Closer to One Great Pool? Evidence from Structural Breaks in Oil Price Differentials

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Federal Reserve Bank of Dallas

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Disclaimer

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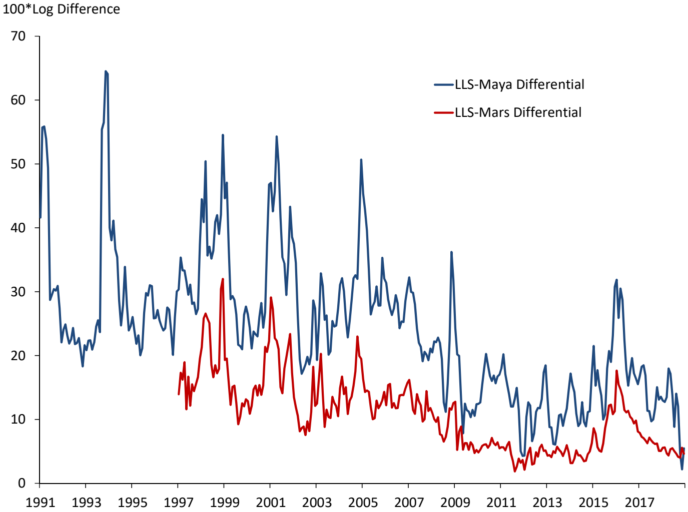
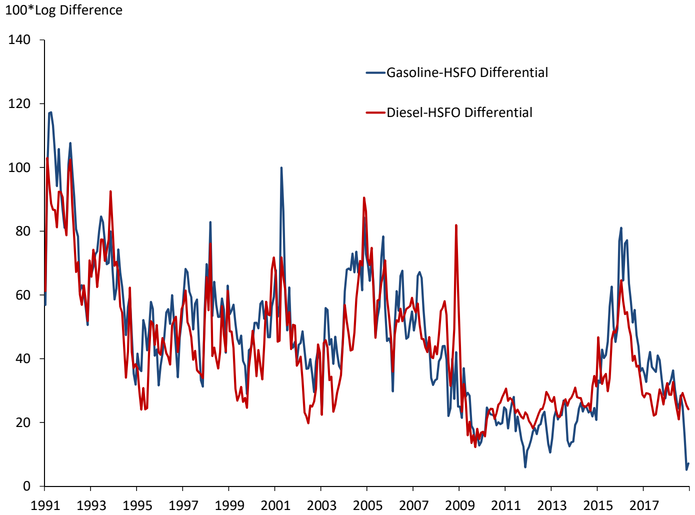
  - Pipeline issues usually not important (except Canada recently)
- Connections with policy issues such as IMO 2020, U.S. export ban
- Our paper discusses some interesting changes in these quality-related crude differentials

Gulf Coast Quality Differentials



"Quality" Differentials for Products



Questions

Visual evidence motivated us to ask:

1. How prevalent are breaks in quality differentials?
2. What are the underlying reasons for the breaks?
3. How does it expand our understanding of the oil market, both upstream and downstream?

Approach

1. Construct pair-wise price differentials using 13 crude oil prices
   - Wide range of qualities
   - Wide range of geographical locations
2. Use structural breakpoint test to formally document breaks in means
3. Use data on crude quality, refining sector, environmental regulations to discuss reasons for breaks

Summary of Findings

1. Most price differentials have at least one break in mean
   - Large cluster of breaks in quality differentials around 2008
   - Similar type oils (e.g. two light sweets) experience different breaks

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   - Large cluster of breaks in quality differentials around 2008
   - Similar type oils (e.g. two light sweets) experience different breaks
2. Major drop in means and volatilities of quality diffs after breaks
3. Why have quality differentials remained low since 2008?
   - Growing ability of refining sector to process low-quality crude
   - Shale boom, which has lowered need for those refiners

Related Literature

- Structural breaks and oil price differentials
  - Buyukahin et al. (2013), Borenstein and Kellogg (2014), Agerton and Upton (2017), and Scheitrum et al. (2018)
- One great pool literature (regional vs. global oil market)
  - Adelman (1984), Weiner (1991), Sauer (1994), Gülen (1997), and Gülen (1999)
- Threshold models of oil price differentials
  - Hammoudeh et al. (2008), Ghoshray and Trifonona (2014), and Fattouh (2010)
- Industry and trade press, policy reports
  - Golden Age of Refining
  - Shale boom, U.S. refining sector and export ban
  - IMO 2020

Overview

1. Economics of Quality Differentials
2. Data and Empirical Method
3. Results

Economics of Quality Differentials

API and Sulfur Content

Light, Medium or Heavy

API gravity is a measure of how dense a crude is compared to water. Light crude has API greater than 33, heavy crude has an API below 25.

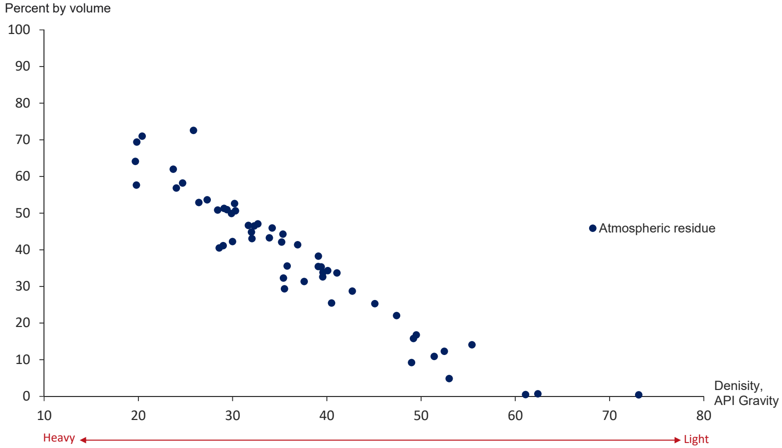
Sweet or Sour

Sulfur content is a measure of what percent sulfur the crude oil is. Less than 0.5% sulfur is sweet, otherwise sour.

Quality Pyramid

Light $>$ medium $>$ heavy; sweet $>$ sour

Heavy Crude Means More Residual



NOTES: Figure plots the amount by volume of atmospheric residue present as a function of API gravity for 54 crude oils. Atmospheric residue and light distillates are the portion of the crude that has a boiling point above 650 or below 330 degrees farenheit, respectively.
SOURCE: Exxon's library of crude oil assays.

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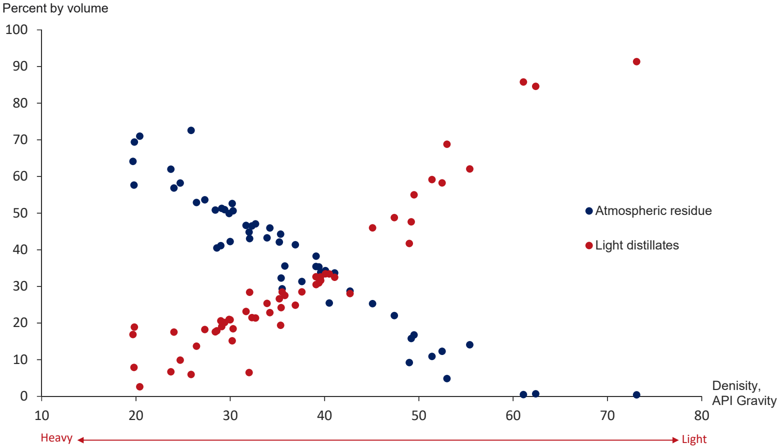

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- **Complex refinery** - Additional capital used to adjust yields
  - Vacuum distillation unit, catalytic crackers
- **Most complex refinery** - Add a coker to transform residual into higher-valued products
  - Specialize in processing heavy sour crude

Data and Empirical Method

Data

- Prices: Series for 13 crude oils
- Source: Bloomberg and HAVER
- Time: Jan. 1997 - Dec. 2018
- Frequency: Daily for 12 series, 1 monthly
- Observations: About 5500 for daily, 264 for monthly

Oil Prices

Name	API gravity	Sulfur	API category	Sulfur category
Cushing, OK				
WTI Cushing (WTIC)	39.0	0.34	Light	Sweet
Midland, TX				
WTI Midland (WTIM)	39.0	0.34	Light	Sweet
West Texas Sour (WTS)	34.0	1.90	Light	Sour
U.S. Gulf Coast (USGC)				
Heavy Louisiana Sweet (HLS)	33.7	0.39	Light	Sweet
Louisiana Light Sweet (LLS)	35.7	0.44	Light	Sweet
Mars	28.9	2.05	Medium	Sour
Maya	21.1	3.38	Heavy	Sour
Europe/Atlantic Basin				
Brent	38.1	0.41	Light	Sweet
Saudi Heavy to Europe (SHE)	27.0	2.80	Medium	Sour
Urals	31.5	1.44	Medium	Sour
Middle East/Asia				
Dubai	31.0	1.70	Medium	Sour
Oman	33.0	1.10	Medium	Sour
Saudi Heavy to Asia (SHA)	27.0	2.80	Medium	Sour
Tapis	44.6	0.03	Light	Sweet

Differentials

- We work with log-differentials:

$$p_{ij,t} = \ln P_{i,t} - \ln P_{j,t} \quad (1)$$

- We consider the following regression model:

$$p_{ij,t} = c_{ij} + u_{ij,t} \quad (2)$$

- c_{ij} reflects "steady-state" influence of:
  - Trade costs + direction of trade
  - Quality differences
- Implement the Bai (1997) sequential breakpoint test

Econometric details

Results

Main Results: Summary

- Run breakpoint test on 27 quality differentials
- Find 25 out of 27 experience a break in mean around 2008
  - Statistical significance well below 1 percent in most cases
  - In appendix: 38 out of 42 breaks in monthly data w/ extra crudes (5 percent significance or better)
- Very similar set of breaks for residual fuel oil differentials (vs. gasoline, diesel, light and medium crude)
- Significant reduction in means and volatilities after the cluster of breaks

▸ Econometric details

Main Results: Continued

- Also tested for breaks in differentials of same type crudes
  - Mainly light, sweet crude differentials
  - Also a few medium, sour differentials
- No evidence of breaks between 2007 - 2009
  - Cluster of breaks affecting U.S. light, sweet crude prices after 2010
  - Another cluster affecting U.S. Gulf Coast light crudes around 2005

Grouping the Breaks

Group	Pair	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18
Quality Differentials	WTIM-WTS											X						X					
	LLS-Mars												X										
	LLS-Maya											X											
	HLS-Mars					X							X										
	HLS-Maya											X											
	Mars-Maya											X											
	Brent-Urals												X										
	Brent-SHE											X											
	Tapis-Oman												X										
	Tapis-Dubai												X										
	Tapis-SHA													X									
	Tapis-Urals												X										
	Tapis-Mars												X			X							
	Brent-Oman												X										
	Brent-Dubai												X										
	Brent-Mars												X					X					
	LLS-Oman												X										
	LLS-Urals													X									
	LLS-Dubai									X			X										
	HLS-Oman												X										
	HLS-Urals											X					X						
	HLS-Dubai									X			X										
	Tapis-Maya											X											
	Brent-Maya											X											
	Oman-Maya											X											
	Dubai-Maya						X																
	Urals-Maya					X																	
Light Crude	LLS-HLS															X			X				
	WTIC-LLS										X				X			X					
	WTIM-LLS										X					X							
	LLS-Tapis									X						X				X			
	LLS-Brent									X						X							
	HLS-Tapis								X														
	HLS-Brent									X								X					

Discussion

- We next ask: Why have quality differentials remained low since 2008?
- We discuss the plausibility of several hypotheses making use of data we gather on crude quality, the global refining sector and global consumption
- No structural model: Not enough data to do proper structural time series model

Why are Differentials Still Low?

Economics of price differentials lead us to consider four possible explanations:

1. Regulations: Relaxation of sulfur content regulations?
2. Consumption: Increased demand for residual fuel oil?
3. Refining sector: Increased upgrading capacity?
4. Shale boom: Unexpected shift in supply of light crude?

Why are Differentials Still Low?

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Consumption Growth U.S. Coking Capacity

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  - Residual fuel oil use has declined by 4 mb/d (a 37 percent decline)
  - Demand for lighter products up 19 mb/d (a 28 percent increase)

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- Fundamental shift in refinery sector
  - Conversion capacity up about 69% (21.7 mb/d) from 2000 - 2017
  - Utilization rate for U.S. coking capacity shows break at start of Great Recession

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  - Utilization rate for U.S. coking capacity shows break at start of Great Recession
- U.S. LTO production up from 0.7 mb/ to 7.6 mb/d (Jan. 2010 - Jun. 2019)

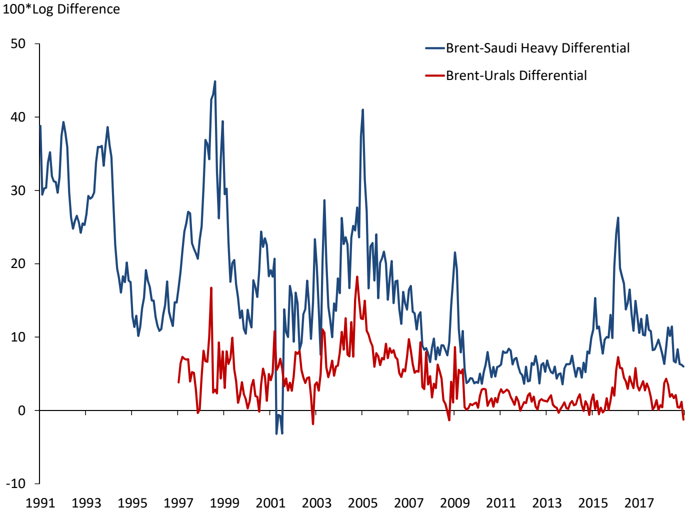
Consumption Growth U.S. Coking Capacity

Key Takeaways and Conclusion

- We document that quality-related oil price differentials have fallen over time
- Permanent decline in means since Great Recession driven by increasingly complex refining sector, shale boom
- Oil market is more effective at transforming supply of low quality crude oil into products people desire

Extra Slides

European Quality Differentials



Within-area Differentials

Differential	API difference	Sulfur difference	Mean	Standard deviation
Midland, TX				
WTIM-WTS	5.0	-1.56	0.046	0.042
U.S. Gulf Coast				
LLS-HLS	2.0	0.05	0.015	0.016
LLS-Mars	6.8	-1.61	0.108	0.061
LLS-Maya	14.6	-2.94	0.227	0.109
HLS-Mars	4.8	-1.66	0.094	0.056
HLS-Maya	12.6	-2.99	0.212	0.102
Mars-Maya	7.8	-1.33	0.118	0.064
Europe / Atlantic Basin				
Brent-Urals	6.6	-1.03	0.043	0.036
Brent-SHE	11.1	-2.39	0.138	0.091
Urals-SHE	4.5	-1.36	0.078	0.060
Middle East / Asia				
Tapis-Oman	11.6	-1.07	0.093	0.053
Tapis-Dubai	13.6	-1.67	0.103	0.055
Tapis-SHA	17.6	-2.77	0.157	0.090
Oman-Dubai	2.0	-0.60	0.010	0.020
Oman-SHA	6.0	-1.70	0.063	0.058
Dubai-SHA	4.0	-1.10	0.053	0.056

Across-area Differentials: Different Quality

Differential	API difference	Sulfur difference	Mean	Standard deviation
Light-medium differentials				
Tapis-Urals	13.1	-1.41	0.099	0.049
Tapis-Mars	15.7	-2.02	0.125	0.061
Brent-Oman	5.1	-0.69	0.040	0.044
Brent-Dubai	7.1	-1.29	0.050	0.047
Brent-Mars	9.2	-1.64	0.072	0.046
LLS-Oman	2.7	-0.66	0.078	0.066
LLS-Urals	4.2	-1.00	0.080	0.059
LLS-Dubai	4.7	-1.26	0.087	0.069
HLS-Oman	0.7	-0.71	0.062	0.062
HLS-Urals	2.2	-1.05	0.065	0.052
HLS-Dubai	2.7	-1.31	0.072	0.065
Light-heavy differentials				
Tapis-Maya	23.5	-3.35	0.244	0.098
Brent-Maya	17	-2.97	0.190	0.086
Medium-heavy differentials				
Oman-Maya	11.9	-2.28	0.150	0.075
Urals-Maya	10.4	-1.94	0.129	0.060
Dubai-Maya	9.9	-1.68	0.141	0.077

Across-area Differentials: Similar Quality

Differential	API difference	Sulfur difference	Mean	Standard deviation
Light-light differentials				
WTIC-LLS	3.3	-0.10	-0.040	0.059
WTIM-LLS	3.3	-0.10	-0.057	0.076
LLS-Tapis	-8.9	0.41	-0.016	0.050
LLS-Brent	-2.4	0.03	0.037	0.045
HLS-Tapis	-10.9	0.36	-0.031	0.048
HLS-Brent	-4.4	-0.02	0.022	0.042
Medium-medium differentials				
Oman-Urals	1.5	-0.34	0.001	0.035
Oman-Mars	4.1	-0.95	0.032	0.049
Urals-Dubai	0.5	-0.26	0.011	0.034
Urals-Mars	2.6	-0.61	0.016	0.037
Dubai-Mars	2.1	-0.35	0.022	0.053

Bai 1997 procedure

- Implement the Bai (1997) sequential breakpoint test
- Use the following regression equation to detect the breaks:

$$p_{ij,t} = c_{ij} + u_{ij,t}$$

- Sample size T is usually about 5500 observations
- Each regime has a minimum length $\approx$ 3 years
- Breaks accepted only if significant at 1% level
- Heteroskedasticity and serial correlation allowed in residuals
- Variance-covariance matrix estimated using Quadratic Spectral kernel, Andrews (1991)

Bai 1997 procedure

1. Run regression using full sample
   - Test searches for break that maximizes the test statistic proposed in Bai and Perron (1998)
2. Consider supF(1|0): if null is rejected at the 1% significance level accept the break.
3. The full sample is split into 2 regimes and the test is repeated separately for the two sub-samples
4. Whichever subsection reveals the largest test statistic, the test supF(2|1) is considered
5. This process continues until the null cannot be rejected
6. Finally there is a repartition which re-estimates breakdates, by modifying sub-samples

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Breakpoint Test Results

Part 1: Crudes Priced in Same Area

				F-statistic		
Differential	Break 1	Break 2	Break 3	0 vs. 1	1 vs. 2	2 vs. 3
Midland, TX						
WTIM-WTS	12/2007	02/2013	-	157.83	14.36	-
U.S. Gulf Coast						
LLS-Mars	02/2008	-	-	62.98	-	-
LLS-Maya	05/2007	-	-	50.14	-	-
HLS-Mars	05/2008	12/2001	-	58.00	14.39	-
HLS-Maya	05/2007	-	-	50.44	-	-
Mars and Maya	04/2007	-	-	47.28	-	-
Europe/Atlantic Basin						
Brent-Urals$^{(m)}$	06/2008	-	-	31.96	-	-
Brent-SHE	02/2007	-	-	29.69	-	-
Middle East/Asia						
Tapis-Oman	05/2008	-	-	29.78	-	-
Tapis-Dubai	05/2008	-	-	39.15	-	-
Tapis-SHA	03/2009	-	-	25.27	-	-

Breakpoint Test Results

Part 2: Crudes Priced in Different Areas

				F-statistic		
Differential	Break 1	Break 2	Break 3	0 vs. 1	1 vs. 2	2 vs. 3
Light-medium						
Tapis-Urals$^{(m)}$	05/2008	-	-	30.10	-	-
Tapis-Mars	02/2008	05/2011	-	32.51	20.00	-
Brent-Oman	05/2008	-	-	18.63	-	-
Brent-Dubai	05/2008	-	-	25.74	-	-
Brent-Mars	02/2008	08/2013	-	15.15	52.19	-
LLS-Oman	12/2008	-	-	100.62	-	-
LLS-Urals$^{(m)}$	05/2009	-	-	51.09	-	-
LLS-Dubai	12/2008	05/2005	-	116.83	14.39	-
HLS-Oman	11/2008	-	-	89.49	-	-
HLS-Urals$^{(m)}$	03/2007	04/2012	-	57.55	16.50	-
HLS-Dubai	11/2008	03/2005	-	105.34	17.24	-
Light-heavy						
Tapis-Maya	06/2007	-	-	47.47	-	-
Brent-Maya	07/2007	-	-	33.67	-	-
Medium-heavy						
Oman-Maya	05/2007	-	-	35.64	-	-
Dubai-Maya	03/2002	-	-	18.25	-	-
Urals-Maya	02/2002	-	-	14.53	-	-

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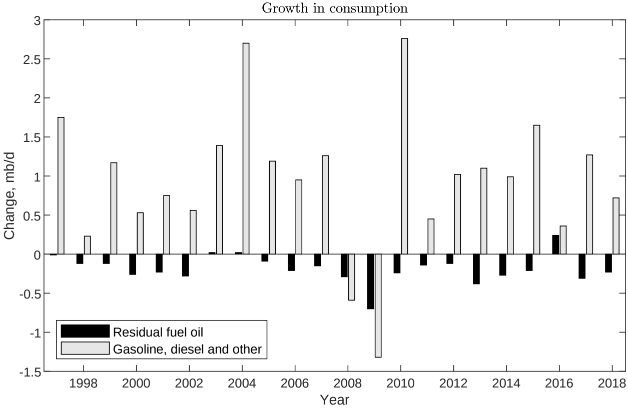
Demand Growth Driven by Light and Mid Distillates



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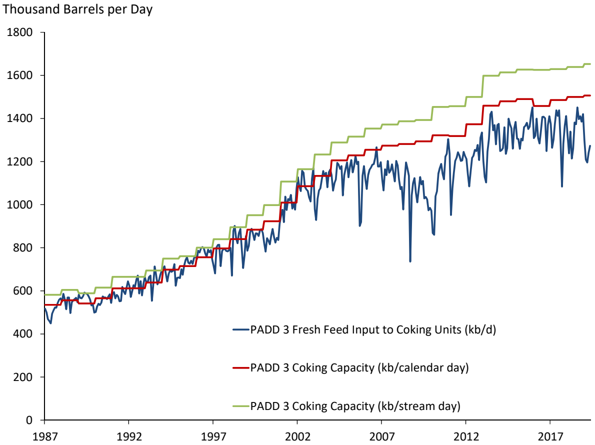
USGC Coking Capacity



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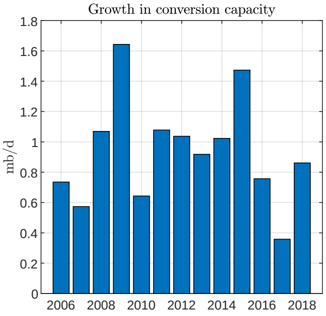
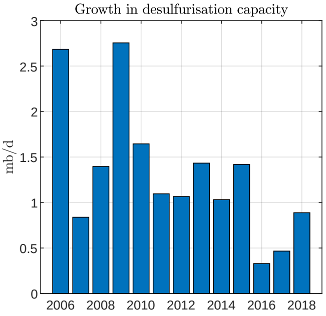
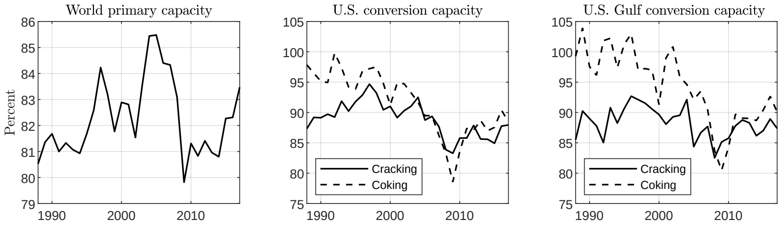
IEA Refinery Data





BP + EIA Refinery Data



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Eni Data

Year	Primary capacity (mb/d)	Conversion capacity (mb/d)	Conversion capacity ratio (percent)	Complexity Ratio Nelson Complexity
2000	83.2	31.6	38	7.9
2005	87.3	37.5	43	8.2
2010	92.4	43.4	47	8.7
2015	96.5	50.2	52	9.1
2016	98.1	52.0	53	9.3
2017	98.7	53.3	54	9.3