Modeling the Dynamic Game Among Oil, Gas, and Shale Producers

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Introduction

- Current world energy consumption level is more than double what its level was in the 1970s.
- Forecasts estimate that world energy consumption will increase by more than 50 percent over the next 30 years.
- Fossil fuels supply more than 80 percent of the energy consumed in the world
  - Petroleum liquids (largest share)
  - Natural gas (3rd largest share)
- Oil and natural gas provide a large share of energy consumption.
- Getting access to secure sources of oil and natural gas is of huge importance for any economy.

- The production and consumption of oil and natural gas raise concerns about:
  - Climate change
  - Fossil fuel price volatility
  - Energy security
  - Possible fossil fuel scarcity
- The impact of oil and natural gas on the future development of renewables is a concern as well.

- It is therefore important to understand the effects of economic factors, strategic factors, and government policy on the production and investment decisions of petroleum producers.

Source: peakoil.com

Source: www.arabianbusiness.com

Research Questions

- How do economic factors, strategic factors, and government policies affect the investment, production, merger, and acquisition decisions of a firm in the petroleum industry?
- How are investment, production, merger, and acquisition decisions of one energy firm influenced by the investment and production decisions of other firms?
- To what extent are current decisions affected by firms' expectations about future economic, strategic, and policy conditions?
- What are the effects of government policies, such as a carbon tax and production quotas; changing geopolitical landscapes, such as the privatization of state-owned oil companies, changes in OPEC policy, and increased costs of mergers; and new technologies, such as new batteries for electric vehicles that may reduce the share of oil and gas in the energy market, on the evolution of the oil and gas industry?
- How should government policies be designed to increase both the profits of energy firms as well as the benefits to consumers and society?

Our Approach

We develop a structural econometric model of petroleum firms' strategic and dynamic decisions regarding:

- Production
- Capital expenditure
- Mergers and acquisitions

Decisions are dynamic:

- Petroleum is a nonrenewable resource => current extraction and production affects the availability of reserves for future extraction and production.
- Investments are irreversible, their payoffs are uncertain, petroleum producers have leeway over the timing of these investment decisions

Decisions are strategic:

- Petroleum producers consider not only future market conditions but also their competitors' investment and production activities when making their current decisions.

Advantages of Dynamic Structural Econometric Model

- Explicitly models the dynamics of production and investment decisions
  - Explicitly models how expectations about future affect current decisions
- Estimates structural parameters of the underlying dynamic game with direct economic interpretations
  - Effects of state variables on firm profits
  - Net effect of strategic interaction
  - Accounts for continuation value
- Parameter estimates can be used to calculate welfare
- Parameter estimates can be used to simulate the effects of counterfactual scenarios on decisions and welfare

Model

We develop and estimate a structural econometric model of a dynamic game among the top 50 petroleum producers in the world.

Each period, each producer decides how much to produce, how much to spend on each type of capital expenditure, whether to merge with or acquire another firm, and whether to be acquired by other firm.

The action a_i of each firm i are assumed to be functions of state variables and private information:

$$a_i = \sigma_i(s, \varepsilon_i),$$

where s is a vector of publicly observable state variables and ε_i is a vector of private information shocks to the agent i which are not observable by either other firms or the econometrician.

State variables include:

- **Firm-specific state variables:**
  - Oil and natural gas reserves
  - Cumulative oil and natural gas output
  - Cumulative exploration, acquisition, and development expenditure
  - Percentage of state ownership
  - OPEC membership
  - Merged in previous year
  - Acquired another firm in previous year
- **Global state variables:**
  - Average industry rate of return on capital for mining and quarry
  - Average capital compensation on other machinery and equipment
  - World population
  - World GDP
  - World motor vehicles
  - World road sector gasoline fuel consumption
  - World electricity production from oil and natural gas sources.

Firm Profits and Payoffs

The per-period profit function from production of oil and natural gas for company i is then given by:

$$\bar{\pi}_i(s, a; \hat{\alpha}, \delta) = \underbrace{\left(p_{oil}(s, Q_{oil})\, q_{i,oil} - \delta_{11} q_{i,oil} - \delta_{12} q_{i,oil}^2 - \delta_{13} z_{i,oil} - \delta_{14} q_{i,oil} \cdot z_{i,oil}\right)}_{\text{Profit from production of oil}}$$
$$+ \underbrace{\left(\sum_{r=1}^{6} p_{ng_r}(s, Q_{ng_r})\, q_{i,ng_r} - \delta_{21} q_{i,ng} - \delta_{22} q_{i,ng}^2 - \delta_{23} z_{i,ng} - \delta_{24} q_{i,ng} \cdot z_{i,ng}\right)}_{\text{Profit from production of natural gas}}$$

Firm i's payoff $\Phi_i(s, a_i)$ from mergers and/or acquisition is also defined as follows:

$$\Phi_i(s, a_i) = \begin{cases} -\Gamma_i^B + EV_j(s; \sigma, \theta) \cdot \eta_1 & \text{if firm } i \text{ acquires firm } j \\ \Gamma_i^S & \text{if firm } i \text{ is acquired by firm } j \\ -\Lambda_i + EV_j(s; \sigma, \theta) \cdot \eta_2 & \text{if firms } i \text{ and } j \text{ merge into one firm} \end{cases}$$

Firms can invest in capital in three forms of exploration, development, and acquisition capital expenditure. Let x_i be the total capital expenditure of firm i, which is given by:

$$x_i = x_{i,exp} + x_{i,dvp} + x_{i,acq}$$

The per-period payoff to a firm is given by:

$$\pi_i(s, a; \hat{\alpha}, \delta, \Gamma, \Lambda) = \pi_i(s, a, \hat{\alpha}, \theta) =$$
$$\bar{\pi}_i(s, a, \hat{\alpha}, \theta) + \omega_1 O_{it,state} + \omega_2 O_{it,OPEC} + \Phi_i(s, a_i) - x_i + \rho_\pi O_{i,state} \bar{\pi}_i + \rho_{CS} O_{i,state} CS_i + \delta_0$$

The expected PDV of the entire stream of per-period payoffs for firm i is given by:

$$V_i(s; \sigma, \theta) = \mathbb{E}\left[\sum_{t=0}^{\infty} \beta^t \pi_i\left(\sigma(s_t, \varepsilon_t), s_t, \varepsilon_{it}; \hat{\alpha}, \theta\right)\right].$$

Data

- We construct a panel data set on the top 50 oil and natural gas producing companies in the world.

- The original source of data is the Petroleum Intelligence Weekly published by Energy Intelligence Group, which reports annual information on different operational criteria as well as financial and other measures of size on the top 50 oil and natural gas producing companies from 1987 to 2011.

Econometric Estimation

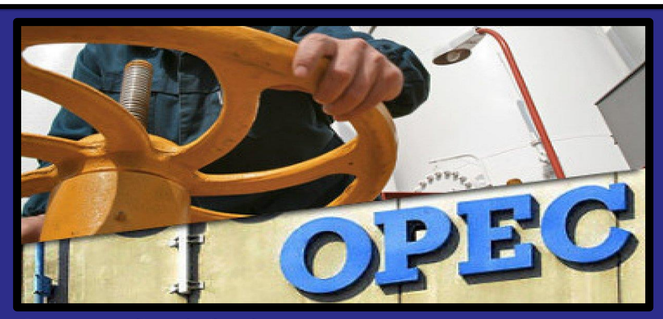
We estimate the structural econometric model in two steps:

First

- Estimate world oil demand and regional natural gas demand.
- Characterize the equilibrium policy functions for the firms' decisions regarding exploration, development, production, merger, and acquisition as functions of state variables by using reduced-form regressions correlating actions to states.
- Estimate the transition density for the state variables.

Second

- In the second step, we use a simulation-based minimum distance estimator to estimate the parameters θ that minimize profitable deviations from the optimal strategy.



Source: www.dispatchtribunal.com

Simulations

- Simulate future evolution of world petroleum industry
- Simulate counterfactual scenarios regarding:
  - Government policies
    - Carbon tax
    - Production quotas
  - Changing geopolitical landscapes
    - Privatization of state-owned oil companies
    - Changes in OPEC policy
    - Increased costs of mergers
  - New technologies
    - New batteries for electric vehicles that may reduce the share of oil and gas in the energy market
- We will analyze the effects of each counterfactual scenario on production, investment, mergers, acquisitions, firm profits, consumer welfare, and net benefits to society.

Conclusions

- We analyze the effects of economic factors, strategic factors, and government policy on the production and investment decisions of petroleum producers.

- It is important to account for both the dynamic and strategic nature of decision-making by petroleum producers.

- Structural econometric models have many advantages, and enable us to examine the effects of counterfactual scenarios and policies on the evolution of the oil and gas industry, firm profits, consumer welfare, and net benefits to society.

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