Testing Quotas: Subgame Perfect Limits on Oligopolies' Market Power

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What are the limits of OPEC’s collusion?

We model OPEC members playing a repeated Cournot production game. Using a broad equilibrium concept—Subgame Perfect Nash Equilibrium (SPNE)—we can find the limits of what OPEC can ask of its membership in this game. We ask:

- How do OPEC’s historic production and quotas compare to the set of SPNE feasible profits?
- We’ve shown in the past Russia’s participation was necessary to enforce collusion among OPEC members since 2017. Iran was exempted from quotas. We present a counterfactual in which Iran would have accepted quotas (and no sanctions were imposed on Iranian production).
The Game

Assume all $N$ OPEC members (players) choose their production, $q$, simultaneously each period. Non-OPEC supply and global demand are time-invariant functions of price, which can be combined to give an inverse excess-demand-for-OPEC-supply function $P$. Let a period $t$'s profits for player $i$ be:

$$\pi_{i,t}(q_1, \ldots, q_N) = P \left( \sum_{j=1}^{N} q_{j,t} \right) \times q_{i,t} - c_i(q_{i,t})$$

where $c_i(\cdot)$ is player $i$'s cost function.
The Game

Producers select a strategy to maximize the (scaled) net present value of their revenue stream:

$$\text{profit}_i \equiv \frac{1}{1 - \delta_i} \sum_{t=0}^{\infty} \delta_i^t \pi_{i,t}(\bar{q}_t)$$ (1)

where $\delta_i$ player $i$'s is a discount factor.

Coalition members are playing a game where they want their revenue stream high: both high oil prices and high production levels. They can't have their cake and eat it too. They jockey to see who will bear the brunt of lower production to get higher prices for everyone else.
A strategy is a mapping from all players’ production levels (and all possible histories of those actions) to a player’s production level for each period.

A Sub-game Perfect Nash Equilibrium is a strategy profile such that in every period, given that all other players are following the prescribed strategy profile, no player can profit from unilaterally deviating to a strategy other than that prescribed in the SPNE. (We'll call this the incentive constraint.) Very broad equilibrium concept.

The algorithm will return a convex set of profit profiles, which we'll call $V$, of all possible profit profiles supported in SPNE. From that we have to back out the strategies involved.
Approximating $V$

Abreu, Pearce, and Stacchetti (1990) find $V$ theoretically. Judd, Yeltekin and Conklin (2002) approximate it in code and suggest it's possible to do so with more than two players.
Inverse (Excess) Demand Function: 2007

Fringe Production (Regression with data from 2006-2008)

Non-OPEC production inelastic $\implies$ OPEC faces global demand elasticity (taken from Hamilton, 2009) $\implies$ $P_t = 90.02 - 2.23Q_t$
Set of Profits Supported in SPNE

<table>
<thead>
<tr>
<th>Quantities</th>
<th>Saudi</th>
<th>Iran</th>
<th>Kuwait</th>
<th>Venezuela</th>
<th>UAE</th>
<th>Supported</th>
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</thead>
<tbody>
<tr>
<td>2007 Quotas</td>
<td>350.9</td>
<td>128.3</td>
<td>82.3</td>
<td>57.1</td>
<td>80.9</td>
<td>false</td>
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<tr>
<td>2007 Actual Production</td>
<td>345.5</td>
<td>123.9</td>
<td>92.1</td>
<td>52.8</td>
<td>84.5</td>
<td>false</td>
</tr>
<tr>
<td>Max Capacity</td>
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<td>107.5</td>
<td>85.2</td>
<td>43.5</td>
<td>75.3</td>
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<td>Gain from Quotas</td>
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<td>20.8</td>
<td>-2.9</td>
<td>13.6</td>
<td>5.5</td>
<td>NA</td>
</tr>
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</table>

Figure: The profit profiles supported by collusion when the fringe is unresponsive and Saudi Arabia’s cost at the margin is $15 pb.
Finding Saudi Cost at Margin

(a) High MC = $18.75  (b) Mid MC = $17.24  (c) Low MC = $15.00

Figure: A two dimensional projection of the set $V$ estimated for Saudi Arabia, Kuwait, UAE, Iran and Iraq onto profit axis for Saudi Arabia and Kuwait. Parameters of $V$ are in-line with market realities in 2007. Discount factor of 0.707.
2007: Saudi Arabia, Russia, Iraq, Kuwait and UAE

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<td>5.5</td>
<td>NA</td>
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Kuwait Production Over Time

Kuwait's Production, Capacity and Quotas from 2006-2009
November 2006 Agreement Denoted by Dotted Vertical Line

Figure: Data from the EIA
Price and Cost Functions: Scenario 2017

Non-OPEC supply is elastic $\implies$ Need to use OPEC production elasticity (Golombek et al., 2018) $\implies$ $P_t^{brent} = 83.08 - 1.19Q_t$
(a) High MC = $45  (b) Mid MC = $35.91  (c) Low MC = $30

Figure: A two dimensional projection of the set $V$ estimated for Saudi Arabia, UAE, Russia, Kuwait and Iraq onto profit axis for Saudi Arabia and the UAE. Parameters of $V$ are in-line with market realities in 2017. Discount factor of 0.707.
UAE Production Over Time

UAE's Production, Capacity and Quotas from 2016 to Present
January 2017 Agreement Denoted by Dotted Vertical Line

Key
- 94.8% of Capacity
- Capacity
- Production
- Quota

Figure: UAE has produced above quota since the January 2017 agreement. Prior to 2017, it produced at capacity, regardless of quota.
Table: Bootstrap simulations finding probability coalitions can enforce production quotas and the gain in profit possible.