A Macroeconomic Analysis of Lifting the U.S. Crude Export Ban

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Overview

Rapidly expanding U.S. shale oil production has dramatically changed the nation's energy landscape in a few short years. Since 2010, the U.S. has increased its oil production by 4 million barrels per day and imports of crude oil have fallen by 20 percent. The ample supplies of crude oil from the U.S. were a factor in the collapse of oil prices in 2014.

An important facet of the shale boom is that the crude oil produced from shale plays is predominantly "light" crude. Although the U.S. has one of the largest refining capacities in the world, it is mostly for non-light crudes. Only 37% of this capacity is for light sweet crude. Hence, the increase of "light" crude oil from shale may have resulted in a mismatch in light inputs and heavier refining capacity.

Refineries can process different types of oil, but the different oils are imperfect substitutes for each other as refinery inputs. There is also specialization of refinery capacity across countries. In particular, the U.S. refining sector processes a relatively large amount of heavy crude oil as a proportion of U.S. refining capacity vis-a-vis the rest of the world. As a result, the large and unexpected increase in U.S. light oil production led to lower domestic light oil prices, higher U.S. refined product supply and exports, and backed out light crude oil imports. This issue was particularly relevant until the end of 2015 because of the U.S. export ban on crude oil, a policy that had been put in place after the 1973 oil embargo.

With these issues in mind, we investigate the impact of the shale oil boom on the upstream and downstream energy industry and the broader economy using a dynamic stochastic general equilibrium (DSGE) model. We then use our model to investigate the distortionary effects of the U.S. crude export ban.

Our model fits into the DSGE literature focused on oil, which includes works such as Backus and Crucini (2000), Leduc and Sill (2007), Bodenstein et. al. (2011), Nakov and Nuno (2013), and Plante (2014). Our work also has connections with the international real business cycle literature, see for example Backus et al. (1992), Backus et al. (1994), Crucini and Kahn (1996). To the best of our knowledge, our paper is the first to model the refining sector in a general equilibrium DSGE model, as well as the first to introduce a distinction between different types of oil.

There are several recent papers analyzing the U.S. shale oil boom and its effects on global oil prices, the global economy and the energy industry (for example, see Manescu and Nuno (2015), Mohaddes and Mehdi (2016), Walls and Zheng (2016), Kang et. al. (2016) and Kilian (2016, 2017)). There is also a large body of non-academic literature discussing the impact of a

U.S. crude oil free trade policy by national and international organizations. These studies are typically qualitative in nature or rely on simple models in order to evaluate the impact. More academic analysis can be found in Brown et. al (2014), Vidas et. al. (2014), Medlock et. al (2015), Langer et.al., (2016), Farrokhi (2016).

Methodology

We investigate the impact of the shale oil boom and the lifting of the U.S. crude oil export ban on the upstream and downstream energy industry and the broader economy through the lens of a DSGE model. In our model, the world economy consists of two countries, the U.S. and the rest of the world (ROW). Both countries produce oil, a non-oil good and refined petroleum products. Oil comes in three types, light, medium and heavy, and they are imperfect substitutes as inputs into the refining process. We calibrate our model to match a variety of macroeconomic and oil market data, and take into account important differences in the refining sectors of the U.S. and the rest of the world.

In our model experiments, we first assume the U.S. is hit with a series of positive productivity shocks that increase light crude oil production, similar to the shale oil boom. We track the impact of the of the shock on the prices and output of the three types of oil, refinery inputs, refinery production, oil imports, product exports, fuel prices and GDP, among others, in both the U.S. and the ROW. We then use our model to investigate the distortionary effects of the U.S. crude export ban.

Results

Our model predicts that the shale production boom causes light oil prices to fall, backs out a significant portion of imported light crude oil, and leads U.S. refiners to process more light oil at the expense of other types. In addition, fuel prices fall and U.S. GDP increases by a modest amount. These features are consistent with the data.

We then introduce the export ban into the model. When the ban binds, we find that the distortions from the policy primarily affect the price of light oil in the U.S. and refining sectors in both the U.S. and the rest of the world. The price of light oil becomes artificially low in the U.S., which provides a cost advantage to the U.S. refining sector. As a result, the U.S. processes more light oil than it would otherwise, and gains market share at the expense of the rest of the world. We find that the impact of the ban on refined fuel prices is negligible, as trade in refined petroleum products are unaffected by the crude oil export ban. Similarly, the impact on GDP is small, as the upstream and downstream sectors are relatively minor components of U.S. GDP.

Conclusion

In this paper, we examine the boom in U.S. shale oil production and its impact on the oil and refined products market and the overall macroeconomy using a two-country, open-economy trade model where countries produce crude oil, refined fuel products and a non-oil good. We also analyze the effects of an oil export ban in the U.S., which had been in effect for decades until it was lifted in December 2015. A large increase in U.S. light crude production can cause the ban to become a binding constraint, making the price of light oil in the U.S. artificially low. We find that this introduces significant distortions in the refinery sector, with the U.S.

producing an inefficiently high amount of refined fuel products vis-a-vis the rest of the world. The impact of the ban on fuel prices is negligible, however, as free trade in those products prevents the ban from having any major impacts on their prices.

The decline in oil production in 2015 likely reduced the initial impact of the removal of the export ban, although it enabled energy markets to become more efficient. If reinstated, an export ban would likely be binding given the return of strong oil production growth in the U.S.

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The views expressed herein are solely those of the authors and do not necessarily reflect the views of the Federal Reserve Bank of Dallas, the Federal Reserve Bank of Kansas City or the Federal Reserve System.

Introduction

- Shale oil boom dramatically increased U.S. oil production
- Key feature of boom: production of primarily "light" oil
- Refining sectors specialize to some degree across types
- U.S. crude oil export ban in place through 2015

▸ Production

▸ Refining

Questions

- What are the implications of the shale boom
  - for oil prices?
  - for the refining sector?
  - for the broader economy?
- What are the implications of an export ban on crude?
  - Are the effects limited to the energy sector?
  - Was the ban actually binding at any point in time?

What we do in the paper

- Develop a two-country, DSGE macro model
  - Different types of oil
  - Refining sector
  - U.S. crude export ban
- Use the model to consider the impacts of the shale boom
- Explore the implications of the (former) U.S. crude oil export ban
- Review the evidence of whether the ban was binding

Our findings

- The model predicts that
  - Light oil prices decline in the U.S. and ROW
  - U.S. refiners process more light oil, less medium and heavy
  - Imports of light oil fall dramatically
  - U.S. GDP rises and fuel prices fall
- In the model, the export ban:
  - Primarily distorts the refining sectors, U.S. light oil prices
  - Has negligible impacts on GDP and fuel prices
  - Was binding in 2013 - 2015
- Model predictions consistent with data

Overview of presentation

- Background info and data overview
- Model
- Results
  - Theoretical (model)
  - Data-driven
- Conclusions

Background info and data overview

Our goal is to document:

- How oils vary in quality/type
- U.S. and rest of world (ROW) oil production by type
- U.S. and ROW refiner oil use by type
- Recent trends since the shale boom

Introduction to crude oil quality

- Oil generally viewed as a homogenous commodity
- But can vary across a number of dimensions
  - Density (light, medium or heavy)
  - Sulphur content (sweet or sour)
  - Other contaminants (acidity, metallic content)
- We split oil into three broad types:
  - Light (API $>$ 35)
  - Heavy (API $<$ 26)
  - Medium (everything in between)

Chart

Data overview

- Production data is from Eni World Oil and Gas Review (2016)
  - Annual data for 2000, 2005, 2010 - 2015
- U.S. crude import data by type from EIA
- U.S. crude export data from EIA
- Refining inputs by type - constructed by authors

Production data

Table: Crude oil production by type, mb/d

	U.S.			Rest of world		
	Light	Medium	Heavy	Light	Medium	Heavy
2000	2.1	2.9	0.8	20.0	34.9	7.6
2005	1.7	2.8	0.7	19.8	40.2	9.4
2010	2.1	2.7	0.6	20.6	39.2	9.8
2011	2.6	2.5	0.6	19.7	40.9	9.8
2012	3.5	2.4	0.6	20.1	41.4	9.6
2013	4.6	2.3	0.6	19.6	40.9	9.7
2014	5.7	2.4	0.6	19.0	41.5	9.9
2015	6.3	2.5	0.6	19.1	42.1	10.8

U.S. import and export data

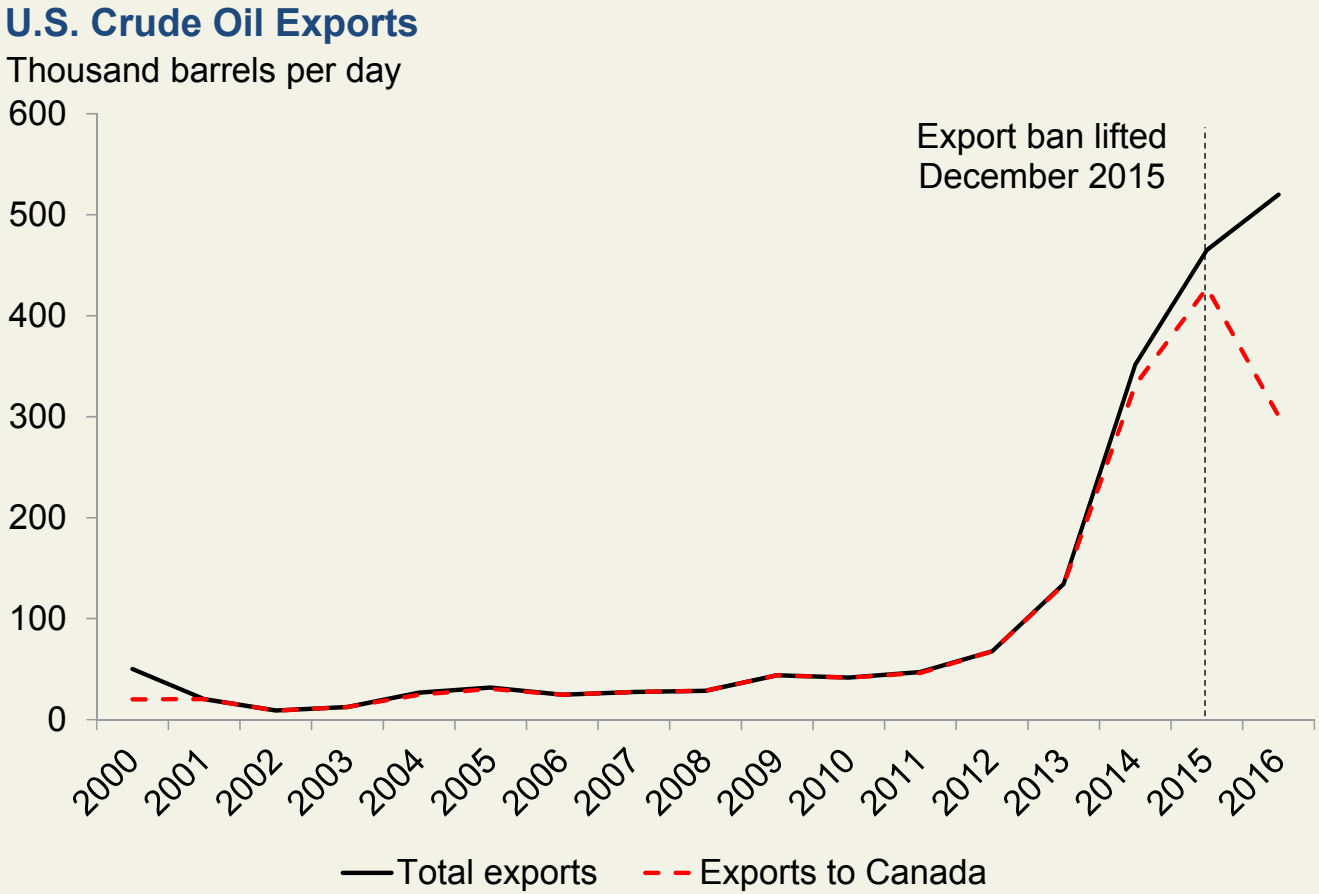
Table: U.S. imports and exports of crude oil, mb/d

	U.S. crude imports			**U.S. crude exports**
	Light	Medium	Heavy	Total
2000	2.2	4.6	2.3	0.05
2005	2.3	4.3	3.5	0.03
2010	2.1	3.3	3.8	0.04
2011	1.7	3.3	4.0	0.05
2012	1.4	3.1	4.0	0.07
2013	0.9	3.0	3.9	0.13
2014	0.6	2.7	4.1	0.35
2015	0.6	2.6	4.2	0.47
2016	0.9	2.6	4.4	0.52

Overview of U.S. export ban policy

- Policy in place since the 1970s, lifted end of 2015
- Prohibited exports of crude oil but not refined products
- Exports possible under several exemptions
  - Exports of Alaskan crude oil (negligible since 2000)
  - Exports to Canada for use there-in
  - Few other exemptions

U.S. crude exports to Canada



SOURCE: Energy Information Administration.

Refiner inputs by type

Table: Refiner inputs by type, U.S. and rest of the world, mb/d

	U.S. refiner inputs			**ROW refiner inputs**		
	Light	Medium	Heavy	Light	Medium	Heavy
2000	4.3	7.5	3.1	17.8	30.4	5.3
2005	4.0	7.1	4.2	17.5	36.0	5.9
2010	4.2	6.1	4.4	18.6	35.9	6.0
2011	4.2	5.7	4.6	18.0	37.6	5.8
2012	4.9	5.5	4.5	18.7	38.3	5.7
2013	5.3	5.3	4.5	18.9	37.9	5.8
2014	5.9	5.1	4.7	18.8	38.8	5.9
2015	6.4	5.1	4.8	19.0	39.5	6.6

▸ Details

Changes since 2010

Table: Change in select data from 2010 to 2015, mb/d

	Production	Imports	Exports	Refiner inputs
Light	4.2	-1.5	0.4	2.2
Medium	-0.2	-0.8		-1.0
Heavy	0.0	0.4		0.5
Total	4.0	-1.9	0.4	1.7

Modeling approach

- Develop a two-country, general equilibrium macro model:
  - IRBC framework (BKK 1992, BKK 1994, Backus and Crucini 2000)
  - Two countries: U.S. and rest of world (ROW)
  - Three sectors: oil, refining sector and a non-oil sector
- What's new: different types of oil, refining sector, U.S. crude export ban
- Calibrate the model using oil market and macro data (pre-shale boom)
- Look at impacts of increased light oil production in U.S.
  - Start with case of no ban
  - Consider implications of export ban

Model - Overview

- Two country model with three sectors
  - oil, refining sector, non-oil sector
  - Countries denoted $i = 1, 2$ (U.S., ROW)
  - Endogenous oil and fuel prices
- Household sector in i modeled as representative agent
- Production is done by profit-maximizing representative firms
- Baseline case is free trade in all goods

Model - Households

- Representative agent in country i maximizes utility subject to budget, time and capital accumulation constrains, where utility given by

$$E_0 \sum_{t=0}^{\infty} \beta^t \frac{(c_{i,t}^{\mu} L_{i,t}^{1-\mu})^{\gamma}}{\gamma}$$

  where $c_{i,t}$ is aggregate consumption and $L_{i,t}$ is leisure.

- Aggregate consumption given by

$$c_{i,t} = \left[\omega_i \left(c_{i,t}^{a} \right)^{-\rho} + (1 - \omega_i) \left(c_{i,t}^{f} \right)^{-\rho} \right]^{-\frac{1}{\rho}}$$

- Key feature: ρ allows for inelastic demand of petroleum products

Model - Non-oil sector

- Firms maximize profit subject to production technologies
- Non-oil good produced using labor, capital and refined products
- Production function is a nested-CES of value-added and fuel

$$y^a_{i,t} = \left[w^a_i \left(z^a_{i,t} (n^a_{i,t})^{\chi^a_i} (K^a_{i,t})^{1-\chi^a_i} \right)^{-\rho^a_i} + (1 - w^a_i)(m^f_{i,t})^{-\rho^a_i} \right]^{\frac{1}{-\rho^a_i}}$$

- Key feature: ρ^a allows for inelastic demand of petroleum products
- Key feature: χ^a and w^a let us match cost-shares

Model - Oil sector

- Introduce a cost function to model production of oil
- Assume it costs C_i^k units of the non-oil good to produce a unit of oil type k in country i
- The level of costs is a convex function of the level of output,

$$C_{i,t}^k = \frac{\left(\frac{y_{i,t}^{ok}}{z_{i,t}^{ok}}\right)^{1+\frac{1}{\eta_i^k}}}{1+\frac{1}{\eta_i^k}}.$$

- Key feature: η allows us to make oil-supply very price-inelastic

Model - Refining sector

- Refined petroleum products are produced using labor, capital and oil
- Production function is a nested Cobb-Douglas of value-added and oil,

$$y_{i,t}^f = z_{i,t}^f \left[(n_{i,t}^f)^{\chi_i^f} (K_{i,t}^f)^{1-\chi_i^f} \right]^{\alpha_i^f} G(o_{L_{i,t}}^f, o_{M_{i,t}}^f, o_{H_{i,t}}^f)^{1-\alpha_i^f}.$$

- Allows us to model differences between U.S. refining sector and ROW in
  - Labor-share of value-added
  - Value-added share of gross output
  - Productivity levels

Model - Refining sector

- Different types of oil are imperfect substitutes as inputs into the refining process
- The aggregator $G(o^f_{L_{i,t}}, o^f_{M_{i,t}}, o^f_{H_{i,t}})$ is given by

$$\left[w^o_i (o^f_{H_{i,t}})^{-\rho^{oil}_i} + (1 - w^o_i) \left(\omega^o_i (o^f_{L_{i,t}})^{-\eta^{oil}_i} + (1 - \omega^o_i)(o^f_{M_{i,t}})^{-\eta^{oil}_i} \right)^{\frac{\rho^{oil}_i}{\eta^{oil}_i}} \right]^{\frac{1}{-\rho^{oil}_i}},$$

  allowing us to capture
  - Differences in use of the oil types across countries
  - Emphasize the fact that substitution is easier between light and medium oils

Model - Trade

- Free trade in all goods in baseline case
- Free trade in all goods except crude oil in export ban case
- Mathematically, the export ban appears as three inequality constraints

$$o^{f}_{k1,t} - y^{ok}_{1,t} \geq 0.$$

- PPP holds for all goods when ban does not bind
  - If ban binds for type k, oil prices for type k can diverge in U.S., ROW

Calibration: Overview

- Starting value and parameters need to be calibrated
- Use data on the oil market, refining sectors and macroeconomy to guide calibration
- ▸ List of data
- ▸ U.S. calibration
- ▸ ROW calibration
- ▸ Model parameters
- ▸ Shocks and dynamics

Calibration: Refining sectors

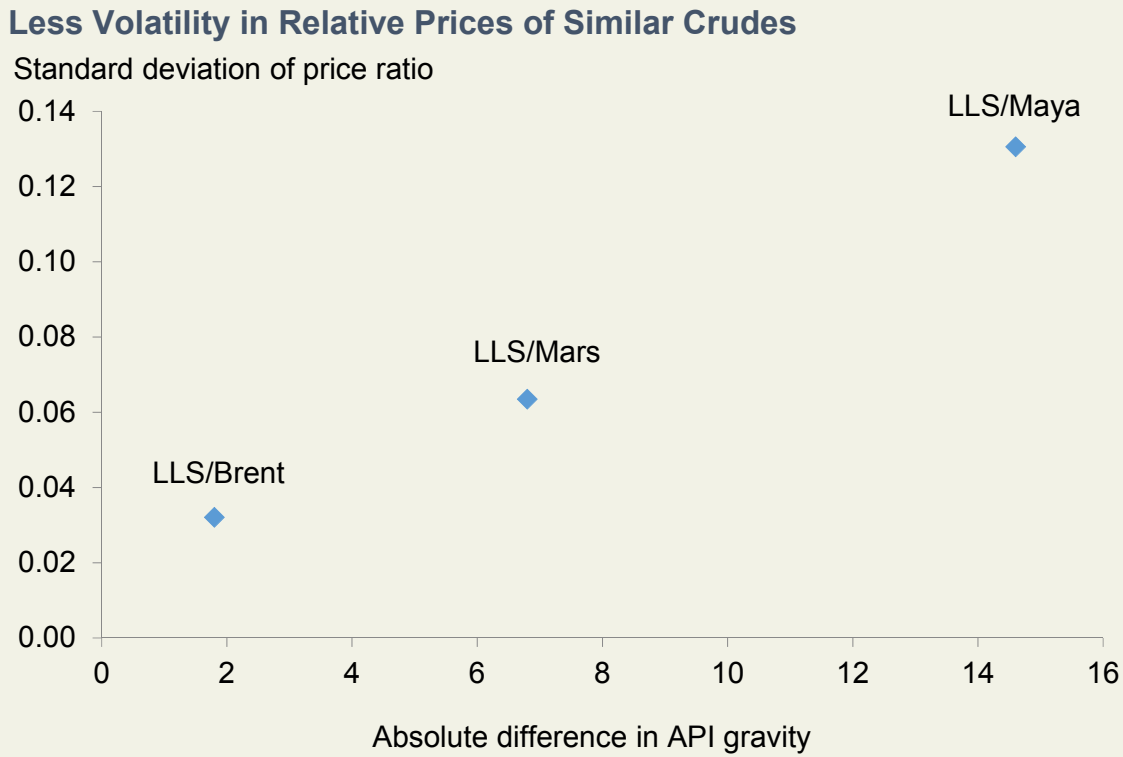
Table: Calibration of refining sector parameters

	U.S.	ROW	Data source
Labor share (χ^f)	.16	.30	WIOD
Capital share ($1 - \chi^f$)	.84	.70	WIOD
Share of value-added (α^f)	.23	.17	WIOD, calculations
Share of light oil	.29	.31	Calculations
Share of medium oil	.41	.59	Calculations
Share of heavy oil	.30	.10	Calculations

Calibration: Refining sector elasticities

- No long time series on refiner inputs by type
- No previous works that calibrate this type of elasticity
- Long time series available on oil prices of different types
- We believe relative prices provide information on ease of substitutability between oil types

Relative price volatility



SOURCES: Bloomberg; Platts.

Calibration: Refining sector elasticities

- Follow the RBC literature and match moments to calibrate the elasticities
- Use price data on LLS (light), Dubai (medium) and Maya (heavy)
- Focus on two moments:
  - Relative volatility of light-medium price-ratio to light price
  - Relative volatility of light-heavy price-ratio to light price
- Our calibration gives us
  - Elasticity between light and medium (η^{oil}) - 5.35
  - Elasticity between heavy and composite (ρ^{oil}) - 3.23

Policy experiment

- Start from initial steady state
- Feed series of positive light oil supply shocks in U.S. over 4 years
- Shocks exactly replicate path of U.S. light oil production from 2011 to 2014
- First consider impacts under free trade scenario
- Then consider impacts under export ban case

Responses to positive U.S. light oil shock

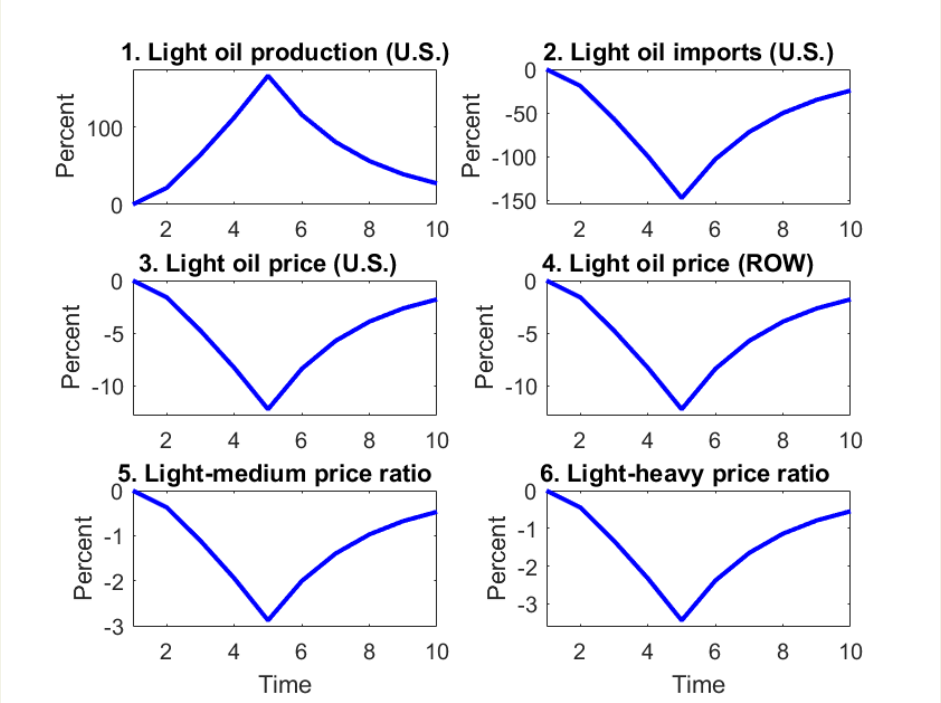


Figure shows percent deviations from steady state

Responses to positive U.S. light oil shock

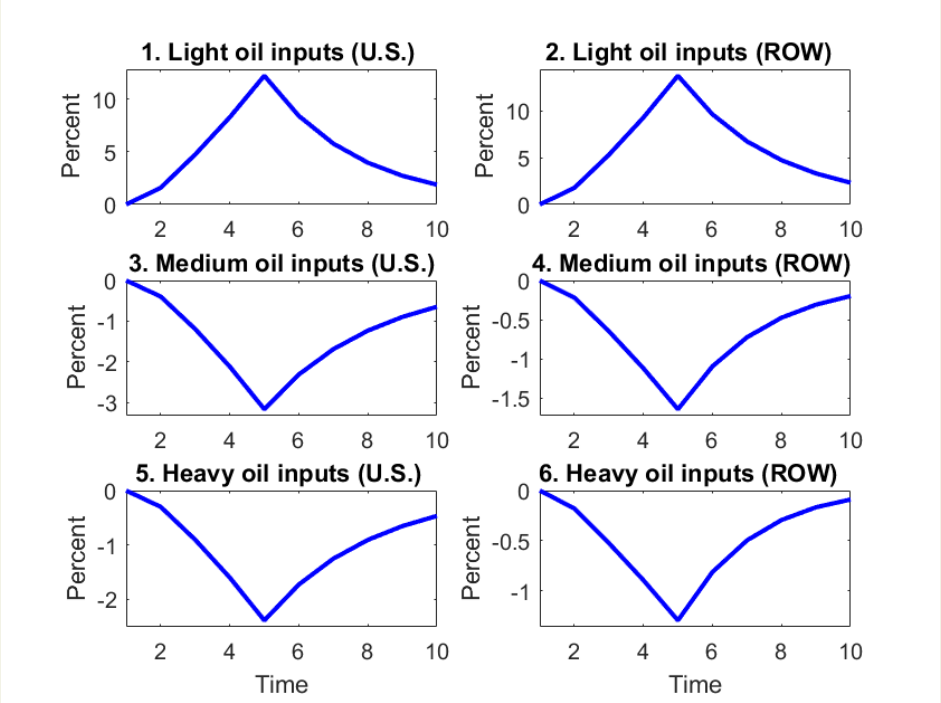


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Responses to positive U.S. light oil shock

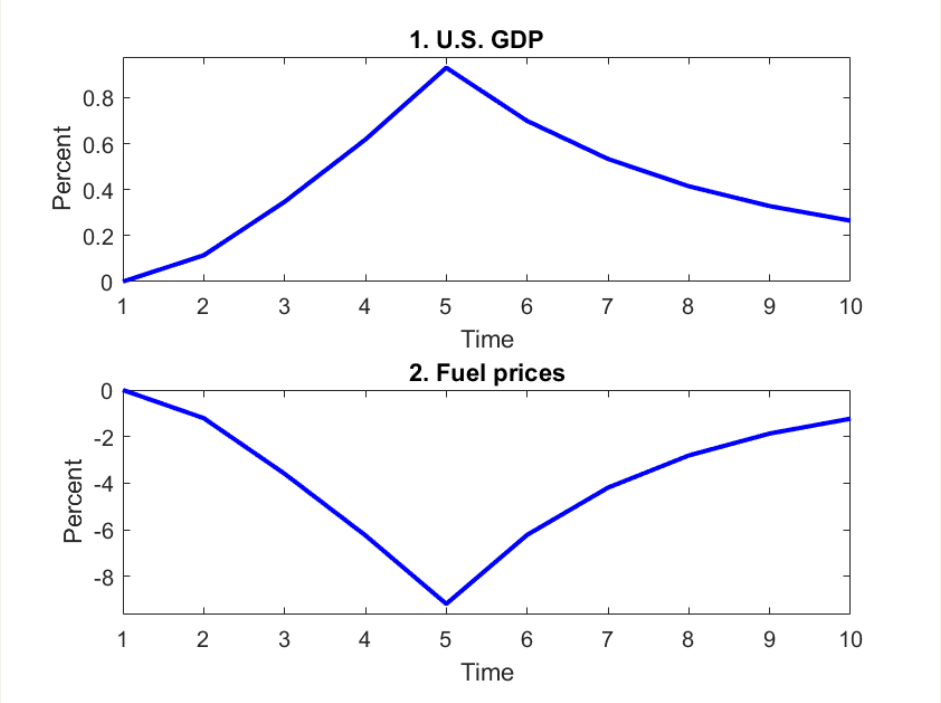


Figure shows percent deviations from steady state

Responses to positive U.S. light oil shock w/ export ban

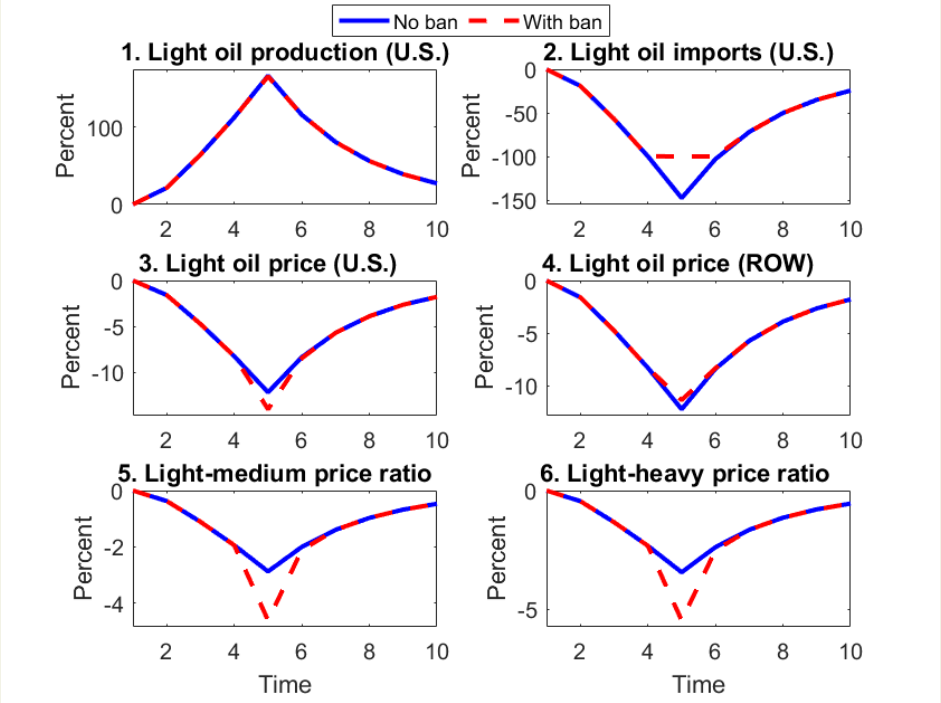


Figure shows percent deviations from steady state

Responses to positive U.S. light oil shock w/ export ban

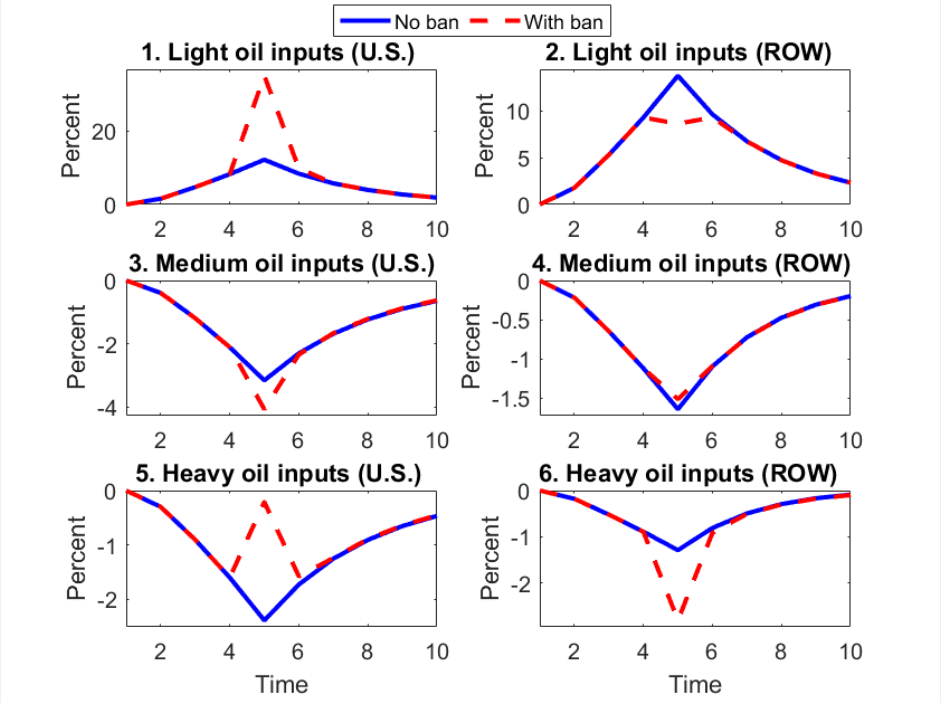


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Responses to positive U.S. light oil shock w/ export ban

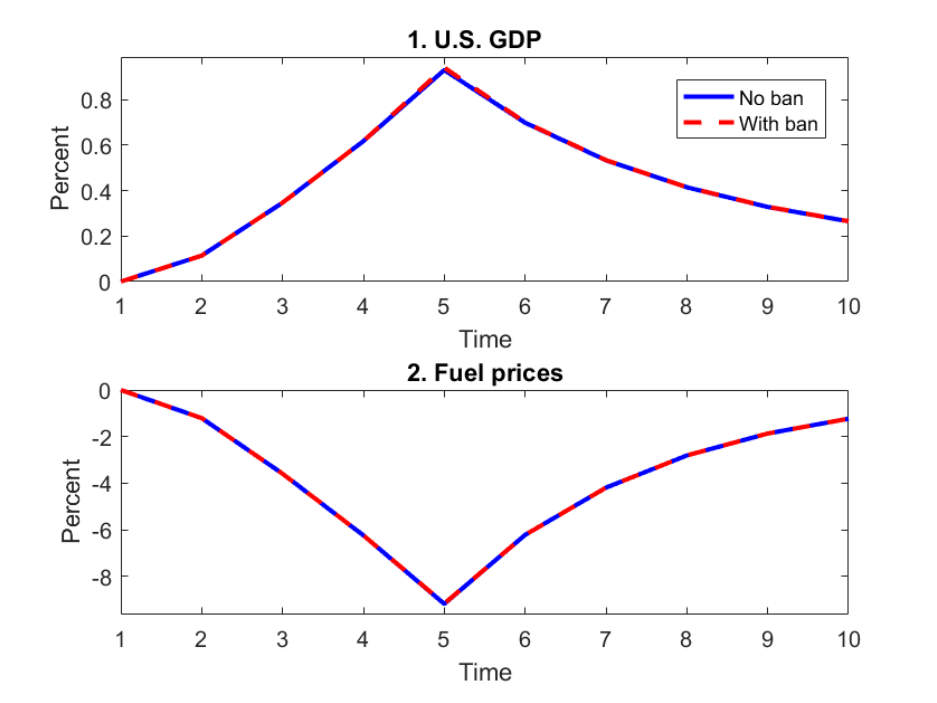


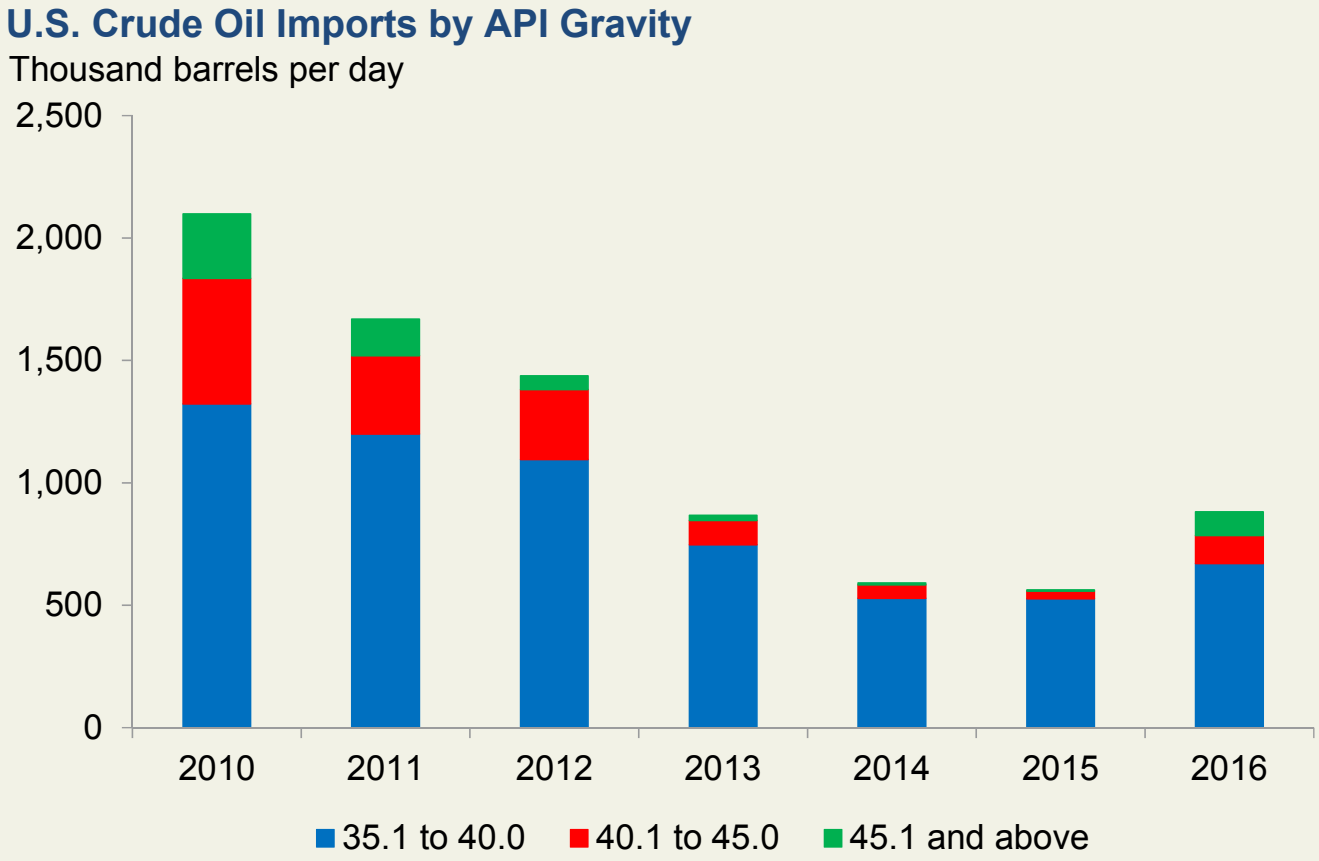
Figure shows percent deviations from steady state

Was the Ban Binding?

Model predictions:

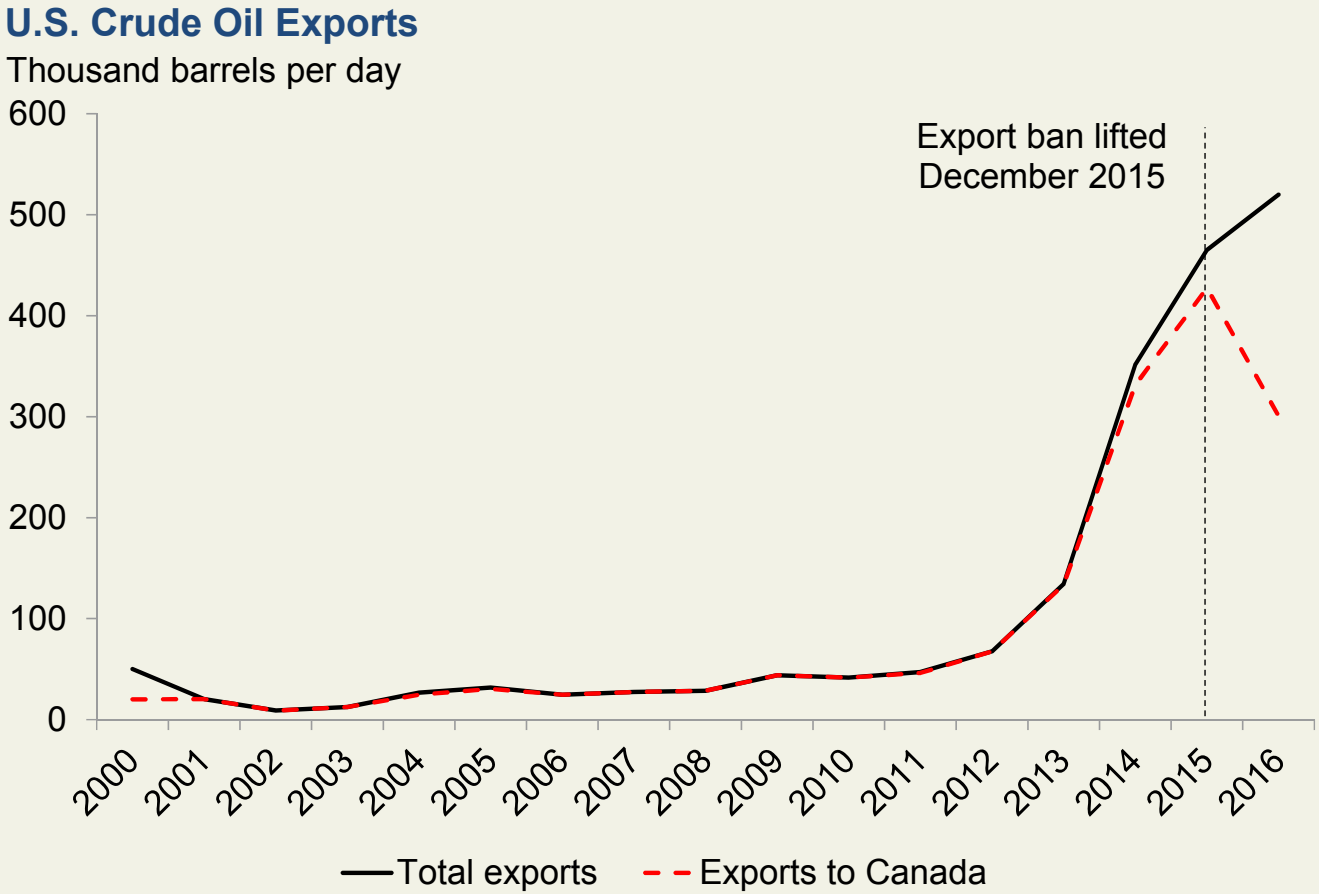
- Light imports go to zero
- Exports of crude oil potentially constrained
  - Increased use of Canada loophole?
- Unusually large spread between light crude oil prices

Imports of very light oil near zero



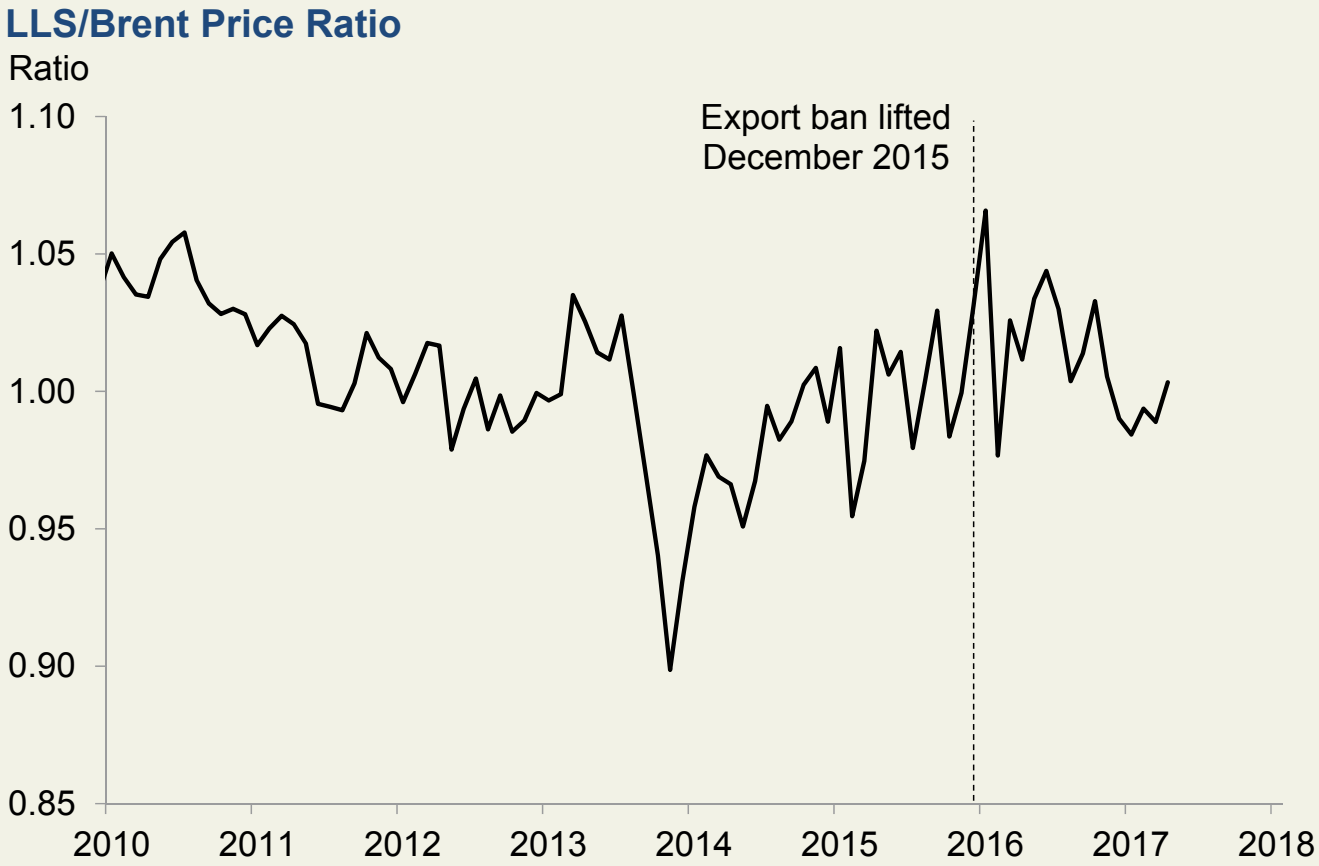
SOURCE: Energy Information Administration.

Crude exports up... even after 2015



SOURCE: Energy Information Administration.

Unusual decline in LLS-Brent relative price in late 2013



SOURCE: Bloomberg.

Conclusions

- We introduce a DSGE model with three types of oil and a refining sector to explore the impacts of the shale oil boom and the U.S. oil export ban.
- We find that the oil boom causes light oil prices and light oil imports to decline.
- It also leads higher processing of light oil at the expense of other types, and yields lower fuel prices.
- GDP increases modestly.
- The export ban primarily distorts the price of light oil and the refining sectors with negligible impact on fuel prices and GDP.

Policy implications

- The removal of the export ban enabled energy markets to be more efficient.
- The ban distorted outcomes in oil and refining sectors:
  - Distributed income from producers to U.S. refiners
  - Distorted refining activity in U.S. vs. ROW
- If reinstated, an export ban would likely be binding given return to strong oil production growth.

Refiner input calculations

1. Assume U.S. crude exports are "light" oil.
2. Construct an estimate for U.S. refiner inputs of type j for each year:

$$\text{Input}_t^j = \text{Production}_t^j + \text{Imports}_t^j - \text{Exports}_t^j.$$

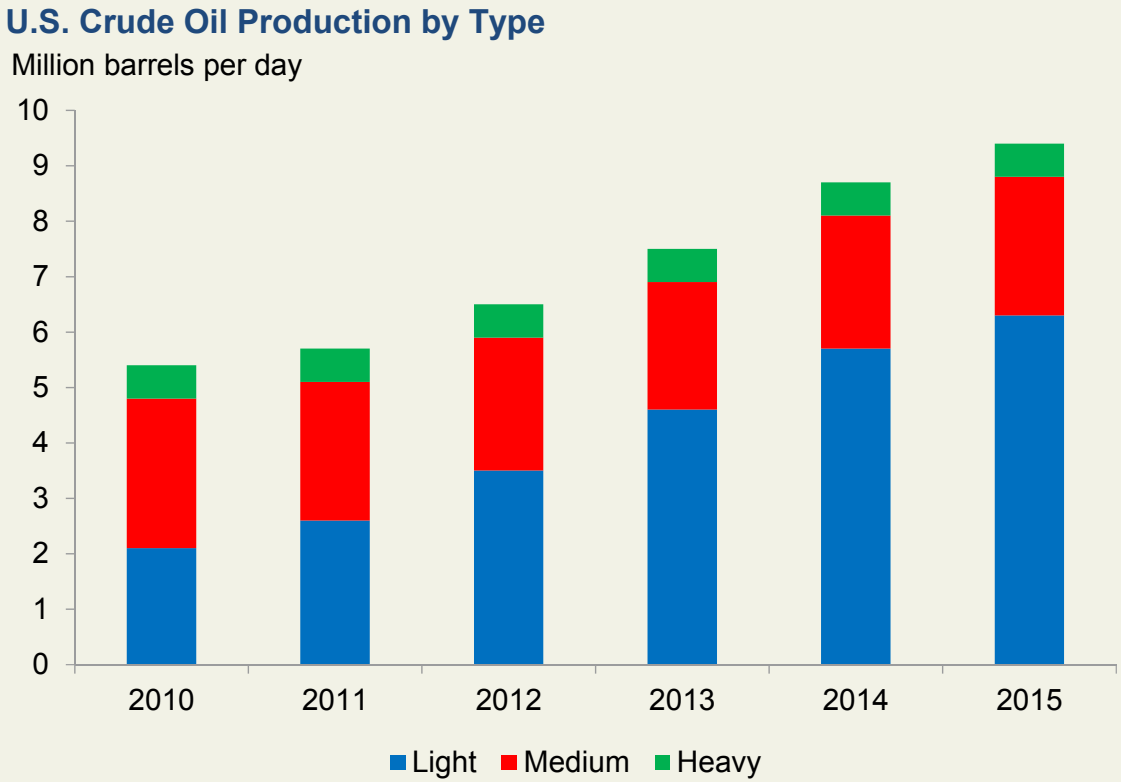
3. ROW estimate for type j is given by

$$\text{ROW input}_t^j = \text{World production}_t^j - \text{U.S. input}_t^j.$$

4. Data limitations prevent us from adjusting for inventories
   - Annual changes for U.S. crude inventories in mb/d relatively small (2010: +.02, 2011: -.01, 2012: +.1, 2013: -.02, 2014: +.1, 2015: +.15)

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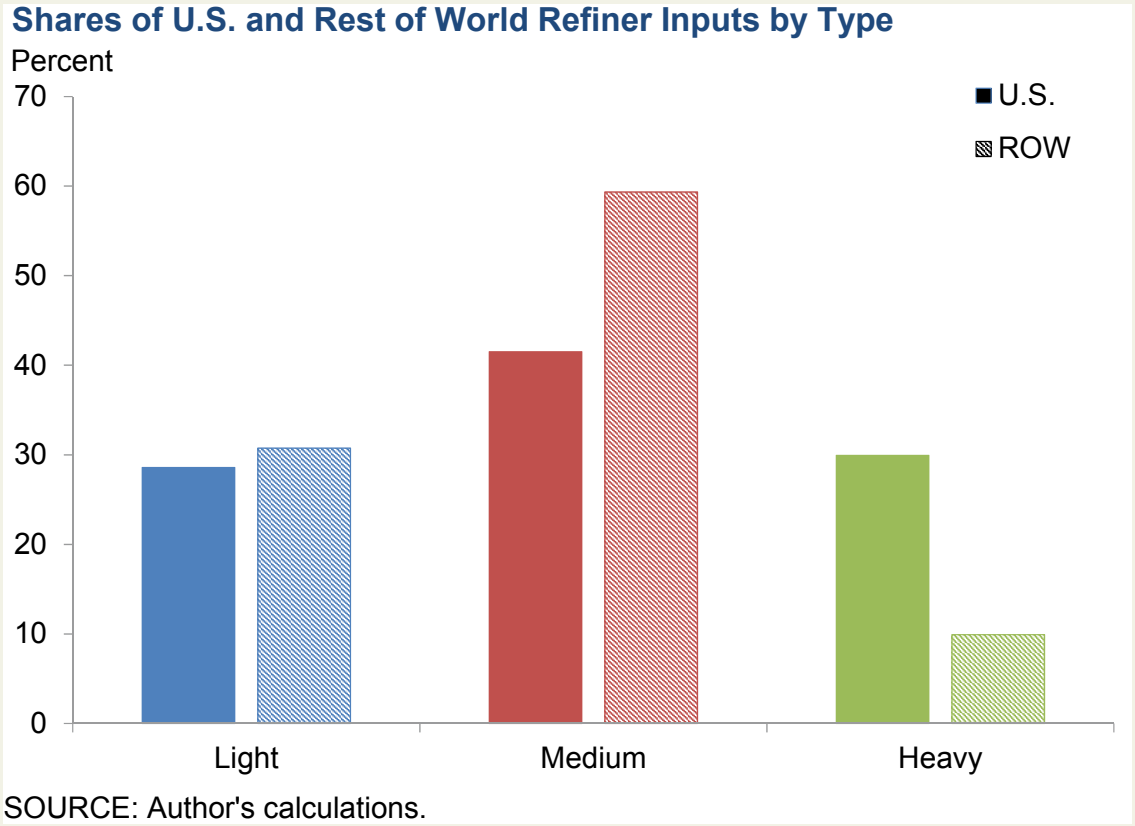
Introduction



SOURCE: Eni.

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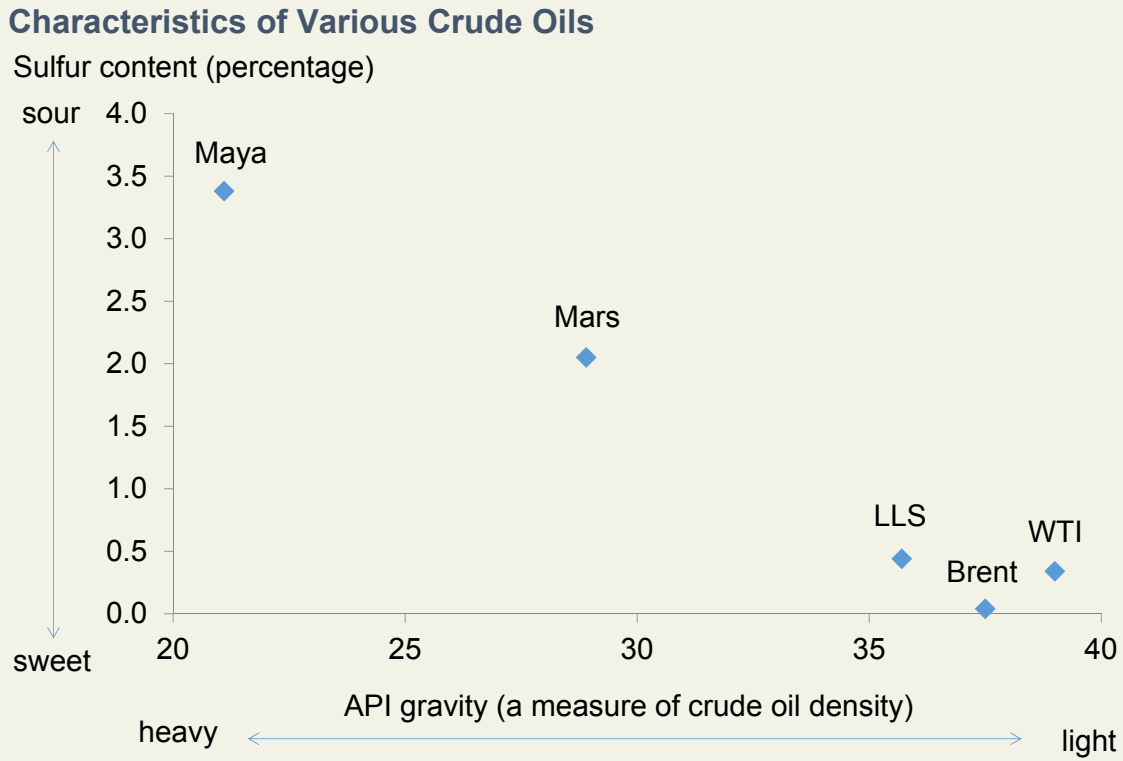
Heavy oil makes up 30 percent of U.S. refiner inputs



SOURCE: Author's calculations.

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Introduction



SOURCES: Bloomberg; Platts.

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Calibration: List of select data and sources

Sources: Bloomberg, BEA, BLS, EIA, Eni, IEA, IMF, Oil and Gas Journal, UN, WIOD

- Light, medium and heavy oil production
- Total crude oil production
- Refined products production
- Energy consumption by sector and source
- Crude input to refineries and refinery processing gains
- U.S. share in world population
- U.S. share in global GDP
- Prices of light and heavy oil
- Others

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Calibration: Moments used for the U.S.

Data	Model	Value	Source
U.S. GDP		1	Normalization
Price of fuel	p_1^f	1	Normalization
Total time	$\bar{L}_1$	1	Normalization
Total time allocated to leisure	L_1	$2/3$	Literature
Household fuel consumption	$p_1^f c_1^f$	0.022	BEA, EIA
Firm fuel use	$p_1^f m_1^f$	0.022	BEA, EIA
Fuel production	y_1^f	$.965\left(c_1^f + m_1^f\right)$	EIA
Total crude oil production	$y^{ol} + y^{om} + y^{oh}$	$.35 y_1^f$	EIA
Total crude oil input to refineries	$o_l^f + o_m^f + o_h^f$	$2.686(y^{ol} + y^{om} + y^{oh})$	EIA

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Calibration: Moments used for ROW

Moment	Model	Value	Source
ROW share of global oil production		0.921	Eni
ROW share of global GDP		0.83	IMF
ROW share of world population		0.955	UN
Time devoted to leisure	L_2	$2/3\bar{L}_2$	Literature
ROW Refinery gains		1.017	IEA, EIA
Ratio of household to firm fuel use	c_2^f / m_2^f	0.50	EIA, Exxon, WIOD

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Calibration: Parameters

Description	Parameter	Value
Discount factor	β	0.96
Substitution parameter	ρ	2.33
Intertemporal substitution	γ	-1
Depreciation rate	δ	.10
Labor share, U.S. non-oil	Determines w_1^a	0.978
Labor share, ROW non-oil	Determines w_2^a	0.979

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Calibration: Shocks and dynamics

- Parameters for the productivity shocks are not determined by the steady state
- We calibrate the parameters such that certain features of simulated data from the model match those same features in the data.
- Our data: U.S. and ROW GDP, U.S. and ROW crude oil production
- We detrend annual data using an HP filter
- We calculate volatilities and first-order autocorrelations for the detrended data
- We treat model deviations from the steady state as de-trended data, match their moments to the actual data.

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