  $t=1$ : hold on to the barrel of oil for sale at a later date (i.e., in order to sell the oil at  $t=2$ )

At  $t=2$ : value of the barrel of oil is now  $\$P_2$

# Equilibrium in Simple Case

- Market will be in equilibrium if

$$\$P_1(1+r) = \$P_2$$

- If  $\$P_1(1+r) < \$P_2$ 
  - No resource owner will want to sell at  $t=1$ , as their final period wealth is higher under strategy B
  - Supply falls in Period 1  $\rightarrow$  higher  $\$P_1$
  - (Expected) supply increases in Period 2  $\rightarrow$  lower  $\$P_2$
  - Move towards equilibrium
- If  $\$P_1(1+r) > \$P_2$ 
  - No resource owner will want to hold onto the resource for sale at a future date ( $t=2$ )
  - Supply \_\_\_\_\_ in Period 1  $\rightarrow$  \_\_\_\_\_
  - (Expected) supply \_\_\_\_\_ in Period 2  $\rightarrow$  \_\_\_\_\_

# Basic Version of Hotelling Rule

- In a competitive market with no extraction costs, the price of an exhaustible energy source will grow by  $r$  % per year, where  $r$  is the rate of interest paid on a risk-free bond
- This is just a re-statement of our equilibrium condition

$$P_1 + P_1 r = P_2 \rightarrow P_1 r = P_2 - P_1$$
$$\rightarrow r = \frac{P_2 - P_1}{P_1}$$

- i.e., if  $r = 0.05$ , we expect the price of oil to grow by 5% per year in this simple ‘world’

# Simple Case with Production Costs of \$c per barrel

- Strategy A

At t=1: sell a barrel of oil, receive  $\$(P_1 - c)$ , invest proceeds in bonds

At t=2: value of bonds is now  $\$(P_1 - c)(1 + r)$  (initial investment plus interest payment)

- Strategy B

At t=1: hold on to the barrel of oil for sale at a later date (i.e., in order to sell the oil at t=2)

At t=2: value of the barrel of oil net of production costs is now  $\$(P_2 - c)$

# Equilibrium in Simple Case

- Market will be in equilibrium if

$$\$(P_1 - c)(1+r) = \$(P_2 - c)$$

- If  $\$(P_1 - c)(1+r) < \$(P_2 - c)$ 
  - No resource owner will want to sell at  $t=1$ , as their final period wealth is higher under strategy B
  - Supply falls in Period 1  $\rightarrow$  higher  $\$P_1$
  - (Expected) supply increases in Period 2  $\rightarrow$  lower  $\$P_2$
  - Move towards equilibrium
- If  $\$(P_1 - c)(1+r) > \$(P_2 - c)$ 
  - No resource owner will want to hold onto the resource for sale at a future date ( $t=2$ )
  - Supply \_\_\_\_\_ in Period 1  $\rightarrow$  \_\_\_\_\_
  - (Expected) supply \_\_\_\_\_ in Period 2  $\rightarrow$  \_\_\_\_\_

# Hotelling Rule with constant (marginal) costs of production

- In a competitive market with constant marginal (equals average) extraction costs, the **net price** of an exhaustible energy source will grow by  $r$  % per year, where  $r$  is the rate of interest paid on a risk-free bond
- This implies that the market price for the resource will grow at a rate that is less than  $r$

$$(P_1 - c)(1 + r) = P_2 - c \rightarrow P_1 - c + P_1 r - cr = P_2 - c$$

$$\rightarrow \frac{P_2 - P_1}{P_1} = r - \left(\frac{c}{P_1}\right)r$$

- How does this differ from Econ 101 results regarding the relationship between Price and Marginal Costs in a competitive industry?

# Exhaustible Resources and Ordinary Goods: A Comparison

- For an ordinary good, the level of production at  $t=1$  does not place a constraint on how much can be produced the next period.
- If it operates over several years, its p.v. of profits will be

$$\sum_{t=1}^T \frac{[ p_t q_t - c q_t ]}{(1 + r)^{t-1}}$$

where there is no fixed relationship between  $q_1, q_2, q_3$ , etc

→ can maximize profits period-by-period , just as in Econ 101

# Exhaustible Resources and Ordinary Goods: A Comparison

- For an exhaustible resource extracted from a fixed stock (deposit), each ‘barrel’ sold today, reduces the amount available for future sales
- If it operates over several years, its p.v. of profits will be

$$\sum_{t=1}^T \frac{[p_t q_t - c q_t]}{(1+r)^{t-1}}$$

where there is a fixed relationship between  $q_1, q_2, q_3$ , etc:

$q_1 + q_2 + q_3 + \dots + q_T = S_1$  ;  $S_1$  is the size of the deposit that the firm starts with

- → can't simply maximize profits period-by-period, ignoring other production decisions in other periods

# Exhaustible Resources and Ordinary Goods: A Comparison

- Solution of the profit-maximizing problem involves “optimal control” or “dynamic programming” methods to find the optimal set of  $q$ 's and  $T$
- Part of the solution is:  $(P_t - c)(1+r) = P_{t+1} - c$
- Exhaustible resources earn a ‘scarcity rent’ or ‘resource rent’ that grows at rate  $r$

# Rents in Resource Markets

- Since price exceeds marginal costs of production, owners of exhaustible resources earn “scarcity rents”
  - the crown, as ultimate owner of the resource in Alberta, collects some of these through royalties and bonus bidding
- Other rents:
  - quality rents (some crudes sold at a premium relative to others)
  - technological rents (some firms may develop and use a better technology → more profits per unit)
  - geological rents (some deposits are easier to extract from due to local geological conditions)
  - locational rents (some deposits are closer to market, closer to existing infrastructure)
  - monopoly rents (some firms may be able to exert “market power”)

# Finding the optimal T

- There are an infinite number of price paths that satisfy  $(P_t - c)(1+r) = P_{t+1} - c$
- Which one is the 'full' equilibrium price path? find the initial price such that the stocks from all producers are exhausted just as demand goes to zero (choke price)
- See series of diagrams from class to go along with the following slides!

# The “optimal” price / supply path with zero costs

- At each point on the price path, there is a corresponding quantity that is demanded (and supplied)
- As time passes, prices rise at rate  $r$  and (moving along the demand curve) per period quantities fall
- Eventually a price  $P_{\max}$  will be reached where demand falls to zero (this is the “choke” price)
  - Case 1: no backstop,  $P_{\max}$  is where demand curve hits price axis
  - Case 2: backstop technology is introduced into the market (a renewable energy source) when the price of the exhaustible resource is sufficiently high;  $P_{\max}$  is associated with positive demand for the backstop, but zero demand for the conventional fuel (perfect substitutes)
- First period price must be such that all deposits (total supply) demand) must be exhausted just as  $P_{\max}$  is reached. Why?

# The “optimal” price / supply path with zero costs

- What if we were on a price path where we would run out of the resource at a price below  $P_{\max}$ ?
  - An astute resource owner would foresee the impending shortage that would occur and would foresee that the price would “jump” to  $P_{\max}$  → incentive to hold back production in order to take advantage of impending price jump
- What if we were on a price path where we would reach  $P_{\max}$  before exhausting the resource?
  - An astute resource owner would foresee that we would end up with a “flat” price path once  $P_{\max}$  (or something just below  $P_{\max}$ ) is reached. If the price can’t grow, better off selling the resource and investing in an alternative financial asset that grows at rate  $r$  → incentive to dump the resource onto the market

# Consider costs that increase from 0 to \$c per unit extracted

$$\frac{P_2 - P_1}{P_1} = r - \left(\frac{c}{P_1}\right)r$$

- Prices now grow over time at a slower rate.
- What would happen if the first period price did not change?
  - Prices in subsequent periods would be lower than when costs were 0
  - More is consumed in each subsequent period (see demand curve)
  - We would run out of the resource before Pmax was reached
- What must happen to the first period price?
- What would happen if a tax were introduced?

# What would happen if ...

- A new deposit of the conventional energy source is found?
- Interest rates on risk-free bonds increased?
- A new alternative energy source is developed?
- Environmental concerns lead to shutting down supply from a particular location?

# Complications: Common Pool Problems

- Consider two firms operating on adjacent tracts of land but extracting from the same pool of oil
- How much can be extracted by one firm (and their costs of extraction) depends on the behaviour of the other firm → externality → excessive drilling, extraction may occur “too quickly” (See “Oil Rush” section in Chapter 14)
- Possible remedies: \_\_\_\_\_

# Other Market Structures: Monopoly

- Monopoly
  - Sets the price in the market: takes into account impact of price on quantity demanded.
  - Since a monopolist is not a “price-taker”, marginal revenue is not the same as price (see diagram in class)

$$\begin{aligned}MR &= P + Q \frac{\Delta P}{\Delta Q} \\ &= P \left[ 1 + \frac{1}{\text{price elasticity of demand}} \right]\end{aligned}$$

# Other Market Structures: Monopoly

- Monopoly
  - “Hotelling” rule becomes  $(MR_t - c)$  grows at rate  $r$   
(since  $P = MR$  for a competitive firm, nothing fundamental has changed here)
  - The Hotelling rule for a monopolist can be written in terms of prices including a component that is a function of what happens to the elasticity of demand as price changes (but it gets a bit ugly).
  - For a straight-line demand curve, it turns out that (see p.223 of textbook):
    - Monopoly price path grows more slowly than competitive price path
    - Monopolist starts at a higher price (why?)
    - The optimal “ $T$ ” is bigger (*friend of the conservationist*)

# Other Market Structures: Cartel (Chapter 14)

- Cartel (OPEC) with competitive fringe (other non-OPEC producers)
  - cartel would like to act as a monopolist, but is not the only owner of the resource
  - Impacts of cartel actions on exploration and development of alternative energy sources
  - Incentive within a cartel to cheat