Are the Responses of the U.S. Economy Asymmetric in Energy Price Increases and Decreases?

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The Literature on Oil Prices and the U.S. Economy

● Since the 1970s oil price shocks have been one of the leading candidates for explaining U.S. postwar recessions.

<u>Problem</u>: Finding an oil price shock measure that "works" in a VAR context is not straightforward (BGW 1997):

→ "anomalous" macroeconomic outcomes relative to the conventional wisdom.
→ "unstable" relationship with macroeconomic outcomes, as the sample is lengthened.

● Search for increasingly complicated specifications of the "true" relationship between oil prices and the U.S. economy, when linear and symmetric models failed to produce the desired results.

Asymmetric Models of the Transmission of Oil Price Shocks

Censored regression models seem to deliver larger and more stable responses:

- 1st Generation (Mork 1989)

Oil price increase:

$$\Delta p_t^+ = \begin{cases} \Delta p_t & if \ \Delta p_t > 0 \\ 0 & if \ \Delta p_t \leq 0 \end{cases}$$

- 2nd Generation (Hamilton 1996, 2003)

Net oil price increase:

$$\Delta p_t^{+,net} = \max[0, p_t - p_t^*],$$

where p_t^* is the highest oil price in the preceding 12 (or 36) months.

Two Types of Studies in the Literature

1. Studies that test for symmetry based on regression slopes (e.g., Mork JPE 1989, Hooker JMCB 2002, Balke et al. EJ 2002, Hamilton JoE 2003).

2. Studies that estimate the dynamic response of macroeconomic aggregates to percent increases or net percent increases in the price of oil. Examples:

Hooker (JME 1996); Bernanke, Gertler and Watson (BPEA 1997); Davis and Haltiwanger (JME 2001); Lee and Ni (JME 2002); Hamilton (JoE 2003); Leduc and Sill (JME 2004); Hamilton and Herrera (JMCB 2004).

Prototypical recursively identified VAR model:

$$\begin{pmatrix} \Delta p_t^{+} \\ \Delta gdp_t \end{pmatrix} \sim VAR(p) \text{ or } \begin{pmatrix} \Delta p_t^{+,net} \\ \Delta gdp_t \end{pmatrix} \sim VAR(p)$$

Consensus in the Macroeconomic Literature

The "evidence for asymmetric responses to oil price ups and downs is well established" (Davis and Haltiwanger 2001).

Why?

- Tests on slope parameters sometimes reject symmetry.

- More stable results?

- Censoring produces "better looking" VAR impulse responses (BGW 1997).

- Nicely complements some theoretical models of the transmission of oil price shocks (Bernanke 1983; Hamilton 1988; Pindyck 1991). We need these models to explain large effects of energy price shocks.

Limitations of Existing Estimates of Asymmetric Responses from Censored VAR Models

1. Censored oil price VAR models are fundamentally misspecified because the asymmetric DGP in question cannot be represented as a VAR model of any kind. As a result, the parameter estimates are inconsistent.

2. The implied impulse responses have been computed incorrectly.

3. Whether asymmetric responses differ from responses based on linear symmetric models has not been tested properly. Existing tests are inadequate for this purpose.

Stylized Static Model: Symmetric Case

<u>DGP:</u>

$$\begin{aligned} x_t &= \alpha_1 + \varepsilon_{1,t} \\ y_t &= \alpha_2 + x_t\beta + \varepsilon_{2,t} \end{aligned} \tag{1}$$

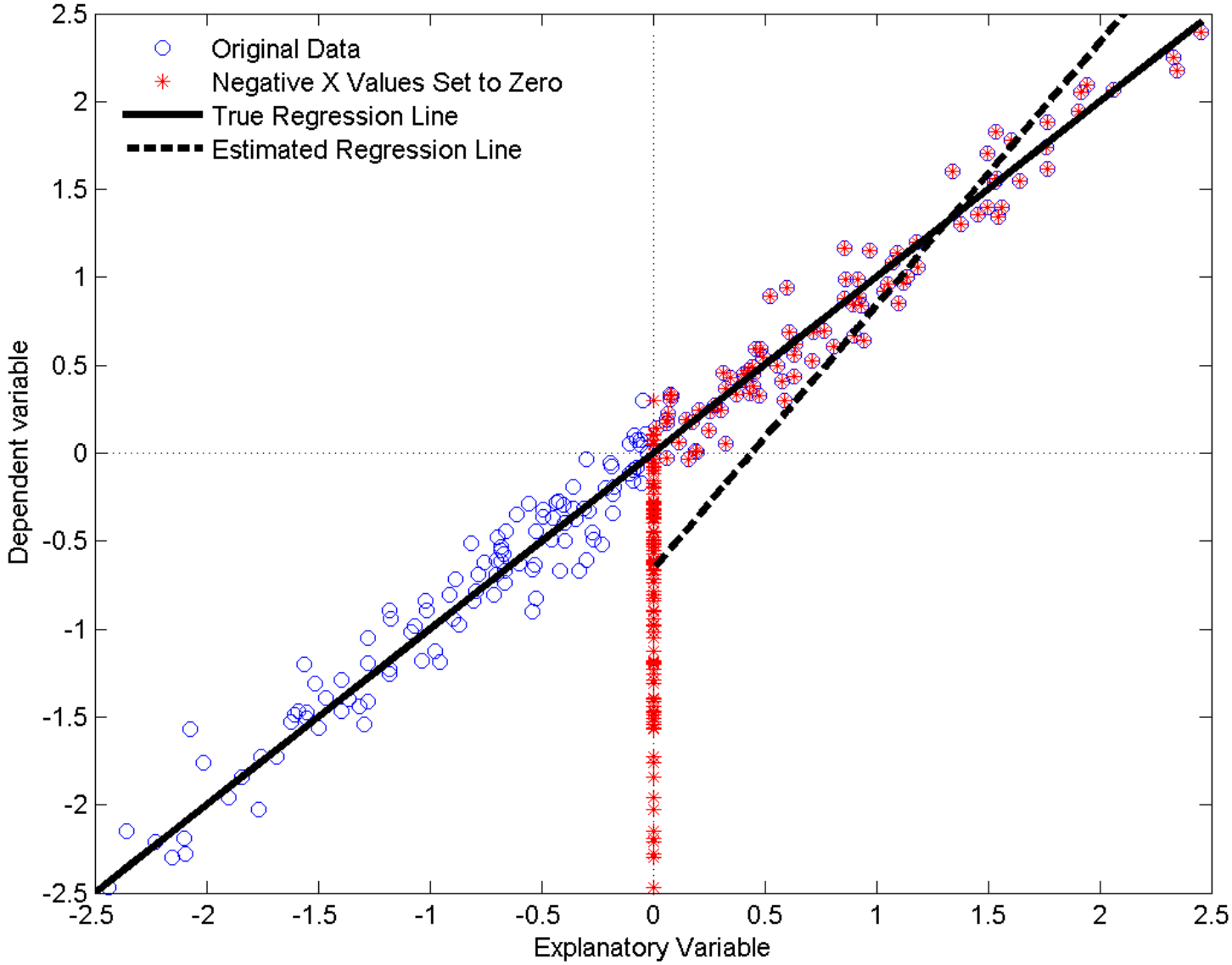
where $\varepsilon_{1,t}$ and $\varepsilon_{2,t}$ are mean zero iid Gaussian with variances σ_1^2 and σ_2^2.

<u>Censored Regressor Model:</u>

$y_t = a + x_t^+ b + u_t$ where $x_t^+ = \begin{cases} x_t & if \;\; x_t > 0 \\ 0 & if \;\; x_t \le 0 \end{cases}$ $\Rightarrow \hat{b}$ is inconsistent for β

(upward bias)

The Effect of Censoring Negative Values of the Regressor



How Big Is the Asymptotic Bias?

- Suppose $\alpha = 0$ and x_t has a symmetric distribution with mean zero and variance 1. Also suppose $\varepsilon_{1,t}$ and $\varepsilon_{2,t}$ are uncorrelated. Then:

$$\hat{b} \xrightarrow{p} -\beta \frac{0.5\mu}{1-0.4\mu^2} \text{ where } \mu \equiv E(x_t \mid x_t > 0).$$

- If $x_t \sim NID(0,1)$, we obtain:

$$\hat{b} \xrightarrow{p} 1.47\beta$$

Stylized Static Model: Asymmetric Case

<u>DGP:</u>

$$\begin{aligned} x_t &= \alpha_1 + \varepsilon_{1,t} \\ y_t &= \alpha_2 + x_t\beta + x_t^+\gamma + \varepsilon_{2,t} \end{aligned} \tag{2}$$

where $\varepsilon_{1,t}$ and $\varepsilon_{2,t}$ are mean zero iid Gaussian with variances σ_1^2 and σ_2^2.

<u>Censored Regressor Model:</u>

$y_t = a + x_t^+ b + u_t$ $\Rightarrow \hat{b}$ is inconsistent for $\beta + \gamma$ unless $\beta = 0$

(upward bias)

Extensions to Dynamic Models

Standard approach:

$$\begin{pmatrix} x_t^+ \\ y_t \end{pmatrix} \sim VAR(p)$$

BGW (BPEA 1997, p. 103):

"Mork provided evidence that only positive changes in the relative price of oil have important effects on output. Accordingly, in our VARs we employ an indicator that equals the log-difference of the relative price of oil when that change is positive and otherwise is zero."

Leduc & Sill (JME 2004, p. 790):

"To get an empirical estimate of the output response to positive oil-price shocks, we run a VAR using … oil-price increases […] constructed by taking the first difference of the log of oil prices, then setting negative values to zero. Thus, only oil-price increases affect the other variables in the system."

What if the DGP is a Linear Symmetric VAR?

- DGP: Linear symmetric VAR(6) fitted on actual data for 1973.1-2007.12.

$$\begin{pmatrix} x_t \\ y_t \end{pmatrix} \sim VAR(6)$$

- Regression model: Recursively identified censored VAR

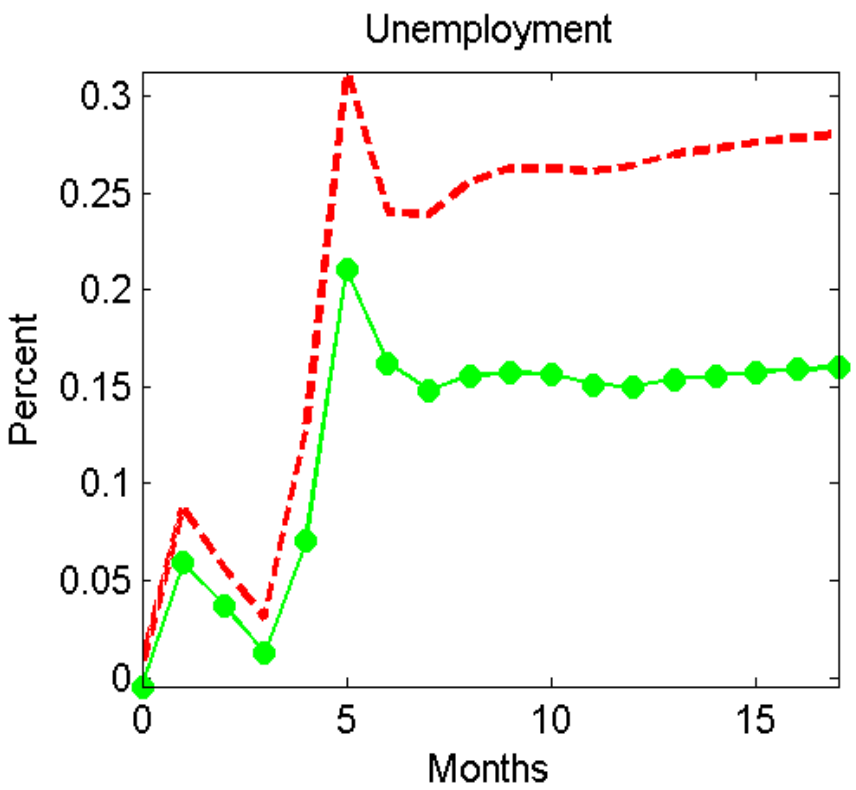
$$\begin{pmatrix} x_t^+ \\ y_t \end{pmatrix} \sim VAR(6)$$

where x_t and y_t are expressed in growth rates and y_t denotes the macroeconomic aggregate of interest.

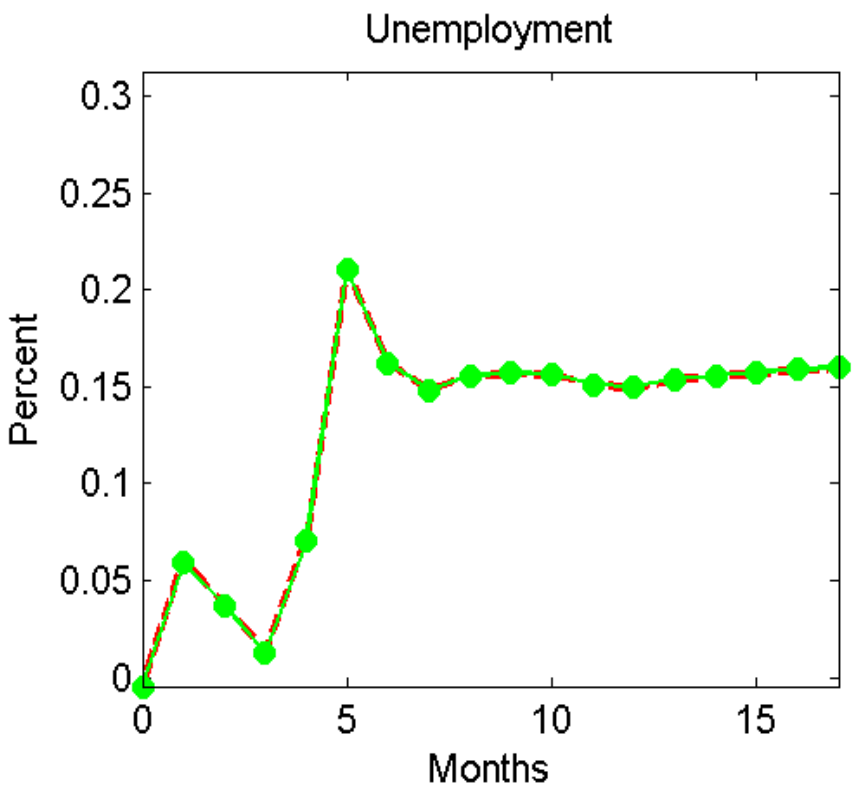
<u>Remark</u>: In the empirical literature, impulse responses from this model have routinely been computed exactly as in linear VAR models. For now, we will follow that practice, so we can assess the empirical results in the literature.

Inconsistency of the Estimated Effect of Energy Price Increases
Symmetric VAR DGP

Censored VAR



Symmetric VAR



Notes: T=100,000.

What if the DGP is an Asymmetric Dynamic Model?

● A censored VAR will generate realizations $x_t^+ < 0$ with positive probability.

The source of this problem is that the regression model is an incomplete description of the DGP.

● It is tempting to deal with this problem by censoring realizations with the wrong sign. In that case, the same type of asymptotic bias from censoring arises, as for the linear symmetric VAR-DGP.

Proposal for a Fully Specified Asymmetric DGP

- Strictly asymmetric structural DGP:

$$
\begin{aligned}
x_t &= \sum_{i=1}^{p} b_{11,i} x_{t-i} + \sum_{i=1}^{p} b_{12,i} y_{t-i} + \varepsilon_{1,t} \\
y_t &= \sum_{i=0}^{p} b_{21,i} x_{t-i}^{+} + \sum_{i=1}^{p} b_{22,i} y_{t-i} + \varepsilon_{2,t}
\end{aligned}
\tag{3}
$$

where the structural shocks $\varepsilon_{1,t}$ and $\varepsilon_{2,t}$ are uncorrelated. Although the slope parameters can be estimated consistently by OLS, the resulting residuals will not be uncorrelated. To impose that restriction, we need a restricted MLE.

- Regression:

$$
\begin{aligned}
x_t^{+} &= \sum_{i=1}^{p} b_{11,i} x_{t-i}^{+} + \sum_{i=1}^{p} b_{12,i} y_{t-i} + \varepsilon_{1,t} \\
y_t &= \sum_{i=1}^{p} b_{21,i} x_{t-i}^{+} + \sum_{i=1}^{p} b_{22,i} y_{t-i} + \varepsilon_{2,t}
\end{aligned}
$$

Unlike in the static model, the censored VAR will be inconsistent even if x_t has zero coefficients $\forall t$ in the second equation of the DGP!

A General Model of the Oil Price-Economy Link

● If we do not know whether there is an asymmetry or what form it takes, we face a dilemma. Which model should we fit to the data?

● Proposal:

$$
\begin{aligned}
x_t &= \sum_{i=1}^{p} b_{11,i} x_{t-i} + \sum_{i=1}^{p} b_{12,i} y_{t-i} + \varepsilon_{1,t} \\
y_t &= \sum_{i=0}^{p} b_{21,i} x_{t-i} + \sum_{i=1}^{p} b_{22,i} y_{t-i} + \sum_{i=0}^{p} g_{21,i} x_{t-i}^{+} + \varepsilon_{2,t}
\end{aligned}
\tag{4}
$$

1. Consistent estimation of each equation by OLS is possible.

2. This model eliminates the inconsistency (at the price of being possibly inefficient).

Computing Asymmetric Impulse Responses Properly

● The standard approach to constructing impulse responses is misleading since it ignores the path dependence of the future values of y_t and their dependence on the magnitude of the shock.

● The computation of impulse responses for nonlinear multivariate reduced form models is discussed in Koop et al. (1996).

<u>Problem</u>: 1. Shock is not uniquely defined.
2. Experiment violates the ceteris paribus assumption.

<u>Solution</u>: In the context of our structural asymmetric model, in contrast, the errors are mutually uncorrelated, so we can compute economically meaningful responses by drawing from the marginal distribution of structural shocks.

Computing Nonlinear Responses to Unanticipated Energy Price Increases

Having estimated the asymmetric model as discussed earlier, proceed as follows:

Step 1: Take a block of p consecutive values of x_t and y_t. This defines a history Ω^i.

Step 2. Given Ω^i, simulate two time paths for x_{t+i} and y_{t+i}, $i = 0,1,...,h$. In generating the first time path, the value of $\varepsilon_{1,t}$ is equal to a prespecified value δ. In generating the other time path, the value of $\varepsilon_{1,t}$ is drawn from the marginal empirical distribution of $\varepsilon_{1,t}$. The values of all subsequent shocks $\varepsilon_{1,t+i}$ and the value of $\varepsilon_{2,t+i}$, $i = 0,1,2,...,h$, are drawn from their respective marginal distributions. In practice, we treat these draws as independent.

Step 3: Calculate the difference between the time paths for y_{t+i}, $i = 0,1,...,h$.

Step 4: Average this difference across *m=10,000* repetitions of Steps 2 and 3.

- This average is the response of y_{t+i} to a shock of magnitude δ <u>conditional</u> on Ω^i :

$$I_y(h,\delta,\Omega^i)$$

is the relevant statistic for forecasting and policy work.

- The corresponding <u>unconditional</u> response

$$I_y(h,\delta) = \int I_y(h,\delta,\Omega^i)d\Omega^i$$

is a measure of the general of the general importance of oil price shocks.

● The response typically used in existing empirical work is

$$I_y^*(h, \delta, \underline{0})$$

where we condition on a <u>hypothetical</u> initial condition, in which all variables equal zero, and substitute expected values of future shocks rather than integrating over all possible shock paths.

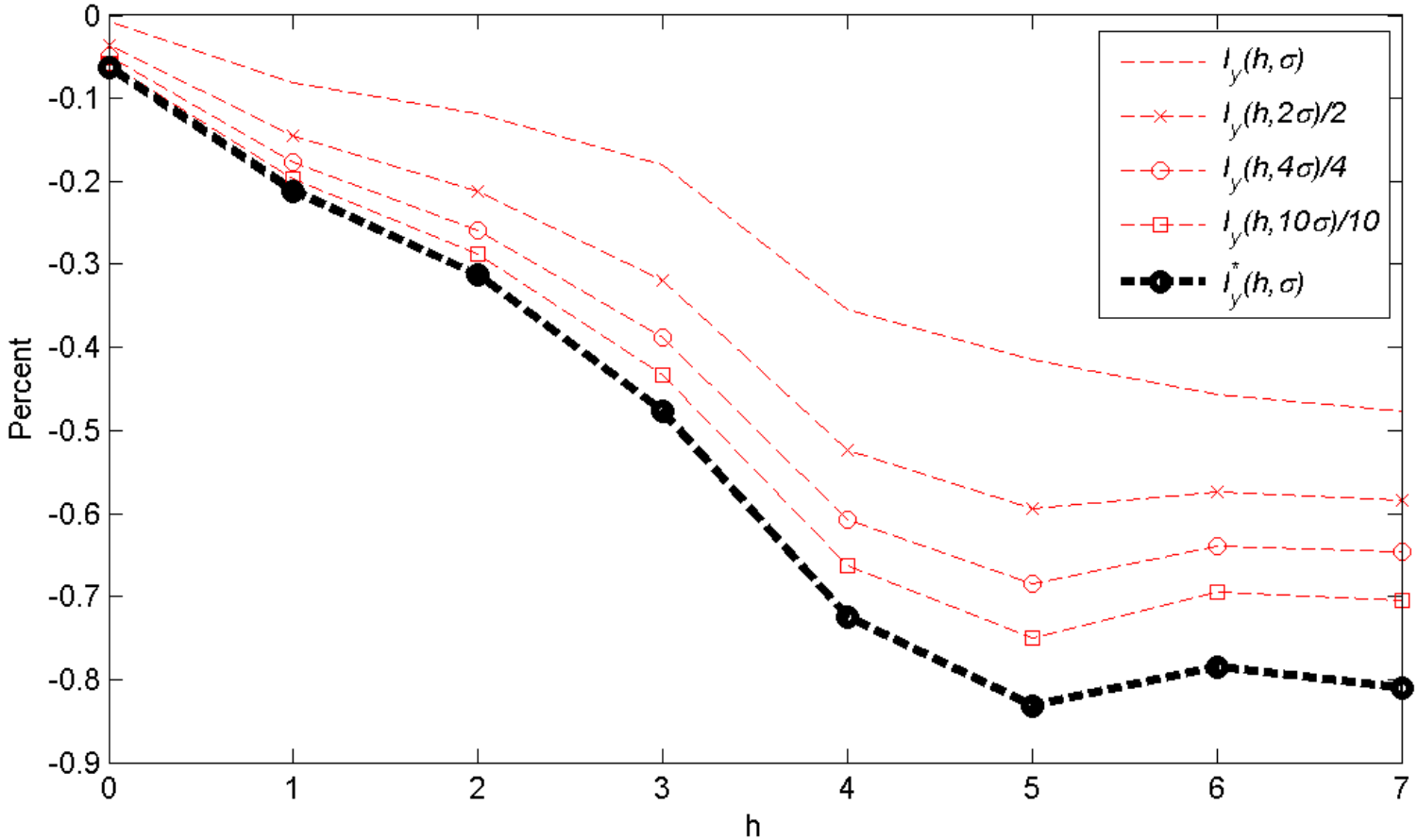
<u>Problems:</u>

1. Koop et al. (1996) show that this traditional impulse response may not converge to zero, even when the stochastic process is stationary.

2. Potter (2000): Theoretical treatment of nonlinear impulse responses is facilitated by treating future shocks as random variables rather than fixed values.

3. Why is this specific history interesting?

How Different is the Traditional Response from the Correctly Computed Unconditional Response?



Notes: Response of GDP to a positive oil price shock. $I_y(h,\sigma)$ is computed by Monte Carlo integration over 300 histories with 10,000 paths each. The responses have been scaled for compatibility. h denotes the horizon.

Testing for Symmetry in the Impulse Responses

● The <u>traditional approach</u> to testing for symmetry in the transmission of energy price shocks involves tests on the symmetry of slope coefficients in regressions of y_t on lagged x_t^+ and x_t^- (e.g., Mork 1989).

This is equivalent to testing $H_0 : g_{21,1} = ... = g_{21,p} = 0$ in the structural model.

● The structural model suggests that Mork's (1989) reduced form test fails to impose all restrictions. A test of all symmetry restrictions on the slopes involves:

$$H_0 : g_{21,0} = ... = g_{21,p} = 0$$

Empirical Results: Slope-Based Symmetry Tests
Baseline Model with 6 Lags

Variable	The Proposed Test of Symmetric Slope Coefficients	Marginal Significance Level	Mork's Test of Symmetric Slope Coefficients	Marginal Significance Level
Unemployment	7.722	0.358	3.132	0.792
Gasoline Consumption	11.376	0.123	9.237	0.161
Real GDP	10.472	0.163	9.757	0.135

Limitations of Slope-Based Symmetry Tests

1. Given the nonlinearity of the impulse response in the reduced form parameters, even 1% rejection of symmetry based on slopes does not guarantee large degree of asymmetry in the impulse responses.

Likewise, statistically insignificant departures from symmetric slopes may translate to a large and/or statistically significant degree of asymmetry in impulse responses.

2. Slope-based tests ignore that the extent to which the responses in the symmetric linear model provide a good approximation depends on the magnitude of the shock we consider.

⇨ This suggests that we test symmetry directly on the object of interest.

A New Test of the Symmetry of Impulse Responses

● Estimate the general (potentially nonlinear) model and compute the impulse responses to a positive and a negative energy price shock, as discussed earlier.

● Construct a Wald test of $H_0 : I_y(h,\delta) = -I_y(h,-\delta)$ for $h = 0,....,H$.

● The test statistic has an asymptotic χ^2_{H+1} distribution.

<u>Remarks:</u>

The variance-covariance matrix of the vector sum of response coefficients can be estimated by bootstrap simulation.

Size of the 5% Test of Symmetric Responses

	Unemployment		Gas Consumption		Real GDP	
H	1 std dev	2 std dev	1 std dev	2 std dev	1 std dev	2 std dev
2	0.06	0.05	0.06	0.05	0.06	0.05
4	0.07	0.05	0.07	0.05	0.07	0.05
6	0.08	0.05	0.08	0.06	0.07	0.05
8	0.09	0.07	0.10	0.07	0.09	0.07

Notes: Based on average of 90 histories and 20,000 draws under the null.

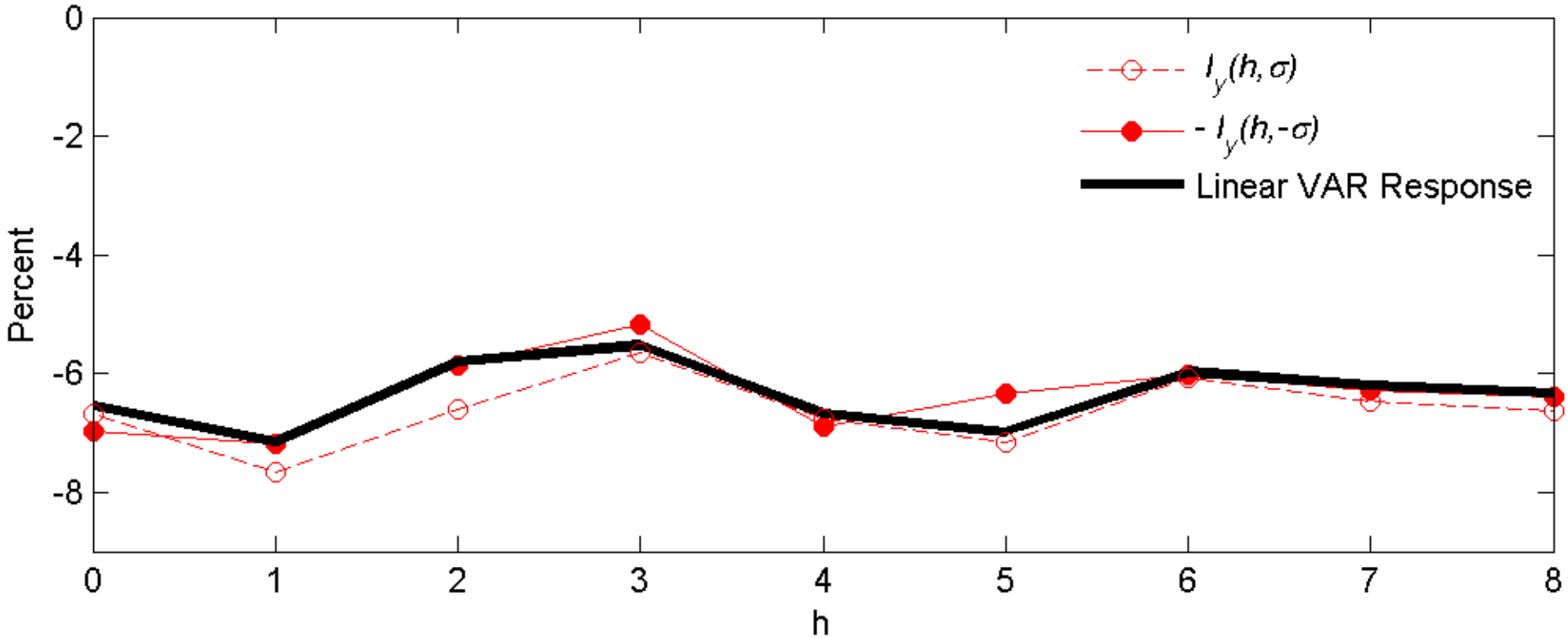
Empirical Results of Tests for Symmetric Responses

p-Values for Test of $H_0 : I_y(h,\delta) = -I_y(h,-\delta)$ for $h = 0,....,H$.

H	Gas Consumption 1 Std. Deviation Shock	Gas Consumption 2 Std. Deviation Shock	GDP 1 Std. Deviation Shock	GDP 2 Std. Deviation Shock	Unemployment 1 Std. Deviation Shock	Unemployment 2 Std. Deviation Shock
0	0.45	0.47	0.40	0.47	0.36	0.43
1	0.13	0.28	0.44	0.54	0.65	0.73
2	0.05	0.15	0.59	0.69	0.83	0.88
3	0.09	0.25	0.56	0.68	0.92	0.96
4	0.07	0.21	0.66	0.78	0.97	0.98
5	**0.04**	0.15	0.78	0.87	0.99	1.00
6	0.06	0.18	0.48	0.59	1.00	1.00
7	0.09	0.26	0.58	0.69	1.00	1.00

Notes: Based on 20,000 simulations of Model (4). p-values based on the χ^2_{H+1}-distribution.

Gasoline Consumption Example:
How Different are the Response Estimates?
Baseline Model with 6 Lags



Testing Models of Net Energy Price Increases

● Existing tests of the net increase model are based on one-step ahead single-equation predictive models:

$$y_t = \sum_{i=1}^{p} \beta_i y_{t-i} + \sum_{i=1}^{p} \gamma_i x_{t-i} + \sum_{i=1}^{p} \delta_i x_{t-i}^{+,net} + u_t \quad \text{Balke et al. (2002)}$$

$$y_t = \sum_{i=1}^{p} \beta_i y_{t-i} + \sum_{i=1}^{p} \delta_i x_{t-i}^{+,net} + u_t \quad \text{Hamilton (2003)}$$

⇨ What are the implications for degree of asymmetry of impulse responses?

⇨ Existing evidence against the linear symmetric VAR model does <u>not</u> justify the model:

$$\begin{pmatrix} x_t^{+,net} \\ y_t \end{pmatrix} \sim VAR(p)$$

That model is misspecified and its impulse responses have been routinely computed incorrectly (also see Balke et al. 2002).

Testing Symmetry in Models of Net Energy Price Increases

$$
\begin{aligned}
x_t &= \sum_{i=1}^{p} b_{11,i} x_{t-i} + \sum_{i=1}^{p} b_{12,i} y_{t-i} + \varepsilon_{1,t} \\
y_t &= \sum_{i=0}^{p} b_{21,i} x_{t-i} + \sum_{i=1}^{p} b_{22,i} y_{t-i} + \sum_{i=0}^{p} g_{21,i} x_{t-i}^{+,net} + \varepsilon_{2,t}
\end{aligned}
\tag{5}
$$

Slope-based test: $H_0 : g_{21,0} = ... = g_{21,p} = 0$

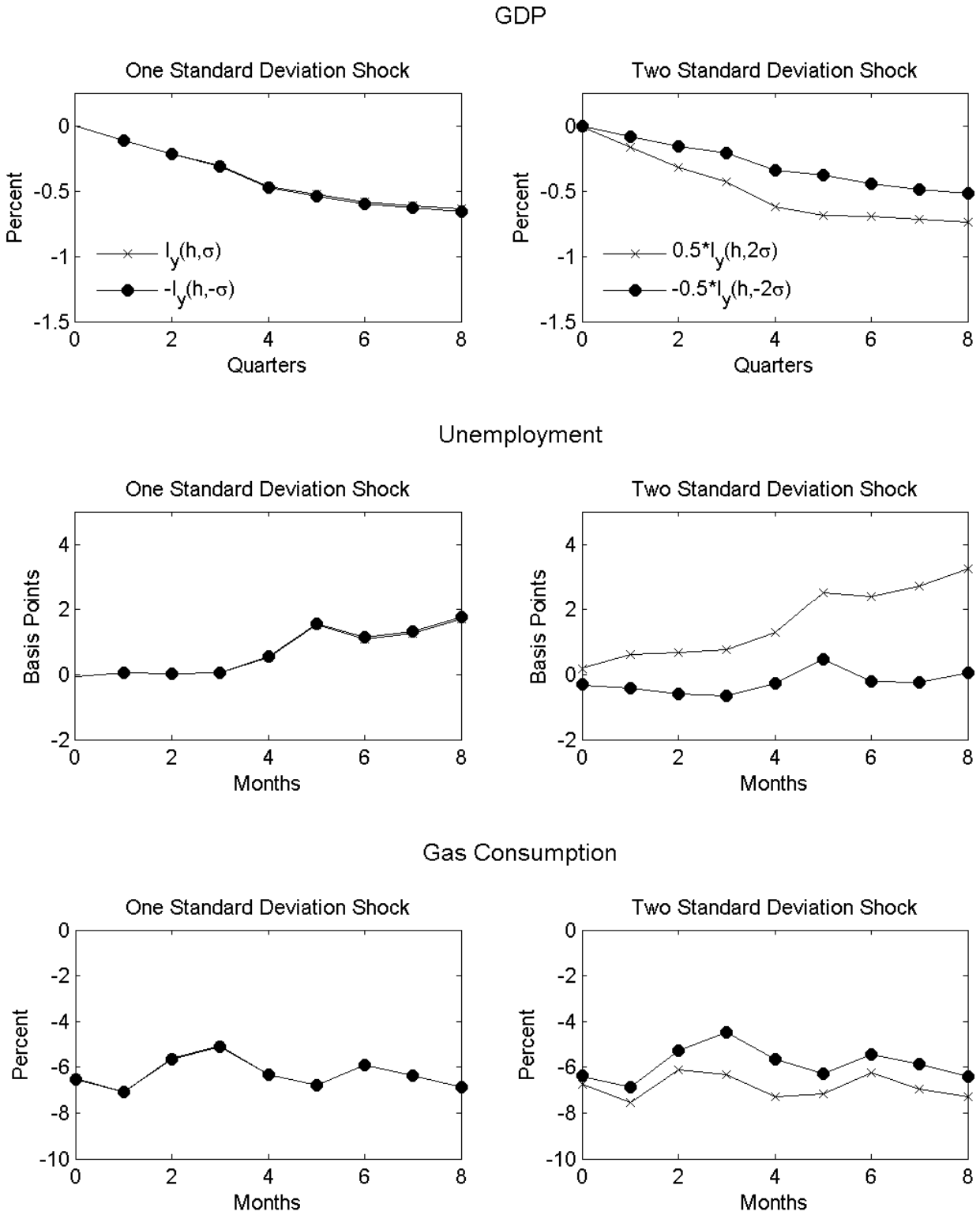
Impulse-response based test: $H_0 :\ I_y(h,\delta) = -I_y(h,-\delta)$ for $h = 0,....,H$.

Slope-Based Test of the Linear Symmetric VAR Model against the 3-Year Net Increase VAR Model

Variable	3-Year Net Increase	
	Test of Linear Symmetric Model	Marginal Significance Level
Unemployment	9.6332	0.210
Gasoline Consumption	14.5307	**0.043**
Real GDP	14.2965	**0.046**

NOTES: *p*-values based on χ^2_{H+1} distribution.

Responses to Energy Price Shocks
3-Year Net Increase Model



p-Values of Tests of $H_0 : I_y(h,\delta) = -I_y(h,-\delta)$ for $h = 0,....,H$

3-Year Net Increase Model

H	Gas Consumption 1 Std. Deviation Shock	Gas Consumption 2 Std. Deviation Shock	GDP 1 Std. Deviation Shock	GDP 2 Std. Deviation Shock	Unemployment 1 Std. Deviation Shock	Unemployment 2 Std. Deviation Shock
0	0.94	0.43	0.98	0.79	0.95	0.13
1	0.98	0.56	0.99	0.30	0.99	0.24
2	1.00	0.66	1.00	0.26	1.00	0.40
3	1.00	0.23	1.00	0.38	1.00	0.57
4	1.00	0.32	1.00	0.41	1.00	0.71
5	1.00	0.44	1.00	0.53	1.00	0.69
6	1.00	0.55	1.00	0.57	1.00	0.69
7	0.94	0.43	0.98	0.79	0.95	0.13

NOTES: p-Values based on χ^2_{H+1} distribution. Bootstrap variance estimates using 20,000 replications of model (5).

Implications for the Literature on the Transmission of Oil Price Shocks

● Theoretical models of sectoral reallocations or of delayed investment are <u>inconsistent</u> with our test results.

These are precisely the models required to explain potentially large effects of oil price shocks on U.S. output.

● In contrast, traditional models of cost-push and aggregate demand reduction are <u>consistent</u> with the lack of asymmetry.

These models do not predict large fluctuations in U.S. output in response to oil price shocks, consistent with the evidence from linear symmetric models.

Conclusions

1. Asymmetric responses should be estimated and tested using the econometric methods outlined in this paper. Earlier methods are invalid.

2. There is no statistically significant evidence of asymmetric responses to energy price shocks:

→ There is no compelling reason to abandon the use of linear symmetric models in empirical work on the transmission of energy price shocks (or the use of linear approximations to the steady state in theoretical work).

→ Theoretical models of the transmission of energy price shocks that imply asymmetries are not consistent with the U.S. data.

3. Key empirical studies that have shaped our thinking about how monetary policy has responded to oil price shocks are invalid.

Much of the evidence on plant level and sectoral effects of oil price shocks will also have to be reexamined.

Does the Fed Respond to Oil Price Shocks?

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The Policy Reaction Hypothesis

Standard models of the transmission of oil price shocks do not generate large recessions in theory or empirically. BGW (1997) propose an explanation of how the effects of oil price shocks may be amplified:

1. The Fed tends to raise the interest rate in response to actual or potential inflationary pressures triggered by positive oil price shocks.

2. This systematic and anticipated policy response is the main cause of the recessions that tend to follow oil price shocks.

3. These recessions could have been avoided (at the cost of higher inflation) by holding the interest rate constant.

What is the Rationale for a Monetary Tightening?

1. Are exogenous oil price shocks inflationary?

AS shock: $Y \downarrow, P \uparrow$ versus AD shock: $Y \downarrow, P \downarrow$

2. What happened to the dual objective of the Fed?

3. Inflation hawks in the 1970s?

4. Oil price shocks reflect deeper demand and supply shocks, each if which may necessitate a different response by the Fed. A policy reaction to oil price shocks makes no sense in a world of endogenous oil price shocks (see Kilian 2009; Nakov and Pecatori 2009)

Critiques of BGW's Empirical Methodology:

● Hamilton & Herrera (2004): BGW's empirical results are questionable

1. Sensitivity of empirical results to the VAR lag order.
2. Policy changes required for counterfactual violate Lucas Critique.

● Kilian and Vigfusson (2009): BGW rely on a censored VAR model in oil price net increases (or oil price increases). That censored VAR analysis is invalid.

1. Parameter estimates of censored VAR models are inconsistent.
2. BGW do not compute the impulse response functions correctly.
3. The null of symmetric response functions cannot be rejected.

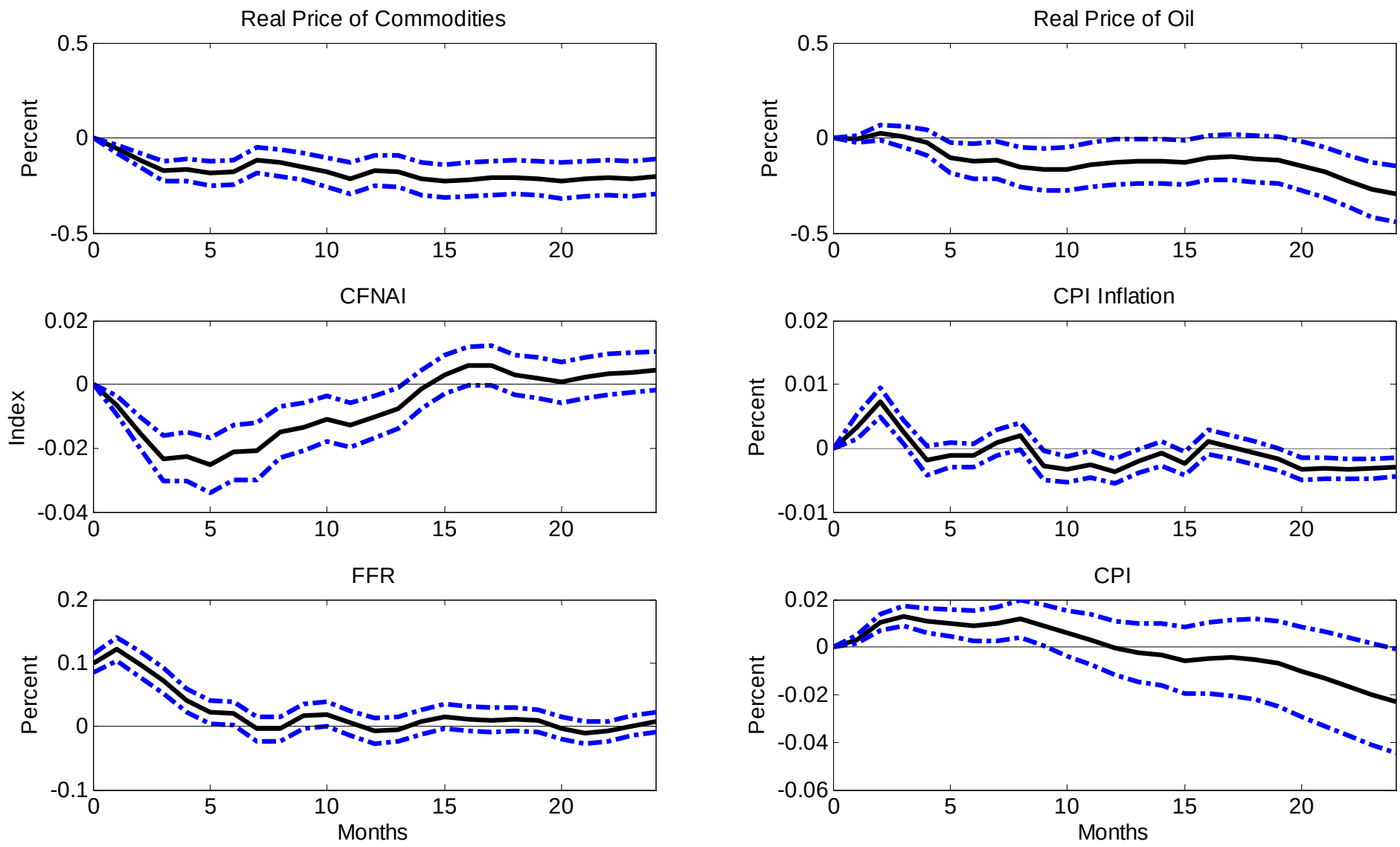
New Baseline Model

- Recursively identified semi-structural linear monthly VAR(12) model with intercept.

- Model variables:

  1. $\Delta\%$ in real price of imported crude oil (rather than nominal net increase)
  2. $\Delta\%$ in real CRB industrial commodity prices (rather than level)
  3. Chicago Fed National Activity Index (CFNAI): principal components index of U.S. real output (rather than interpolated real GDP)
  4. CPI Inflation (rather than price level)
  5. Federal funds rate

Responses to a 10 Basis Points Exogenous Increase in the Fed Funds Rate 1967.5-1987.7



Split-Sample Analysis

1967.5-1987.7

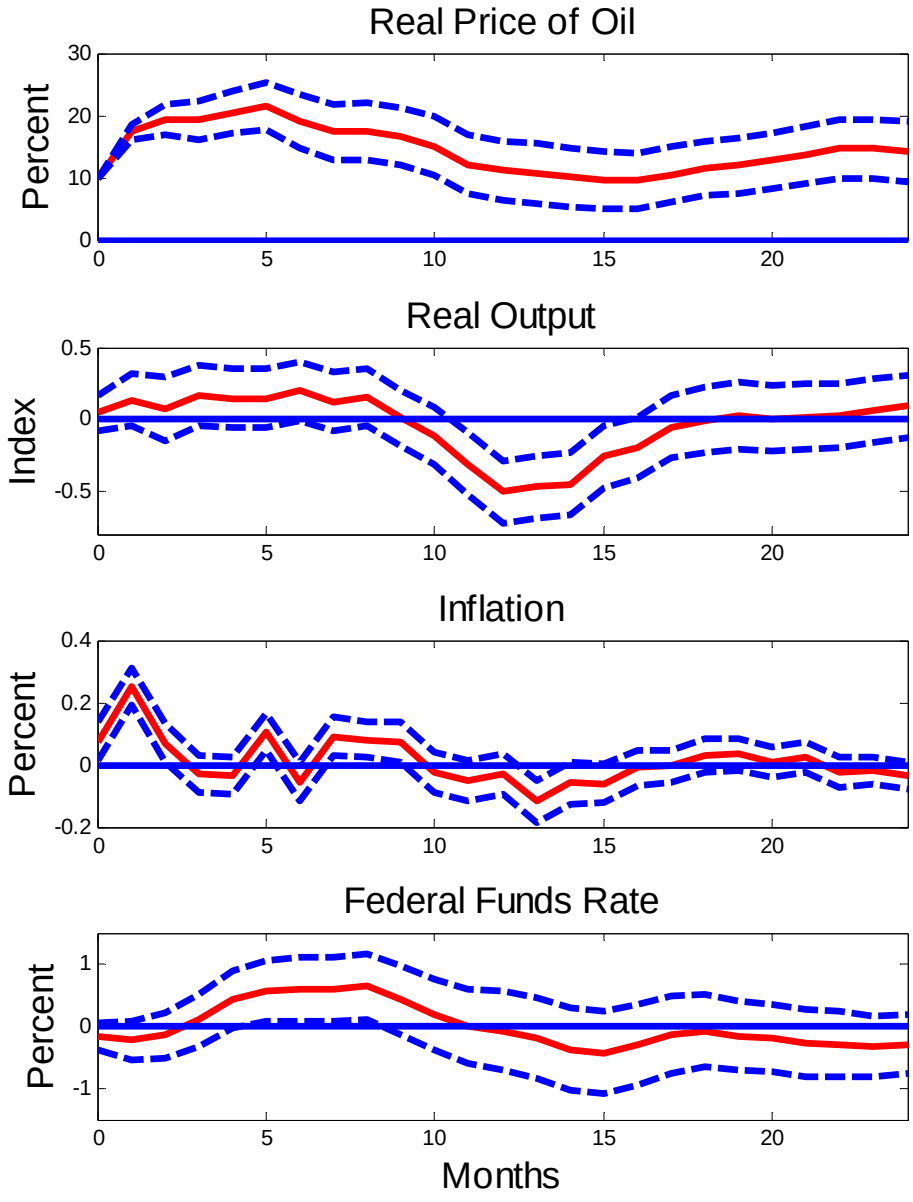
Our sample starts slightly later than BGW's due to data constraints.
Similar results with sample starting in the early 1970s.
Results not sensitive to ending date. BGW sample ends in 1990s.

(Additional sensitivity analysis with pre-Volcker sample not shown.)

1987.8-2008.6

Greenspan-Bernanke period
Financial crisis deliberately excluded (change in policy reaction function?)

U.S. Responses to a 10 Percent Real Oil Price Shock: 1967.5-1987.7



What is the Nature of the Policy Response?

A statistical decomposition of the response of the Federal funds rate to the oil price shocks suggests that:

- The Federal Reserve is not responding to *actual* inflationary pressures triggered by the oil price shock, but is responding preemptively to *potential* inflationary pressures (e.g., wage-price spiral?).

- There is no response to output dynamics triggered by the oil price shocks either.

Counterfactual Analysis

How much of a difference does the Fed's response to oil price shocks make?

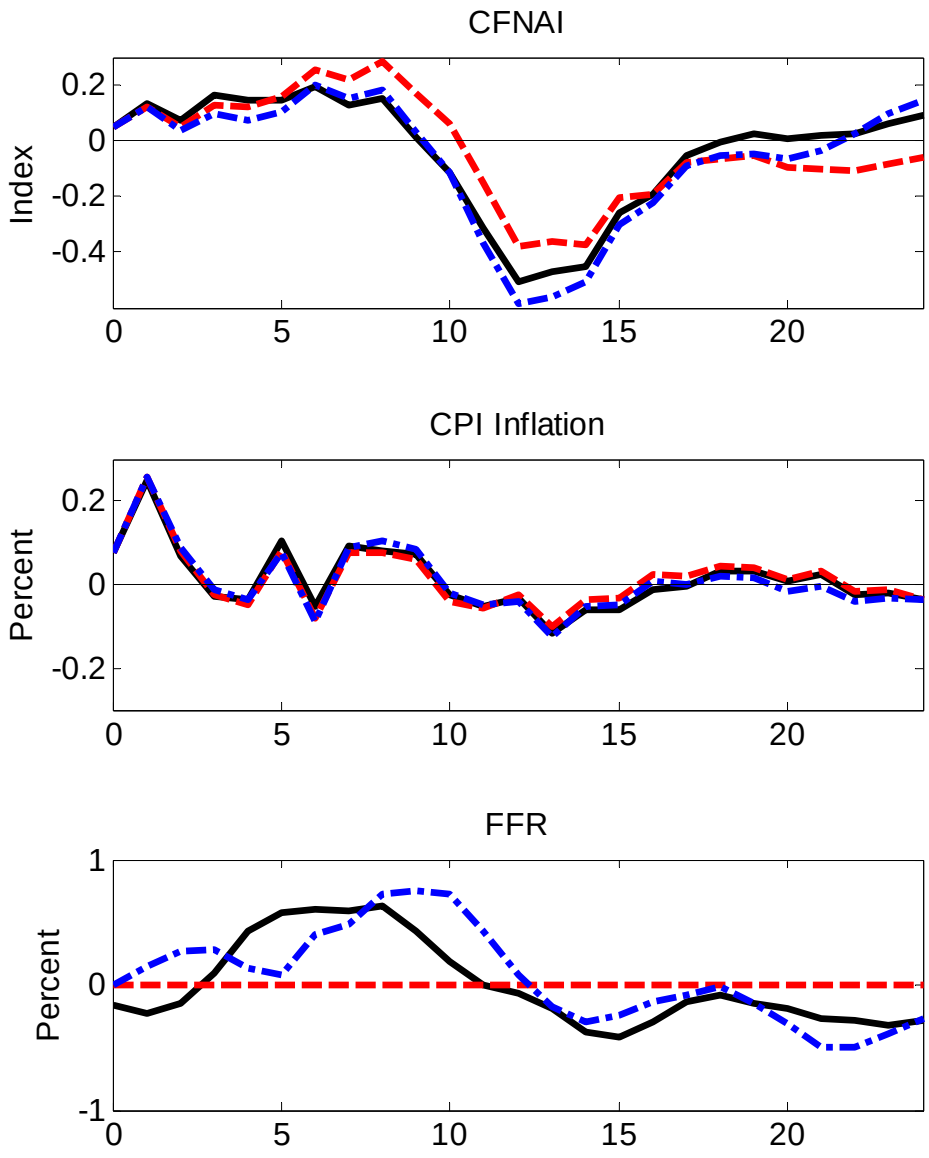
1. BGW's counterfactual:

   The Fed holds the interest rate constant.

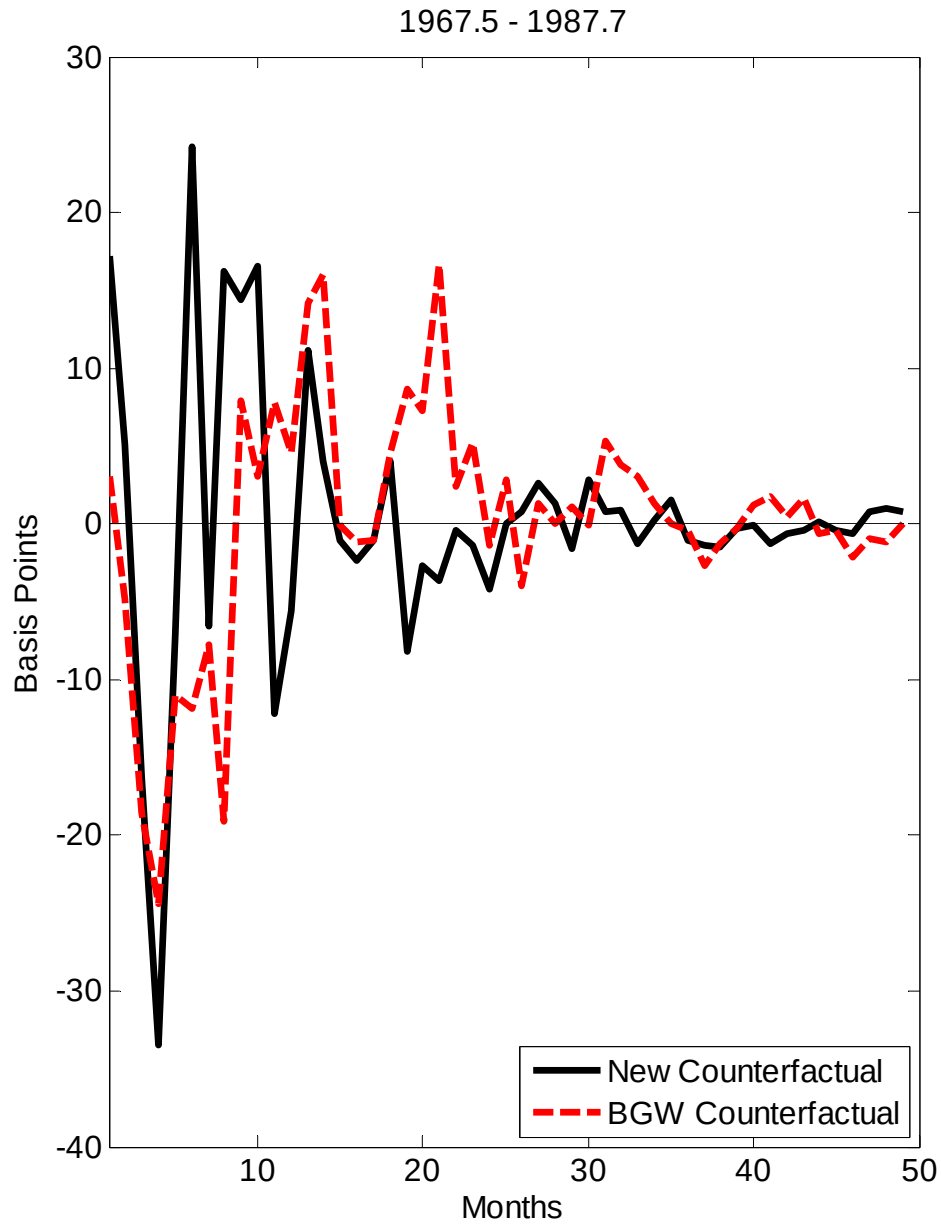
2. A more relevant counterfactual:

   The Fed reacts to fluctuations in other macroeconomic state variables (such as inflation and real output) as it normally would with only the *direct* response to the real price of oil shut down.

Counterfactual Simulations: 1967.5-1987.7



Policy Shocks Required for the Implementation of the Counterfactual



Identification Issues

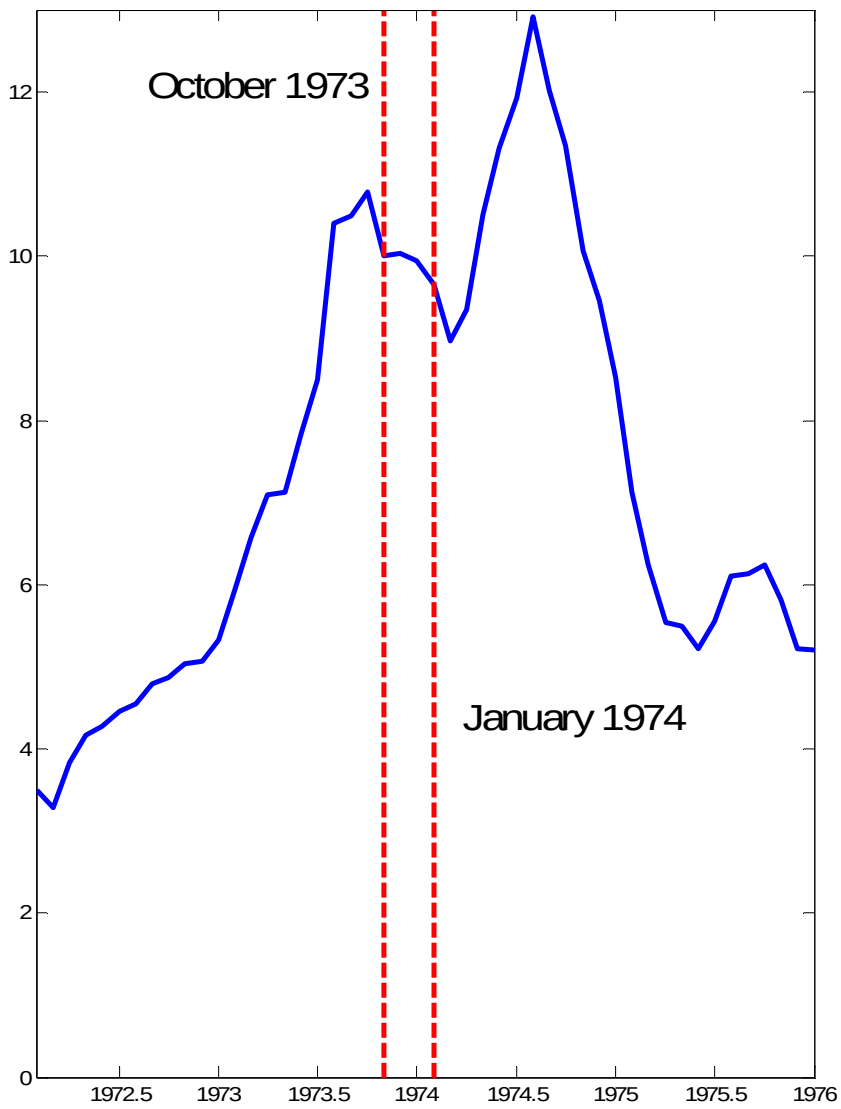
● BGW reported that there was no evidence of a policy response to the 1973/74 oil price shock; rather the Fed responded to commodity price inflation.

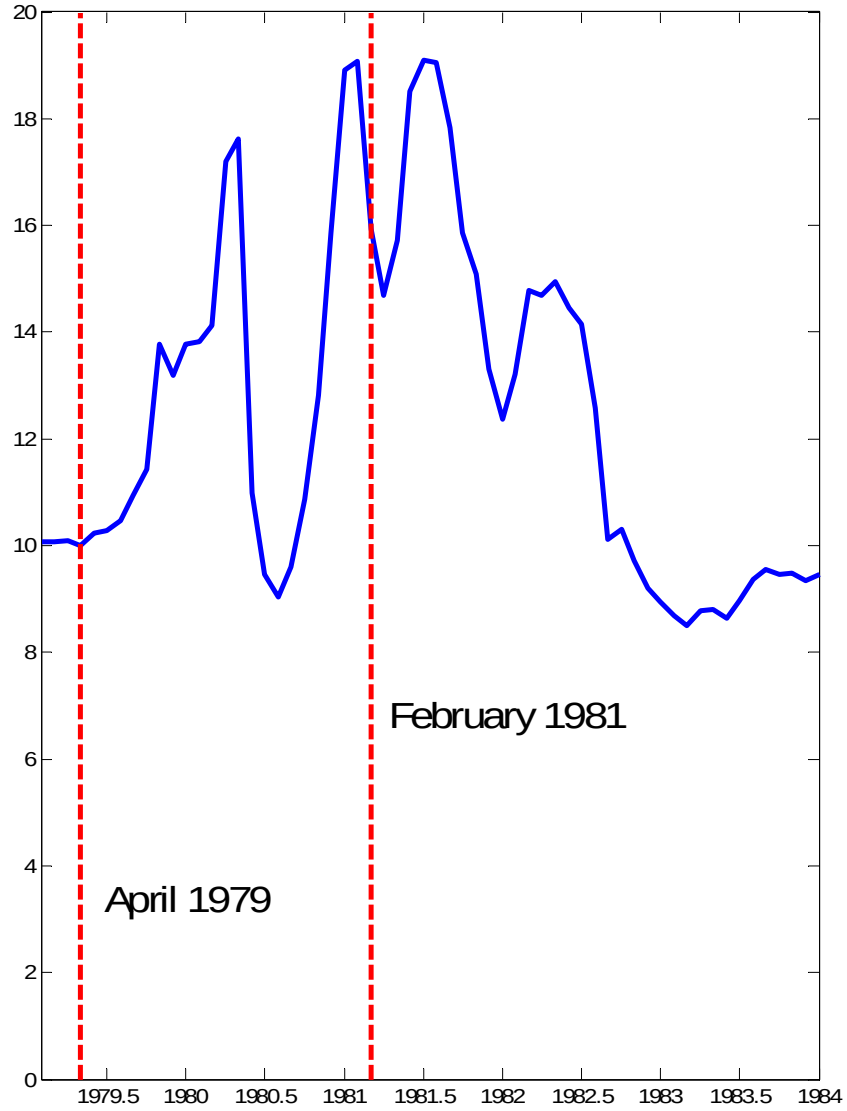
This is consistent with narrative evidence in Barsky and Kilian (2002) that the Fed raised the interest rate starting in late 1972 in response to an overheating economy.

● Nor is the 1991 episode supportive of the BGW hypothesis.

Thus, BGW's evidence rests squarely on the 1979 oil price shock episode.

Evolution of the Federal Funds Rate during the Oil Price Shocks of the 1970s and Early 1980s





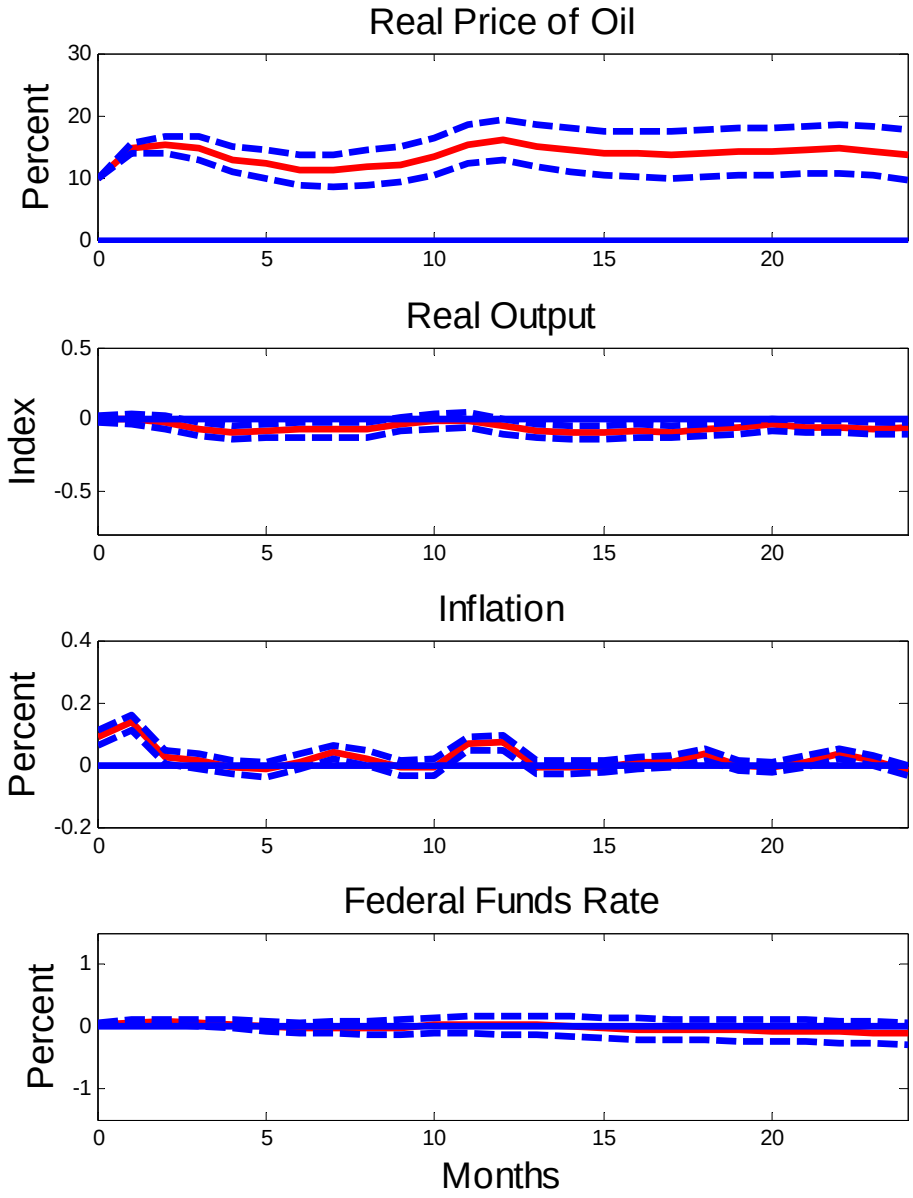
Key identification problem: Did Volcker raise interest rates in 1979 to fight domestic inflation unrelated to oil prices or in response to the 1979 oil price shock?

A legitimate test of this proposition is to evaluate the BGW hypothesis on data not yet available to BGW, namely 1987.8-2008.6.

Rationale:

- Greenspan and Bernanke are inflation hawks, as postulated by BGW.
- Fairly long sample and arguably homogenous data.
- There is a sufficient number of oil price shocks in that sample period to allow identification.

U.S. Responses to a 10 Percent Real Oil Price Shock: 1987.8-2008.6



Alternative Explanations in the Literature

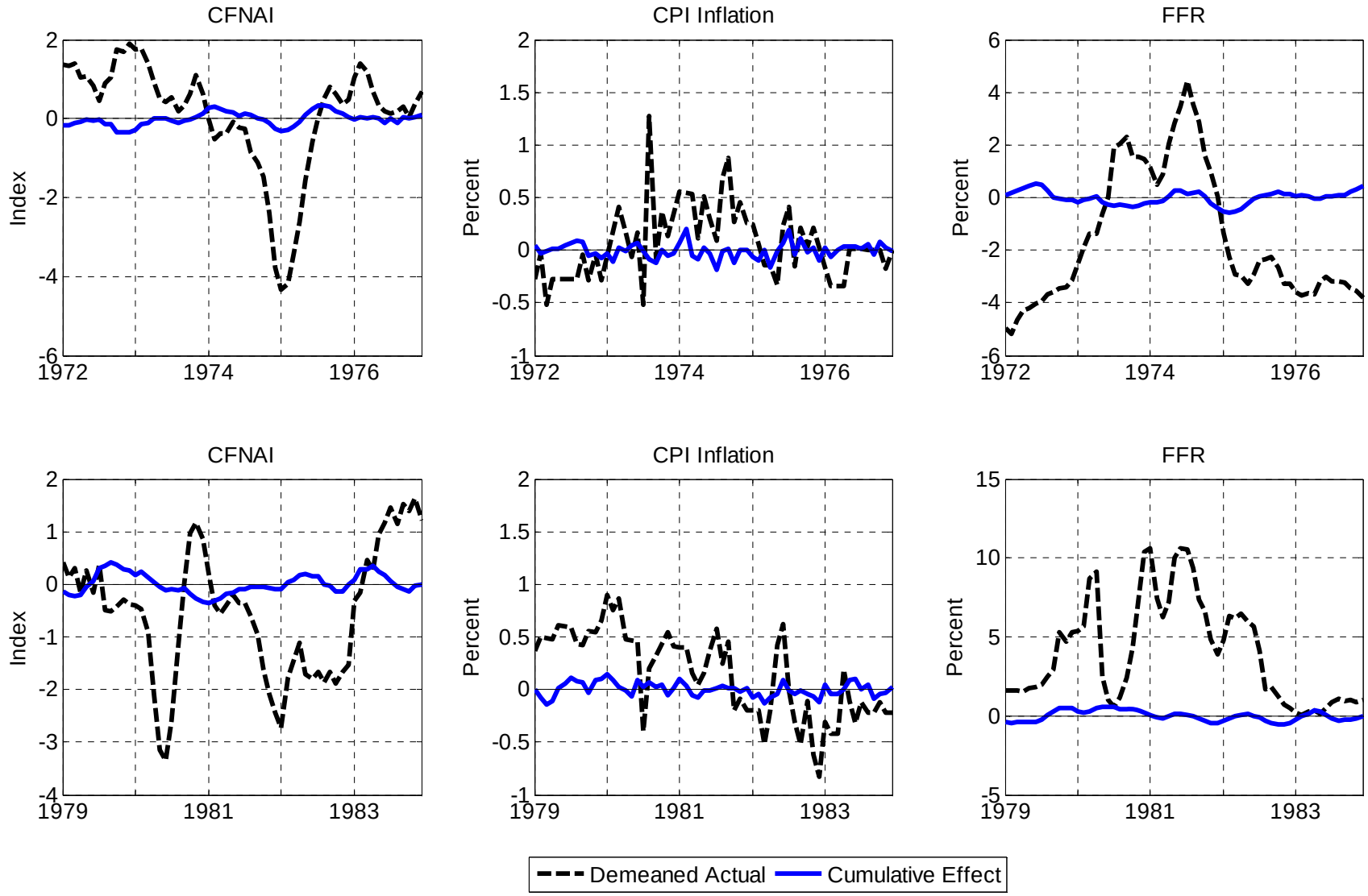
1. Improved monetary policy reaction?

   If so, where is the recession?

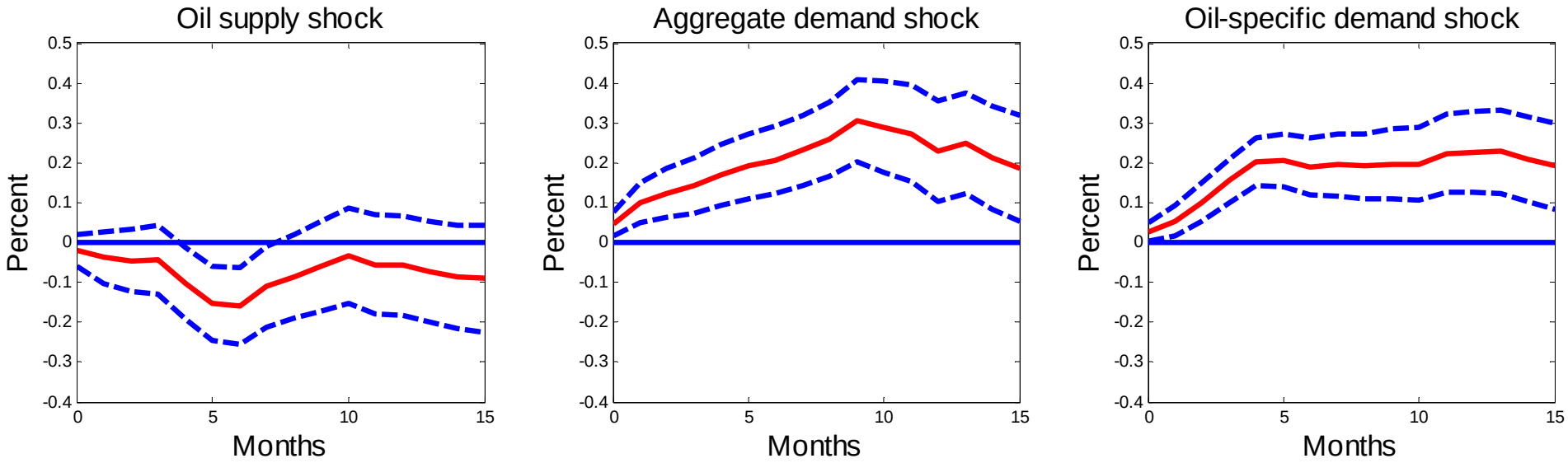
2. Oil price shocks not as inflationary as they used to be?

   - Changes in the composition of oil demand and oil supply shocks (Kilian, AER 2009)
   - Lower energy share in the economy? (Edelstein and Kilian, JME 2009)
   - Reduced real wage rigidities? (Blanchard and Gali, NBER 2009)

Cumulative Effect of Real Oil Price Shocks on U.S. Real Output, Inflation and Interest Rates



Response of the Effective Federal Funds Rate to Oil Demand and Oil Supply Shocks



Conclusions

1. There is no evidence that monetary policy responses to oil price shocks had large effects on U.S. real activity or CPI inflation in the 1970s and 1980s. That conclusion is *independent* of the choice of counterfactual.

2. The search for explanations of the diminished importance of the BGW channel of transmission after the 1980s is moot because that channel never was quantitatively important even in the 1970s and 1980s.

3. Our analysis suggests that the traditional monetary policy reaction framework explored by BGW and incorporated in subsequent DSGE models has outlived its usefulness.

Lessons for Policymakers

1. Rather than respond to relative price shocks that often are merely symptoms of broader global macroeconomic developments, central banks must identify and respond to the deeper causes of oil price shocks.

2. This requires a different class of structural models than are customarily used by policy makers, namely DSGE models that explicitly model the endogenous determination of the real price of oil.

3. The question of how to respond to higher oil prices is likely to take on a new urgency, as the world economy recovers from the current crisis.

The Role of Inventories and Speculative Trading in the Global Market for Crude Oil

Lutz Kilian
University of Michigan
CEPR

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Competing Views of the Global Market for Crude Oil

1. Oil is an asset, the price of which is determined by desired stocks. Shifts in the expectations of forward-looking traders are reflected in changes in the real price of oil and in changes in oil inventories.

2. The price of oil is determined by shocks to the flow supply of oil and to the flow demand for oil.

- ⇨ There has been increasing recognition that both elements of price determination matter (e.g., Dvir and Rogoff 2009; Einloth 2009; Frankel and Rose 2009; Hamilton 2009a;b; Kilian 2009; Alquist and Kilian 2010).

Key Contributions of this Paper

- We propose a structural VAR model of the global market for crude oil that explicitly embeds these two explanations of the determination of the real price of oil.

- Using a new approach to identification, we show how the forward-looking element of the real price of oil can be identified with the help of data on crude oil inventories.

- The proposed model allows us to study the role of storage in oil markets and to shed light on the extent of speculation.

- We contribute to the recent policy debate about lessons from 2003-08.

The Role of Expectation Shifts in Oil Markets

There is a forward-looking element in the real price of oil driven by shifts in oil traders' expectations.

This forward-looking element has proved elusive, but it is exactly this expectational component that underlies speculation.

Problem:
Traditional oil market VAR models are backward-looking.

Market expectations of future oil demand and oil supply are equated with econometric expectations in these VAR models.

Examples of Expectations Shocks

1. First moment shocks:

<u>Supply side</u>: New discoveries (Brazilian off-shore oil fields)

Anticipation of a War in the Middle East

Anticipation of "peak oil" effects

<u>Demand side</u>: Anticipation of a booming world economy

Anticipation of a major global recession

New technologies that reduce need for oil

2. Second moment shocks:

Uncertainty about future oil supply shortfalls

Why Is It So Difficult to Model Expectation Shifts?

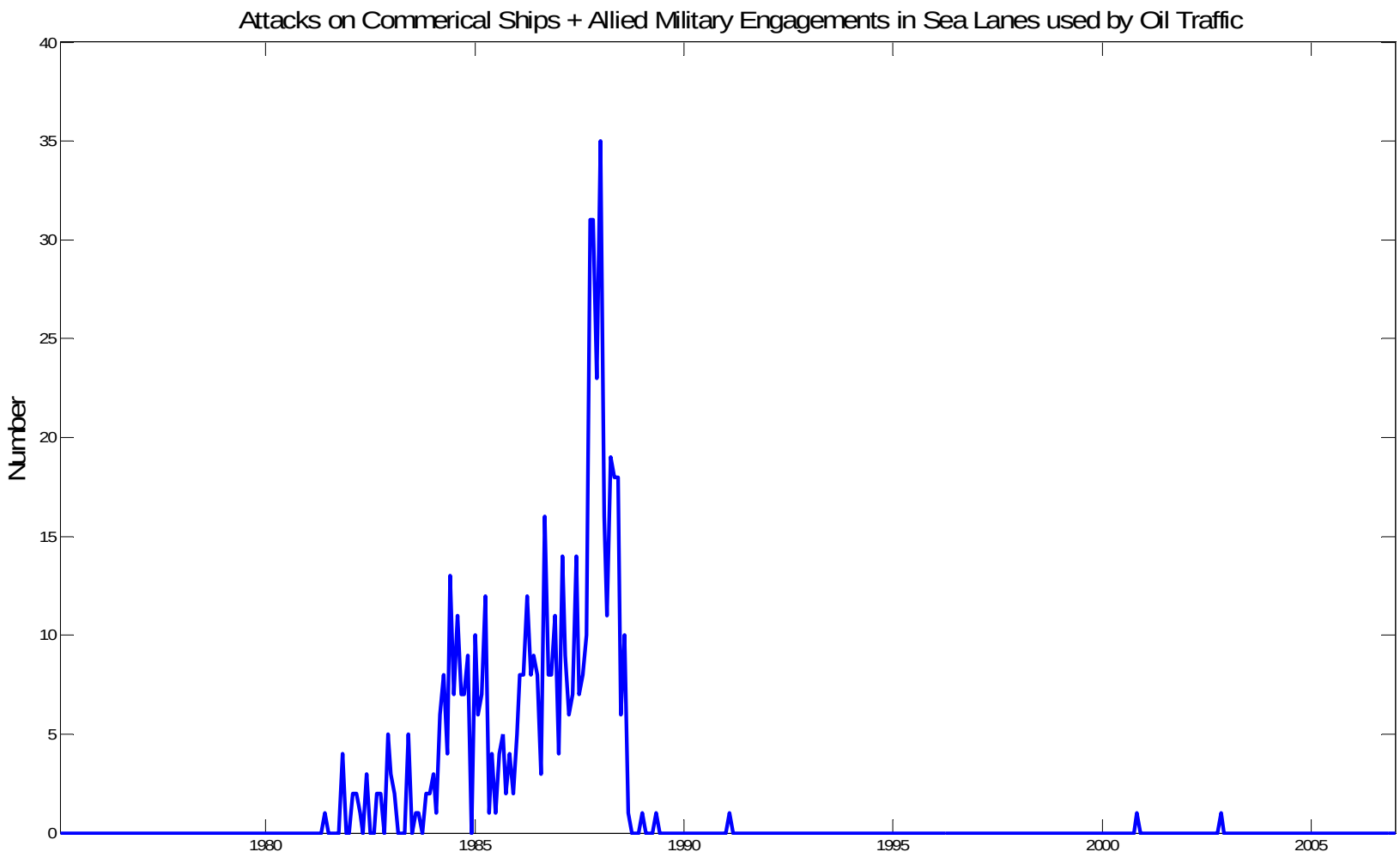
- Expectations shifts are not directly observable.

- Even if we could observe proxies, the causal chain is nonlinear:

Observables → Expectations → Speculative Demand → Oil Price

<u>Example</u>: Attacks on oil tankers in the Persian Gulf

Number of Military and Terrorist Attacks on Tankers in the Middle East: 1973.1-2006.12



Our Indirect Approach

- Speculative demand for oil manifests itself as demand for oil inventories.

  ⇨ By including changes in oil inventories in an econometric model we are able to identify the effects of expectations shifts <u>without</u> explicit measures of expectations.

- Revisions to expectations shift the contemporaneous oil demand curve (conditional on past data) without affecting the contemporaneous oil supply curve.

Structural VAR Model of the Global Crude Oil Market

- Monthly data for 1973.2-2009.8:
    1. Percent change in global crude oil production
    2. Global real activity in deviations from trend
    3. Real price of oil
    4. Change in Global Crude Oil Inventories

- VAR(24) with seasonal dummies

- Preliminary tests provided no evidence of cointegration between oil production and oil inventories.

The Crude Oil Inventory Data

- Given the lack of data for other countries, we follow Hamilton (2009) in using the data for U.S. crude oil inventories provided by the EIA.

- These data are scaled by the ratio of OECD petroleum stocks over U.S. petroleum stocks for each time period.

- We express the resulting proxy for global crude oil inventories in changes rather than percent changes.

Structural Shocks

The structural model can be expressed as:

$$B_0 y_t = \sum_{i=1}^{24} B_i y_{t-i} + \varepsilon_t .$$

The vector ε_t of orthogonal structural innovations consists of:

1. Shock to the flow supply of crude oil
2. Shock to the flow demand for crude oil
3. Shock to the demand for oil inventories arising from forward-looking behavior ("speculative demand shock")
4. Residual shock that captures all structural shocks not otherwise accounted for and has no direct economic interpretation.

The Economic Model: Flow Supply

- The flow supply of crude oil is measured by the global production of crude oil.

- An unexpected disruption of that flow (embodied in a shift to the left of the contemporaneous oil supply curve along the oil demand curve) on impact will cause:

Global oil production ↓

Real price of oil ↑

Oil inventories ↓

Real activity ↓

The Economic Model: Flow Demand

- The flow demand for crude oil is driven by unexpected fluctuations in global real activity. These represent shifts in the demand for all industrial commodities including crude oil associated with the global business cycle.

- An unanticipated increase in global real activity (embodied in a shift to the right of the contemporaneous oil demand curve along the oil supply curve) on impact will cause:

  Real activity ↑

  Real price of oil ↑

  Oil inventories ↓

  Global oil production ↑

The Economic Model: Speculative Demand

- Given that crude oil is storable, it may also be viewed as an asset, the real price of which is determined by the demand for inventories.

We must allow the price of oil to jump in response to any news about *future* oil supply or *future* oil demand, as inventory demand incorporates these news.

- A positive speculative demand shock causes on impact:

  Real price of oil ↑

  Oil inventories ↑

  Real activity ↓

  Global oil production ↑

How Expectations May Affect Oil Demand: (1)

● Upward revisions to expected future demand for crude oil (or downward revisions to expected future production of crude oil) increase the demand for crude oil inventories in the current period, resulting in an <u>instantaneous</u> shift of the demand curve for oil along the oil supply curve.

● No direct effect on global real activity or oil production within the month (because the shock is defined as an innovation about *future* global real activity or oil production).

● Only to the extent that the real price of oil jumps on impact, one would expect this shock to lower global real activity and to stimulate oil production.

How Expectations May Affect Oil Demand (2)

● An unexpected increase in the uncertainty about future oil supply shortfalls would have the much same effect (Alquist and Kilian, JAE 2010).

● The difference is that pure uncertainty shocks would not be associated with expected changes in future oil production or real activity.

Identifying Assumptions on Signs of Impact Responses

	Flow Supply Shock	Flow Demand Shock	Speculative Demand Shock
Oil Production	-	+	+
Real Activity	-	+	-
Real Oil Price	+	+	+
Inventories	-	-	+

Note: Unlike in Kilian (AER 2009) we do not impose any exclusion restrictions on the impact responses. All sign restrictions involve weak inequalities and allow for the response to be zero.

The Need for Additional Identifying Restrictions

- Sign restrictions alone are typically too weak to be informative about the effects of oil demand and oil supply shocks.

- Remaining overtly "agnostic" is not an option.
  1. Sets of response functions cannot be interpreted.
  2. Median responses are not measures of the responses associated with the most likely structural model.

- It is important therefore to impose <u>all</u> credible identifying restrictions to allow us to narrow down the set of admissible structural models.

- We introduce a novel set of economically motivated restrictions.

1. Bound on Impact Price Elasticity of Supply

- The impact price elasticity of oil supply must be small.
- Our bound of 0.0259 is based on the production response of producers in the rest of world in the first month following the invasion of Kuwait on August 2, 1990.
    - Exogenous shock
    - Timing of shock coincides with calendar time
    - Concerted effort by all oil producers to increase production
    - Spare capacity available (Kilian, REStat 2008)
- Our main results are robust to a bound as high as 0.1.

2. Bound on Impact Price Elasticity of Demand

● The impact price elasticity of oil demand can be estimated from the VAR by evaluating the ratio of the impact responses of oil production and of the real price of oil to an unexpected oil supply disruption.

● This ***oil demand elasticity in production*** equates the production of oil with the consumption of oil. In the presence of changes in oil inventories that conventional assumption is inappropriate.

The relevant quantity measure instead is the sum of the flow of oil production and the depletion of oil inventories triggered by an oil supply shock.

- Natural additional identifying assumption:

  The implied impact ***oil demand elasticity in use*** must be weakly negative on average over the sample.

- No need to restrict the oil demand elasticity in production. Our impact sign restrictions ensure that this elasticity is negative on impact.

NOTE: The use of bounds imposes no further restrictions on the level of the impact responses!

3. Relative Order of Magnitude Restrictions

● Because there are two oil demand shocks in the model, the model allows the construction of two estimates of the impact price elasticity of oil supply. In population, these elasticities must be identical.

● Identifying assumption: Discard all structural models that imply estimates of the same elasticity that are different by an order of magnitude.

<u>Example</u>: We would discard a model solution in which one of the impact elasticities of oil supply is 0.001, while the other is 0.023.

3. Relative Order of Magnitude Restrictions (contd.)

- The model also implies that the ratio of the impact response of real activity to the impact response of the real price of oil should be the same in response to negative oil supply shocks as in response to positive speculative demand shocks.

In both cases, the impact response of real activity is driven by the response of the real price of oil. In particular, a speculative demand shock by construction will not affect real activity directly within the month.

NOTE: Equal order of magnitude restrictions merely represent cross-equation restrictions!

4. Shape Restrictions

- Expectations shocks should result in a jump of the real price of oil on impact followed by a decline in the long run (Alquist and Kilian 2010).

- Identifying assumption:

The price response to speculative demand shocks must not be higher at the maximum horizon than it is on impact (without taking a stand on the evolution of the response function at intermediate horizons).

5. Dynamic Sign Restrictions

- Models in which unanticipated oil supply disruptions cause a decline in the real price of oil below its starting level are at odds with the standard view in the literature.

- Identifying assumption:

The sign of the response of the real price of oil to negative oil supply shocks must remain positive for one year.

<u>Implication</u>: Because the positive price response is accompanied by a persistently negative response of oil production and the decline in inventories does not offset the shortfall of production, the response of global real activity must be negative for the first year.

Implementation

● Consider the N-dimensional reduced-form VAR model $A(L)y_t = e_t$, where e_t is the vector of white noise reduced-form innovations with variance-covariance matrix Σ_{e_t}. The construction of structural impulse response functions requires an estimate of the $N \times N$ matrix $\tilde{B}$ in $e_t = \tilde{B}\varepsilon_t$.

● Let $\Sigma_{e_t} = P\Lambda P'$ and $B = P\Lambda^{0.5}$ such that B satisfies $\Sigma_{e_t} = BB'$. Then $\tilde{B} = BD$ also satisfies $\tilde{B}\tilde{B}' = \Sigma_{e_t}$ for any orthonormal $N \times N$ matrix D. One can construct many candidate solutions $\tilde{B}$ by repeatedly drawing at random from the set **D** of orthonormal rotation matrices D.

● We discard all candidate solutions that do not satisfy the set of a priori restrictions on the implied impulse responses functions and retain the set $\tilde{\mathbf{B}}$ of admissible models.

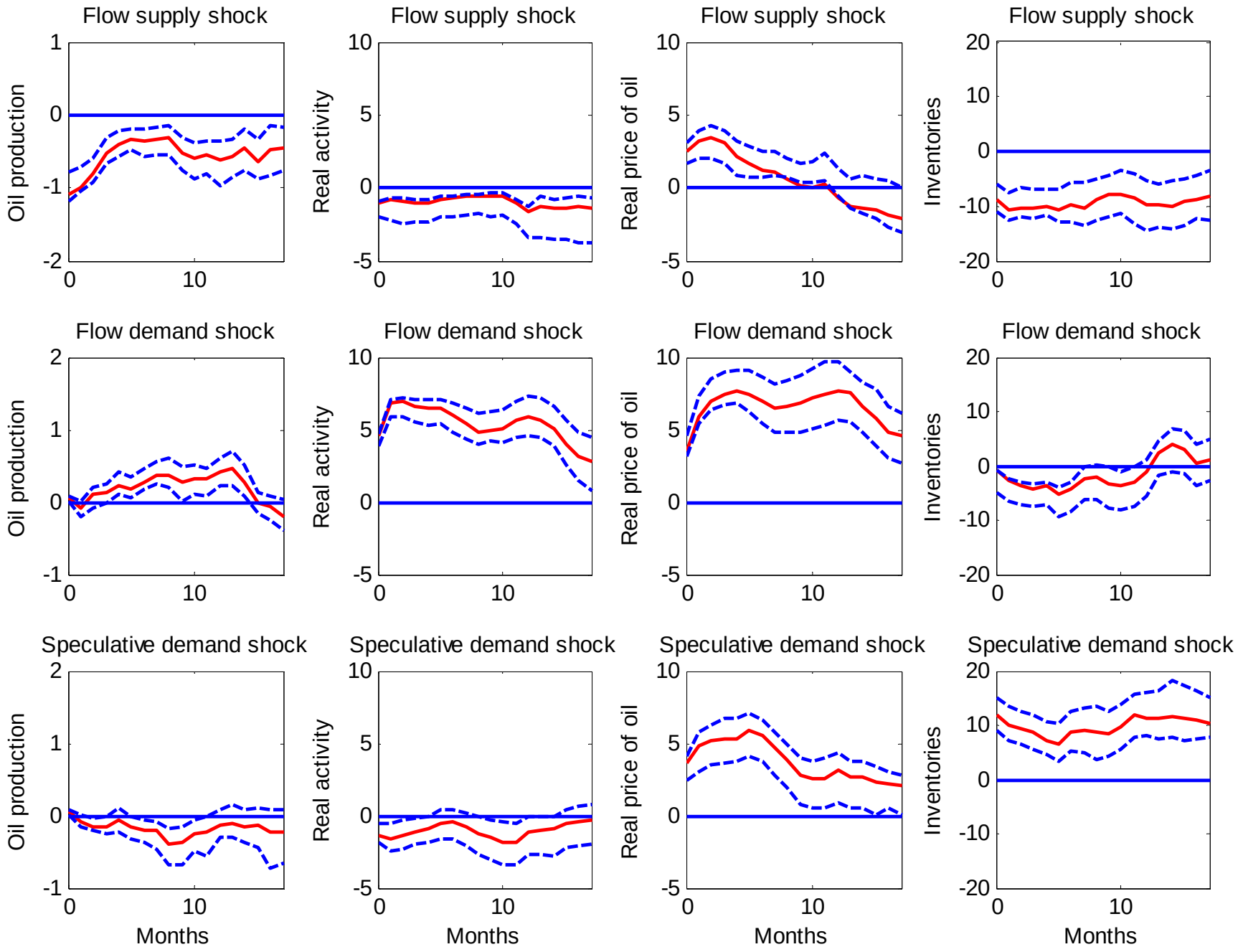
Benchmark Model

- 60 million draws

- 13 admissible models (with nearly observationally equivalent responses)

- WLOG we report as the benchmark results for the model that yields the ***impact price elasticity of oil demand in use*** closest to the posterior median of that elasticity.

Structural Impulse Responses: 1973.2-2009.8

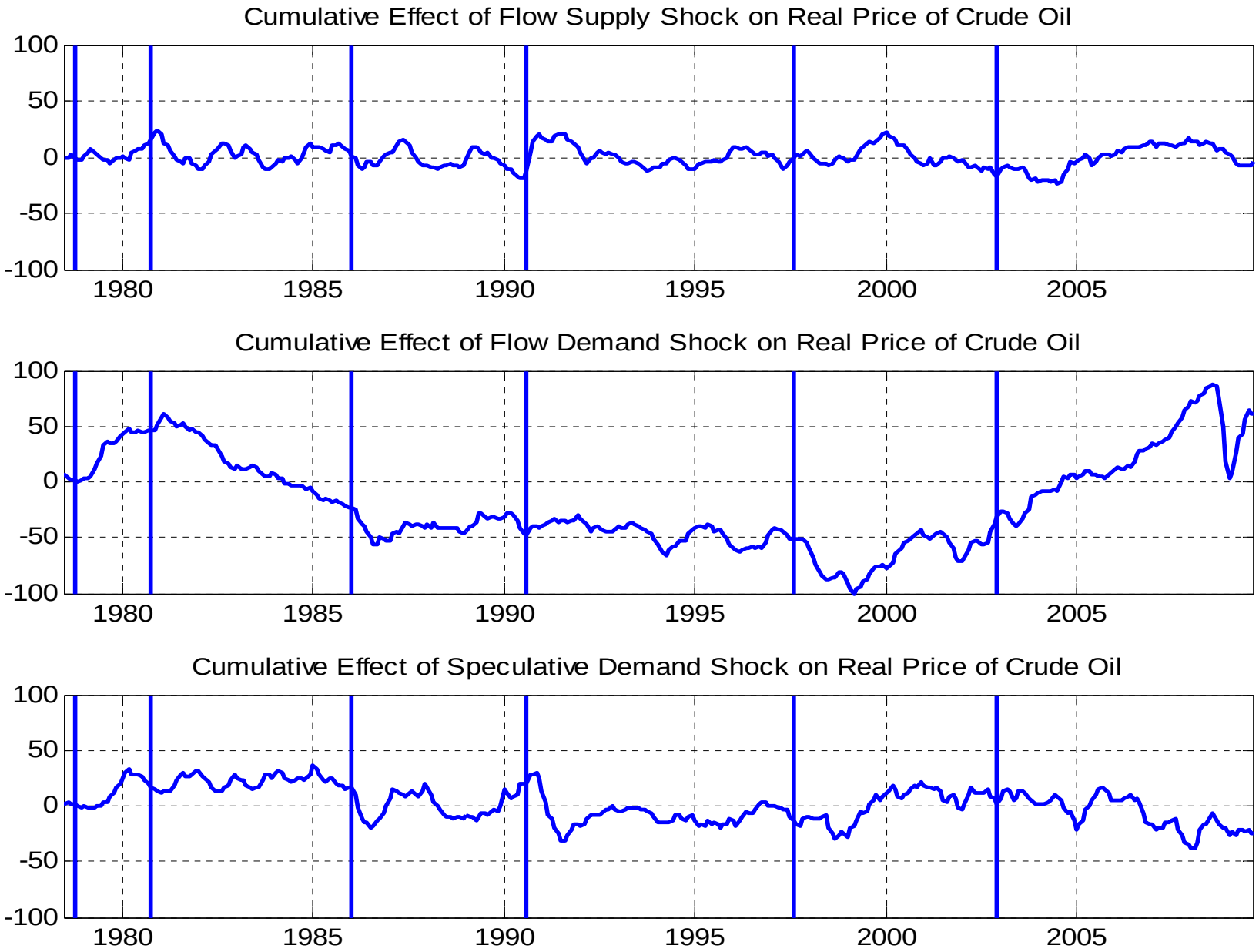


Percent Contribution to Variability of the Change in Inventories

Horizon	Flow supply shock	Flow demand shock	Speculative demand shock
3	23.1	1.4	41.3
6	22.7	2.3	41.2
9	22.7	3.5	41.1
12	22.5	4.0	41.3
∞	21.4	14.8	35.7

Note: Results from a structural forecast error variance decomposition of the benchmark model estimate. The infinite horizon is approximated by 600.

Historical Decompositions for 1978.6-2009.8



The Inventory Puzzle

On August 2, 1990, Iraq invaded Kuwait and the real price of oil spiked. Starting in late 1990, the real price collapsed.

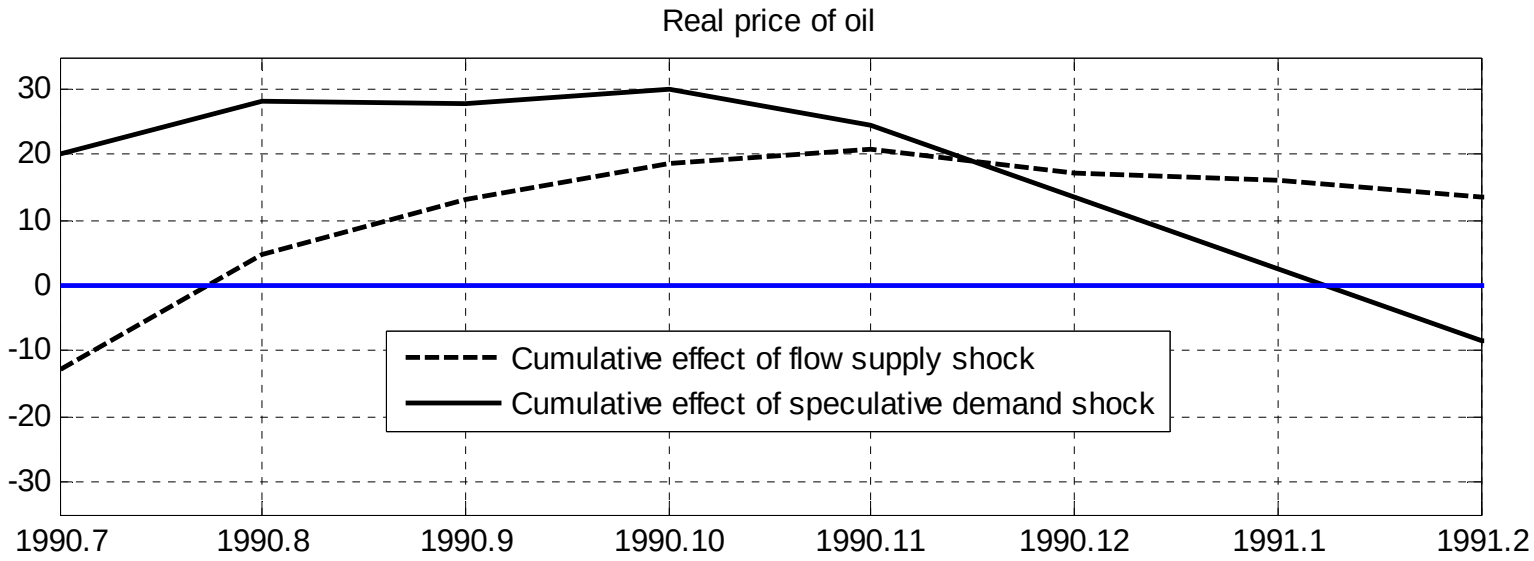
Kilian (AER 2009): This must be a response to fears that Saudi Arabia would be invaded next, which were alleviated in late 1990, when U.S. troops had arrived in strength.

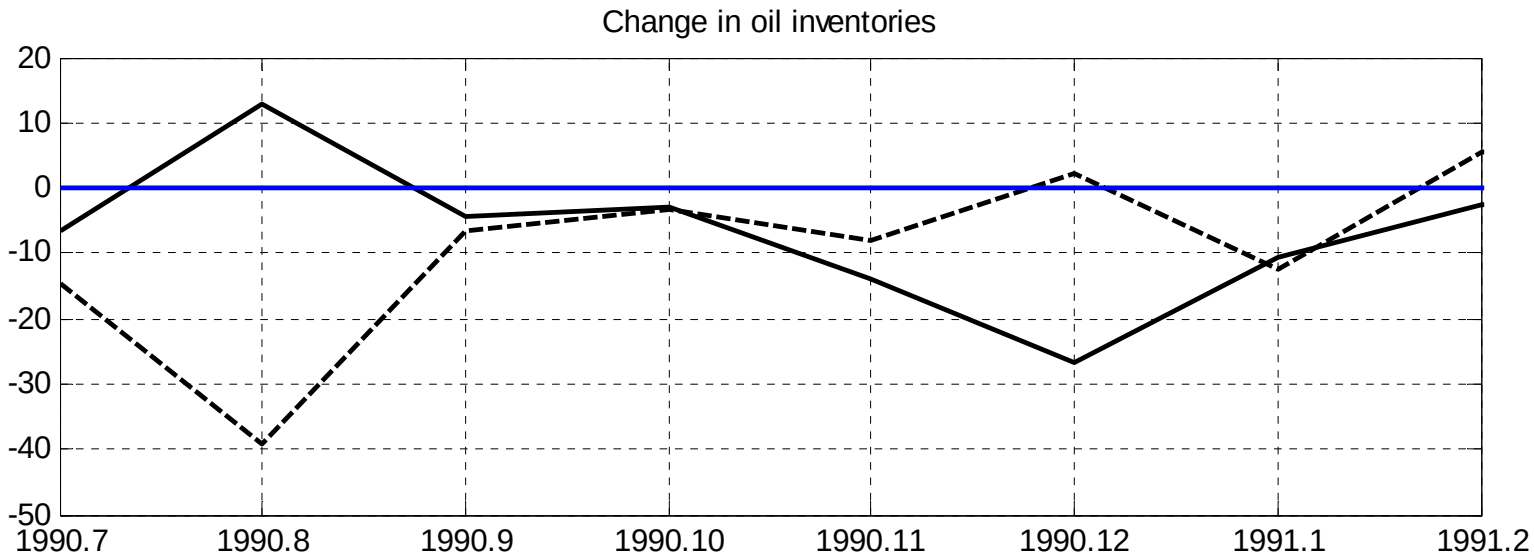
● Oil inventories did not increase in August of 1990 as one would have expected in response to a positive speculative demand shock (Hamilton, BPEA 2009).

● At the same time, the absence of a sharp decline in oil inventories in August of 1990 is inconsistent with the view that the price increase reflected a negative oil supply shock.

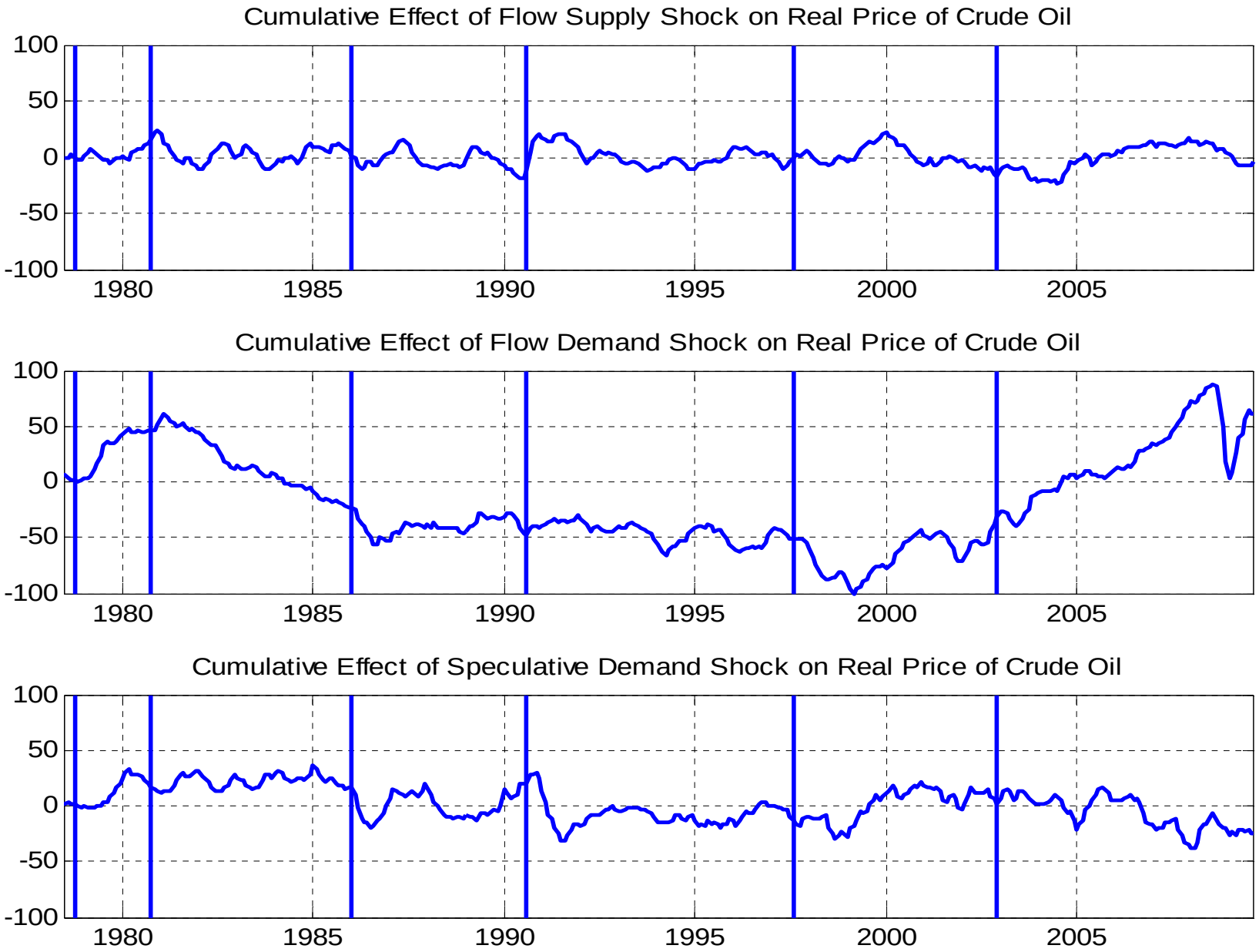
● There were no positive supply shocks in late 1990 that could explain the sharp decline in the real price (Kilian, REStat 2008).

Historical Decompositions for the Persian Gulf War Episode

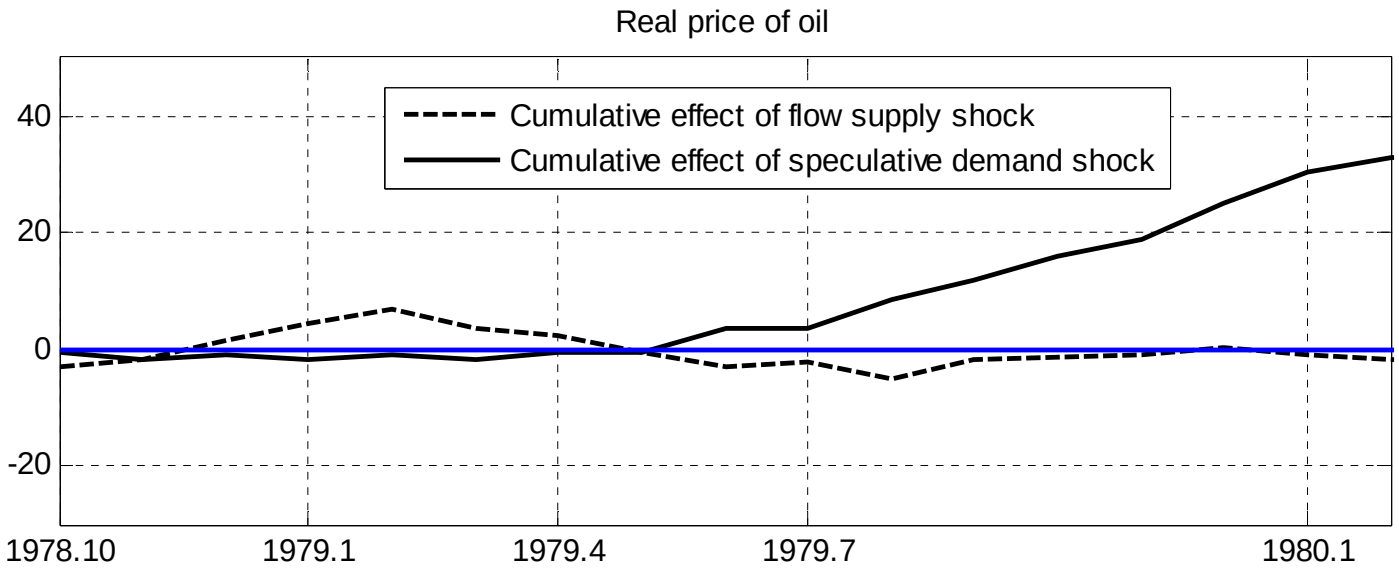


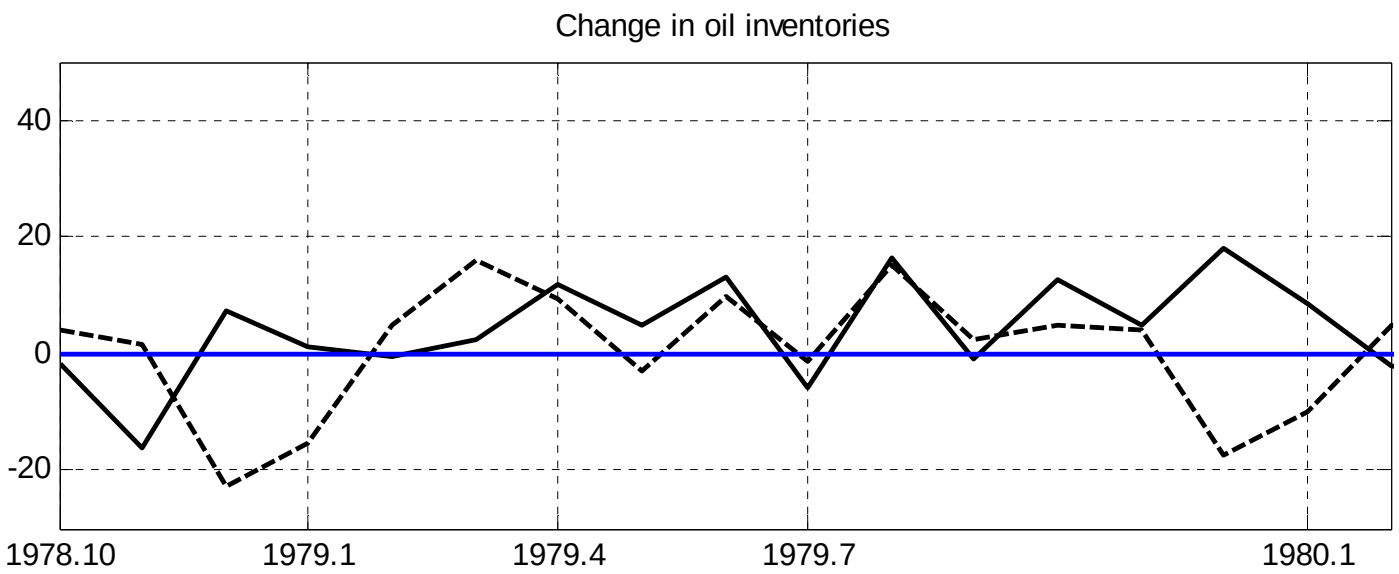


Historical Decompositions for 1978.6-2009.8

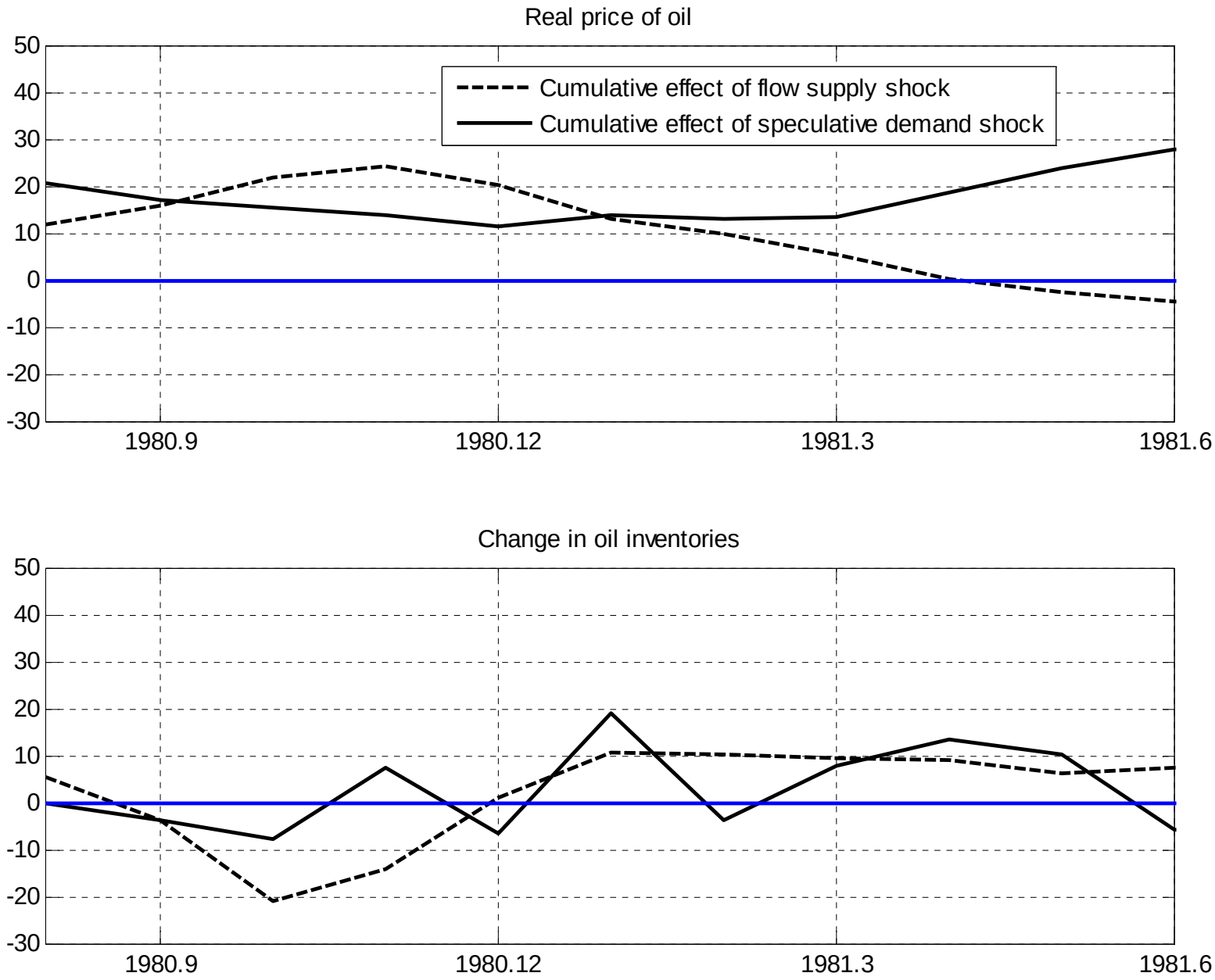


Historical Decompositions for the Iranian Revolution

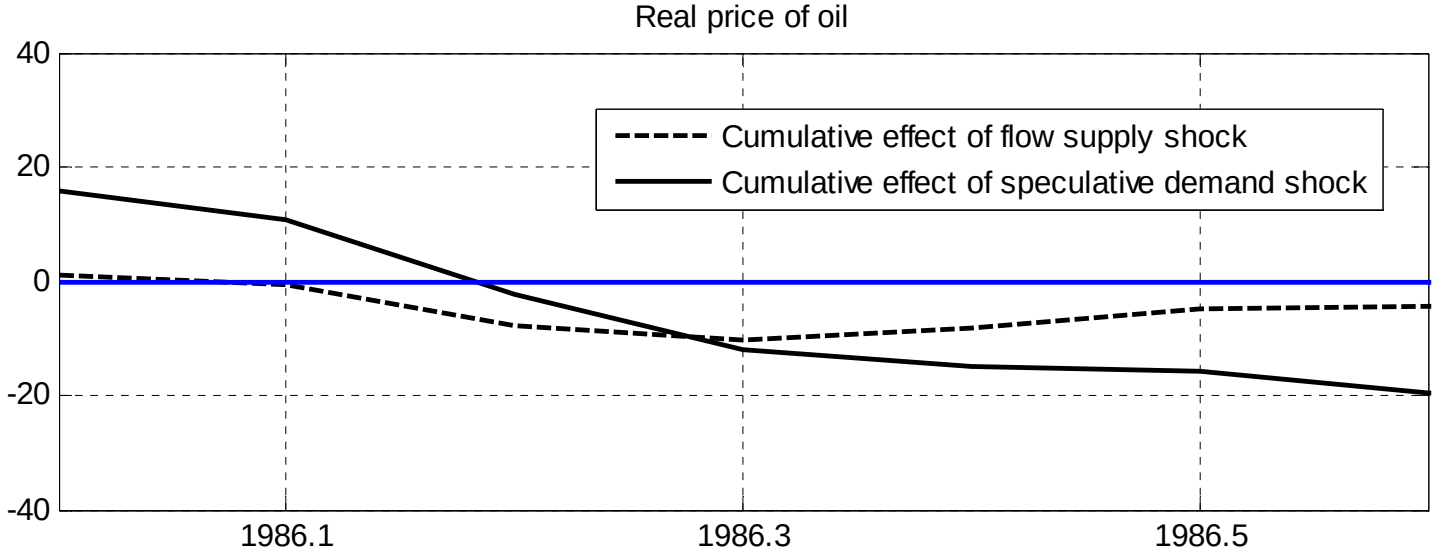


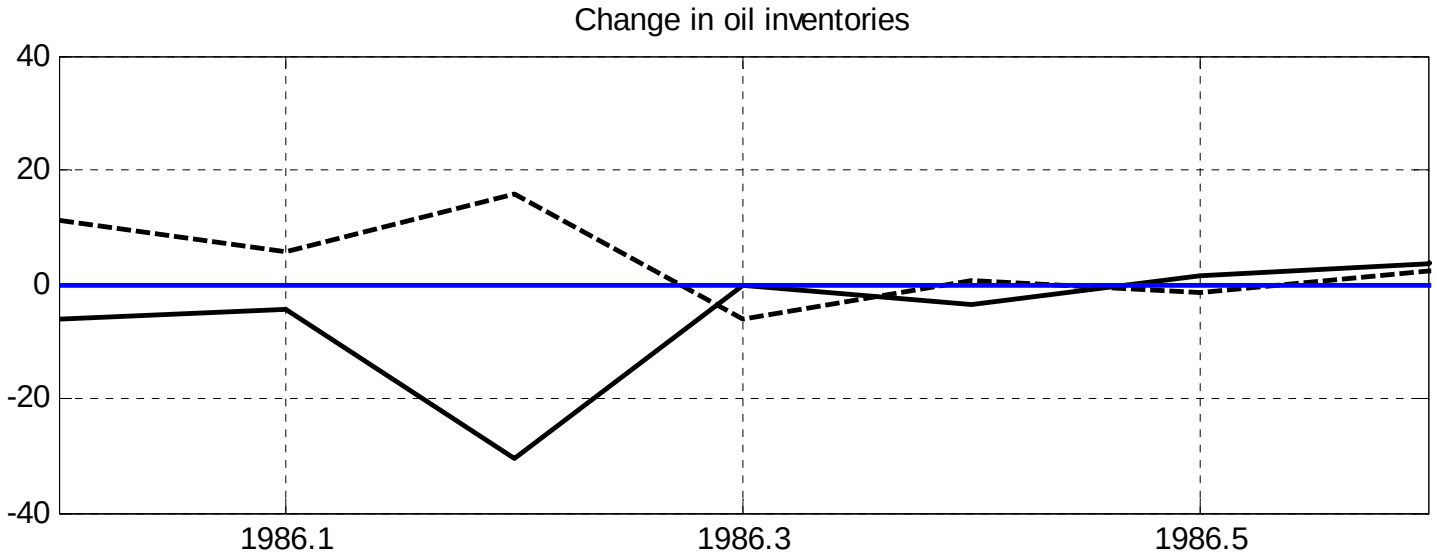


Historical Decompositions for the Outbreak of the Iran-Iraq War

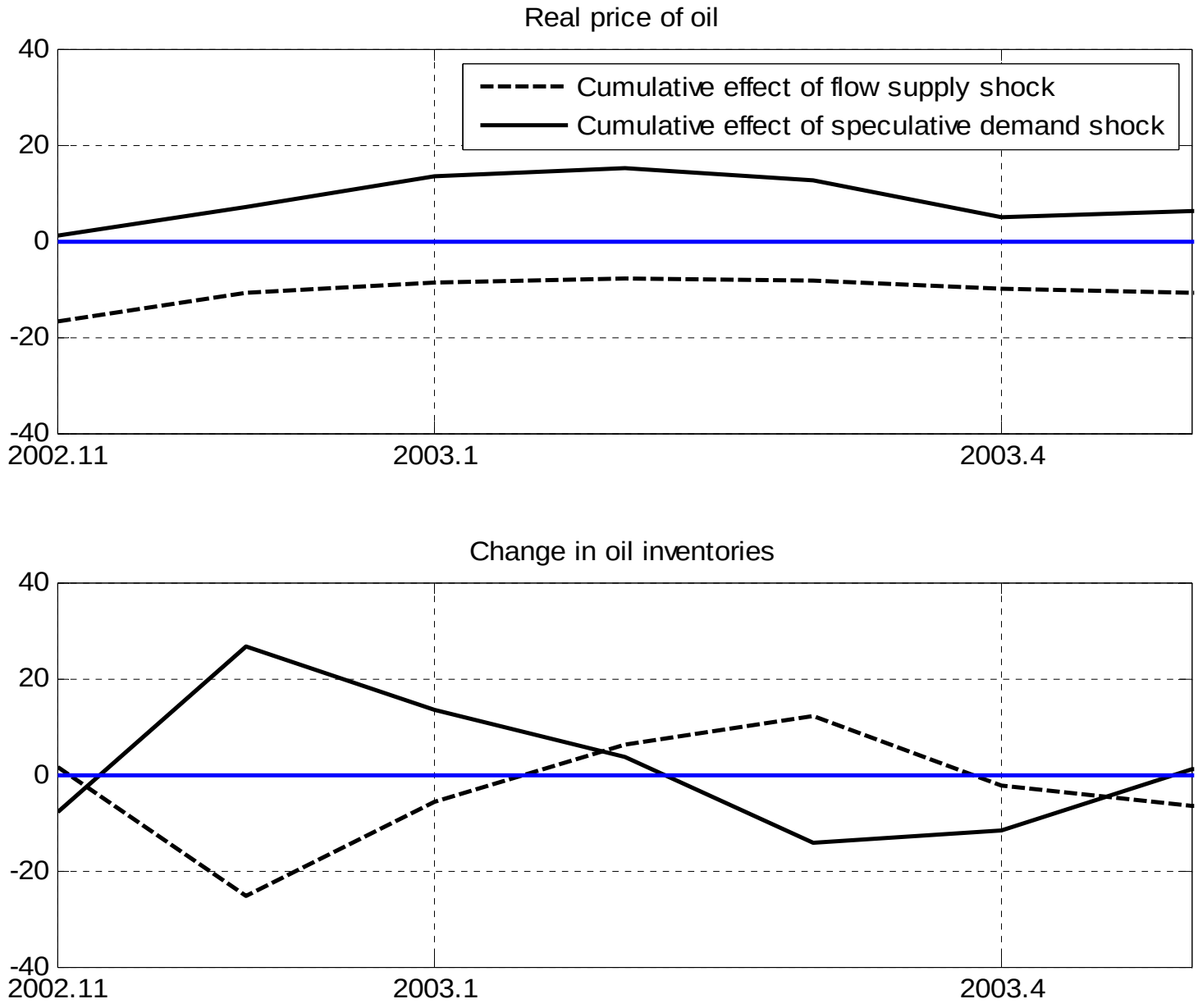


Historical Decompositions for the Collapse of OPEC in 1986

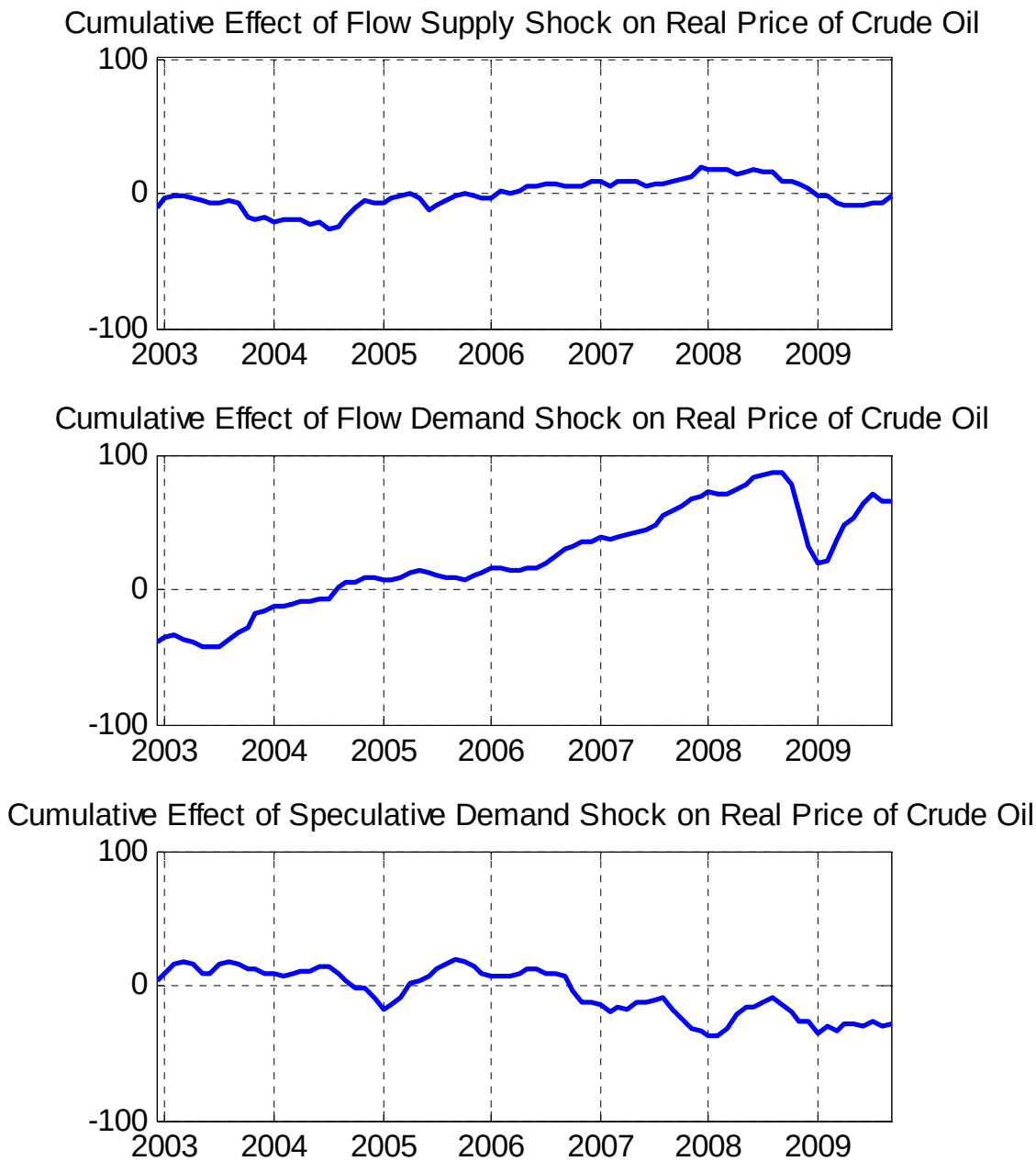




Historical Decompositions for Venezuelan Crisis and Iraq War



Historical Decompositions for 2002.12-2009.8



Speculation without a Change in Oil Inventories?

- Hamilton (BPEA 2009): Only possible if the short-run price elasticity of gasoline demand is zero.

- This elasticity is closely related to the short-run price elasticity of oil demand.

  ⇨ Our model may be used to obtain direct estimates of the short-run price elasticities of oil supply and oil demand.

  ⇨ Theory may be used to infer the corresponding short-run price elasticity of gasoline demand.

Short-Run Oil Demand and Oil Supply Elasticities

<u>Consensus view on price elasticity of oil supply:</u>

- Short-run supply elasticity is near zero (Hamilton 2009, Kilian 2009).
- Our estimate is about 0.01 or 0.02.
- This is consistent with the conventional view that the short-run oil supply curve is nearly vertical.

<u>Consensus view on price elasticity of oil demand:</u>

- Hamilton (2009): Short-run demand elasticity is -0.06.
- Dahl (1993); Cooper (2003): -0.05, -0.07.

Problems with the Consensus on the Demand Elasticity

- The identification of this parameter requires an exogenous shift of the contemporaneous oil supply curve along the contemporaneous oil demand curve.

- Much of the existing literature on estimating oil demand elasticities does not distinguish between oil demand and oil supply shocks.

  Standard approach: OLS regressions of log quantity on log price.

- Standard approach suffers from downward bias. IV infeasible.

- Our structural VAR model provides an alternative.

Posterior Distribution of the Standard Short-Run Price Elasticity of Demand for Crude Oil

16th Percentile	-0.64
50th Percentile	-0.44
84th Percentile	-0.28

Note: Based on 150 admissible structural models drawn from the posterior.

Remarks:

- The standard OLS estimate on our data yields a demand elasticity of - 0.02.
- Baumeister and Peersman (2009) in a quarterly structural model obtain a median estimate of -0.38.

Posterior Distribution of the Appropriately Measured Short-Run Price Elasticity of Demand for Crude Oil

	$\eta^{O,\,\mathrm{Pr}\,oduction}$	$\eta^{O,\,Use}$
16th Percentile	-0.64	-0.42
50th Percentile	-0.44	-0.24
84th Percentile	-0.28	-0.09

Note: Based on 150 admissible structural models drawn from the posterior. $\eta^{O,\,\mathrm{Pr}\,oduction}$ refers to the price elasticity of oil demand in production and $\eta^{O,\,Use}$ to the price elasticity of oil demand in use.

The Link to the Impact Elasticity of Gasoline Demand

- Profit-maximizing refiners are price-takers in the crude oil market and choose the quantity of their gasoline output, given the outputs of other refiners.
- Production function $G = \min\left(K, L, \alpha O\right)$.
- Capital is fixed in the short run.
- Refiners' labor input can be varied on the intensive margin.
- Refiners pay a marginal cost equal to the price of oil, P_O, plus the marginal cost of labor, $MC = P_O + c$.
- Constant price elasticity of demand for gasoline, η^G.

● After solving for the market price and aggregating gasoline output across firms, log-linearization yields

$$\eta^{O,Use} \approx \frac{P_O}{P_O + c}\eta^G,$$

where $\eta^{O,Use}$ denotes the price elasticity of demand for crude oil in use.

- ⇨ If $\eta^{O,Use}$ were zero, then by construction so would be η^G.
- ⇨ If the price of oil constitutes the largest component of refiners' marginal cost, then $0 \le c \le P_O$, which in turn implies:

$$\eta^{O,Use} \le \eta^G \le 2\eta^{O,Use}.$$

- ⇨ Considine (REStat 1997): $c \approx 0$, so $\eta^G \approx \eta^{O,Use}$.

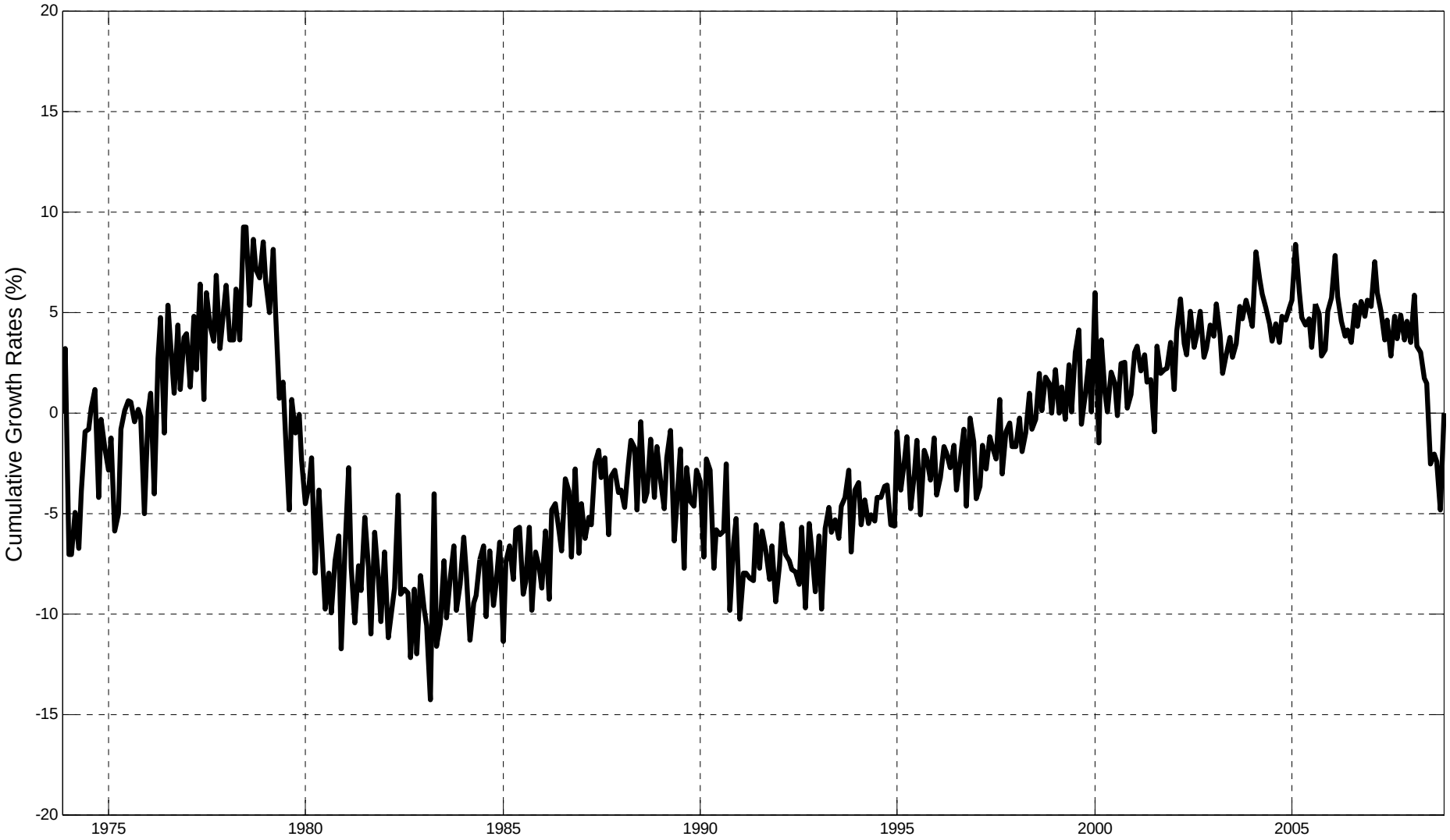
The Impact Price Elasticity of Gasoline Demand

- ⇨ Median estimate of the short-run price elasticity of gasoline demand is -0.24.
- ⇨ Given 68% error band, anywhere between -0.09 and -0.42.

<u>Consensus view from reduced form:</u>

- ○ Dahl and Sterner (1991): -0.20
- ○ Hughes, Knittel and Sperling (2008): Recently between -0.04 and -0.08
- ○ Time Variation?

U.S. Gasoline Consumption 1973.10-2008.10



No Speculation without a Change in Oil Inventories

- Our identifying assumptions encompass the limiting case of a short-run elasticity of oil demand (and hence gasoline demand) equal to zero

- Not only is our elasticity-in-use estimate so large as to immediately rule out this limiting case, but we also find a large positive inventory response to speculative demand shocks.

  ⇨ We can unambiguously rule out the limiting case discussed in Hamilton (BPEA 2009).

The Long-Run Price Elasticity of Gasoline Demand

- It is commonly thought that the adjustment toward more energy-efficient technologies occurs over a horizon of perhaps five or ten years (e.g., Sweeney, AER 1984).

  ⇨ Long-run price elasticities of demand are potentially much higher than short run estimates.

- Cross-sectional studies of nonparametric gasoline demand functions:

  Hausman and Newey (Ecta 1995): -0.8 (United States)

  Yatchew and No (Ecta 2001): -0.9 (Canada)

Policy Debate about the Lessons from 2003-08

1. Did speculators cause this surge in the real price of oil?

⇨ Regulate oil futures markets.

2. Is OPEC to blame for withholding oil supplies from the market?

⇨ Put political pressure on oil producers.

3. Has global oil production peaked ("peak oil hypothesis")?

⇨ Promote energy conservation and alternative sources of energy.

4. Has this surge been driven by unexpectedly strong economic growth in the global economy, in particular in emerging Asia?

⇨ Efforts aimed at reviving the global economy after the financial crisis are likely to cause the real price of oil to recover as well, creating a policy dilemma.

What Explains the 2003-08 Oil Price Shock?

- No evidence that “peak oil” has been the cause.
- No evidence that OPEC was behind the oil price increase.
- No evidence that oil speculators were responsible.
- Strong evidence that a booming world economy was the cause.

Policy Conclusions

● It is popular to blame others for high oil prices (OPEC, oil speculators), but increased regulation of oil traders will not keep the price of oil down.

In reality, oil consumers worldwide collectively are to blame for high oil prices.

● Efforts to revive the world economy will cause the real price of oil to recover, creating a policy dilemma.

Only energy conservation and the development of alternative sources of energy will overcome this dilemma.