Short run effects of bleaker prospects for oligopolistic producers of a non-renewable resource

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Introduction

- Nonrenewable resource theory:
  - Dynamic analysis crucial (Hotelling, JPE 1931)
  - Market effects may differ substantially from static analysis

- Future market signals affect current behavior
  - Profitable to extract today or in the future?
  - Example: Shale gas revolution
    - Major, unexpected increase in shale gas reserves
    - How will gas markets respond?
  - Another example: Green paradox literature (Sinn, ITPF 2008; Gerlagh, CESifo 2011)
    - Climate policies may increase current emissions
Large players in non-renewable resource markets

- Oil market: OPEC
- European gas market: Russia, Norway, Algeria, Netherlands
- Salant (JPE 1976), Loury (IER 1986) Polasky (JEEM 1992), Boyce and Voitassak (REE 2008)

How do oligopolistic producers of non-renewable resources respond to future market signals?

- How will large players in the European gas market respond to more shale gas supply in the future?
- Different response for different types of players?

Analytical part: Qualitative results for oligopolistic, non-renewable resource markets

Numerical part: Quantitative analysis for European gas market
Analytical Model

- Two Cournot producers:
  - Produces $q_{it}, q_{jt}$
  - Reserve stocks $S_{it}, S_{jt}$
  - Unit costs $c_i, c_j$

- Linear demand function $p_t = K_t - q_{it} - q_{jt}$
  - $p_t$ is the product price
  - $K_t$ is the choke price

- Continuous time partitioned into two discrete time periods; period 1 ($t \in [0, T]$) and period 2 ($t \in [T, \infty)$).

- Consider effects of change in $K$ at time $T$
Period 2

- Producer \( i \) (and \( j \)) maximizes profits:

\[
\pi_i(S_{iT}) = \max_{q_{it}} \int_{T}^{\infty} e^{-rt} [(K_2 - q_{it} - q_{jt}) - c_i] q_{it} \, dt
\]

subject to:

\[
\dot{S}_{it} = -q_{it}
\]

- Profits in period 2 is the salvage value of the resource at the end of period 1

  - Shadow value of resource stock is positive: \( \partial \pi_i / \partial S_{iT} > 0 \)
  - The shadow value is increasing in \( K_2 \): \( \partial (\partial \pi_i / \partial S_{iT}) / \partial K_2 > 0 \)
Period 1

- Producer $i$ (and $j$) maximizes profits:

$$\max_{q_{it}} \int_0^T e^{-rt} [(K_1 - q_{it} - q_{jt}) - c_i] q_{it} \, dt + \pi_i(S_{iT})$$

subject to: $\dot{S}_{it} = -q_{it}$

- This leads to the following conditions:

$$K_1 - c_i - 2q_{it} - q_{jt} - \lambda_{it} = 0$$

$$\dot{\lambda}_{it} - r \lambda_{it} = -H_{S_{it}} = 0$$

$$\lambda_{iT} = \frac{\partial \pi_i}{\partial S_{iT}}$$

- Transversality condition implies that the marginal discounted value of the resource must be equal across the two time periods.
Production in Period 1

- Solving the system gives optimal production in period 1:

\[ q_{it} = \frac{1}{3} \left( A_{it} + \left( \frac{\partial \pi_j}{\partial S_{j,T}} - 2 \frac{\partial \pi_i}{\partial S_{i,T}} \right) e^{r(t-T)} \right) \]

with \( A_{it} = K_t - 2c_i + c_j \)

- Differentiating wrt. \( K_2 \) yields:

\[ -\frac{\partial q_{it}}{\partial K_2} = \frac{1}{3} \left( 2 \frac{\partial (\partial \pi_i / \partial S_{i,T})}{\partial K_2} - \frac{\partial (\partial \pi_j / \partial S_{j,T})}{\partial K_2} \right) e^{r(t-T)} \]

- Two opposing effects:
  - Intertemporal effect: Shadow value in period 2 is changed
  - Competition effect: Competitor’s output is changed

  - Due to intertemporal effect for the competitor
Effect of a drop in future residual demand

- Alternative 1: Identical producers
  - Production in period 1 increases
    - Intertemporal effect dominates – cf. «Green paradox» literature

- Alternative 2: Producer $i$ has largest reserves
  - Total production in period 1 increases
  - If producer $i$’s reserves are sufficiently large, its production in period 1 decreases
    - Intertemporal effect vanishes for producer $i$, but not for producer $j$
    - Competition effect remains for producer $i$
Effect of a drop in future residual demand

- Proposition: Consider a non-renewable resource market with two Cournot players, linear demand and two time periods, where both Cournot players produce in each period. Consider a downward shift in the second period demand. We then have:
  - Aggregate initial production increases.
  - A resource owner that endows sufficiently large reserves will reduce initial production.
Response of large firm to a drop in future residual demand

Parameter values
\( K_1 = 500, K_2 = 400, \)
\( c_i = c_j = 0, r = 0.04 \)
Solved in GAMS

Large firm’s reserves
The small firms’ share of reserves constant at 1000 units
Numerical example: the European gas market

- «Shale gas revolution»
  - Major shift in expectations regarding shale gas production
    - Technological progress: «Fracking» and horizontal drilling
  - Example: U.S. gas import/export expectations
    - EIA (2007): Gradually increasing import – 20% in 2030
    - EIA (2013): Net gas export from 2020
    - LNG will be shipped to Europe/Asia instead of the U.S.
  - Increased expectations about shale gas production outside North America, too
    - Europe: Poland
    - Large uncertainties
    - IEA/EIA: Unconventional gas will double its share of global gas production from 12% today to 22-25% in 2035
Numerical example: the European gas market

- Market power in European gas market:
  - Five countries supply around 80% of EU gas consumption
    - Russia: 25%
    - Norway: 20%
    - The Netherlands: 15%
    - Algeria and the UK: 10% each
  - Often modelled as Cournot game (Golombok et al., EJ 1995/1998; Holz et al., EE 2008/EJ 2009; Zwart, EJ 2009)
    - The UK: Competitive supply
  - Our model: Consider four Cournot players
Numerical example: the European gas market

- Large differences in reserves:
  - Russia: 45 tcm - R/P (Reserve/Production) = 74
    - Russia supplies own domestic market, too
  - Algeria: 4.5 tcm - R/P = 58
  - Norway: 2.1 tcm - R/P = 20
  - The Netherlands: 1.1 tcm - R/P = 17

- Assume that unit extraction costs increase with accumulated extraction
  - Instead of fixed reserve stock

- Account for different transport costs across producers
Numerical example: the European gas market

- Model two consumer markets:
  - European market: Iso-elastic demand (elasticity = -0.5)
  - Russian market: Iso-elastic demand (elasticity = -0.25)
  - Demand growth calibrated based on IEA

- European market:
  - Four Cournot producers
  - Fixed supply from other European producers
  - Price-responsive, competitive import from other sources
    - No intertemporal behavior

- Russian market:
  - Only Russia supplies at price equal to marginal costs
    - Including the shadow value of the resource
Benchmark scenario: Supply to Europe (bcm)
Benchmark scenario: Price ($ per toe)
Effects of shale gas: Price (\$ per toe)

- Add shale gas supply from 0 in 2020 to 150 bcm in 2035.
Effects of shale gas: Supply to Europe (bcm)

- Russia produces less in all periods
  - Competition effect dominates intertemporal effect
Unit costs and rents for Russia ($ per toe)

- Oligopoly rent much more important than shadow value for Russia
Unit costs and rents for Norway ($ per toe)

- Shadow value more important than oligopoly rent for Norway
Summary and conclusion

- Changed expectations about future demand may affect large producers of non-renewable resources quite differently than small producers.
- Increased future supply of unconventional gas reduces Russia’s market dominance both today and in the future.
  - Sensitivity analysis: Robust qualitative conclusion.
- Related example: Announcing strong future climate policies could reduce current market share for OPEC.
Thank you