Market Power in the World Oil Market: Evidence for an OPEC Cartel and an Oligopolistic Non-OPEC Fringe

C.-Y. Cynthia Lin
University of California at Davis
OPEC strategy

The US-OPEC Game

©Hassan Bleibel
Research Questions

• Have OPEC producers colluded?

• Do non-OPEC producers have market power?
Methodology

• Estimate an empirical dynamic model of the world oil market

• Test for market power and collusion
Contributions

• Empirical estimation of Hotelling’s theoretical model

• Addresses identification problem using instruments

• Dynamic model of market power
Hotelling Model

\[ \max_{\{Q(t)\}} \int_0^\infty G(S(t),Q(t)) \, e^{-rt} \, dt \]

s.t.

- \[ S(t) = -Q(t) : p(t) \]
- \[ Q(t) \geq 0 \]
- \[ S(t) \geq 0 \]
- \[ S(0) = S_0 \]
First-order conditions (FOCs)

[#1] perfect competition:
\[ P(t) = \frac{\partial c}{\partial q} + p(t) \]
collusion:
\[ P(t) = -\frac{\partial D^{-1}}{\partial q} Q(t) + \frac{\partial c}{\partial q} + p(t) \]
Cournot:
\[ P(t) = -\frac{\partial D^{-1}}{\partial q} q_j(t) + \frac{\partial c_j}{\partial q_j} + p(t) \]
OPEC as dominant cartel producer:
\[ P(t) = -\frac{\partial D^{-1}}{\partial q} \left( 1 + \sum_{j \notin \text{OPEC}} \frac{\partial q_j(Q_{\text{OPEC}})}{\partial q_{\text{OPEC}}} \right) Q_{\text{OPEC}}(t) + \frac{\partial c_j}{\partial q_j} + p(t) \]

[#2] \[ \dot{p}(t) = \frac{\partial c}{\partial s} + rp(t) \]

[#3] \[ \lim_{t \to \infty} p(t)S(t)e^{-rt} = 0 \]
First-order conditions (FOCs)

[1]
perfect competition:
\[ P(t) = \frac{\partial c}{\partial Q} + p(t) \]
collusion:
\[ P(t) = -\frac{\partial D^{-1}}{\partial Q} Q(t) + \frac{\partial c}{\partial Q} + p(t) \]
Cournot:
\[ P(t) = -\frac{\partial D^{-1}}{\partial Q} q_j(t) + \frac{\partial c_j}{\partial q_j} + p(t) \]
OPEC as dominant cartel producer:
\[ P(t) = -\frac{\partial D^{-1}}{\partial Q} \left(1 + \sum_{j\notin OPEC} \frac{\partial q_j(Q_{OPEC})}{\partial Q_{OPEC}}\right) Q_{OPEC}(t) + \frac{\partial c_j}{\partial q_j} + p(t) \]

[2] \[ \dot{p}(t) = \frac{\partial c}{\partial S} + rp(t) \]

[3] \[ \lim_{t \to \infty} p(t)S(t)e^{-rt} = 0 \]

In the absence of stock effects,
\[ p(t) = p(0)e^{rt} \]
(\text{Hotelling rule})
General supply-side FOC

\[ P(t) = -\theta_1 \frac{\partial D^{-1}}{\partial Q} q_j(t)(1 - I_j^{OPEC}) - \theta_2 \frac{\partial D^{-1}}{\partial Q} Q_{OPEC}(t)I_j^{OPEC} + \frac{\partial C_j}{\partial q_j} + p_j(t) \]
General supply-side FOC

\[ P(t) = \theta_1 \frac{\partial D^{-1}}{\partial Q} q_j(t) (1 - I_j^{OPEC}) - \theta_2 \frac{\partial D^{-1}}{\partial Q} Q_{OPEC}(t) I_j^{OPEC} + \frac{\partial C_j}{\partial q_j} + p_j(t) \]

conduct parameters
General supply-side FOC

\[ P(t) = \theta_1 \frac{\partial D^{-1}}{\partial Q} q_j(t)(1 - I_j^{OPEC}) - \theta_2 \frac{\partial D^{-1}}{\partial Q} Q_{OPEC}(t) I_j^{OPEC} + \frac{\partial C_j}{\partial q_j} + p_j(t) \]

- \( \theta_1 = 0 \Rightarrow \)
  - non-OPEC producers are perfectly competitive price takers
General supply-side FOC

\[ P(t) = \theta_1 \frac{\partial D^{-1}}{\partial Q} q_j(t)(1 - I_j^{OPEC}) - \theta_2 \frac{\partial D^{-1}}{\partial Q} Q_{OPEC}(t)I_j^{OPEC} + \frac{\partial C_j}{\partial q_j} + p_j(t) \]

- \( \theta_1 = 0 \) => non-OPEC producers are perfectly competitive price takers
- \( \theta_1 = 1 \) => non-OPEC producers are Cournot oligopolists
General supply-side FOC

\[ P(t) = -\theta_1 \frac{\partial D^{-1}}{\partial Q} q_j(t)(1 - I_j^{OPEC}) - \theta_2 \frac{\partial D^{-1}}{\partial Q} Q_{OPEC}(t)I_j^{OPEC} + \frac{\partial C_j}{\partial q_j} + p_j(t) \]

- \( \theta_1 = 0 \Rightarrow \) non-OPEC producers are perfectly competitive price takers
- \( \theta_1 = 1 \Rightarrow \) non-OPEC producers are Cournot oligopolists
- \( \theta_1 \in (0,1) \Rightarrow \) non-OPEC producers have intermediate degree of market power
General supply-side FOC

\[ P(t) = -\theta_1 \frac{\partial D^{-1}}{\partial Q} q_j(t)(1 - I_j^{OPEC}) - \theta_2 \frac{\partial D^{-1}}{\partial Q} Q_{OPEC}(t)I_j^{OPEC} + \frac{\partial C_j}{\partial q_j} + p_j(t) \]

- \( \theta_2 = 1 \Rightarrow \) OPEC producers are colluding
General supply-side FOC

\[ P(t) = -\theta_1 \frac{\partial D^{-1}}{\partial Q} q_j(t)(1 - I_j^{OPEC}) - \theta_2 \frac{\partial D^{-1}}{\partial Q} Q_{OPEC}(t) I_j^{OPEC} + \frac{\partial C_j}{\partial q_j} + p_j(t) \]

- \( \theta_2 = 1 \Rightarrow \) OPEC producers are colluding
- \( \theta_2 = 0 \Rightarrow \) OPEC producers are not colluding
General supply-side FOC

\[ P(t) = -\theta_1 \frac{\partial D^{-1}}{\partial Q} q_j(t) (1 - I_j^{OPEC}) - \theta_2 \frac{\partial D^{-1}}{\partial Q} Q_{OPEC}(t) I_j^{OPEC} + \frac{\partial C_j}{\partial q_j} + p_j(t) \]

- \( \theta_2 = 1 \Rightarrow \) OPEC producers are colluding
- \( \theta_2 = 0 \Rightarrow \) OPEC producers are not colluding
- \( \theta_2 \in (0,1) \Rightarrow \) OPEC producers are colluding, but imperfectly
Empirical Estimation

- **General supply-side FOC:**
  \[ P(t) = -\theta_1 \frac{\partial D^{-1}}{\partial q} q_j(t)(1 - I_j^{\text{OPEC}}) - \theta_2 \frac{\partial D^{-1}}{\partial q} Q_{\text{OPEC}}(t)I_j^{\text{OPEC}} + \frac{\partial c_j}{\partial q_j} + p_j(t) \]

- **2SLS regression:**
  \[ P_t = \tilde{\theta}_1 q_{jt}(1 - I_j^{\text{OPEC}}) + \tilde{\theta}_2 Q_{\text{OPEC},t}I_j^{\text{OPEC}} + \beta A_C j_t + p_j 0 e^{-rt} + \alpha_j + v_{jt} \]
  - Include country fixed effects and country fixed effects interacted with \( e^{-rt} \)
  - IV for quantity in non-OPEC countries: country population
  - IVs for total OPEC quantity: country population, world population, real world GDP
Empirical Estimation

- Allow variation by decade
- Vary interest rate $r$
Data

- country-level
- extraction, price and cost for oil
- 1970 to 2004
Results

- OPEC countries collude as the dominant cartel producer
- Non-OPEC countries behave as an oligopolistic fringe
- Market demand for oil is inelastic
- Market demand has become more inelastic over time
- Residual demand faced by OPEC is more elastic than market demand
Results

- Oligopolistic behavior among non-OPEC producers is consistent with Roncaglia (1985)
  - Characterized world oil market until early 1980s as trilateral oligopoly

- Collusion among OPEC producers is consistent with the results of Griffin (1985)
  - Finds that over 1971-1983, the partial market-sharing cartel model could not be rejected for all 11 countries
Conclusion

- Results of the analysis by decade support OPEC countries colluding as the dominant cartel producer and non-OPEC countries behaving as an oligopolistic fringe.

- The residual demand faced by OPEC is more elastic than market demand, which is relatively inelastic.

- Market demand has become more inelastic over time over the period of study.
Thank you
Variables in Model

- \( q_j(t) \) = quantity supplied by producer \( j \) at time \( t \)
- \( Q(t) = \sum_j q_j(t) \) = total quantity supplied
- \( S(t) \) = stock of oil remaining in the ground
- \( P(t) \) = market price of oil
- \( p(t) \) = shadow price of oil
Functions

- **Demand:** $D(P)$
  - markets clear $\forall t$:
    $$Q(t) = D(P(t))$$

- **Cost:** $C(S,Q)$
Per-period profits

- Perfect competition
  \[ G(S,Q) = U(Q) - C(S,Q) \]

- Monopoly (perfect collusion)
  \[ G(S,Q) = D^{-1}(Q)Q - C(S,Q) \]

- Cournot oligopoly
  \[ G(S,q_j) = D^{-1}(Q)q_j - C_j (S,q_j) \]
Per-period profits

- Perfect competition
  \[ G(S,Q,\lambda) = U(Q) - C(S,Q) \]

- Monopoly (perfect collusion)
  \[ G(S,Q) = D^{-1}(Q)Q - C(S,Q) \]

- Cournot oligopoly
  \[ G(S,q_j) = D^{-1}(Q)q_j - C_j(S,q_j) \]
Per-period profits

- Perfect competition
  \[ \pi(S,Q) = U(Q) - C(S,Q) \]

- Monopoly (perfect collusion)
  \[ \pi(S,Q) = D^{-1}(Q)Q - C(S,Q) \]

- Cournot oligopoly
  \[ \pi(S,q_j) = D^{-1}(Q)q_j - C_j(S,q_j) \]
FOCs

perfect competition:  \( P(t) = \frac{\partial c}{\partial q} + p(t) \)

collusion:  \( P(t) = -\frac{\partial D^{-1}}{\partial q} Q(t) + \frac{\partial c}{\partial q} + p(t) \)

Cournot:  \( P(t) = -\frac{\partial D^{-1}}{\partial q} q_j(t) + \frac{\partial c_i}{\partial q_j} + p(t) \)

OPEC as dominant cartel producer:
\[
P(t) = -\frac{\partial D^{-1}}{\partial q} \left( 1 + \sum_{j \notin OPEC} \frac{\partial q_j(Q_{OPEC})}{\partial Q_{OPEC}} \right) Q_{OPEC}(t) + \frac{\partial c_j}{\partial q_j} + p(t)
\]

\( \Rightarrow \) General supply-side FOC:
\[
P(t) = -\theta_1 \frac{\partial D^{-1}}{\partial q} q_j(t) \left( 1 - I_j^{OPEC} \right) - \theta_2 \frac{\partial D^{-1}}{\partial q} Q_{OPEC}(t) I_j^{OPEC} + \frac{\partial c_j}{\partial q_j} + p_j(t)
\]
FOCs

perfect competition: \( P(t) = \frac{\partial c}{\partial q} + p(t) \)
collusion: \( P(t) = -\frac{\partial D^{-1}}{\partial q} Q(t) + \frac{\partial c}{\partial q} + p(t) \)
Cournot: \( P(t) = -\frac{\partial D^{-1}}{\partial q} q_j(t) + \frac{\partial c_j}{\partial q_j} + p(t) \)

OPEC as dominant cartel producer: \( P(t) = -\frac{\partial D^{-1}}{\partial q} \left( 1 + \sum_{j \notin \text{OPEC}} \frac{\partial q_j(Q_{\text{OPEC}})}{\partial Q_{\text{OPEC}}} \right) Q_{\text{OPEC}}(t) + \frac{\partial c_j}{\partial q_j} + p(t) \)

\( \Rightarrow \) General supply-side FOC:

\[
P(t) = -\theta_1 \frac{\partial D^{-1}}{\partial Q} q_j(t) (1 - l_j^{\text{OPEC}}) - \theta_2 \frac{\partial D^{-1}}{\partial Q} Q_{\text{OPEC}}(t) l_j^{\text{OPEC}} + \frac{\partial c_j}{\partial q_j} + p_j(t)
\]
FOCs

perfect competition: $P(t) = \frac{\partial c}{\partial q} + p(t)$
collusion: $P(t) = -\frac{\partial D^{-1}}{\partial q} Q(t) + \frac{\partial c}{\partial q} + p(t)$
Cournot: $P(t) = -\frac{\partial D^{-1}}{\partial q} q_j(t) + \frac{\partial c_j}{\partial q_j} + p(t)$

OPEC as dominant cartel producer: $P(t) = -\frac{\partial D^{-1}}{\partial q} \left( 1 + \sum_{j \in \text{OPEC}} \frac{\partial q_j(Q_{\text{OPEC}})}{\partial q_{\text{OPEC}}} \right) Q_{\text{OPEC}}(t) + \frac{\partial c_j}{\partial q_j} + p(t)$

$\Rightarrow$ General supply-side FOC:

$$P(t) = -\theta_1 \frac{\partial D^{-1}}{\partial Q} q_j(t)(1 - I^\text{OPEC}_j) - \theta_2 \frac{\partial D^{-1}}{\partial Q} Q_{\text{OPEC}}(t) I^\text{OPEC}_j + \frac{\partial c_j}{\partial q_j} + p_j(t)$$

$\theta_1 = 0 \Rightarrow$

non-OPEC producers are perfectly competitive price takers
FOCs

perfect competition: $P(t) = \frac{∂c}{∂Q} + p(t)$
collusion: $P(t) = -\frac{∂D^{-1}}{∂Q} Q(t) + \frac{∂c}{∂Q} + p(t)$
Cournot: $P(t) = -\frac{∂D^{-1}}{∂Q} q_j(t) + \frac{∂c_j}{∂q_j} + p(t)$

OPEC as dominant cartel producer: $P(t) = -\frac{∂D^{-1}}{∂Q} \left(1 + \sum_{j\notin OPEC} \frac{∂q_j(Q_{OPEC})}{∂Q_{OPEC}}\right) Q_{OPEC}(t) + \frac{∂c_j}{∂q_j} + p(t)$

$⇒$ General supply-side FOC:

$$P(t) = -\theta_1 \frac{∂D^{-1}}{∂Q} q_j(t) (1 - I_j^{OPEC}) - \theta_2 \frac{∂D^{-1}}{∂Q} Q_{OPEC}(t) I_j^{OPEC} + \frac{∂c_j}{∂q_j} + p_j(t)$$

$θ_1 = 0 ⇒$
non-OPEC producers are perfectly competitive price takers

$θ_1 = 1 ⇒$
non-OPEC producers are Cournot oligopolists
FOCs

perfect competition: \( P(t) = \frac{\partial c}{\partial q} + p(t) \)
collusion: \( P(t) = -\frac{\partial D^{-1}}{\partial q} Q(t) + \frac{\partial c}{\partial q} + p(t) \)
Cournot: \( P(t) = -\frac{\partial D^{-1}}{\partial q} q_j(t) + \frac{\partial c_j}{\partial q_j} + p(t) \)
OPEC as dominant cartel producer: \( P(t) = -\frac{\partial D^{-1}}{\partial q} \left( 1 + \sum_{j \notin OPEC} \frac{\partial q_j(Q_{OPEC})}{\partial Q_{OPEC}} \right) Q_{OPEC}(t) + \frac{\partial c_j}{\partial q_j} + p(t) \)

⇒ General supply-side FOC:

\[
P(t) = -\theta_1 \frac{\partial D^{-1}}{\partial q} q_j(t)(1 - l_j^{OPEC}) - \theta_2 \frac{\partial D^{-1}}{\partial q} Q_{OPEC}(t)l_j^{OPEC} + \frac{\partial c_j}{\partial q_j} + p_j(t)
\]

\( \theta_1 = 0 \Rightarrow \)
non-OPEC producers are perfectly competitive price takers

\( \theta_1 = 1 \Rightarrow \)
non-OPEC producers are Cournot oligopolists

\( \theta_1 \in (0,1) \Rightarrow \)
non-OPEC producers have intermediate degree of market power
FOCs

perfect competition: \( P(t) = \frac{\partial c}{\partial q} + p(t) \)
collusion: \( P(t) = -\frac{\partial D^{-1}}{\partial q} Q(t) + \frac{\partial c}{\partial q} + p(t) \)
Cournot: \( P(t) = -\frac{\partial D^{-1}}{\partial q} q_j(t) + \frac{\partial c_j}{\partial q_j} + p(t) \)

OPEC as dominant cartel producer: \( P(t) = -\frac{\partial D^{-1}}{\partial q} \left( 1 + \sum_{j \not\in \text{OPEC}} \frac{\partial q_j(Q_{\text{OPEC}})}{\partial Q_{\text{OPEC}}} \right) Q_{\text{OPEC}}(t) + \frac{\partial c_j}{\partial q_j} + p(t) \)

\( \Rightarrow \) General supply-side FOC:

\[
P(t) = -\theta_1 \frac{\partial D^{-1}}{\partial Q} q_j(t)(1 - I_j^{\text{OPEC}}) - \theta_2 \frac{\partial D^{-1}}{\partial Q} Q_{\text{OPEC}}(t)I_j^{\text{OPEC}} + \frac{\partial c_j}{\partial q_j} + p_j(t)
\]
FOCs

perfect competition: \[ P(t) = \frac{\partial c}{\partial q} + p(t) \]
collusion: \[ P(t) = -\frac{\partial D^{-1}}{\partial q} Q(t) + \frac{\partial c}{\partial q} + p(t) \]
Cournot: \[ P(t) = -\frac{\partial D^{-1}}{\partial q} q_j(t) + \frac{\partial c_j}{\partial q_j} + p(t) \]

OPEC as dominant cartel producer: \[ P(t) = -\frac{\partial D^{-1}}{\partial q} \left( 1 + \sum_{j \notin \text{OPEC}} \frac{\partial q_j(\text{OPEC})}{\partial q_{\text{OPEC}}} \right) q_{\text{OPEC}}(t) + \frac{\partial c_j}{\partial q_j} + p(t) \]

\( \Rightarrow \) General supply-side FOC:

\[ P(t) = -\theta_1 \frac{\partial D^{-1}}{\partial Q} q_j(t)(1 - l_j^{\text{OPEC}}) - \theta_2 \frac{\partial D^{-1}}{\partial Q} Q_{\text{OPEC}}(t) l_j^{\text{OPEC}} + \frac{\partial c_j}{\partial q_j} + p_j(t) \]

\( \theta_2 = 1 \Rightarrow \)

OPEC producers are colluding
FOCs

perfect competition: \( P(t) = \frac{\partial c}{\partial q} + p(t) \)
collusion: \( P(t) = -\frac{\partial D^{-1}}{\partial q} Q(t) + \frac{\partial c}{\partial q} + p(t) \)
Cournot: \( P(t) = -\frac{\partial D^{-1}}{\partial q} q_j(t) + \frac{\partial c_j}{\partial q_j} + p(t) \)

OPEC as dominant cartel producer: \( P(t) = -\frac{\partial D^{-1}}{\partial q} \left( 1 + \sum_{j \in OPEC} \frac{\partial q_j(Q^{OPEC})}{\partial Q^{OPEC}} \right) Q^{OPEC}(t) + \frac{\partial c_j}{\partial q_j} + p(t) \)

\( \Rightarrow \) General supply-side FOC:

\[ P(t) = -\theta_1 \frac{\partial D^{-1}}{\partial Q} q_j(t)(1 - I^{OPEC}_j) - \theta_2 \frac{\partial D^{-1}}{\partial Q} Q^{OPEC}(t)I^{OPEC}_j + \frac{\partial c_j}{\partial q_j} + p_j(t) \]

\( \theta_2 = 1 \Rightarrow \)
OPEC producers are colluding

\( \theta_2 = 0 \Rightarrow \)
OPEC producers are not colluding
FOCs

perfect competition: \( P(t) = \frac{\partial c}{\partial q} + p(t) \)
collusion: \( P(t) = -\frac{\partial D^{-1}}{\partial q} Q(t) + \frac{\partial c}{\partial q} + p(t) \)
Cournot: \( P(t) = -\frac{\partial D^{-1}}{\partial q} q_j(t) + \frac{\partial c_j}{\partial q_j} + p(t) \)

OPEC as dominant cartel producer: \( P(t) = -\frac{\partial D^{-1}}{\partial q} \left( 1 + \sum_{j \notin \text{OPEC}} \frac{\partial q_j(\text{OPEC})}{\partial q_{\text{OPEC}}} \right) Q_{\text{OPEC}}(t) + \frac{\partial c_j}{\partial q_j} + p(t) \)

\[ \Rightarrow \text{General supply-side FOC:} \]

\[ P(t) = -\theta_1 \frac{\partial D^{-1}}{\partial q} q_j(t) (1 - I_j^{\text{OPEC}}) - \theta_2 \frac{\partial D^{-1}}{\partial Q} Q_{\text{OPEC}}(t) I_j^{\text{OPEC}} + \frac{\partial c_j}{\partial q_j} + p_j(t) \]

\[ \theta_2 = 1 \Rightarrow \]
OPEC producers are colluding

\[ \theta_2 = 0 \Rightarrow \]
OPEC producers are not colluding

\[ \theta_2 \in (0,1) \Rightarrow \]
OPEC producers are colluding, but imperfectly
National Oil Companies

• NOCs control 77 % of world proven reserves
  • No equity participation by foreign international oil companies
  • Western int’l oil companies control <10 %
• Comprise 14 of the top 20 oil producing companies
• Achieve lower return on capital than major Western oil companies
Objectives of NOCs

• Profit maximization
• International geopolitical and strategic aims
• Domestic politics
• Religion
• Nationalism