The U.S. shale oil boom, the oil export ban, and the economy: A general equilibrium analysis

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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

Motivation:

- 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
Questions

- What are the implications of the shale boom
  - for oil prices?
  - for refining sectors?
  - for the broader economy?

- What are the implications of an export ban on crude?
  - Was the ban actually binding at any point in time?
  - How did it affect the energy sector? The broader economy?
What we do in the paper

- Develop a two-country, DSGE model with three sectors (oil, refining, non-oil)
  - What's new: *Different types of oil, refining sectors, crude oil export ban*

- Calibrate the model using oil market and macro data (pre-shale boom)

- Use the model to consider the impacts of:
  - Shale oil boom
  - U.S. crude oil export ban

- Compare the model predictions to some data
Main findings from the model:

- Shale boom boosted U.S. GDP by 1.4 percent
- U.S. net imports of crude decline dramatically
- Export ban was binding from 2013 to 2015
- Ban distorted oil prices and refining sectors, minimal impacts on macroeconomy
Overview of presentation

- Data
- DSGE model
- Results
- Conclusions
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)
  - Sulfur content (sweet or sour)
  - Other contaminants (acidity, metallic content)

Characteristics of several crudes

- We split oil into three broad types:
  - Light (API gravity $\geq 35^\circ$)
  - Heavy (API gravity $< 26^\circ$)
  - Medium (everything in between)
Data overview

Key changes from 2010 to 2015:

- Production data available from Eni
  - U.S. light production more than tripled from 2010 to 2015
  - Outside U.S., medium and heavy production up

- Import data by type available from EIA
  - U.S. light imports down 1.5 mb/d
  - Imports of crude API > 40 near 0 in 2014, 2015

- Export ban exemptions used in 2014, 2015

- U.S. refiner use of light oil up 57 percent, medium down 16 percent
Model - Overview

- Develop a two-country, general equilibrium macro model

- 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
  - Model net trade flows

- Free trade case, export ban on crude case
- Household sector in $i$ modeled as representative agent
  - Utility from consuming fuel, non-oil good
  - Provides labor and capital to private sector

- Production is done by profit-maximizing representative firms
  - Production in the non-oil sector uses fuel, labor and capital
  - Production in the refining sector uses oil, labor and capital
  - Producing oil requires the non-oil good (convex cost function)
Refined petroleum products are produced using labor, capital and oil.

Production function, $y_{i,t}^f$, is a nested CES of value-added and oil:

$$
[w_i^f \left( z_i^f (n_{i,t}^f)^{\chi_i^f} (K_{i,t}^f)^{1-\chi_i^f} \right)^{-\rho_i^f} + (1 - w_i^f) G(o_{L_i,t}^f, o_{M_i,t}^f, o_{H_i,t}^f)^{-\rho_i^f}]^{1/1-\rho_i^f}
$$

allowing us to model differences between U.S. and ROW refining sectors in

- labor-share of value-added
- value-added share of gross output

$\rho_i^f$ allows us to model the fact that it is hard to substitute between oil and other inputs when it comes to producing fuel.
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

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

allowing us to capture

- Differences in use of the oil types across countries
- The fact that substitution is easier between light and medium oils
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
Table: Calibration of refining sector parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>U.S.</th>
<th>ROW</th>
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<td>Labor share ($\chi^f$)</td>
<td>.16</td>
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<td>Light oil share in $i$</td>
<td>.29</td>
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Calibration: Refining sector elasticities

- Follow the RBC literature and match moments to calibrate the three elasticities
- Focus on three moments:
  - Correlation of light and medium prices (LLS, Dubai)
  - Correlation of light and heavy prices (LLS, Maya)
  - Volatility of U.S. oil inputs (total)
- Our calibration gives us
  - elasticity between oil and value-added ($\rho^f$): 0.285
  - elasticity between light oil and medium oil ($\eta^{oil}$): 3.65
  - elasticity between heavy and composite ($\rho^{oil}$): 2.13
Policy experiment

- Start from initial steady state (2010)
- Exactly replicate path of U.S. light oil production from 2011 to 2015
- 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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Figure shows percent deviations from steady state
Was the Ban Binding?

Model predictions versus data:

- Light crude unusually cheap in U.S. relative to ROW
  - data: unusual decline in LLS-Brent relative price in late 2013

- Light imports go to zero
  - data: imports of very light oil near zero

- Exports of crude oil before and after the removal of the ban (Çakır Melek and Ojeda (2017))
  - Increased use of Canada exemption prior to the removal of the ban
  - Exports to Canada decreased, exports to ROW increased after the removal of the ban
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.

- Our main findings:
  - Shale boom boosted U.S. GDP by 1.4 percent
  - Export ban was binding from 2013 to 2015
  - Ban distorted oil prices and refining sectors, minimal impacts on macroeconomy
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: -0.01, 2012: +0.1, 2013: -0.02, 2014: +0.1, 2015: +0.15)
U.S. Crude Oil Production by Type
Million barrels per day

SOURCE: Eni.
U.S. processed 40 percent of world’s heavy crude

Source: Authors' calculations.
Introduction

Sulfur content (percentage)

API gravity (a measure of crude oil density)
sour

sweet

heavy

light

Maya

Mars

Dubai

LLS

Brent

WTI

SOURCES: Bloomberg; Platts.
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.
Households
Model schematic

Households

Investment + Consumption
Model schematic

Households

Investment + Consumption

Capital

Labor

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Presented by Michael Plante - Dallas Fed
Representative agent in country $i$ maximizes utility subject to budget, time and capital accumulation constrains, where utility given by

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

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: $\rho$ allows for inelastic demand of petroleum products
Representative firms maximize profits subject to production technologies

- Introduce a cost function to model production of oil, as in Balke, Plante, and Yucel (2015)

- Assume it costs $C^k_i$ units of the non-oil good to produce a unit of oil type $k$ ($k = L, M, H$) in country $i$

- Production cost is a convex function of the level of output

$$C^k_{i,t} = \frac{\left(\frac{y^{ok}_{i,t}}{z^{ok}_{i,t}}\right)^{1+\frac{1}{\eta_i^k}}}{1 + \frac{1}{\eta_i^k}}$$

- Key feature: $\eta^k_i$ allows us to make oil supply price-inelastic
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

\[ y_{i,t}^a = \left[ w_i^a \left( z_{i,t}^a(n_{i,t}^a)\chi_i^a(K_{i,t}^a)^{1-\chi_i^a} \right)^{-\rho_i^a} + (1 - w_i^a)(m_{i,t}^f)^{-\rho_i^a} \right]^{\frac{1}{-\rho_i^a}} \]

Key feature: \( \rho^a \) allows for inelastic demand of petroleum products

Key feature: \( \chi^a \) and \( w^a \) let us match cost-shares
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:

\[ o_{k1,t} - y_{1,t}^{ok} \geq 0. \]

- 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
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
Calibration: Moments used for the U.S.

<table>
<thead>
<tr>
<th>Data</th>
<th>Model</th>
<th>Value</th>
<th>Source</th>
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<tbody>
<tr>
<td>U.S. GDP</td>
<td>$p_1^f$</td>
<td>1</td>
<td>Normalization</td>
</tr>
<tr>
<td>Price of fuel</td>
<td>$p_1^f$</td>
<td>1</td>
<td>Normalization</td>
</tr>
<tr>
<td>Total time</td>
<td>$L_1$</td>
<td>1</td>
<td>Normalization</td>
</tr>
<tr>
<td>Total time allocated to leisure</td>
<td>$L_1$</td>
<td>$2/3$</td>
<td>Literature</td>
</tr>
<tr>
<td>Household fuel consumption</td>
<td>$p_1^f c_1^f$</td>
<td>0.022</td>
<td>BEA, EIA</td>
</tr>
<tr>
<td>Firm fuel use</td>
<td>$p_1^f m_1^f$</td>
<td>0.022</td>
<td>BEA, EIA</td>
</tr>
<tr>
<td>Fuel production</td>
<td>$y_1^f$</td>
<td>$.995\left(c_1^f + m_1^f\right)$</td>
<td>EIA</td>
</tr>
<tr>
<td>Total crude oil production</td>
<td>$y^{ol} + y^{om} + y^{oh}$</td>
<td>$.35 y_1^f$</td>
<td>EIA</td>
</tr>
<tr>
<td>Total crude oil input to refineries</td>
<td>$o_1^f + o_m^f + o_h^f$</td>
<td>$2.675(y^{ol} + y^{om} + y^{oh})$</td>
<td>EIA</td>
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## Calibration: Moments used for ROW

<table>
<thead>
<tr>
<th>Moment</th>
<th>Model</th>
<th>Value</th>
<th>Source</th>
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</thead>
<tbody>
<tr>
<td>ROW share of global oil production</td>
<td></td>
<td>0.927</td>
<td>Eni</td>
</tr>
<tr>
<td>ROW share of global GDP</td>
<td></td>
<td>0.83</td>
<td>IMF</td>
</tr>
<tr>
<td>ROW share of world population</td>
<td></td>
<td>0.955</td>
<td>UN</td>
</tr>
<tr>
<td>Time devoted to leisure</td>
<td>$L_2$</td>
<td>(2/3L_2)</td>
<td>Literature</td>
</tr>
<tr>
<td>ROW Refinery gains</td>
<td></td>
<td>1.017</td>
<td>IEA, EIA</td>
</tr>
<tr>
<td>Ratio of household to firm fuel use</td>
<td>$c_f^2/m_f^2$</td>
<td>0.50</td>
<td>EIA, Exxon, WIOD</td>
</tr>
</tbody>
</table>
## Calibration: Parameters

<table>
<thead>
<tr>
<th>Description</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discount factor</td>
<td>$\beta$</td>
<td>0.96</td>
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<tr>
<td>Substitution parameter</td>
<td>$\rho$</td>
<td>4</td>
</tr>
<tr>
<td>Intertemporal substitution</td>
<td>$\gamma$</td>
<td>$-1$</td>
</tr>
<tr>
<td>Depreciation rate</td>
<td>$\delta$</td>
<td>0.10</td>
</tr>
</tbody>
</table>
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.