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

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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?

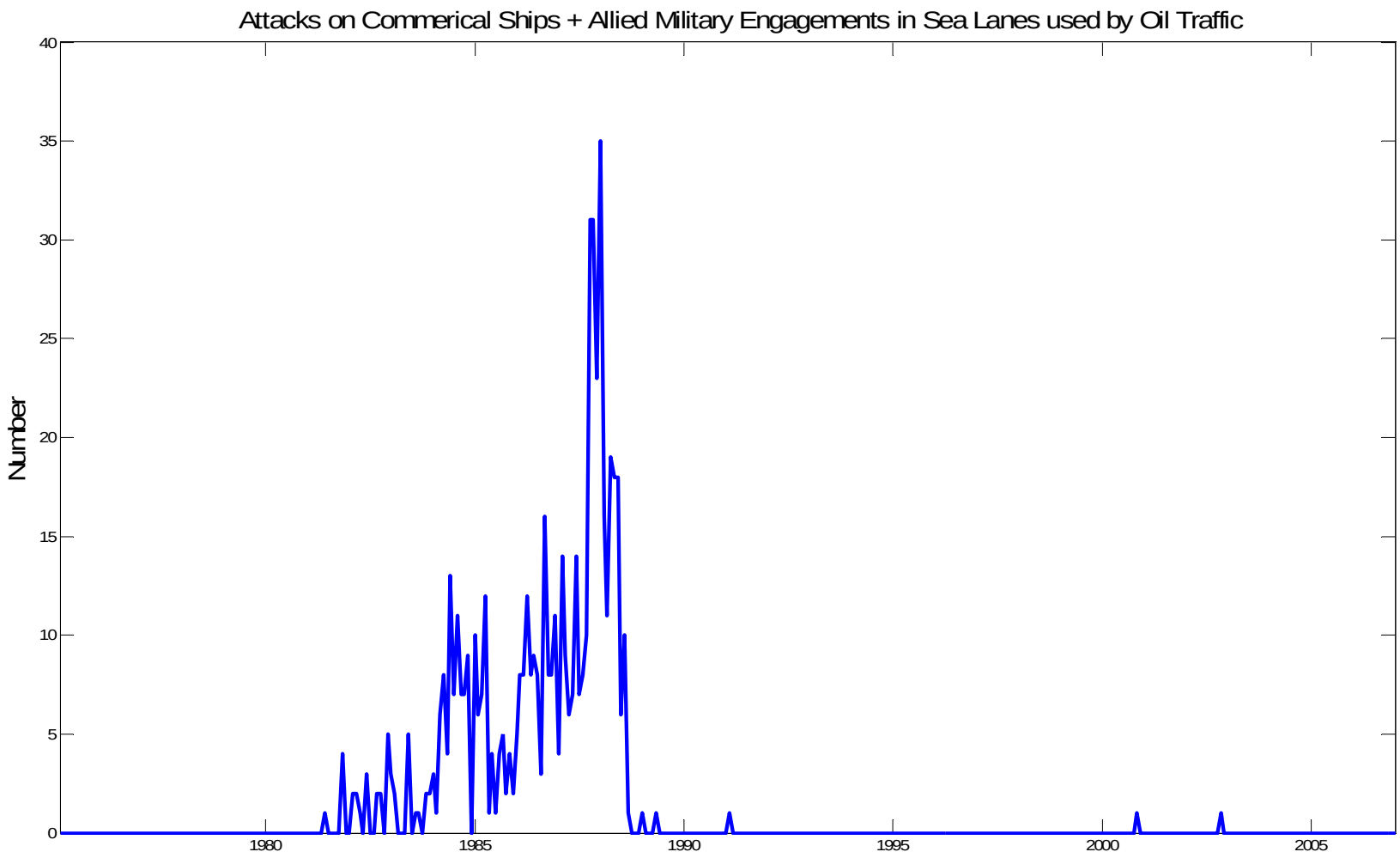
- Expectations shifts are not directly observable.

- 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. 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).

4. 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.

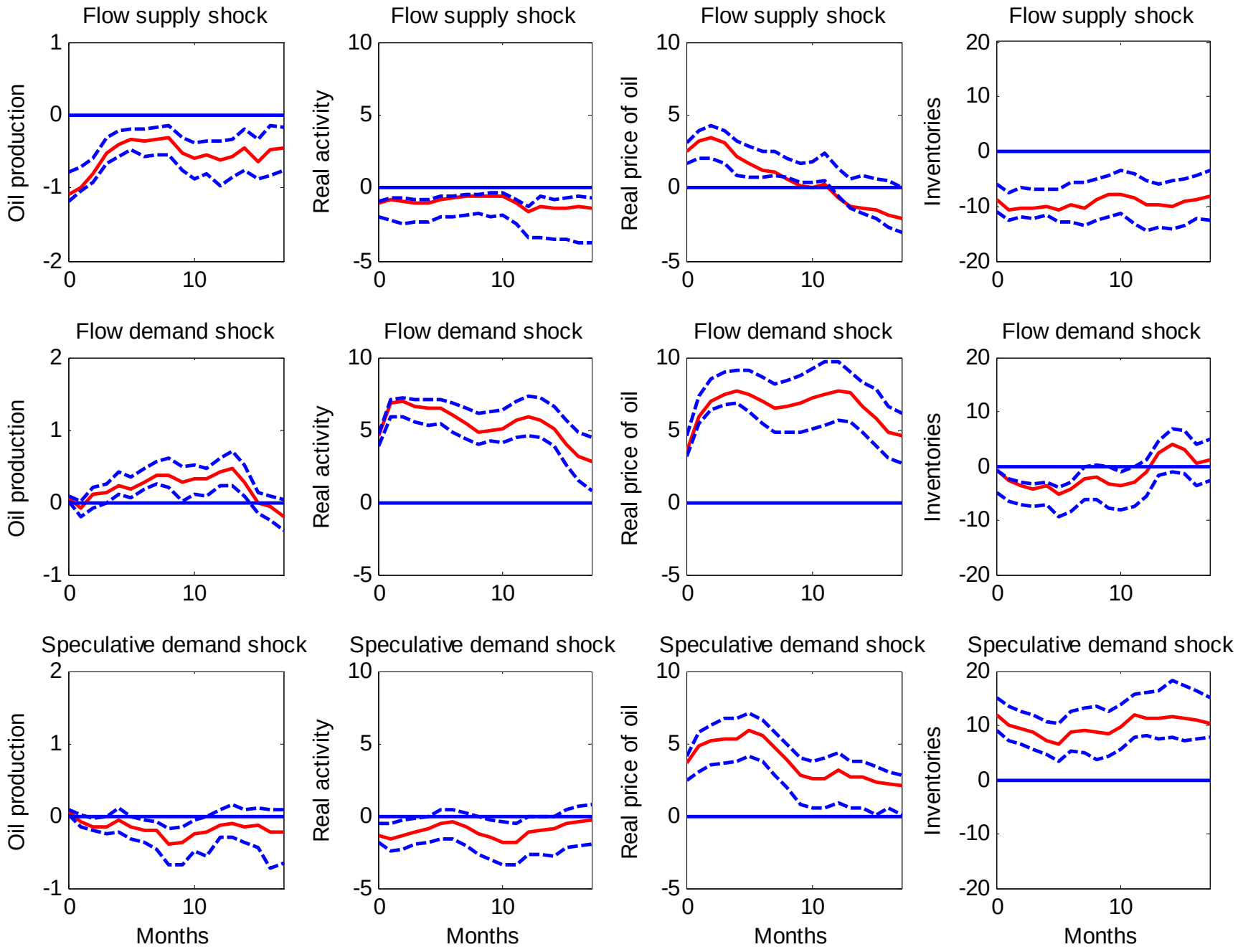
Benchmark Model

- 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

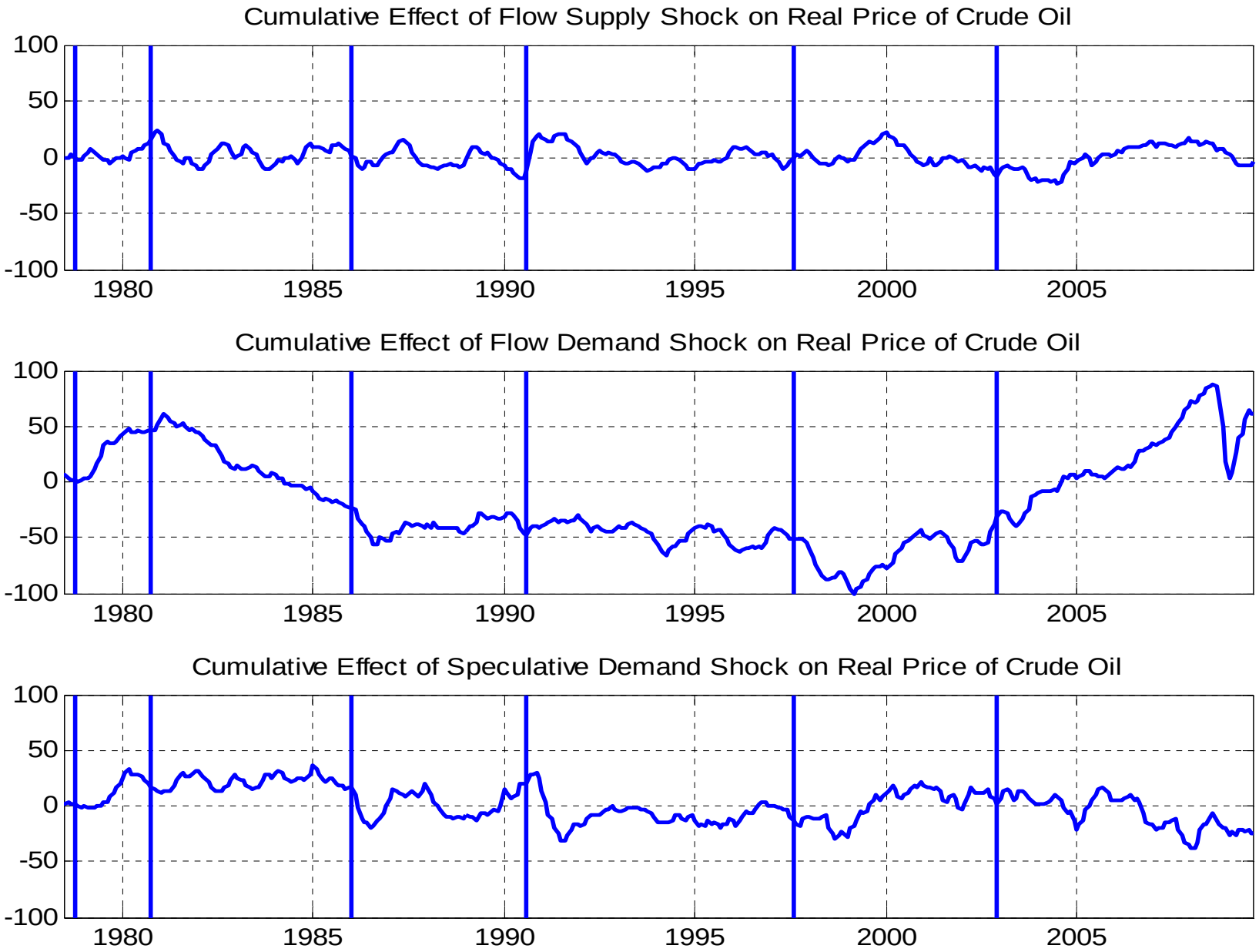


Percent Contribution to Variability of the Change in Inventories

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.

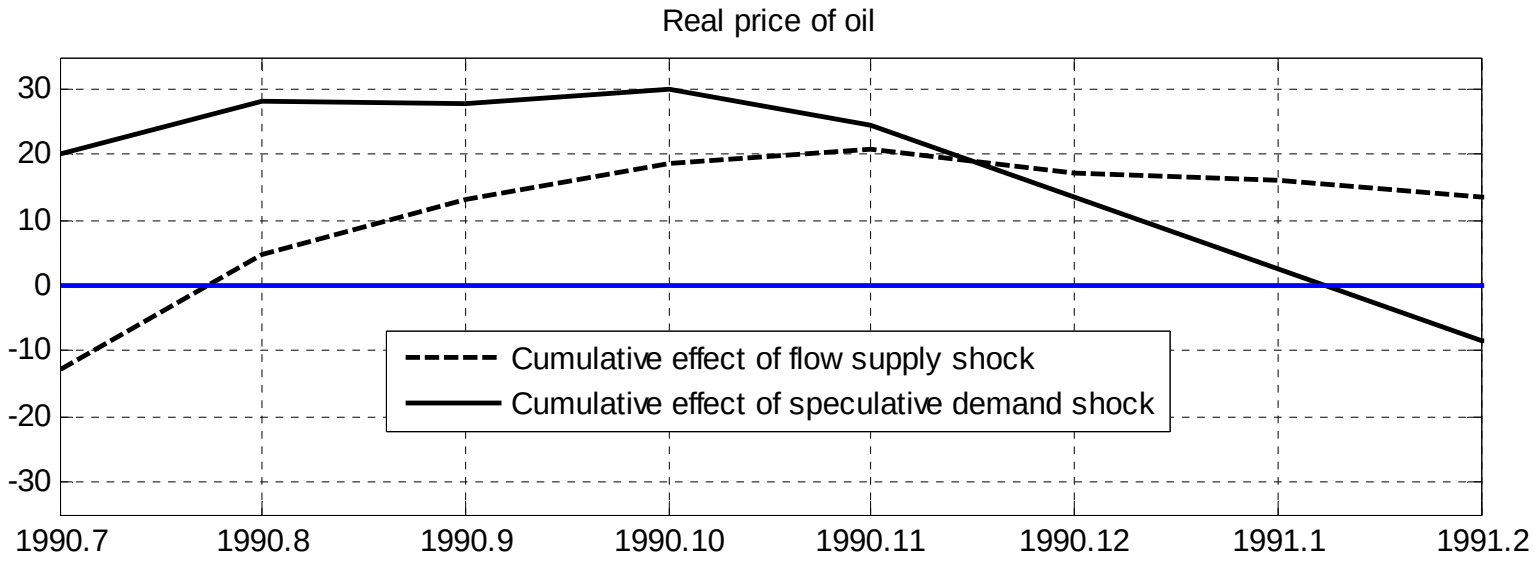
Kilian (AER 2009): This must be a response to fears that Saudi Arabia would be invaded next, which were alleviated in late 1990, when U.S. troops had arrived in strength.

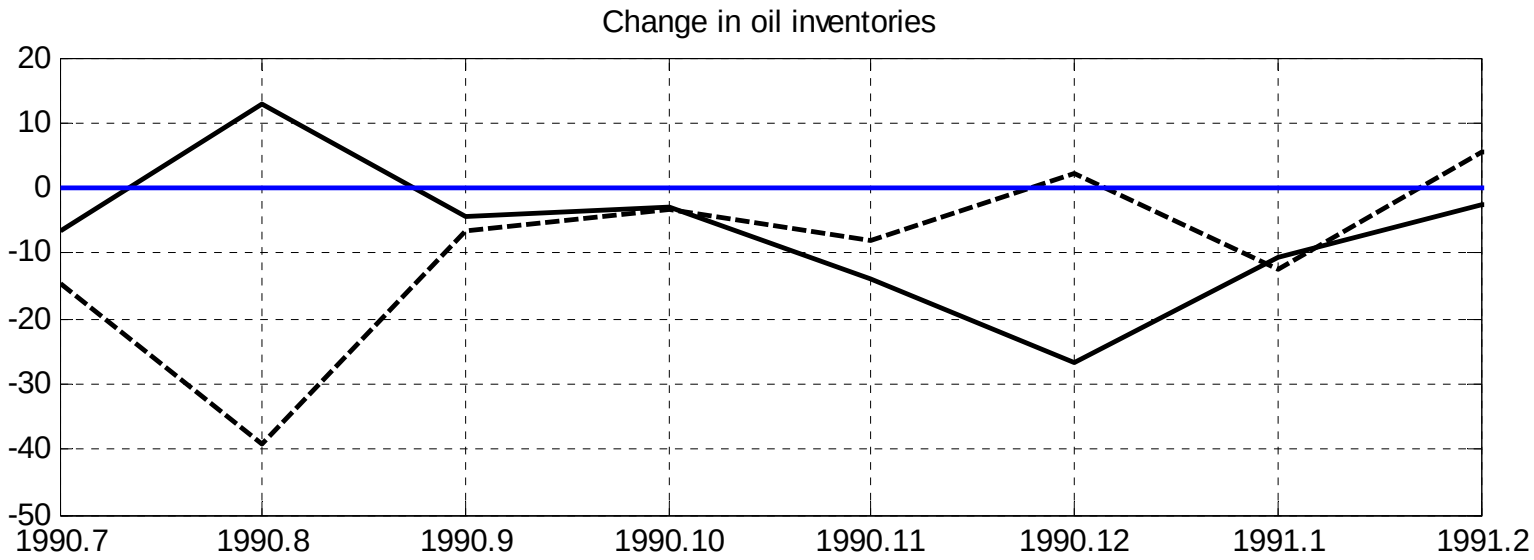
● Oil inventories did not increase in August of 1990 as one would have expected in response to a positive speculative demand shock (Hamilton, BPEA 2009).

● 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.

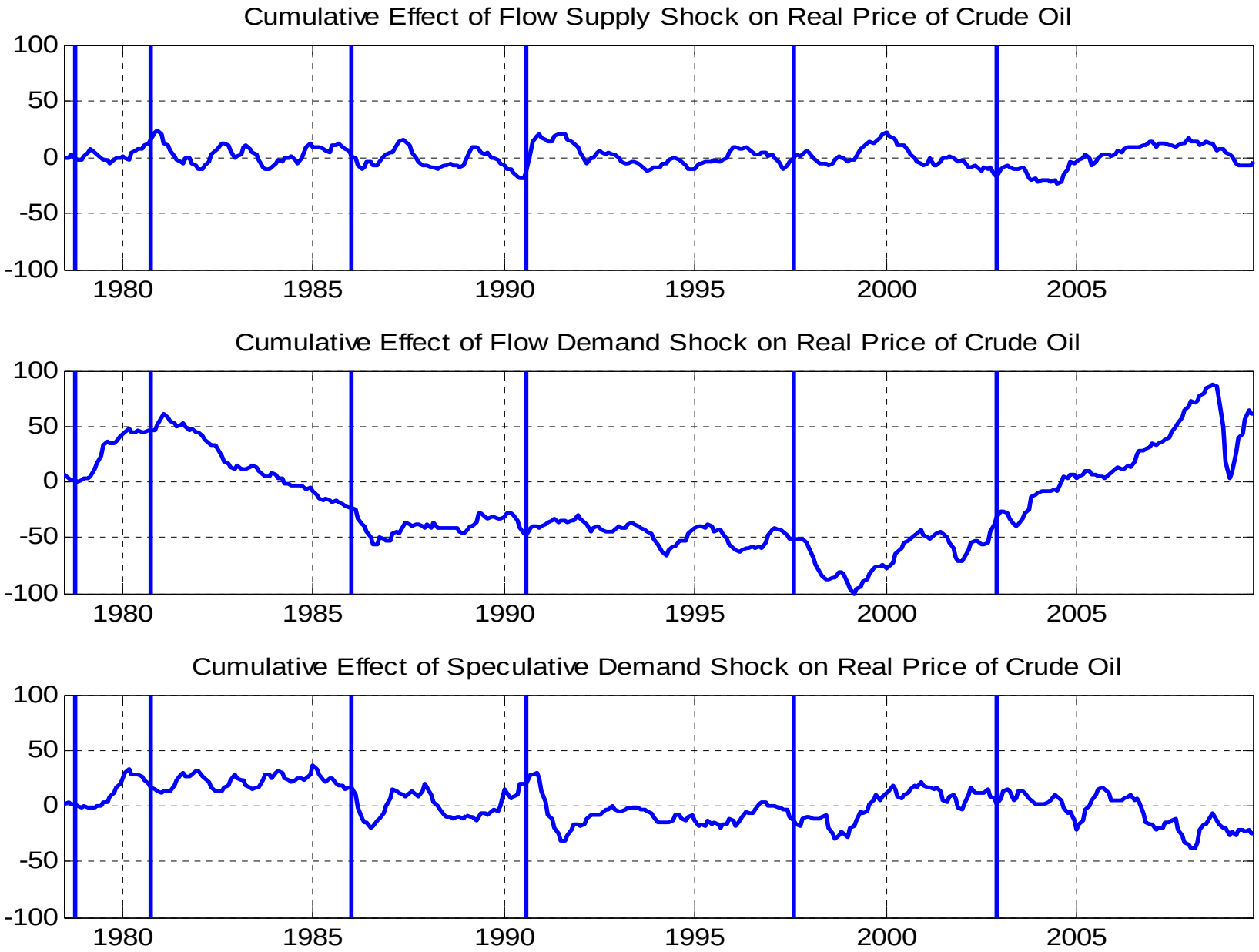
● There were no positive supply shocks in late 1990 that could explain the sharp decline in the real price (Kilian, REStat 2008).

Historical Decompositions for the Persian Gulf War Episode

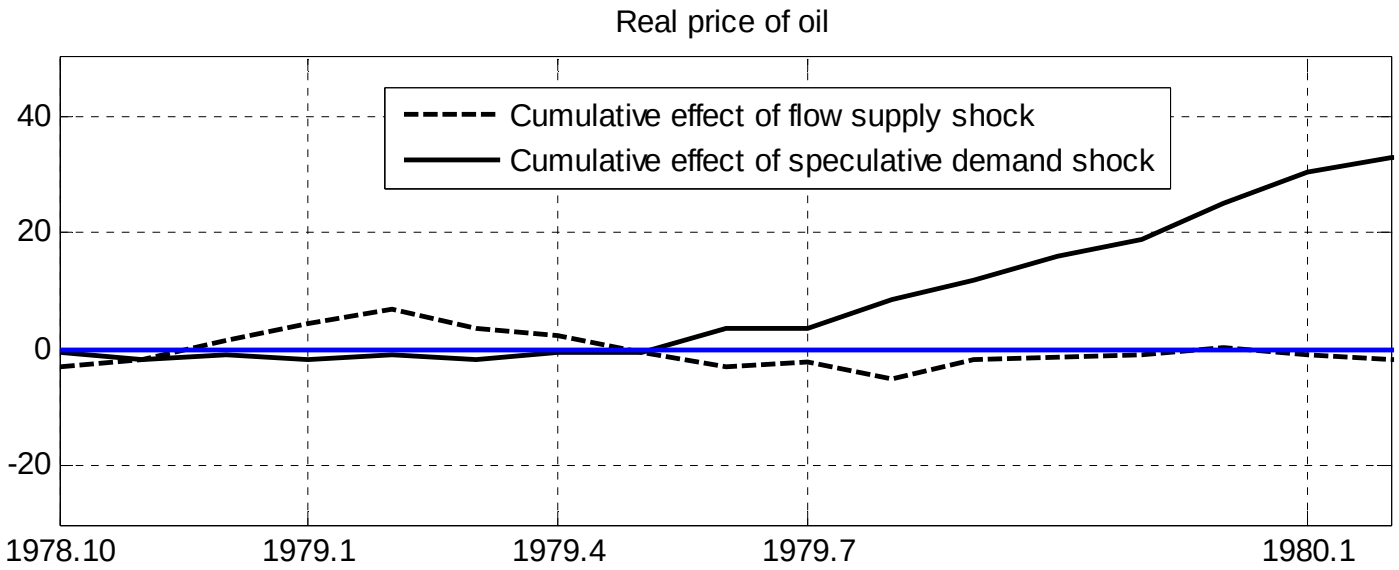


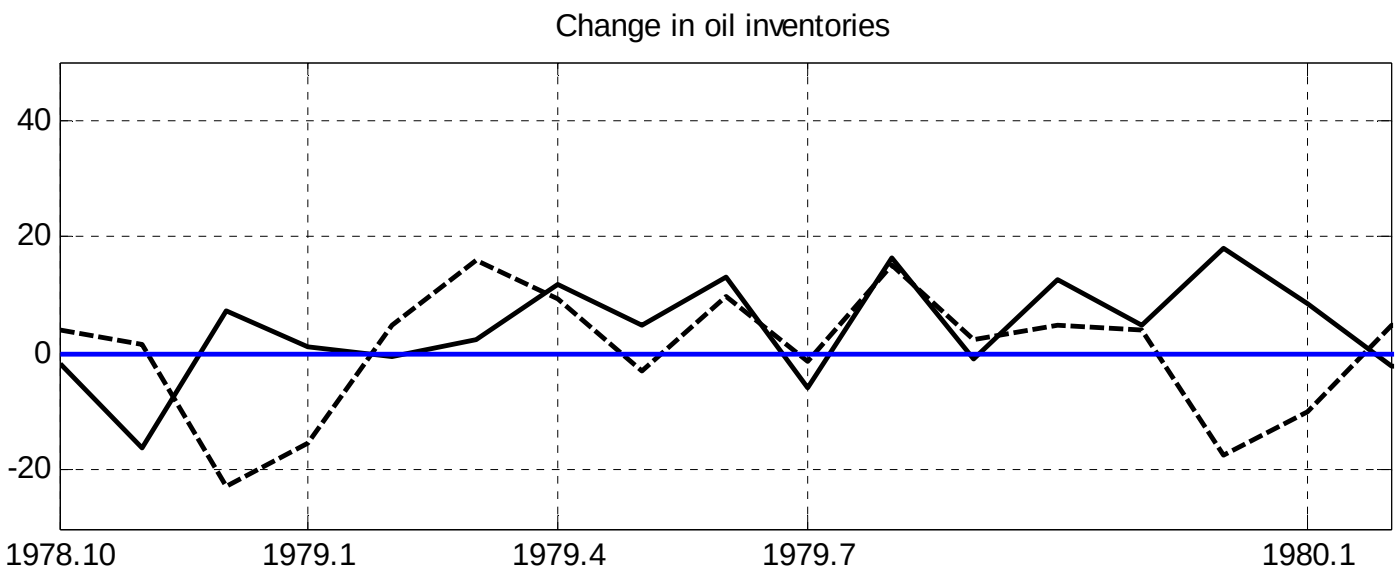


Historical Decompositions for 1978.6-2009.8

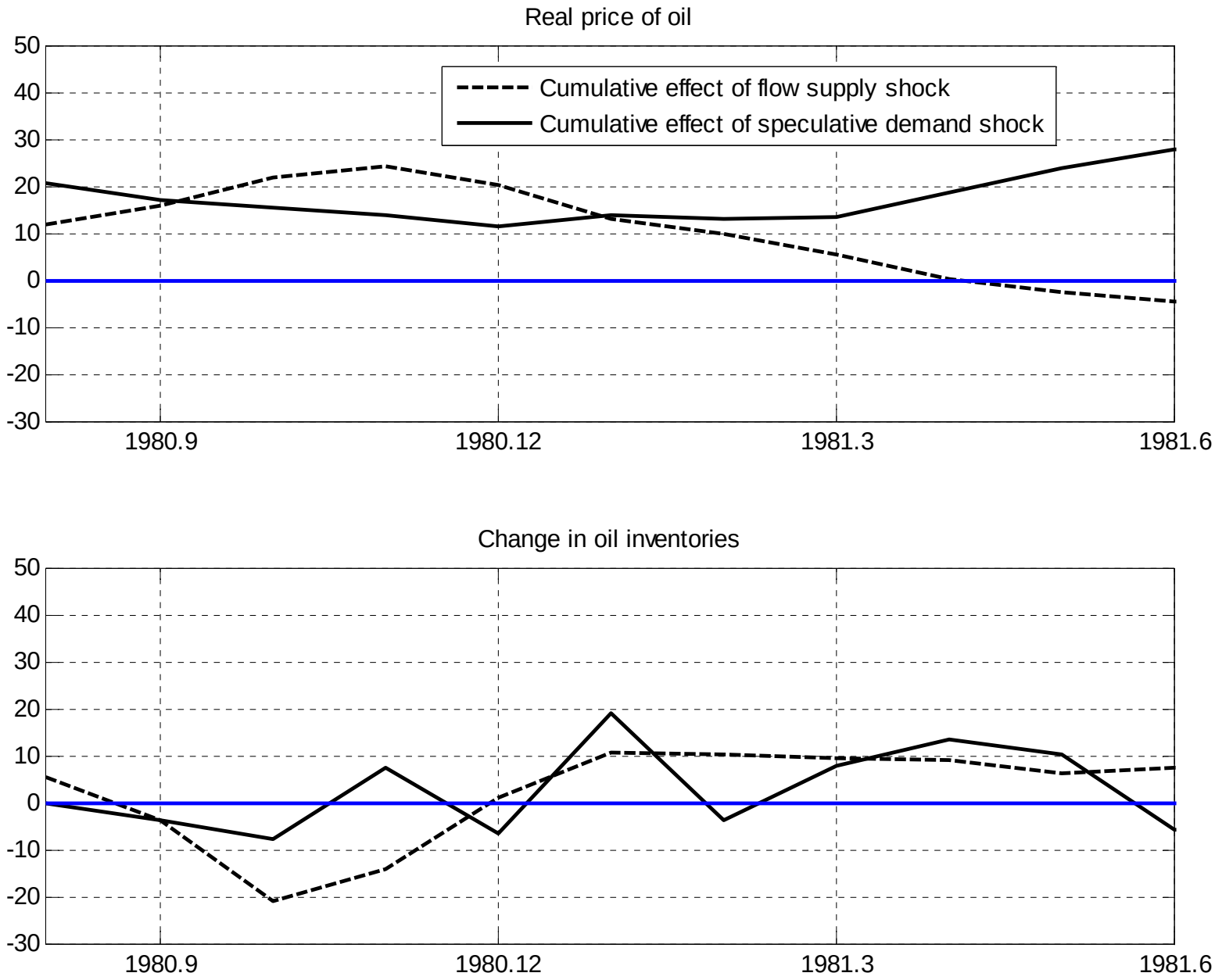


Historical Decompositions for the Iranian Revolution

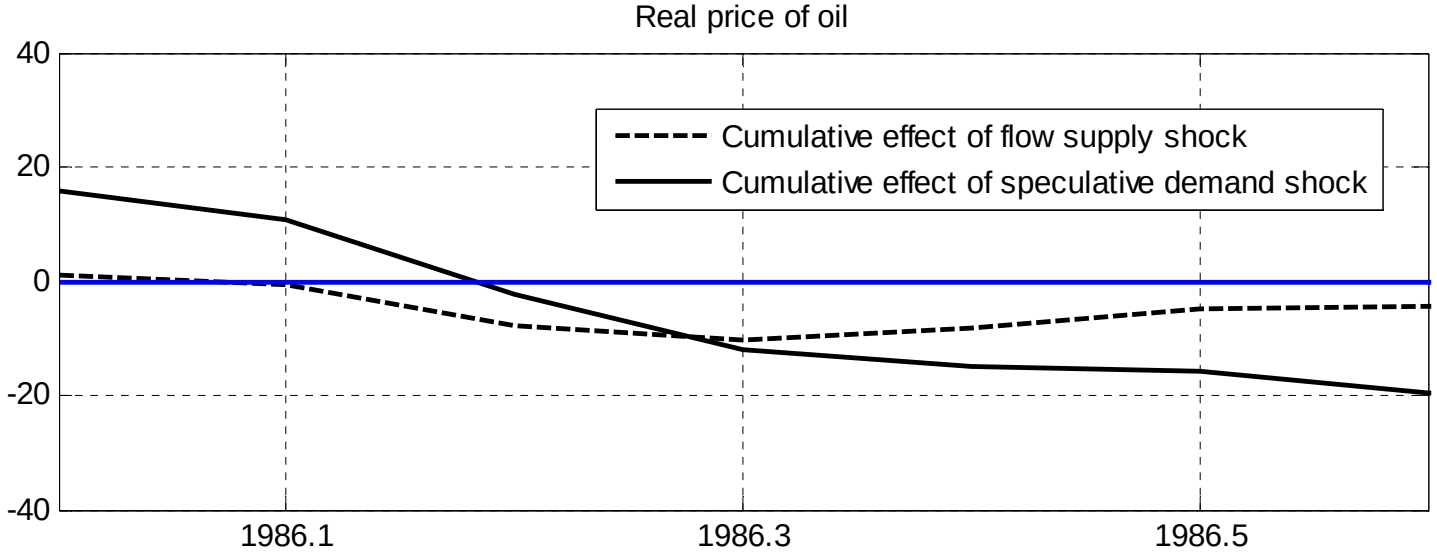


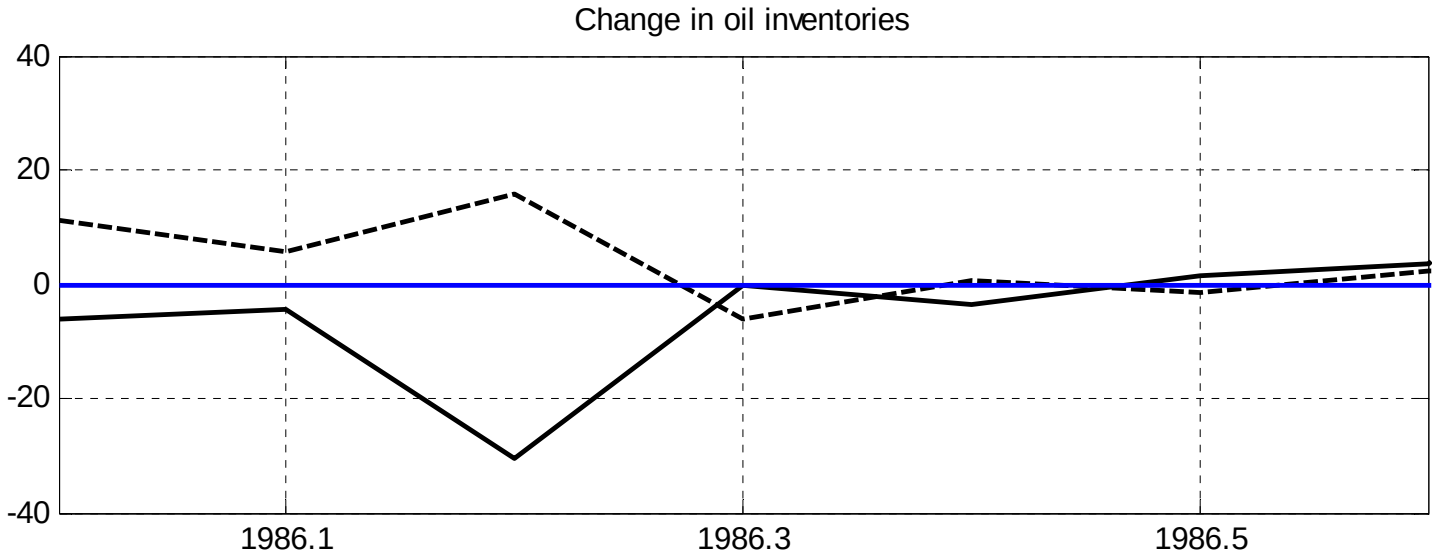


Historical Decompositions for the Outbreak of the Iran-Iraq War

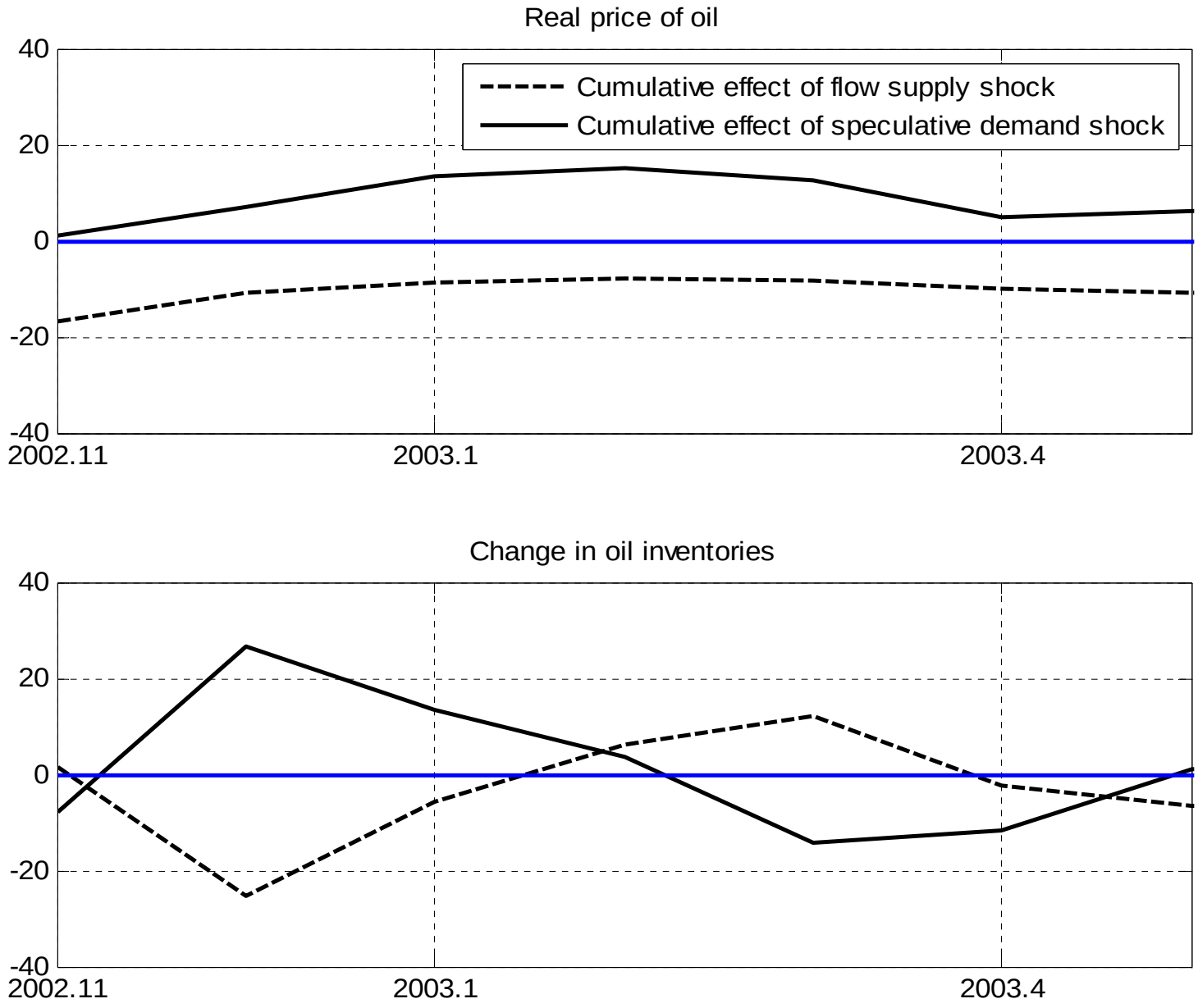


Historical Decompositions for the Collapse of OPEC in 1986

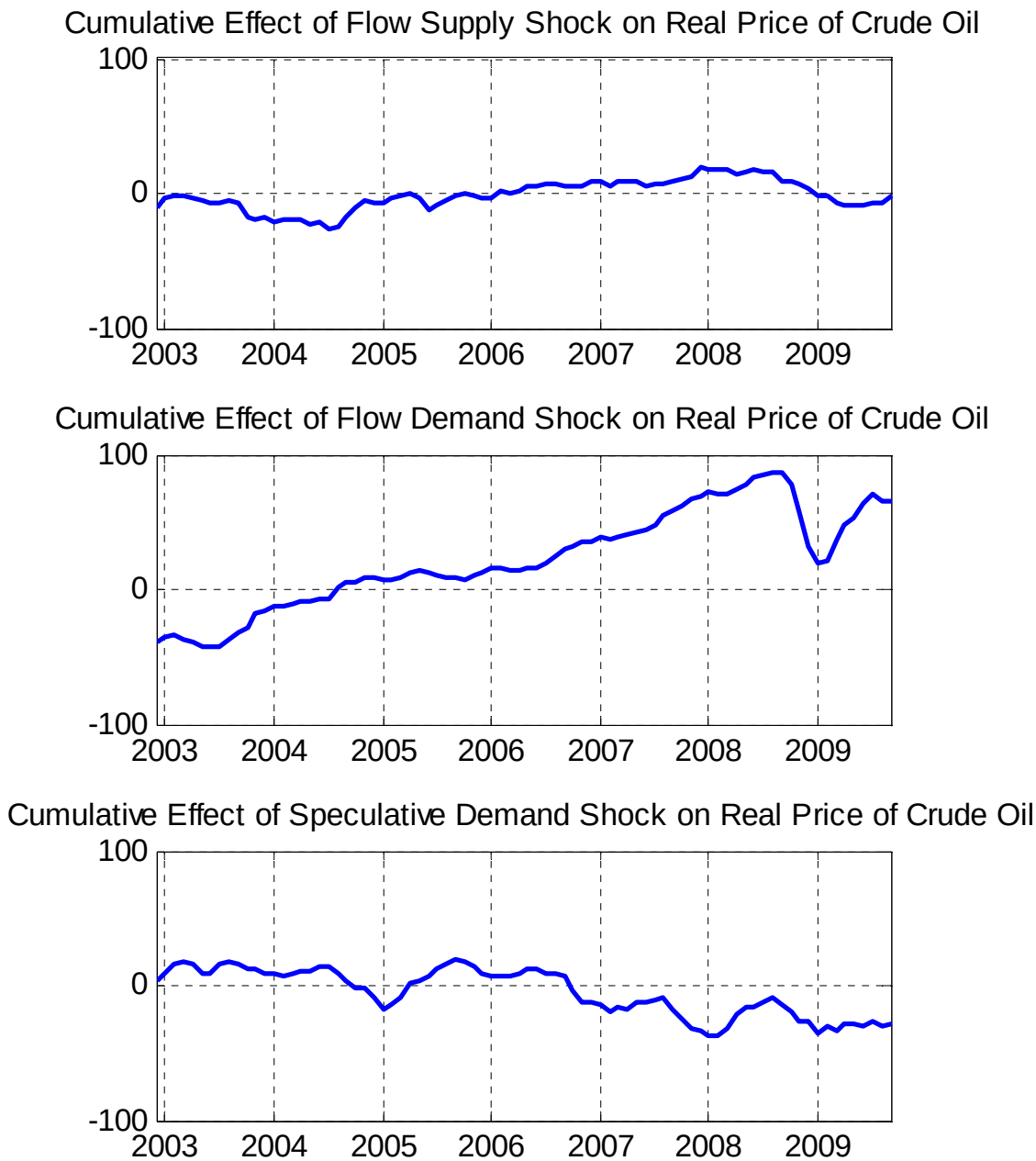




Historical Decompositions for Venezuelan Crisis and Iraq War



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 $\eta^G \approx \eta^{O,Use}$.

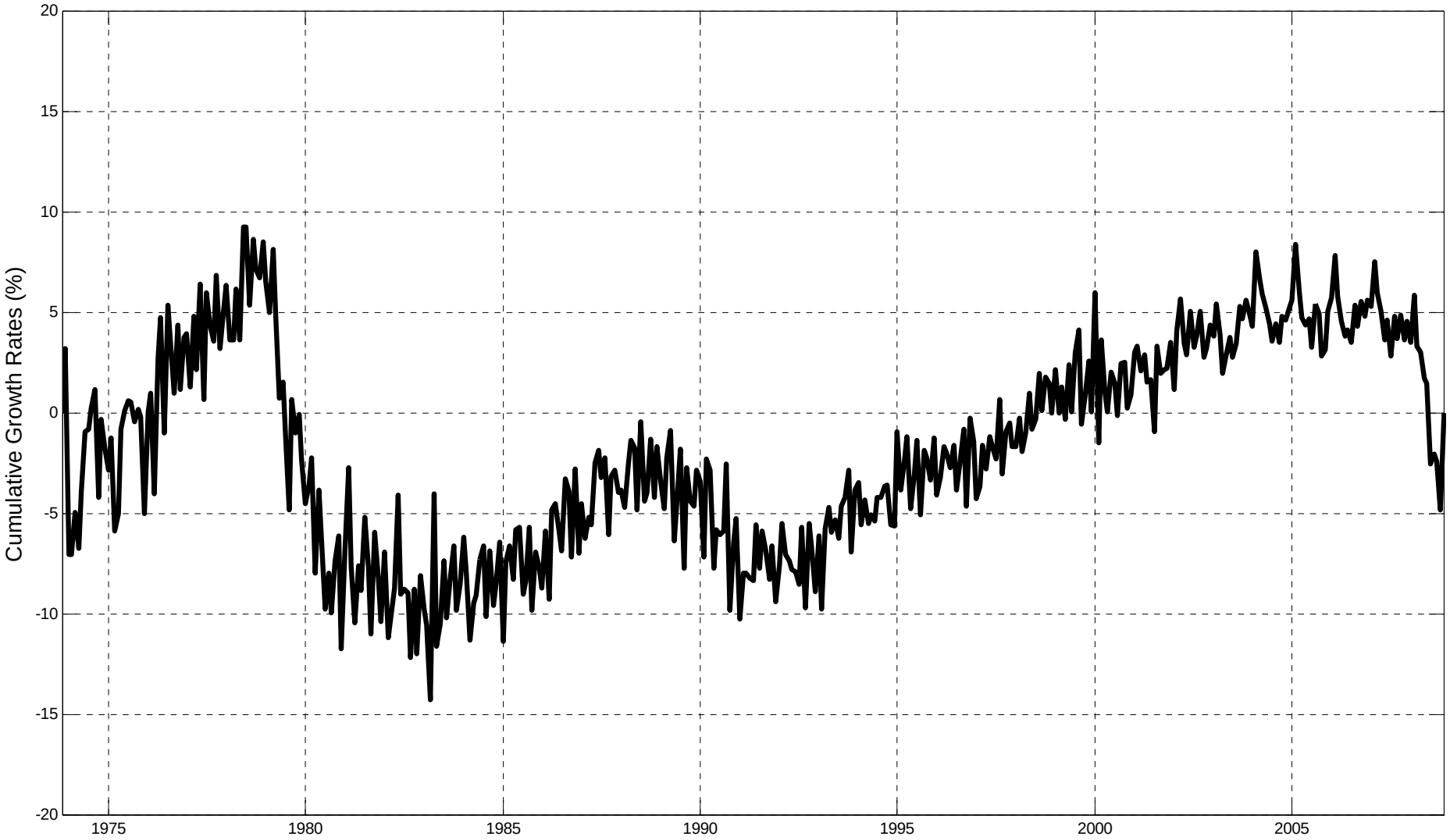
The Impact Price Elasticity of Gasoline Demand

- ⇨ 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.