The Impact of Content Regulation on the US Oil Refining Industry
RFF Retrospective Analysis Workshop
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A look back at the cost of fuel content regulations

- Refineries are one of the largest sources of air pollution in the US
  - Direct and Indirect

- Fuel content regulation (1990 Clean Air Act Amendments)
  - Reformulated gasoline (RFG)
    - required in regions with severe ozone pollution (1995, 2000)
  - Lower sulfur diesel (LSD)
    - required for highway distillate (1994)

How did content regulation affect consumer surplus and refinery profits?
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Reformulated Gasoline (RFG) Program

- Mandatory in counties with high smog levels
  - Others opted in
  - 30% of US gasoline market
- Series of performance standards
  - Remove VOCs, toxics, etc
  - Add oxygenates
  - Stricter requirements in summer
  - CA and AZ adopted a more stringent version
- No specific technology involved
Reformulated Gasoline (RFG) Map
Low Sulfur Diesel (LSD)

- Announced 1990, implemented in 1994
- Fragmented the No.2 distillate market
  - Heating oil and non-highway diesel unaffected
  - Highway diesel sulfur capped at 500 ppm
    - Facilitated new heavy-duty engine requirements aimed at reducing particulates
  - Average at the time was 2500 ppm
  - CA adopted a more stringent version
- Sulfur can be removed with desulfurization technology
Low Sulfur Diesel (LSD) Map

NOTE: Circles proportional to the average fraction of distillate that is low-sulfur for each refinery
Important: Refined product markets are interrelated

Multiproduct firms
- Gasoline
- No.2 distillate
- Jet fuel
- RFO

Ship these products to multiple geographic markets

Regulating one market will affect all markets
Refineries serve many markets, but not all markets
Empirical Strategy

1. Estimate structural model of the industry
   - Monthly refinery level data from EIA, 1986-2003
   - Assume firms compete in quantities (Static Cournot-Nash)
   - Demand (Wholesale)
     - Constant elasticity at state-product level
   - Supply
     - Use logit transformation to capture joint production
     - Estimate variable cost of content regs.
     - RFG - no technology
     - LSD - desulfurization

2. Simulate counterfactuals in all markets with regulations removed
Residual demand is fairly elastic

<table>
<thead>
<tr>
<th></th>
<th>Gasoline</th>
<th>All Distillate</th>
<th>High Sulfur Distillate</th>
<th>Low Sulfur Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uninstrumented</td>
<td>0.569</td>
<td>0.790</td>
<td>0.852</td>
<td>0.756</td>
</tr>
<tr>
<td></td>
<td>(0.163)</td>
<td>(0.177)</td>
<td>(0.149)</td>
<td>(0.248)</td>
</tr>
<tr>
<td>Instrumented</td>
<td>1.119</td>
<td>0.425</td>
<td>1.157</td>
<td>1.268</td>
</tr>
<tr>
<td></td>
<td>(0.371)</td>
<td>(1.326)</td>
<td>(2.430)</td>
<td>(0.910)</td>
</tr>
<tr>
<td>First Stage F-stat</td>
<td>25.35</td>
<td>4.35</td>
<td>11.56</td>
<td>8.5</td>
</tr>
<tr>
<td>Joint Estimates</td>
<td>1.324</td>
<td>2.046</td>
<td>4.335</td>
<td>2.219</td>
</tr>
<tr>
<td></td>
<td>(0.032)</td>
<td>(0.092)</td>
<td>(0.208)</td>
<td>(0.089)</td>
</tr>
</tbody>
</table>

Notes: All regressions contain state-month and time dummies. Standard errors in parentheses. Offline regressions clustered at state level. Joint standard errors are robust.

Results consistent with Muehlegger & Sweeney (2021)
## Reformulated Gasoline Costs (c / gal)

<table>
<thead>
<tr>
<th>Reformulated Gasoline</th>
<th>Est</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>9.3</td>
<td>(0.56)</td>
</tr>
<tr>
<td>RFG 1 Summer</td>
<td>0.0</td>
<td>(0.36)</td>
</tr>
<tr>
<td>RFG 2</td>
<td>-0.7</td>
<td>(0.15)</td>
</tr>
<tr>
<td>RFG 2 Summer</td>
<td>3.1</td>
<td>(0.29)</td>
</tr>
<tr>
<td>CARB</td>
<td>0.7</td>
<td>(0.68)</td>
</tr>
<tr>
<td>CARB Summer</td>
<td>3.4</td>
<td>(0.41)</td>
</tr>
<tr>
<td>MTBE</td>
<td>-3.8</td>
<td>(0.29)</td>
</tr>
</tbody>
</table>

**Average RFG Cost**  7.1  (0.93)

### EPA Estimates

- **Phase 1**: 4.8-7.8
- **Phase 2**: 8.6

### NPC Estimates

- **Phase 1**: 8.6
- **Phase 2**: 11.5
Estimated RFG Cost by Refinery

Estimated Cost of RFG ($\beta_r$) by Refinery

Vertical Bars Reflect 95% Confidence Intervals
### Low Sulfur Diesel Costs (c / gal)

<table>
<thead>
<tr>
<th>Low Sulfur Diesel</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.7</td>
</tr>
<tr>
<td>Upgrading Capacity</td>
<td>-2.8</td>
</tr>
<tr>
<td>% Desulfurization</td>
<td>7.2</td>
</tr>
<tr>
<td>% Desulfurization $^2$</td>
<td>1.1</td>
</tr>
<tr>
<td>Crude Sulfur</td>
<td>1.1</td>
</tr>
<tr>
<td>% Desulfurization * Sulfur</td>
<td>-2.1</td>
</tr>
<tr>
<td>API Gravity</td>
<td>17.2</td>
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<tr>
<td>% Desulfurization * API</td>
<td>-32.8</td>
</tr>
<tr>
<td>CA</td>
<td>2.4</td>
</tr>
<tr>
<td>Small Refinery</td>
<td>1.5</td>
</tr>
</tbody>
</table>

**Average LSD Cost**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3</td>
<td>(0.42)</td>
</tr>
</tbody>
</table>

EPA Estimate 4.3

NPC Estimate 6.8

A 50% increase in desulfurization leads to a 1.5-cent decrease in cost.
Estimated LSD Cost by Refinery

Estimated Cost of LSD ($\beta_t$) by Refinery

- Vertical Bars Reflect 95% Confidence Intervals
How would prices and profits differ without RFG and LSD requirements?

- Group states into 9 regions
- Counterfactuals remove cost of RFG and LSD

NOTE: Triangles indicate refineries which exited by 2012.
Counterfactual Results

Reformulated Gasoline Surplus Change:

- Regulated consumers: -$2.85 billion/year
- Unregulated consumers: $1.27 billion/year

Low Sulfur Diesel Surplus Change:

- Regulated consumers: -$885 million/year
- Unregulated consumers: $241 million/year

Change in Refinery Profits:

- Markups on RFG increased 0.3 to 2.5 cpg
- LSD markups decrease slightly
- Total operating profits decrease by $1.1 billion/year (8%)
Summary

▶ Comparison with ex ante cost predictions.
  ▶ RFG cost per gallon of RFG was in mid range of EPA estimates. Below the NPC.
  ▶ Low sulfur diesel costs below both EPA and NPC.

▶ Significant heterogeneity in costs across refineries.
  ▶ For RFG, this “flexibility” may have undermined program benefits (Auffhammer and Kellogg, 2011)
  ▶ For LSD, this was due to large investment in desulfurization technology. Possibly in anticipation of subsequent sulfur regulations.

▶ Important to account for spillovers across markets.
  ▶ 40% of the consumer costs in regulated markets offset by consumer gains in Unregulated markets.
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Thank You