Impacts of Oil Price Shocks on the U.S. Economy

A Meta-Analysis of Oil Price Elasticity of GDP for Net Oil-Importing Economies

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Impacts of oil price shocks on the US economy is a crucial policy concern but estimates vary widely

• Policymakers require estimates of the impacts of oil price shocks
  • ...to quantify the economic costs of these shocks
  • ...and evaluate the benefits of policy response options
  • Economic impacts can be summarized using “the oil price elasticity of GDP”

• Estimates of the “GDP elasticity” in the literature vary widely
  • ...due to fundamental and methodological factors, including:
    • Drivers of shocks (supply or demand)
    • Size, duration and speed of shocks
    • State of the economy
    • Modeling approach
    • Petroleum dependence
    • etc.

• Study aim is to explore sources of variations in GDP elasticities
  • ...and produce combined mean and confidence intervals for policy needs
Meta-analysis is used to synthesis GDP elasticity estimates and explore sources of variation

- Meta-analysis can be described as quantitative literature review
  - ...for synthesizing parameter estimates across multiple studies
  - 3 meta-analysis approaches for synthesizing varying estimates across studies
    - Fixed effects model ➔ difference in sampling information
    - Random effects model ➔ plus randomly distributed heterogeneity
    - Meta-regression analysis (MRA) ➔ plus systematic sources of heterogeneity

- MRA is the most common approach in the economic literature
  - Used in this study to explore role of different factors in GDP elasticities
  - Can be used even when standard errors are unavailable

- Literature search and data collection
  - Focuses on net oil-importing economies and studies since 2000
  - ~150 papers initially identified as relevant
  - 19 papers found to have accessible, quantitative information
  - Extracted about 2000 point estimates; about half are mean estimates
  - Collected information on study characteristics and other data
Studies come from energy-economy journals and other sources

- **Study sources include:**
  - Energy Economics, Energy Policy, Economic Modeling, European Central Bank, etc.

- **Model type often important**
  - Focus here is on broad model classes
  - ...most are VAR-type models

- **Studies mostly use quarterly data**
  - ...a few are monthly or annual

SEEC = Single equation econometric
VAR-type = Vector autoregression-type
MACRO = Macro-econometric
CGE = Computable general equilibrium
DSGE = Dynamic stochastic general equilibrium
GDP elasticity estimates include many net oil importing economies and span a wide range

Summary of GDP Elasticity Estimates from the Literature

- **US & Europe account for ~90% of data**
  - Overall range of the data is -0.174 to 0.090
  - ...SR mean is -0.017 range: -0.166 to +0.030
  - US range is: -0.124 to +0.017
  - ...SR mean is -0.019; range: -0.124 to +0.016

- **Time profile of regional impacts vary**
  - ...and important for policy analysis
MRA variables aimed at capturing fundamental and methodological sources of variation

- Meta-regression equation estimated (with/without $VR_i$ term)
  
  $e_i = \beta_0 + \beta_1 VR_i + \sum_k \alpha_k X_{i,k} + \epsilon_i$
  
  - $e_i = \text{GDP elasticity estimates}; X_{i,k} = \text{determinant factors};$
  - $VR_i = \text{variance of estimates for (quadratic) publication bias term}$*

- Continuous variables
  
  - **Size of shock** (rate of price change, **centered at +5%**)
  - **Number of quarters after shock to account for time profile** (**centered at 1**)
  - **Normalized average quarterly elasticity** for correlation among estimates
  - **Energy-economy variables**: Real GDP per capita (**centered at $40,000$**); Petroleum (use and imports) to energy use ratios (**centered at 0.4 and 0.2**)

- Dummy variables
  
  - **Regions** (**US**, Europe, Japan, China, etc.)
  - **Model class** (**SEEC**, CGE, DSGE, MACRO, VAR-type)
  - **Years covered by data** in 5-year intervals from 1970-2015 (**1981-1985**)
  - **Price type** (Linear = 1)
  - **Supply shock/variable** (Yes = 1)
  - **Demand shock/variable** (Yes = 1)

- Bolded values represent the **Baseline**

Diagnostics show there are issues with OLS estimates but PRM* is effective

- OLS estimation and diagnostics were performed
- Variance inflation factors (VIF) used to check multi-collinearity
  - Almost all dummy variables have high VIF values
  - Energy-economic variables also have high VIF values
  - Requires special attention because it inflates the size of coefficients
- Partial Robust M-Regression (PRM) estimation combines:
  - PLS (partial least squares) to address multicollinearity and
  - ...M-Regression which addresses outliers, leverage and heteroscedasticity
- Normal Q-Q Plots
  - PRM has close to normal distribution of residuals
  - Publication bias variable ($VR_i$) not useful in this MRA

PRM estimates are generally smaller in magnitude than OLS due to correction for multi-collinearity

- Coefficients are generally smaller in magnitude for PRM than OLS
  - Shows that PRM is effective in dealing with multi-collinearity

- Coefficient for size of shock is positive and significant
  - Gross economic impacts increase at a decreasing rate with size of shock

- Energy-economic variables are negative but small in magnitude
  - Data for these variables are cross-sectional in nature
  - Needs to be interpreted in the context of meta-analysis

**Note: * and ** indicate significance at the 10% and 5% levels for PRM estimates**
Regions, except China and India, are less sensitive to oil price shocks than the US all else same

- Positive and significant estimates for Europe, Australia, Japan
  - Magnitudes vary from +0.0008 to + 0.0194

- China is more sensitive than the United States
  - India is also slightly more sensitive but not significantly
Price, supply and demand coefficients match expectations; model type coefficients vary

- Linear price variable $\Rightarrow$ more positive GDP elasticities
  - Matches use of non-linear price variables to isolate shocks

- Isolating supply or demand shocks $\Rightarrow$ more negative elasticities
  - Marginal effect of a demand-driven price shock would be negative net of the source of the shock

- VAR-type model $\Rightarrow$ more positive, MACRO $\Rightarrow$ negative GDP elasticities than SEEC
Coefficients for data years capture notion that oil price shocks impacts have declined since the 1970s

- Years covered by data variable reflect start/end locations and span of data for GDP elasticity estimates
- Only coefficient for 1970-1975 is negative, significant and sizeable
  - 1991 to 1995 is also negative but small and insignificant
- Other years are positive and generally significant
Simulation of final MRA model produces mean and confidence intervals useful for policy analysis

- Monte Carlo simulation
  - 250,000 replications
- Mean estimate negative
  - \(~-0.015\) in 1\textsuperscript{st} quarter
  - \(~-0.024\) by 8\textsuperscript{th} quarter
- Over all 12 quarters
  - 68\% CI: -0.038 to -0.001
  - 95\% CI: -0.051 to +0.012

Variable Settings for Monte Carlo Distribution

<table>
<thead>
<tr>
<th>Uniform random distribution for:</th>
<th>Other variables have fixed values:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of shock (+1% to +100% in 10 increment)</td>
<td>Normalized average quarterly elasticity (actual values by quarter)</td>
</tr>
<tr>
<td>Number of quarters after shock (1-12 quarters)</td>
<td>2005 Real GDP per capita ($44,00)</td>
</tr>
<tr>
<td>Model type (for model agnosticism)</td>
<td>2005 Petroleum-energy use ratio (0.51)</td>
</tr>
<tr>
<td>Price, supply and demand (equal weighting of 1/0 values)</td>
<td>2005 Net petroleum import-energy use ratio (0.15)</td>
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<tr>
<td><strong>Normal random distribution</strong></td>
<td>Region dummy (baseline: United States; others set to zero)</td>
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<tr>
<td>Multivariate for MRA Coefficients</td>
<td>Years covered by the data (all set to 1 for estimate based on 1970-2015 data)</td>
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<tr>
<td>Normal random distribution of residuals</td>
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Concluding remarks

• Policy analysis of oil markets requires estimates of the economic impacts of oil price shocks, but these cover a wide range

• Meta-regression model
  • Found significant roles for fundamental and methodological factors
    • Price type, Supply and Demand shocks; Model type; Regions; Years of data
  • Monte Carlo simulation generates values for policy analysis
    • US estimate (4 quarters after a shock): -0.020 (68% CI: -0.035 to -0.006)

• Caveats and future efforts
  • Meta-analysis data and results depend on available studies
  • Should be used with variable values not too far from estimation levels
  • Variables are not direct measures, but often composite in nature
    • Coefficients cannot be interpreted in isolation
  • Future efforts will continue to improve the analysis and add newer studies
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Supplemental Slides
## Illustration of the Years Covered by Data Variable

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<td>1</td>
<td>1</td>
<td>1</td>
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<td>1</td>
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<tr>
<td>Estimate B</td>
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<td>1</td>
<td>1</td>
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<tr>
<td>Estimate C</td>
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<td>1</td>
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<td>1</td>
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<tr>
<td>Estimate D</td>
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<td>1</td>
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Asymmetry of funnel plot could imply publication bias or heterogeneity of the GDP elasticity data

- Funnel plots are graphs of mean estimates vs. standard errors
  - Used in meta-analysis to identify potential publication bias
  - ...strictly applicable to fixed effects model of the data
  - ...in other cases, it could indicate heterogeneity in the data

- Pseudo-standard errors for GDP elasticities were calculated
  - ...using available confidence bounds
  - ...imputed for other estimates

Funnel plots of mean elasticities vs. pseudo-standard errors
Visual exploration of averages over groups of potential determinants as background for MRA (1)

- Model class graphs suggest average is generally negative
  - SEEC model class has the largest magnitude
  - DSGE model class has the smallest magnitude

- Non-linear oil price variable often used to isolate shocks in studies
  - Non-linear examples: 1) only positive or negative shocks; 2) Net oil price index
  - Average GDP elasticity estimates are similar until the 8^{th} quarter
    - …non-linear has larger magnitude after 8 quarters
Visual exploration of averages over groups of potential determinants as background for MRA (2)

- **Supply variable or shock**
  - ...suggests that separating drivers of shocks may be important to the MRA
  - ...larger in magnitude when isolating supply shocks or variables

- **Demand variable or shock**
  - ...larger in magnitude when demand shocks or variables are not isolated
F-tests used to check the contribution of different groups variables in the estimation

- All variable groups, except number of quarters under the PRM estimator contributed significantly to the MRA estimates

Table 6. Partial F-tests for coefficient groups in the full meta-regression model

<table>
<thead>
<tr>
<th>Test Description</th>
<th>PRM (Eq. 6a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F(Size of shock)</td>
<td>34.43*</td>
</tr>
<tr>
<td>F(Number of quarters after shock)</td>
<td>-74.11</td>
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<tr>
<td>F(Normalized average quarterly elasticity)</td>
<td>11.55*</td>
</tr>
<tr>
<td>F(Energy-economy variables)</td>
<td>9.76*</td>
</tr>
<tr>
<td>F(Region dummy)</td>
<td>7.2*</td>
</tr>
<tr>
<td>F(Model class dummy)</td>
<td>10.44*</td>
</tr>
<tr>
<td>F(Price type dummy)</td>
<td>10.46*</td>
</tr>
<tr>
<td>F(Supply or demand shock/variable dummy)</td>
<td>32.18*</td>
</tr>
<tr>
<td>F(Years covered by data dummy)</td>
<td>41.02*</td>
</tr>
</tbody>
</table>

*Means significance at the 10% level or below