U.S. GDP, Oil Price Shocks and Domestic Oil Production: An ARDL Analysis

Gbadebo Oladosu, Paul Leiby, David Bowman, Rocio Uria-Martinez, Megan Johnson

Oak Ridge National Laboratory

November 19, 2020
Does the Change in Domestic Oil Production Affect U.S. Economic Sensitivity to an Oil Price Shock?

• It has been suggested that domestic oil production can reduce U.S. economic impacts of oil price shocks to zero
  • ...but rigorous research on this topic is lacking

• Study objective: Evaluate U.S. economic sensitivity to oil price shocks controlling for oil production/trade changes
  • The “GDP elasticity” with respect to the oil price is crucial for evaluating the benefits of measures to respond to oil price shocks
Domestic oil production is one of many potential factors in estimating the economic impacts of oil price shocks*

- Characteristics of the oil price shock:
  - Size of the shock; supply or demand driven; temporary or permanent

- Domestic market factors:
  - Share of oil in production/GDP; Domestic oil production; Energy substitution possibilities in the short- and long-run
  - Economic cycle - consumption, investment & savings responses

- Wealth transfer; terms of trade and balance of accounts:
  - Net oil trade price/quantity effects of oil price shocks
  - Relative commodity trade prices, current/capital account effects

- Study related factors:
  - Model type, data periodicity and coverage, oil price measure, etc.

Data and Sources

- **Oil market data**: Energy Information Administration (EIA)
  - Price: Spot Prices, Refiner’s Acquisition Cost, Futures Price
  - Consumption: U.S. Petroleum Products Supplied

- **Macroeconomic data**: FRED* and Other Sources
  - U.S. GDP, Consumer Price Index, Interest Rate, Exchange Rate
  - OECD + six Non-Members** GDP Index (OECD Leading Economic Indicators)
  - Kilian’s Global Economic Index

- **All variables, except U.S. GDP, are monthly**
  - Official U.S. GDP is quarterly/annual
  - …we found monthly components for ~70% of the U.S. GDP
  - and estimated the other 30% from known quarterly & monthly data

*Federal Reserve St. Louis Database
**China, Brazil, India, Indonesia, South Africa, Russia
U.S. Petroleum Production, Price and Import Data

- Crude & product imports (MMBD)
- Refiner Crude Acquisition Cost ($/bbl)
- Crude Production (MMBD)
U.S. GDP, CPI and Real Exchange Rate Data

• Consumer price index (1982-84=100)

• Calculated monthly nominal GDP (Billion $)

• Real exchange rate (1973=100)
Method: Auto-regressive Distributed Lag (ARDL) Model

• **Single-equation method is less complex & starting point**
  - ARDL allows cointegration test for mix of I(1) & I(0) variables

• **Error-Correction form of the Asymmetric ARDL Model:**
  - \( \Delta y_t = \alpha + \rho y_{t-1} + \beta z_{t-1} + \theta^- x_{t-1}^- + \theta^+ x_{t-1}^+ + \sum_{i=1}^{p} (\theta_i \Delta y_{t-i}) \)
    \[ + \sum_{i=0}^{p} (\gamma_i \Delta z_{t-i} + \pi_{t-i}^- \Delta x_{t-i}^- + \pi_{t-i}^+ \Delta x_{t-i}^+) + e_t \]
  - \( y, z \) = “Linear” variables; \( x \) = Asymmetric variable
  - \( x^+ / x^- \) = cumulative positive/negative changes in \( x \)

• **Bounds Cointegration test** (Pesaran et al., 2001; Shin et al, 2014)
  - F- and t-statistics tests to validate long-run parameters: \((\rho; \beta; \theta^-; \theta^+)\)

• **Impacts of shocks can be calculated as:**
  - **Short run** \((\gamma_i; \pi_i^+; \pi_i^-)\); **Long-run** \((-\beta/\rho; -\theta^+ / \rho; -\theta^- / \rho)\)
Method: ARDL Model Variables and Implementation

• **Dependent variable:** Monthly Real GDP
  - Variables are in natural logs, except Federal Funds Rate
  - Monetary variables are real 2015$

• **Initial variable tests:**
  - Unit root & structural breaks
    - ADF, KPSS, Zivot-Andrews

• **Model diagnostics:**
  - Weak exogeneity of regressors
  - Autocorrelation of residuals
  - Normality of residuals

• **Bounds cointegration tests**

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Linear</th>
<th>Asymm.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil Market</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U.S. Petroleum Consumption</td>
<td></td>
<td>Oil Price: U.S. Refiner’s Cost</td>
</tr>
<tr>
<td>U.S. Oil Production</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U.S. Petroleum Stocks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U.S. Petroleum Imports</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OECD + 6 GDP Index</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Real Exchange Rate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Federal Funds Rate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consumer Price Index</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Macro
Unit Root Test Results: Structural breaks important

• Unit root test results
  • All variables have unit root under the ADF & KPSS tests
  • First differences are $I(0)$ ➔ stationary

• Zivot-Andrew test implies structural breaks
  • Stationary: petroleum import & consumption
  • Mixed results: petroleum production & stock
Final Model Diagnostics: Few outliers affect residuals

• **Additional variables**
  - Month dummies (excludes Jan.)
  - Structural break variables*
    - 4 vs. 8 initial lags

• **Dummy variables for outliers**
  - Great Recession:
  - Other dates:

• **Heteroscedastic-consistent covariance estimator**
  - For remaining heteroscedasticity in residuals

* Based on Enders et al. (2016)
Regressors are found to be weakly exogenous; Cointegrated with real U.S. GDP

• **Wu-Hausmann test of weak exogeneity**
  • Regressors found to be weakly exogenous

<table>
<thead>
<tr>
<th>statistic</th>
<th>p.value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wu-Hausman</td>
<td>0.47</td>
</tr>
</tbody>
</table>

• **Bounds cointegration test results**
  • Asymptotic F- & t-test were inconclusive
  • Bootstrapped cointegration tests (McNown et. al., 2018)
    • For resolving inconclusive asymptotic bounds test
    • Result: Real GDP is cointegrated with regressors
Positive and negative oil price components have significant U.S. GDP impacts

<table>
<thead>
<tr>
<th></th>
<th>Coefficient</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative Oil Price</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diff</td>
<td>0.000</td>
<td>0.97</td>
</tr>
<tr>
<td>lag 1</td>
<td>-0.003</td>
<td>0.32</td>
</tr>
<tr>
<td>lag Diff 1</td>
<td>-0.005</td>
<td>0.41</td>
</tr>
<tr>
<td>lag Diff 2</td>
<td>0.010</td>
<td>0.02</td>
</tr>
<tr>
<td>lag Diff 3</td>
<td>0.005</td>
<td>0.33</td>
</tr>
<tr>
<td>Positive Oil Price</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diff</td>
<td>0.000</td>
<td>0.96</td>
</tr>
<tr>
<td>lag 1</td>
<td>-0.004</td>
<td>0.10</td>
</tr>
<tr>
<td>lag Diff 1</td>
<td>0.002</td>
<td>0.73</td>
</tr>
<tr>
<td>lag Diff 2</td>
<td>-0.003</td>
<td>0.53</td>
</tr>
<tr>
<td>lag Diff 3</td>
<td>-0.007</td>
<td>0.20</td>
</tr>
<tr>
<td>Real U.S. GDP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>lag 1</td>
<td>-0.172</td>
<td>0.00</td>
</tr>
<tr>
<td>lag Diff 1</td>
<td>-0.419</td>
<td>0.00</td>
</tr>
<tr>
<td>lag Diff 2</td>
<td>-0.235</td>
<td>0.00</td>
</tr>
<tr>
<td>lag Diff 3</td>
<td>-0.054</td>
<td>0.21</td>
</tr>
</tbody>
</table>

- **Oil price coefficients:**
  - Negative oil price component has significant short-run impacts on U.S. GDP
  - Positive oil price component has significant long-run impacts on U.S. GDP

- **Real GDP coefficients:**
  - Rate of real GDP adjustment to equilibrium after a shock is about 17% per month
  - Positive (negative) real GDP change followed by negative (positive) changes
Oil production and import coefficients are insignificant; consumption has significant coefficients

**Coefficient Probability**

<table>
<thead>
<tr>
<th>Crude Production</th>
<th>Coefficient</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diff</td>
<td>-0.003</td>
<td>0.79</td>
</tr>
<tr>
<td>lag 1</td>
<td>-0.004</td>
<td>0.75</td>
</tr>
<tr>
<td>lag Diff 1</td>
<td>-0.013</td>
<td>0.31</td>
</tr>
<tr>
<td>lag Diff 2</td>
<td>0.022</td>
<td>0.17</td>
</tr>
<tr>
<td>lag Diff 3</td>
<td>0.016</td>
<td>0.19</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Petroleum Import</th>
<th>Coefficient</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diff</td>
<td>-0.002</td>
<td>0.75</td>
</tr>
<tr>
<td>lag 1</td>
<td>0.000</td>
<td>1.00</td>
</tr>
<tr>
<td>lag Diff 1</td>
<td>-0.002</td>
<td>0.85</td>
</tr>
<tr>
<td>lag Diff 2</td>
<td>0.008</td>
<td>0.33</td>
</tr>
<tr>
<td>lag Diff 3</td>
<td>0.005</td>
<td>0.26</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Petroleum Supplied (Consumption)</th>
<th>Coefficient</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diff</td>
<td>-0.015</td>
<td>0.35</td>
</tr>
<tr>
<td>lag 1</td>
<td>0.057</td>
<td>0.08</td>
</tr>
<tr>
<td>lag Diff 1</td>
<td>-0.037</td>
<td>0.09</td>
</tr>
<tr>
<td>lag Diff 2</td>
<td>-0.057</td>
<td>0.01</td>
</tr>
<tr>
<td>lag Diff 3</td>
<td>-0.013</td>
<td>0.23</td>
</tr>
</tbody>
</table>

- **Oil Production and Import coefficients:**
  - Oil production & import coefficients are all insignificant

- **Petroleum consumption coefficients:**
  - Positive long-run real GDP effect of shocks to petroleum consumption
  - Negative short-run real GDP effects of shocks to petroleum consumption
Long-run Elasticities for Significant Coefficients

• Long-run “GDP elasticity” with respect to the oil price:
  • -0.022 for the positive oil price component

• Long-run elasticity for other significant variables
  • Magnitudes of elasticities are large
  • Positive long-run elasticity with respect to CPI is unexpected
  • May reflect missing interactions among independent variables
    • e.g. Oil consumption, stock, production & import are directly related

<table>
<thead>
<tr>
<th></th>
<th>Coefficient</th>
<th>Probability</th>
<th>Long-run Elasticity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real GDP</td>
<td>-0.178</td>
<td>0.00</td>
<td>N/A</td>
</tr>
<tr>
<td>Positive Oil Price</td>
<td>-0.004</td>
<td>0.10</td>
<td>-0.02</td>
</tr>
<tr>
<td>Petroleum Supplied</td>
<td>0.057</td>
<td>0.08</td>
<td>0.32</td>
</tr>
<tr>
<td>OECD+6 GDP Index</td>
<td>0.110</td>
<td>0.08</td>
<td>0.62</td>
</tr>
<tr>
<td>Consumer Price Index</td>
<td>0.089</td>
<td>0.02</td>
<td>0.50</td>
</tr>
<tr>
<td>Real Exchange Rate</td>
<td>-0.026</td>
<td>0.01</td>
<td>-0.14</td>
</tr>
</tbody>
</table>
Summary and Future Work

• Estimate of U.S. GDP elasticity with respect to the oil price
  • Consistent with previous meta-analysis findings
  • Recent literature provides some supporting evidence*

• Domestic oil’s role in GDP impacts of oil price shocks
  • May be in changing the nature (size, persistence, etc.) of shocks
  • ...Not the marginal GDP response to a given shock size
  • ...which is what the “GDP” elasticity represents

• Future work
  • Simultaneous equation framework i.e. VAR/VEC
  • Would capture explicit interactions among variables
  • ...and potential changes in characteristics of shocks

* Herrera & Rangaraju (2020); Lyu (2020)
References

ACKNOWLEDGMENTS
This material is based upon work supported by the US Department of Energy under the Strategic Petroleum Reserves Office, and performed at Oak Ridge National Laboratory under contract number DE-AC05-00OR22725. The views in this paper are those of the authors, who are also responsible for any errors or omissions.

Copyright Notice
This manuscript has been authored by UT-Battelle, LLC under Contract No. DE-AC0500OR22725 with the US Department of Energy. The United States Government retains and the publisher, by accepting the article for publication, acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for United States Government purposes. The Department of Energy will provide public access to these results of federally sponsored research in accordance with the DOE Public Access Plan (http://energy.gov/downloads/doe-public-accessplan).
Appendix
Monthly GDP Estimated from Available Quarterly & Monthly GDP Components Data

• Examined U.S. BEA* accounts for monthly GDP-related data
  • ~70% of Value-Added GDP Components are available monthly

• Estimated the other 30% from quarterly & monthly data
  • Generally combines appropriate quarterly rates with monthly data:
    • \( M_x = M_y \times \left( \frac{Q_x}{Q_y} \right) \): \( Q_x \) and \( Q_y \) are known quarterly data
    • \( M_x \) = Unknown monthly data; \( M_y \) = Known monthly data

• Monthly GDP estimate are reliable and useful:
  • Based on readily available quarterly & monthly data
  • Discussed with Bureau of Economic Analysis (BEA) personnel
  • Consistent with IHS Global Insight data but longer historical period
  • Triples the size of database for analysis (130 vs 390: 1986-2018)

*BEA = Bureau of Economic Analysis
Monthly GDP Estimation: Overall

- Monthly data on compensation of employees is ~52% of GDP
- Component percentage of nominal GDP in “Black”
- Estimation approach at the bottom ("Brown" and "Green")

### Monthly Value-Added GDP

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross Operating Surplus</td>
<td>(25%)</td>
</tr>
<tr>
<td>Net Operating Surplus (25%)</td>
<td></td>
</tr>
<tr>
<td>Depreciation (15%)</td>
<td></td>
</tr>
<tr>
<td>Indirect Taxes (6%)</td>
<td></td>
</tr>
<tr>
<td>Domestic (52%)</td>
<td></td>
</tr>
<tr>
<td>ROW (&lt;1%)</td>
<td></td>
</tr>
<tr>
<td>Residual (1%)</td>
<td></td>
</tr>
<tr>
<td>Employees Compensation</td>
<td></td>
</tr>
<tr>
<td>Net Prod. &amp; Import Tax</td>
<td></td>
</tr>
<tr>
<td>Tax</td>
<td></td>
</tr>
<tr>
<td>Net Pro. &amp; Import &amp; Tax</td>
<td></td>
</tr>
<tr>
<td>Employees Compensation</td>
<td></td>
</tr>
</tbody>
</table>

**Estimation Method**

- EC = Employee Compensation
- NOS = Net Operating Surplus
- Dep = Depreciation

See Next Slide

Quarterly Values

Quarterly Ratio to EC+NOS+Dep

Monthly Data

Residual
Monthly GDP Estimation: Net Operating Surplus

- **Net Operating Surplus** (25% GDP): 15% have monthly components
- Component as percentage of nominal GDP in “Black”
- Estimation approach at the bottom ("Brown" and "Green")

- IHS monthly estimates are available from 1992
  - ORNL estimate, and the IHS are highly consistent
  - …despite different estimation methods

- IHS monthly estimates are available from 1992
  - ORNL estimate, and the IHS are highly consistent
  - ...despite different estimation methods
Explaining large fluctuations in ORNL estimates for late 2004 & 2012

• Actual monthly components of the Operating Surplus
  – Large monthly fluctuations in corporate revenues
  – Large changes are averaged out in the quarterly data
Bootstrapped Bounds Cointegration Test Results

- Deals with inconclusive bounds cointegration test
  - McNown et. al. (2018)

- Fixed-design wild bootstrap

- Test Result:
  - Real GDP is cointegrated with independent variables

<table>
<thead>
<tr>
<th></th>
<th>F_Both</th>
<th>F_DV</th>
<th>F_IDV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model Statistics</td>
<td>2.9*</td>
<td>14.1*</td>
<td>2.9*</td>
</tr>
<tr>
<td>Bootstrapped Statistics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1%</td>
<td>0.4</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>5%</td>
<td>0.5</td>
<td>1.2</td>
<td>0.5</td>
</tr>
<tr>
<td>10%</td>
<td>0.5</td>
<td>1.7</td>
<td>0.6</td>
</tr>
<tr>
<td>90%</td>
<td>1.2</td>
<td>7.4</td>
<td>1.3</td>
</tr>
<tr>
<td>95%</td>
<td>1.4</td>
<td>8.6</td>
<td>1.5</td>
</tr>
<tr>
<td>99%</td>
<td>1.7</td>
<td>11.7</td>
<td>1.9</td>
</tr>
</tbody>
</table>

F_Both = F-Statistic on lags of Real GDP and independent variables
F_DV = F-Statistic on lag of Real GDP
F_IDV = F-Statistic on lag independent variables