Environmental Regulation and Market Structure: Evidence from US Oil Refineries

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Motivation

- **Environmental:** - Petroleum products are a major source of criteria air pollutants. Significant regulation over the past two decades
- **Economic:** - Americans spend about $500B/ year on gasoline.
- **Political:** - House Energy committee recently passed the *Gasoline Regulations Act of 2012* H.R. 4471 - Prevents enactment of new EPA gasoline regulation until an appointed panel assesses the impact on **gas prices, refining costs, potential loss of refining capacity and domestic employment**.

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- Refining characterized by large capital investments and perennial competitive concerns (FTC 2006, 2011).
- Structural model will be able to estimate welfare (costs) of existing policies and simulate counterfactuals of current policy interest.

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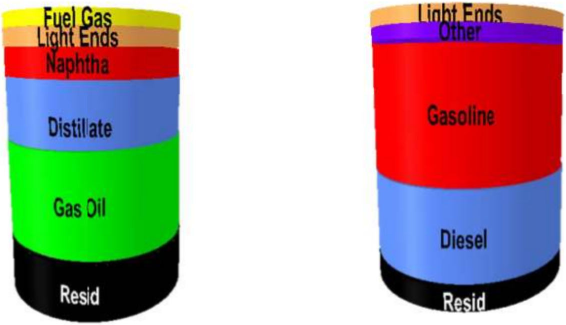
- Refinery Economics
- Industry Trends
- Research Questions / Existing Literature
- Data
- Estimation Overview

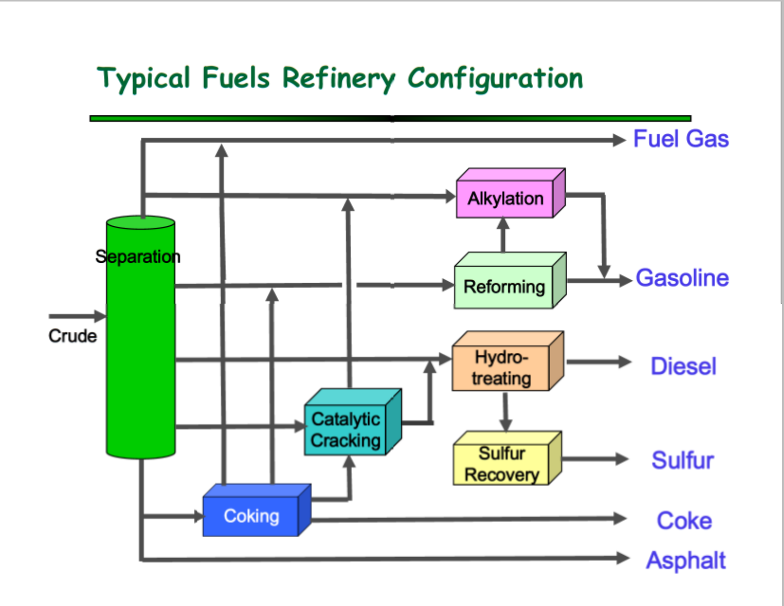
Why Crude Needs Processing

What We Have | **What We Need**



What refineries do

- Buy crude, convert it into end products we consume (gasoline, jet fuel, heating oil, etc)
- During this process they also remove contaminants the oil (Sulfur, Nitrogen, Heavy Metals).
- They may also improve fuel quality to meet specifications, but end product is essentially undifferentiated.
- By far most valuable end product is gasoline, then diesel. All else equal refineries aim to increase yields of these products.

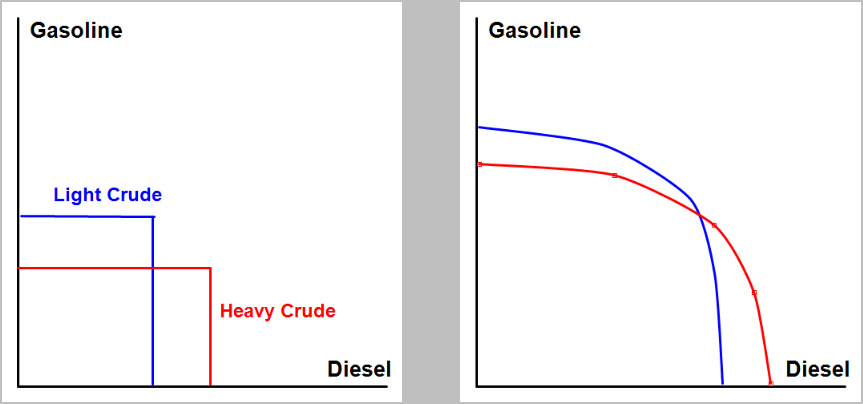

Typical Fuels Refinery Configuration
Fuel Gas
Alkylation
Separation
Reforming
Gasoline
Crude
Hydro-
treating
Diesel
Catalytic
Cracking
Sulfur
Recovery
Sulfur
Coking
Coke
Asphalt

All Crudes Are Not The Same

Crude differentiated along two dimensions:

- **API Gravity (density)** - "Heavier" crudes have lower API Gravity
- **Sulfur Content** - Crudes with higher sulfur content are called "sour"
- The heavier and more sour the crude, the more difficult and expensive it is to turn into usable light refined products.
- The price of oil you usually hear quoted ($107 a barrel this week) is the price of a light, sweet grade like West Texas Intermediate.

PPF with and without Downstream Technology



3 Important Trends

Trend 1: Lots of Environmental Regulation

- The 1990 Clean Air Act Amendments:
  - Reid Vapor Pressure Regulation (summer, regional)
  - Oxygenate Programs (winter, regional)
  - Reformulated Gasoline Program (regional) → Today, 15 distinct fuels are required in portions of 12 different states.
- Tier II Gasoline Sulfur program (2004). Average sulfur content was capped at 30 ppm, down from avg. of 270 (national)
- Ultra-low-sulfur Diesel program. Beginning June 2006 highway diesel sulfur content capped at 15 ppm, down from 500 (national).
- Renewable Fuels Mandate
- Numerous Point Source Regulations

Trend 2: Exit From The Industry

- In 1982 there were 301 operable refineries in the United States. Today there are 148 (around 10 of them are idle).
- Exit Only. No new refineries built in the US since the 1970s.
- However total capacity has actually increased.

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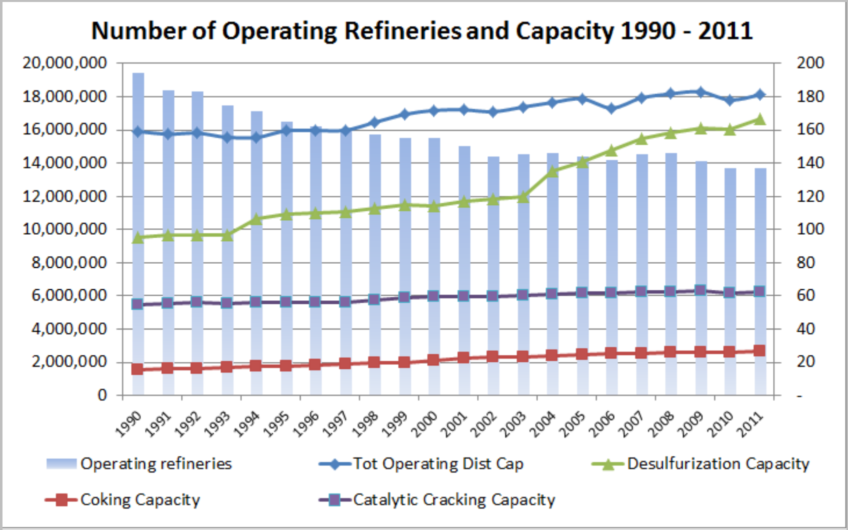
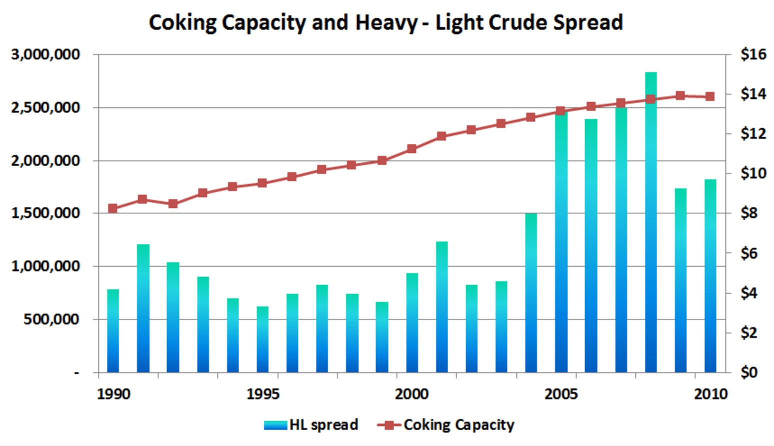


Number of Operating Refineries and Capacity 1990 - 2011
20,000,000
18,000,000
16,000,000
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
200
180
160
140
120
100
80
60
40
20
-
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011
Operating refineries
Tot Operating Dist Cap
Desulfurization Capacity
Coking Capacity
Catalytic Cracking Capacity

Trend 3: Increasing Heavy-Light Crude Spreads



Conflicting Pressures on Market Structure

Reformulation and blending requirements increase marginal cost of transportation fuels...... But exits due to fixed costs associated with compliance means that refineries that stay face less competition.

Advent of cheap heavy crude increase value of investing in upgrading..... But content regulations were relatively more binding on these lower quality crudes that require lots of processing.

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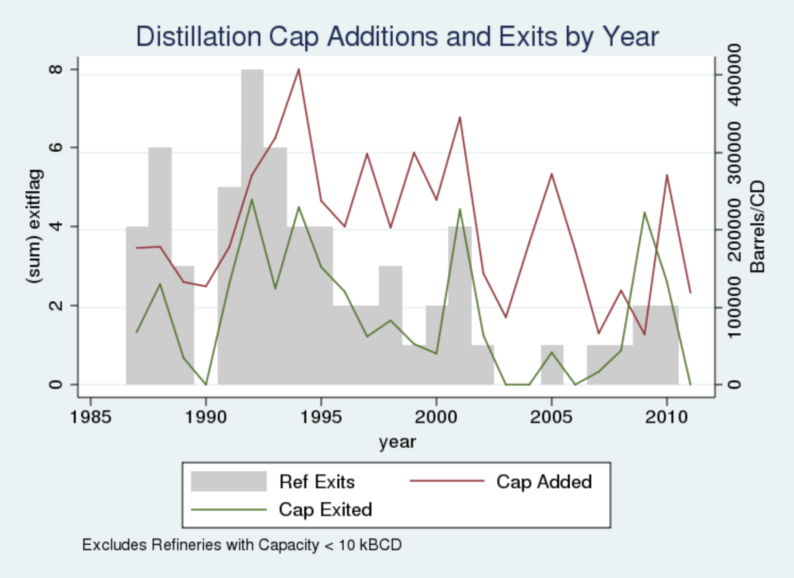
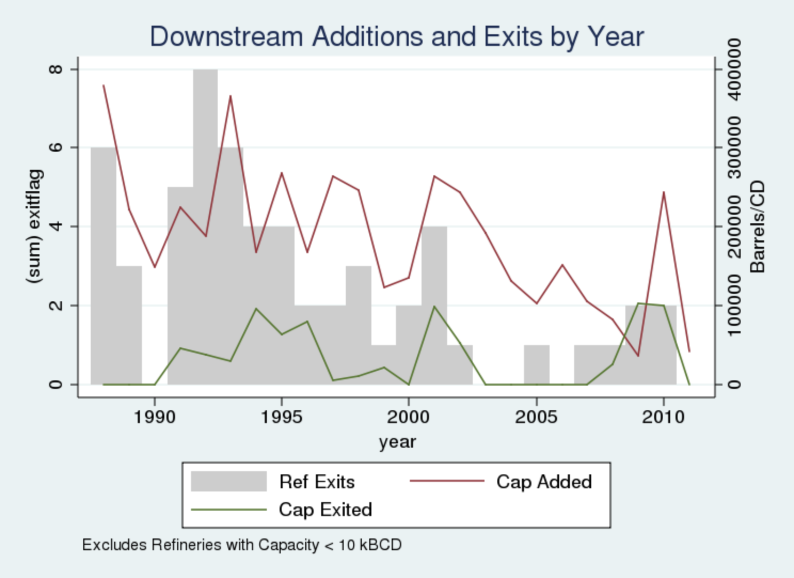

Distillation Cap Additions and Exits by Year
(sum) exitflag
0
2
4
6
8
Barrels/CD
0
100000
200000
300000
400000
1985
1990
1995
2000
2005
2010
year
Ref Exits
Cap Added
Cap Exited
Excludes Refineries with Capacity < 10 kBCD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0
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1990
1995
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Ref Exits
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Cap Exited
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Research Questions

1. What are the costs of gasoline content regulation?
   - Impact prices, both through cost changes and competitive effects.
   - Are environmental regulations to blame for refinery exit?
   - What would the technology mix of refinery fleet look like without regulation?
2. Policy counterfactuals:
   - What are the implied regulatory costs of bringing a new refinery on line? How would it effect gas prices?
   - Keystone XL
   - Tier III Sulfur Regulations
   - Mergers

Existing Literature

- Muehlegger (2006) - finds that boutique fuels increase gas price volatility
- Brown et al. (2008) - find that RFG program increased gas prices by 3 cents/ gal. on average. Range 0 - 8 cents, correlated with number of suppliers to the market.
- Berman and Bui (2001) - Look at impact of strict local regulations on SCAQMD refineries in late 1980s, find regulations were productivity enhancing (Porter hypothesis).
- Ryan (2006) - fixed costs of environmental regulation are important.

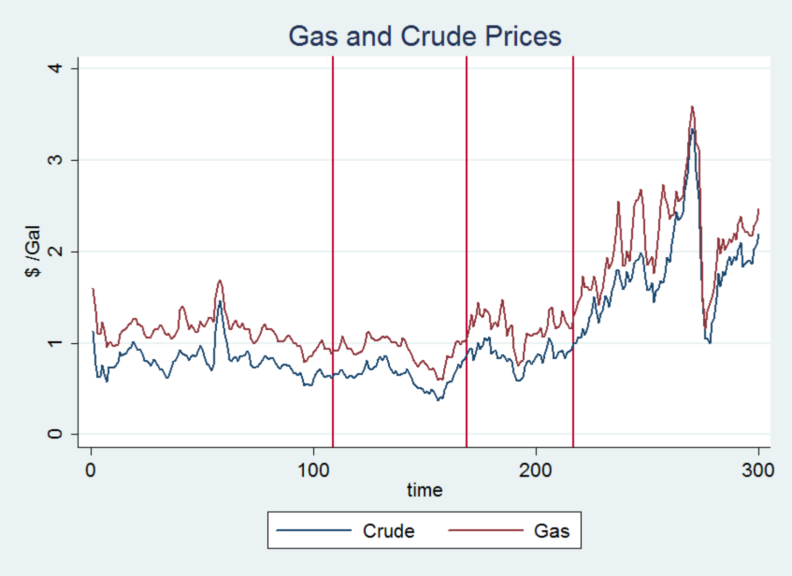
Data

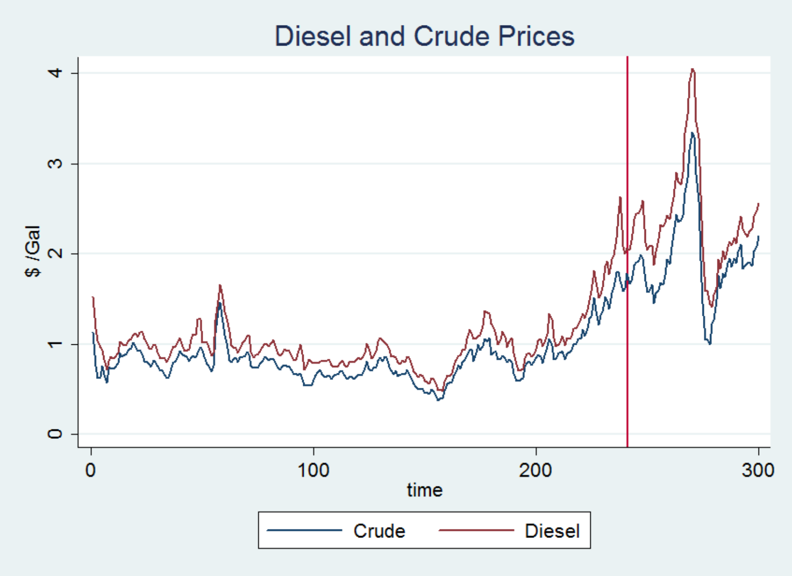
Confidential monthly data for every US refinery from 1986 - 2011:

- **Inputs:** Actual crude input volume, along with the average sulfur content and gravity of that crude.
- **Technology:** Total capacity for all major post-distillation processes: Catalytic Reformation, Catalytic Cracking, Catalytic Hydrocracking, Fluid and Delayed Coking, and Hydrotreating.
- **Production:** Actual production of all end products, including gasoline, diesel, jet fuel and fuel oil.
- Sales volumes and prices, by firm, by state, for all end products.

Empirical Challenges

- Lots of regulation implemented nationally (no easy control group)
- Even regional regulation is tricky because markets are all linked (Bullow et al. 1985)
- Lots of other stuff going on on affecting demand: CAFE, ethanol mandates, etc.


Gas and Crude Prices
$ /Gal
0
1
2
3
4
0
100
200
300
time
Crude
Gas


Diesel and Crude Prices
$ /Gal
0
1
2
3
4
0
100
200
300
time
Crude
Diesel

Estimation Overview

- General idea is to estimate a dynamic structural model of the industry and to use this to simulate policy counterfactuals.
- Static game: Nash in quantities
- Dynamic game: Incomplete information investment game
  - both discrete (exit) and continuous (investment) controls
- Estimate as much as possible in static setting, then use these parameters as inputs to the dynamic model.

Static Competition

Conditional on the technology installed, producer's problem is:

$$max_q \ \ \pi_{jmt} = P(Q_{mt})q - \Psi(q, X_{jmt})$$

X_{jmt} includes Technology, API Gravity, Sulfur Content, Crude Price, Regulations, and Transportation Costs.

$$\textbf{FOC:} \quad P(Q_{mt}) + P'q - \psi(q, X_{jmt}; \theta) + \epsilon_{ijfmt} = 0$$

Where ϵ_{ijfmt} is the structural error. Could include fixed effects to highlight identification:

$$\epsilon_{ijfmt} = \nu_i + \nu_t + \nu_{mjt} + \eta_{ifjt}$$

Moments: $E[z_i \eta_{ifjt}] = 0$

Two Approaches to Estimate ψ

Option 1: Assume multiproduct output transformation function takes CES form (Arrow, Chenery, Minhas and Solow (1961); Zhang (2011))

Option 2 Estimate Translog Cost Function

Demand

- Only need to estimate aggregate demand by wholesale market.
- CES demand function: $Q = AP^{\alpha}$
- A includes month and year fixed effects, state population and GDP/cap
- Instrument for price with crude price
- Estimate: $\hat{\alpha} = -.067(.0061)$, $R^2 = .9716782$
- Consistent with Hughes, Knittel, Sperling (2008): -0.034 to -0.077 from (2001 to 2006)

Dynamic Game

Timing:

1. At the beginning of each period, firms realize investment outcomes, learn who's in the market this period, and observe every firm's static cost shock ν.
2. Firms realize demand shocks and play Cournot.
3. Firms draw a period specific exit value ϕ and investment cost ζ_k draws, and decide whether to exit or invest (x).

This leads to the Bellman equation,

$$V_j(s;\sigma(s),\nu_j,\theta) = \pi_i(s;\theta) + Max\Big\{\phi_j, Max_x\Big\{ -f(x,\zeta_k) \\ + \beta \int E_\nu V_j(s';\sigma(s'),\nu_j,\theta)dP(s_j + x, s'_{-j}; s, \sigma(s))\Big\}\Big\}$$

Dynamic Estimation

Challenges:

- Large state space: 200 refineries, 4+ types of capital, crude price, demand, heavy-light spread
- Overlapping markets + No Entry → Only observe most states once

On the plus side:

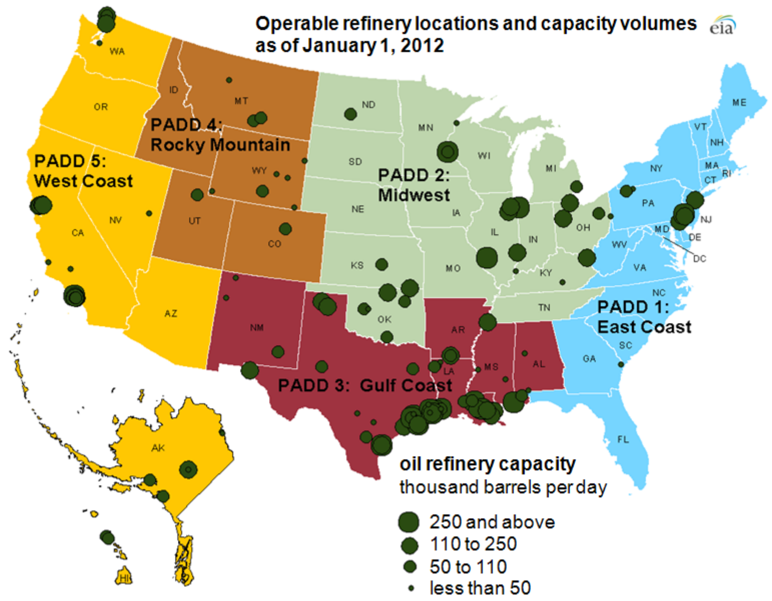
- Good estimate of static profit function
- Observable information about expectations: crude futures.
- Use complexity index from refining lit to reduce technology state space to single dimension.

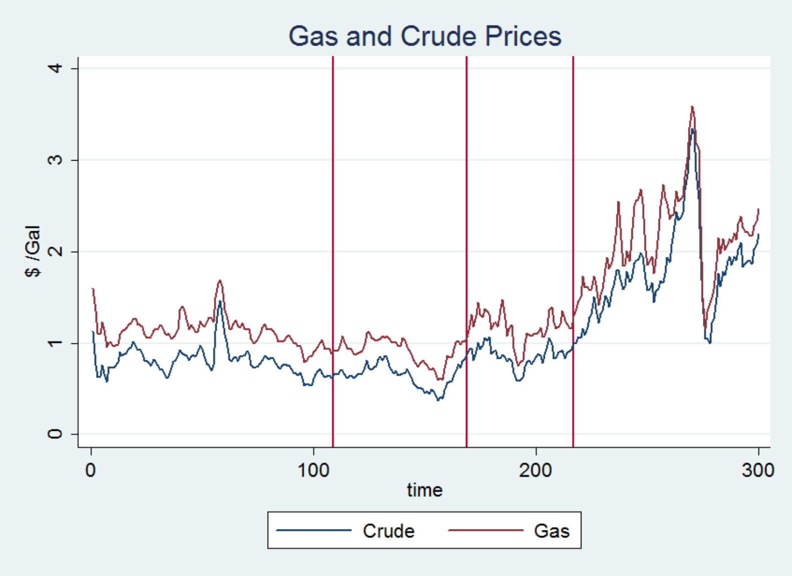
Possible Solutions

- Brute Force - Use MPEC (Judd and Su 2012)
- Two Step Estimators: BBL, POB
- Reduced Form Approximation to Value Function (Pakes 2012) //
$$V_j(s;\sigma(s),\nu_j,\theta) = \pi_i(s;\theta) + F(s) + ...$$
- Berry and Pakes (2002) show future profits can be used to replace value function
- Repeated two-stage game

Thank You!

BACKUP


Operable refinery locations and capacity volumes as of January 1, 2012
eia
PADD 5: West Coast
PADD 4: Rocky Mountain
PADD 2: Midwest
PADD 3: Gulf Coast
PADD 1: East Coast
WA
OR
CA
NV
AZ
AK
HI
ID
MT
WY
UT
CO
NM
ND
SD
NE
KS
OK
TX
MN
IA
MO
AR
LA
WI
IL
MI
IN
OH
KY
TN
MS
AL
ME
VT
NH
MA
RI
CT
NY
PA
NJ
DE
MD
DC
WV
VA
NC
SC
GA
FL
oil refinery capacity
thousand barrels per day
250 and above
110 to 250
50 to 110
less than 50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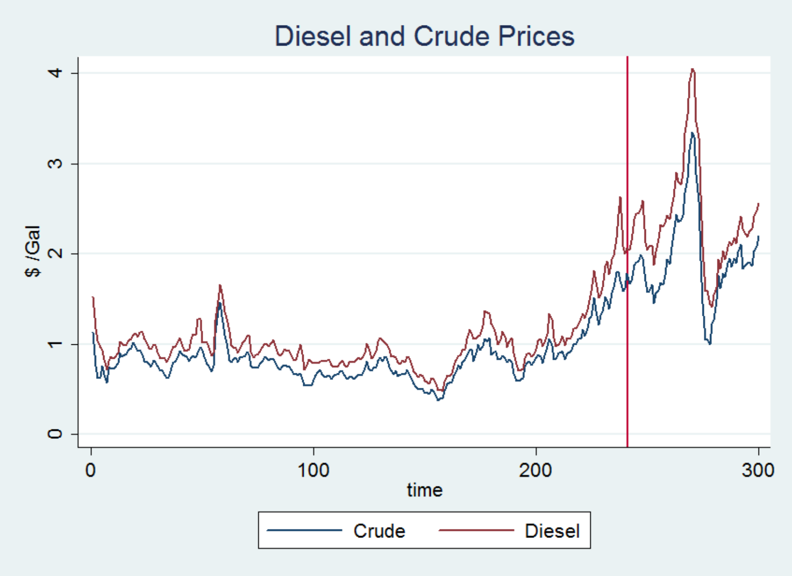
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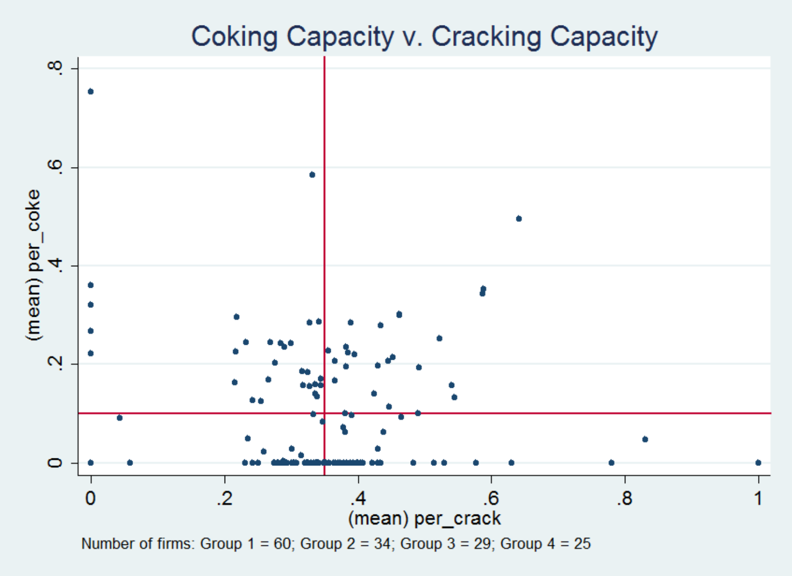
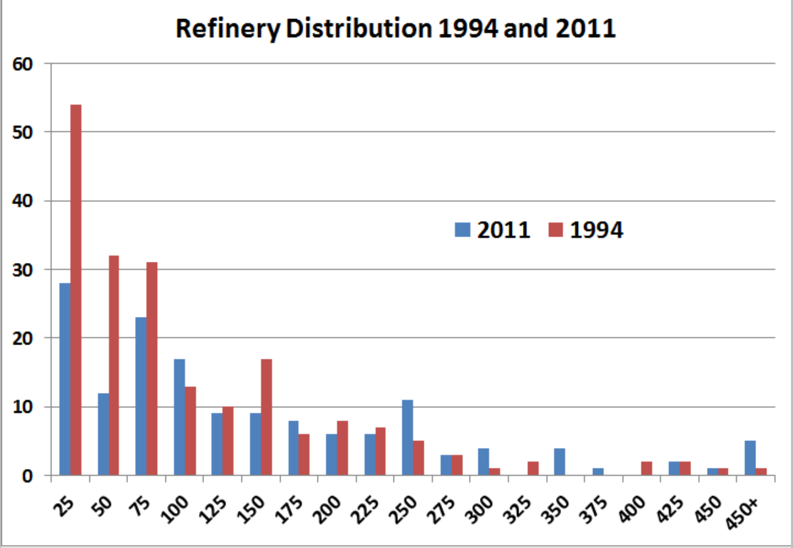
0
1
2
3
4
0
100
200
300
time
Crude
Diesel


Coking Capacity v. Cracking Capacity
(mean) per_coke
0
.2
.4
.6
.8
0
.2
.4
.6
.8
1
(mean) per_crack
Number of firms: Group 1 = 60; Group 2 = 34; Group 3 = 29; Group 4 = 25


Refinery Distribution 1994 and 2011
60
50
40
30
20
10
0
2011
1994
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425
450
450+

Industry Concentration

	Company	Num. of Refineries	Capactity (bbl/cd)	Market Share
1	Valero	12	2,310,000	13%
2	ConocoPhillips	13	2,226,400	12%
3	Exxon/ Mobil	7	2,065,500	11%
4	BP	5	1,539,000	8%
5	Shell	7	1,470,000	8%
6	Marathon	7	1,188,000	6%
7	Chevron	6	1,021,000	6%
8	Flint Hills	4	840,000	5%
9	Citgo	3	770,000	4%
10	Sunoco	3	685,000	4%
	Rest	70	4,215,150	23%
	Total	**137**	**18,330,050**	