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Modeling Oil Prices and Their Effects

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Motivation

● What is the response of macroeconomic aggregates to changes in the price of oil?

Implicit in this question is a thought experiment in which one varies the price of oil holding all other variables constant. This thought experiment is not well defined:

1. Reverse causality from macro aggregates to oil prices (see Barsky and Kilian 2002).
2. Oil prices are driven by distinct oil demand and oil supply shocks, each of which triggers different dynamics, so the composition matters.
3. Some demand shocks have a <u>direct</u> effect on the U.S. economy and an <u>indirect</u> effect working through the price of oil, violating the *ceteris paribus* assumption.

● Recent work by Kilian (2008) utilizes a structural VAR model of the global crude oil market that addresses these three issues.

● This presentation will motivate and explain that approach to modeling oil markets and highlight its implications for DSGE modeling.

Outline

1. The Determinants of the Real Price of Crude Oil
2. A Simple Structural Model of the Global Crude Oil Market
3. Understanding the Evolution of the Real Price of Oil Since 2000
4. The Transmission of Oil Demand and Oil Supply Shocks to the U.S. Economy
5. Implications for DSGE Models of the Transmission of Oil Price Shocks

Part 1:
The Determinants of the Real Price of Crude Oil

Determinants of the Real Price of Oil

Three Key Determinants:

(1) Global crude oil production.

(2) Global real economic activity

(3) Expectations shifts in oil markets

Other Determinants:

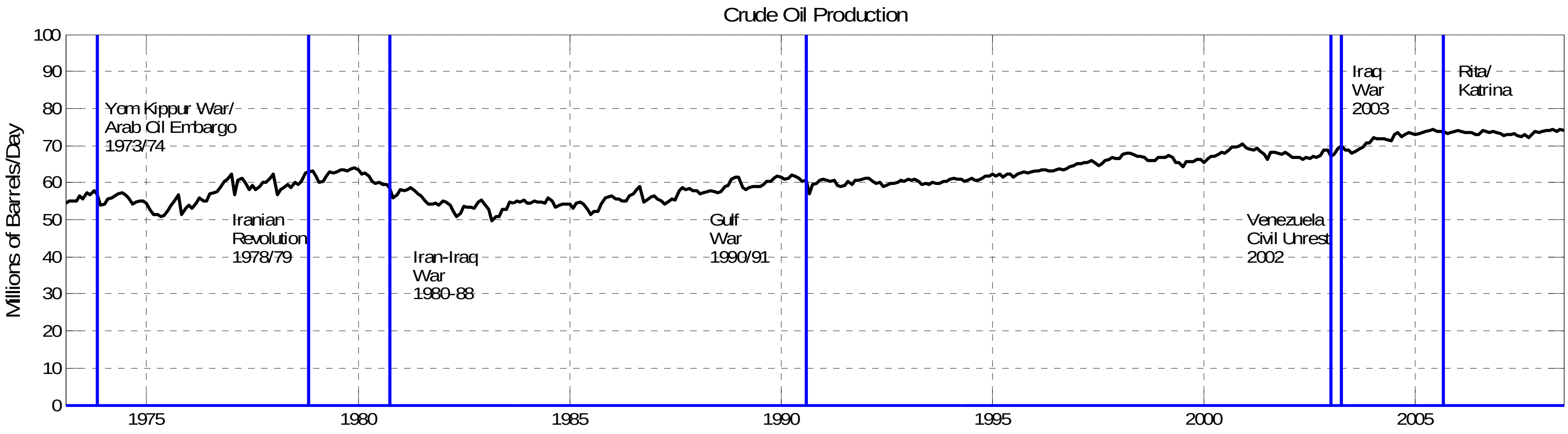
(4) Dollar exchange rates

(5) Interest rates

(6) Inflation

Determinant 1: Global Oil Production

Global Crude Oil Production: 1973.1-2008.5



Identifying Exogenous Oil Supply Shocks

● Global oil production is endogenous with respect to macroeconomic conditions (even under a cartel regime).

● Wars and other exogenous political events in OPEC countries may cause exogenous oil production shortfalls.

Examples: Iranian revolution (1978/79), Iran-Iraq War (1980-1988), Persian Gulf War (1990/91), Iraq War (2003), Civil unrest in Venezuela (2002/03), and perhaps the Yom Kippur War/Arab oil embargo (1973/74)

● Key questions:

1. How large are the exogenous fluctuations in the production of oil?
2. To what extent do exogenous oil supply shocks explain changes in the real price of oil?

Measuring Exogenous Oil Supply Shocks

- Hoover-Perez: Qualitative Dummies

- Hamilton (JoE 2003): Quantitative Dummies

- Kilian (REStat 2008): Any attempt to identify the timing and magnitude of these exogenous production shortfalls requires explicit assumptions about the <u>counterfactual path of oil production</u> in the absence of the exogenous event in question.

Example: Counterfactual for the October 1973 War and the 1973/74 Arab Oil Embargo

● It is well known that oil production from Arab OPEC countries fell between September and November of 1973, whereas oil production in the rest of the world did not.

● This observation suggests that we take non-OPEC oil producers as our benchmark. Non-OPEC growth of oil production becomes the counterfactual.

● Simply comparing the production decisions in non-OPEC countries and Arab-OPEC countries in late 1973 would be misleading, however, because of differences in economic incentives across these countries.

1971 Tehran/Tripoli agreements

- Contract between the oil companies and Middle Eastern OPEC oil producers
- Duration of five years
- Moderate improvement in the financial terms that host governments receive from oil companies for each barrel of oil extracted by the oil companies …

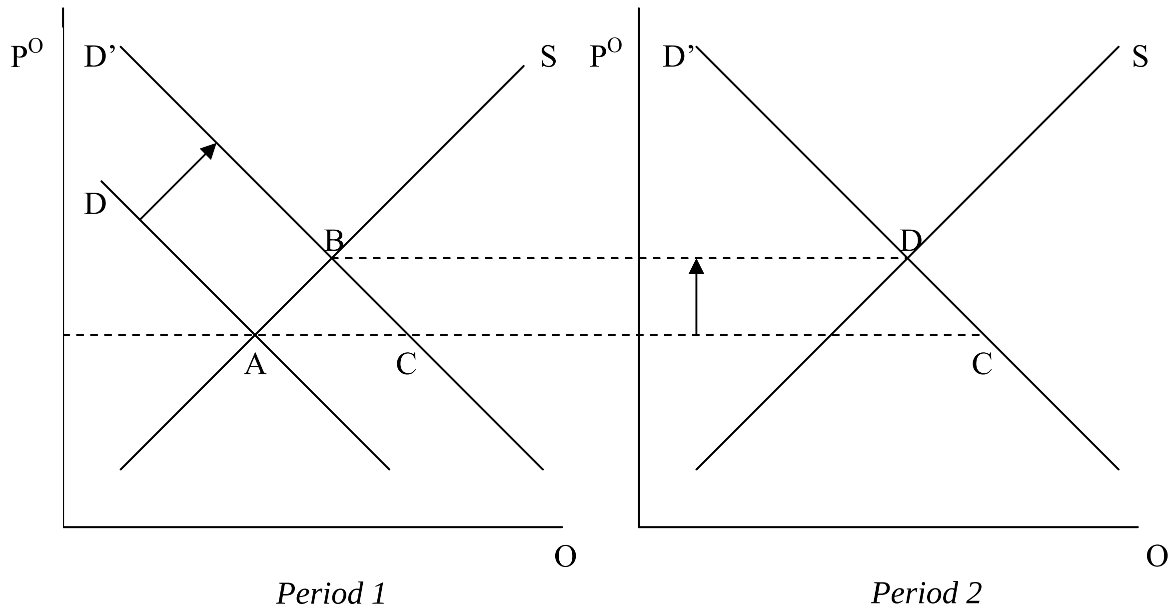
  … in exchange for assurances that these governments would allow the oil companies to extract as much oil as they saw fit on those terms.

● Latent problem: No allowance for excessive inflation or dollar devaluation

● Starting in early 1973 Arab OPEC oil producers complained of excessive oil production.

● The agreements were unilaterally terminated by Middle Eastern OPEC in early October of 1973, after unsuccessful attempts to renegotiate the terms in response to the unanticipated dollar devaluation and high dollar inflation.

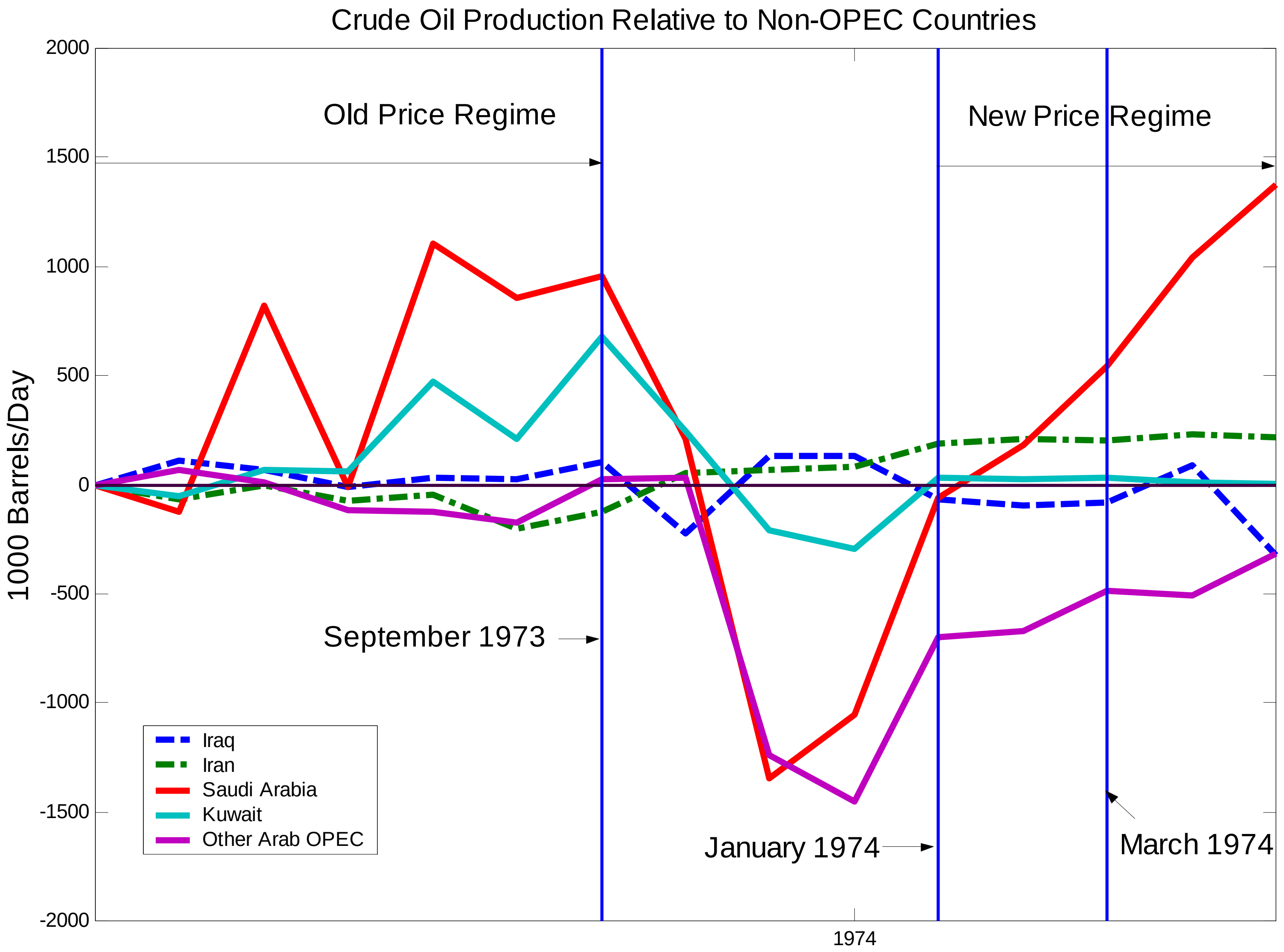
What happened?
A Two-Period Disequilibrium Analysis of the Oil Market in the Early 1970s



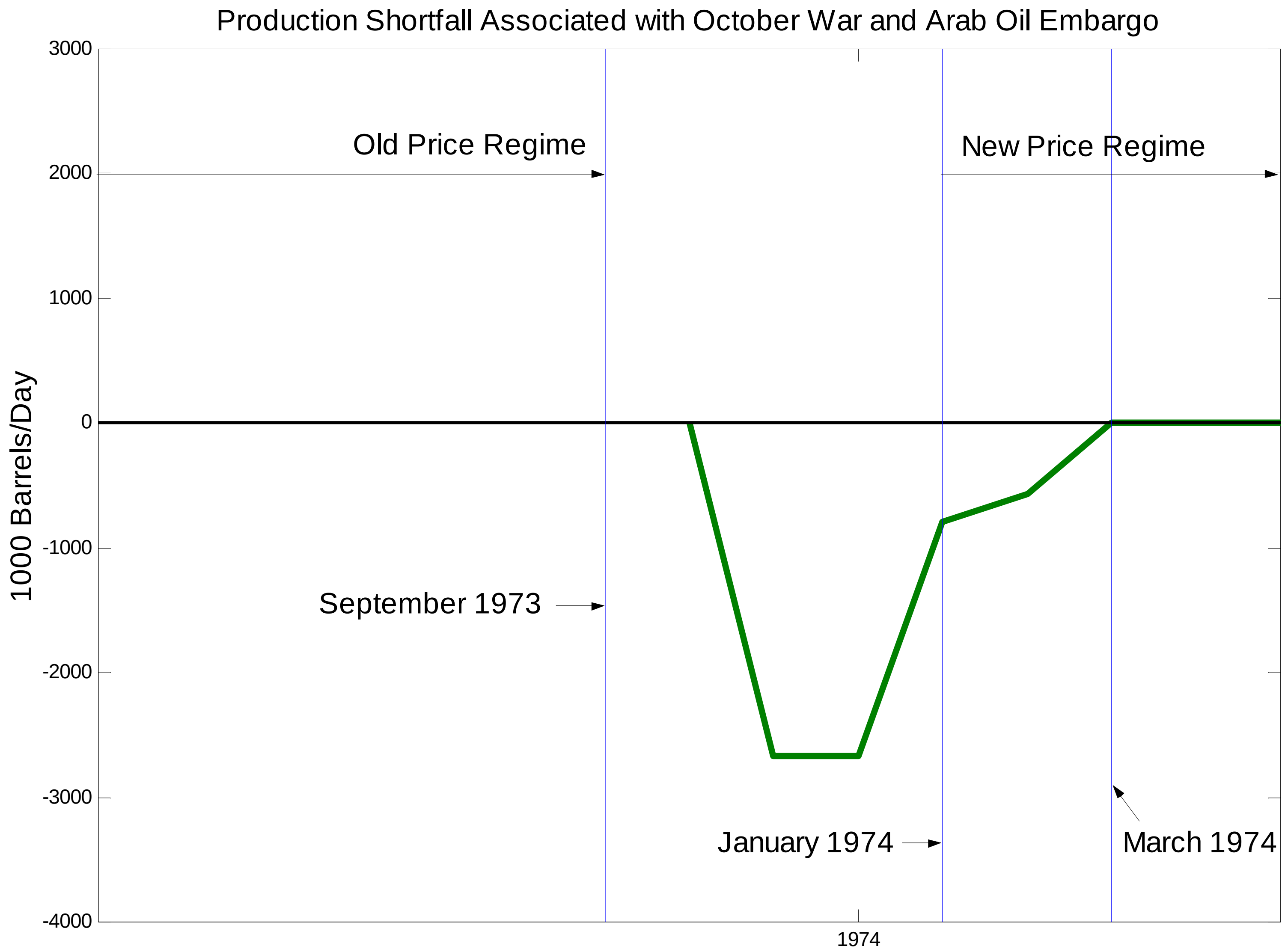
Price fixed, Quantity ↑ Price ↑, Quantity ↓

Implication: Price ↑, Quantity ↓ need not reflect supply disruption!

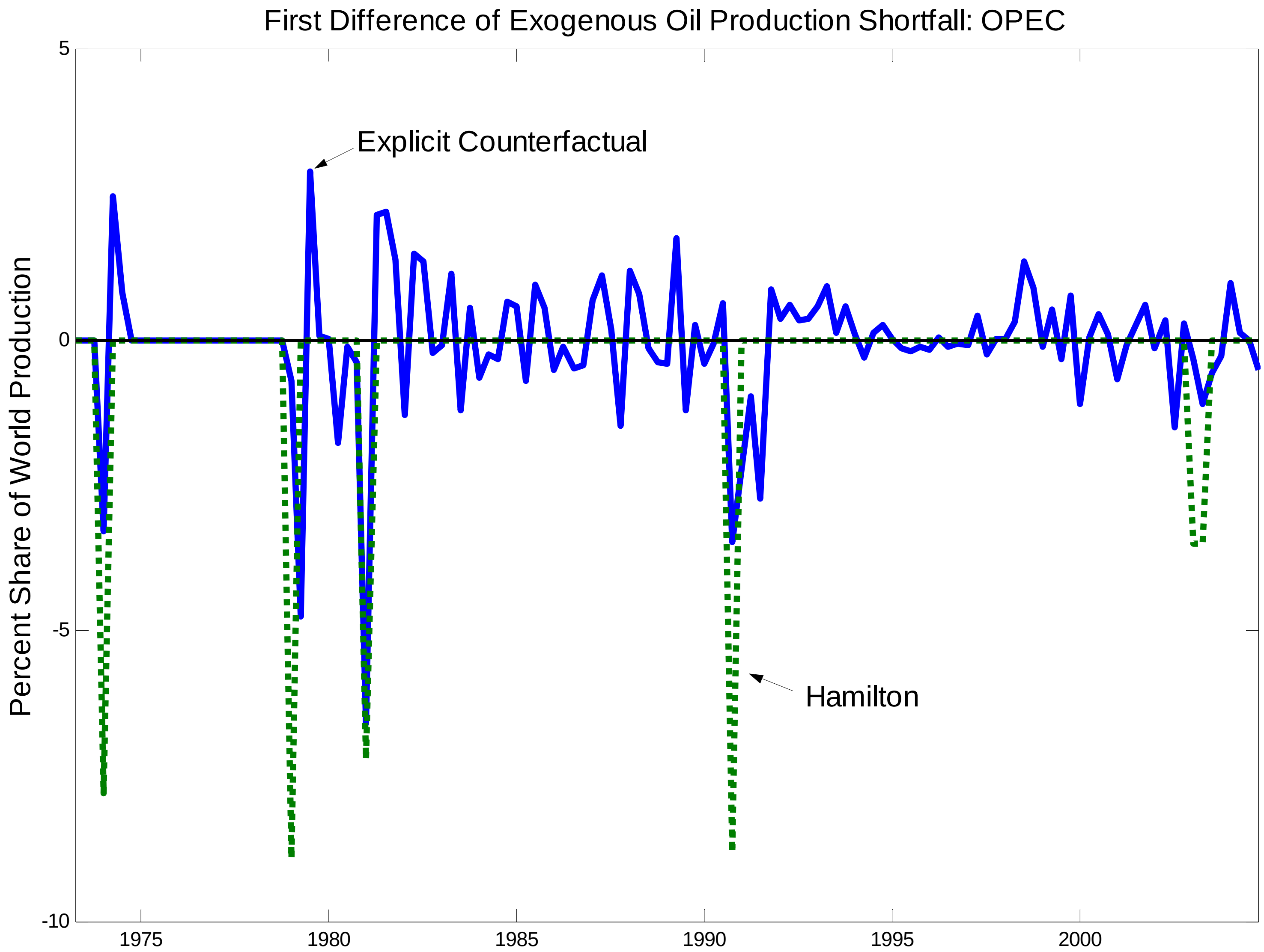
The October 1973 War and 1973/74 Embargo: Production



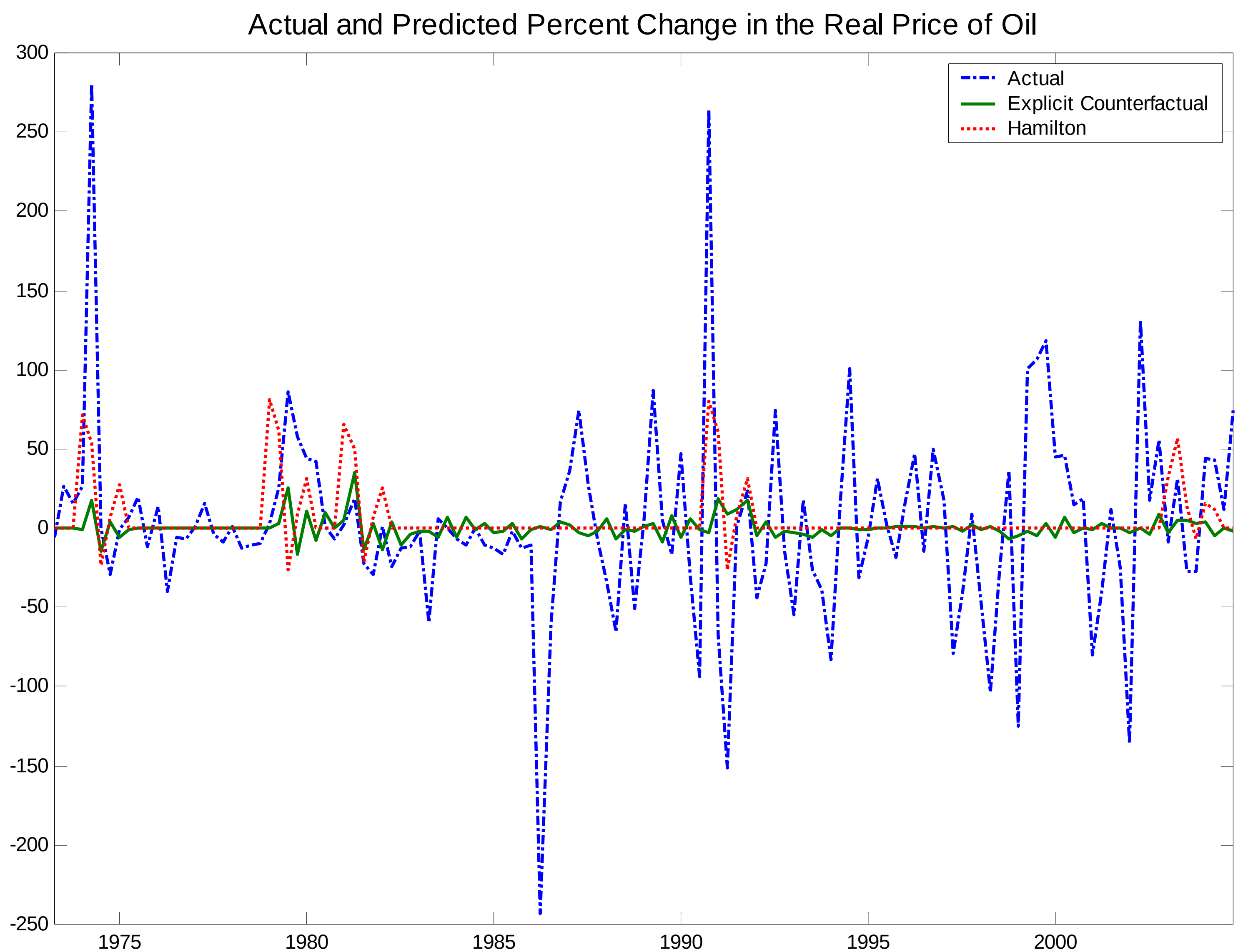
The October 1973 War and 1973/74 Embargo: Production Shortfall



Baseline Exogenous Oil Supply Shock Series for all of OPEC



Actual Oil Price Changes and Oil Price Changes Explained by Exogenous Oil Supply Shocks



What Explains the Remaining 80-100% of the 1973/74 Oil Price Hike?

● Global demand boom driven by world-wide monetary expansion (Barsky and Kilian 2002, 2004).

● Simultaneous peak of the business cycle in U.S., Japan and Europe in 1972/73.

● Strong demand pressures in industrial commodity markets.

Percent Increase in Real Price	1971.11-1974.2
Crude Oil	125.3
Industrial Raw Materials	92.6
Metals	95.9

<u>Example</u>:
The price of scrap metal nearly doubled between October 1972 and October 1973 and continued to rise to nearly four times its initial level by early 1974.

Exogeneity via a Nonlinear Transformation of the Price of Oil?

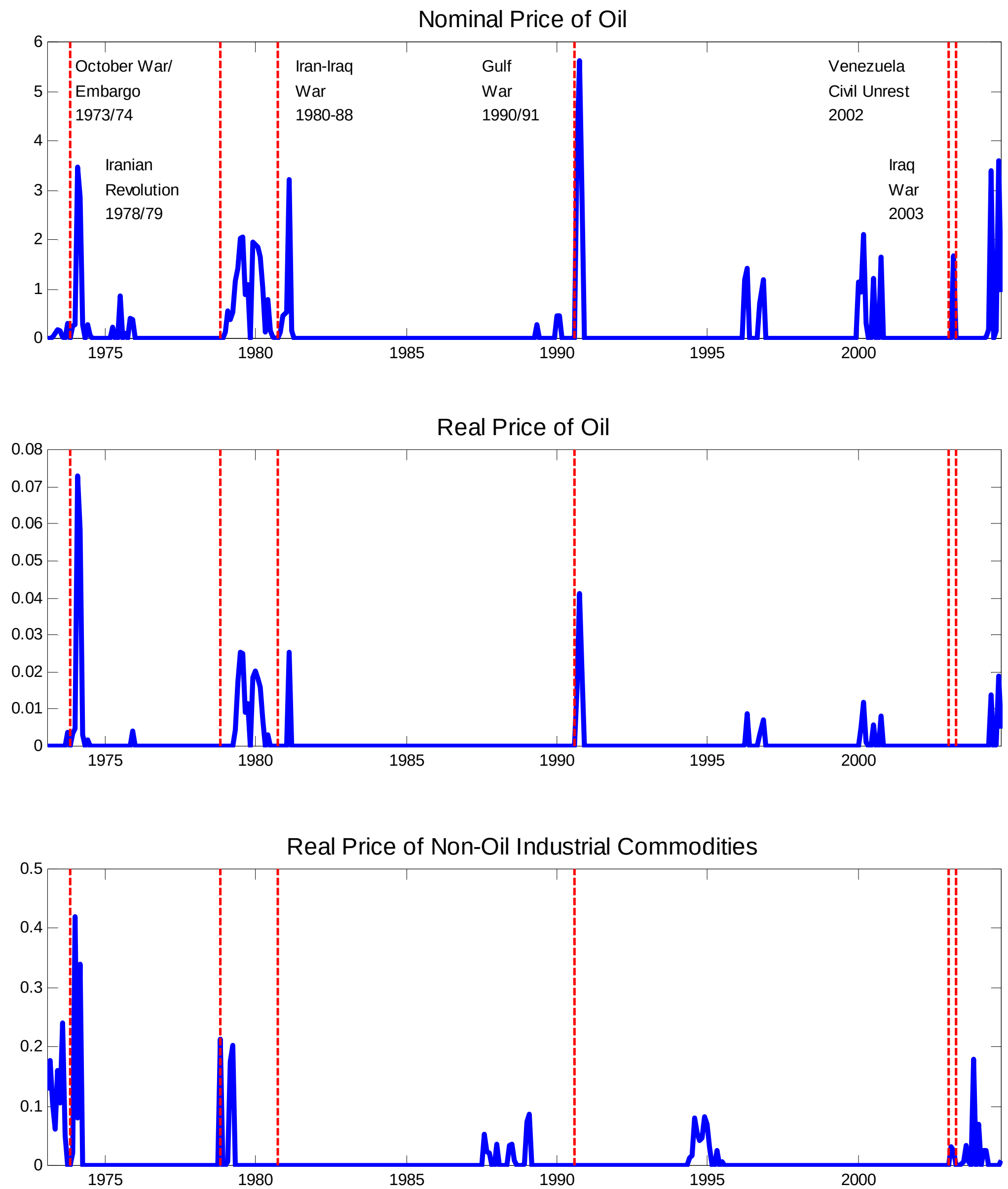
Recently the case has been made that nonlinear transformation of the price of oil designed to capture "oil price shocks" effectively identify the exogenous component of the price of oil (driven by events in the Middle East).

<u>Example:</u> Hamilton's (2003) net increase in the nominal price of oil relative to the maximum of the price of oil over the previous three years.

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

where p_t^* is the maximum oil price over the preceding 3 years.

Oil Price Shocks Measured by 3-Year Net Oil Price Increase



● Clearly, the net increase measure is not exogenous with respect to macroeconomic conditions (previous evidence to the contrary has been inadmissible).

● The recent literature has instead treated the net increase measure as predetermined with respect to the domestic macro economy:

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

Kilian and Vigfusson (2009) show that such regressions are inherently mispecified, the parameter estimates are inconsistent, and the impulse response estimates have been computed incorrectly, resulting in response estimates that are typically upward biased.

● Moreover, there is no formal evidence supporting this type of model of the transmission of oil price shocks.

Determinant 2: Global Real Economic Activity

<u>Barsky and Kilian (2002, 2004):</u>

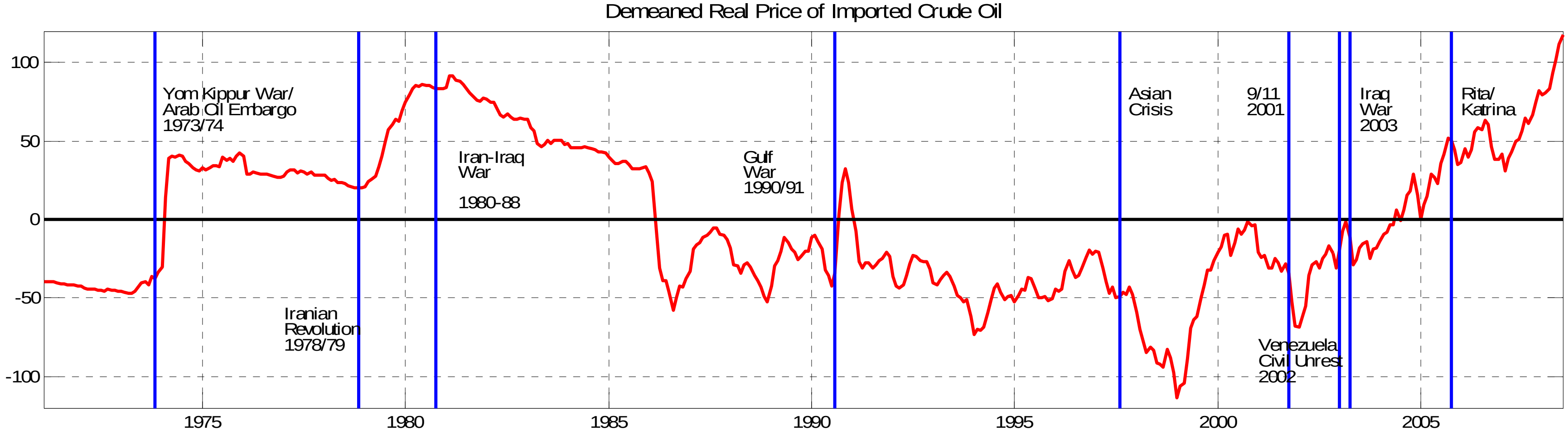
● As with any other industrial commodity, the demand for crude oil depends on global real economic activity.

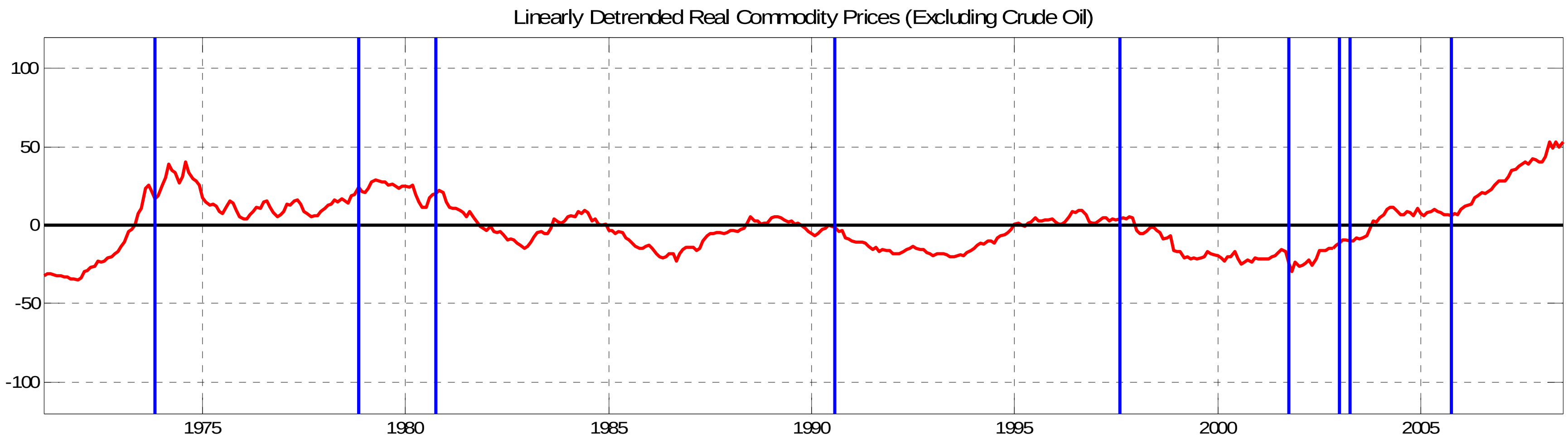
● There are long swings in the demand for industrial commodities.

● Sustained demand increases may interact with supply constraints to produce sharp price increases.

● Measuring shifts in global demand for industrial commodities at monthly frequency is nontrivial.

Cycles in Inflation-Adjusted Prices of Crude Oil and Commodities for 1971.1-2008.6





Growth Rates of Inflation-Adjusted Commodity Prices (%)

	1971.11-1974.2	1977.8-1980.2	2001.6-2008.6
Crude Oil	125.3	70.7	327.5
Industrial Raw Materials	92.6	24.2	66.7
Metals	95.9	27.6	234.6

<u>1971.1-1974.2:</u>
1. Major OECD monetary expansion as the primary cause.
2. Supply side constraints interact with rising demand for all industrial materials.

<u>1977.8-1980.2:</u>
1. Somewhat smaller OECD monetary expansion as the primary cause.
2. Supply side constraints interact with rising demand for industrial materials.
3. Oil demand amplified by increased uncertainty about oil supply shortfalls in 1979.

<u>2001.6-2008.6:</u>
1. Expansion in emerging Asia on top of strong OECD economy (followed by collapse of growth in OECD <u>and</u> emerging Asia in late 2008).
2. Supply side constraints interact with rising demand for all industrial commodities.

A Monthly Index of Global Real Activity based on Ocean Shipping Freight Rates

● Based on representative ocean shipping freight rates collected by Drewry Shipping Consultants Ltd. for various bulk dry cargoes including grain, oilseeds, coal, iron ore, fertilizer and scrap metal.

● Available at monthly frequency as far back as January 1968.

● Not without precedence:

1. Economists have long observed a positive correlation between ocean freight rates and economic activity (see, e.g., Isserlis 1938, Tinbergen 1959, Stopford 1997).
2. It is widely accepted that world economic activity is by far the most important determinant of the demand for transport services (see, e.g., Klovland 2004).
3. The same approach is used by market practitioners (Baltic Dry Cargo Index).

How Freight Rates Reflect Real Economic Activity

- At low levels of freight volumes the supply curve of shipping is relatively flat in the short and intermediate run, as idle ships may be reactivated or active ships may simply cut short layovers and run faster.
- As the demand schedule for shipping services shifts out due to increased economic activity, the slope of the supply curve becomes increasingly steeper and freight rates increase. At full capacity the supply curve becomes effectively vertical, as all available ships are operational and running at full speed.
- This line of reasoning suggests that net increases in freight rates relative to the recent past may be used as indicators of strong cumulative global demand pressures.

Disadvantages and Advantages of the Proposed Index

Disadvantages:

The presence of a ship-building and scrapping cycle may weaken the business cycle in global commodity markets and the freight rate index.

Given the pro-cyclicality of ship-building, one would expect the real freight rate index to lag increases in real economic activity (as spare capacity in shipping cushions the impact of higher demand on freight rates) and to lead decreases in real economic activity (as the arrival of new ships depresses freight rates), thus accentuating upswings in real activity.

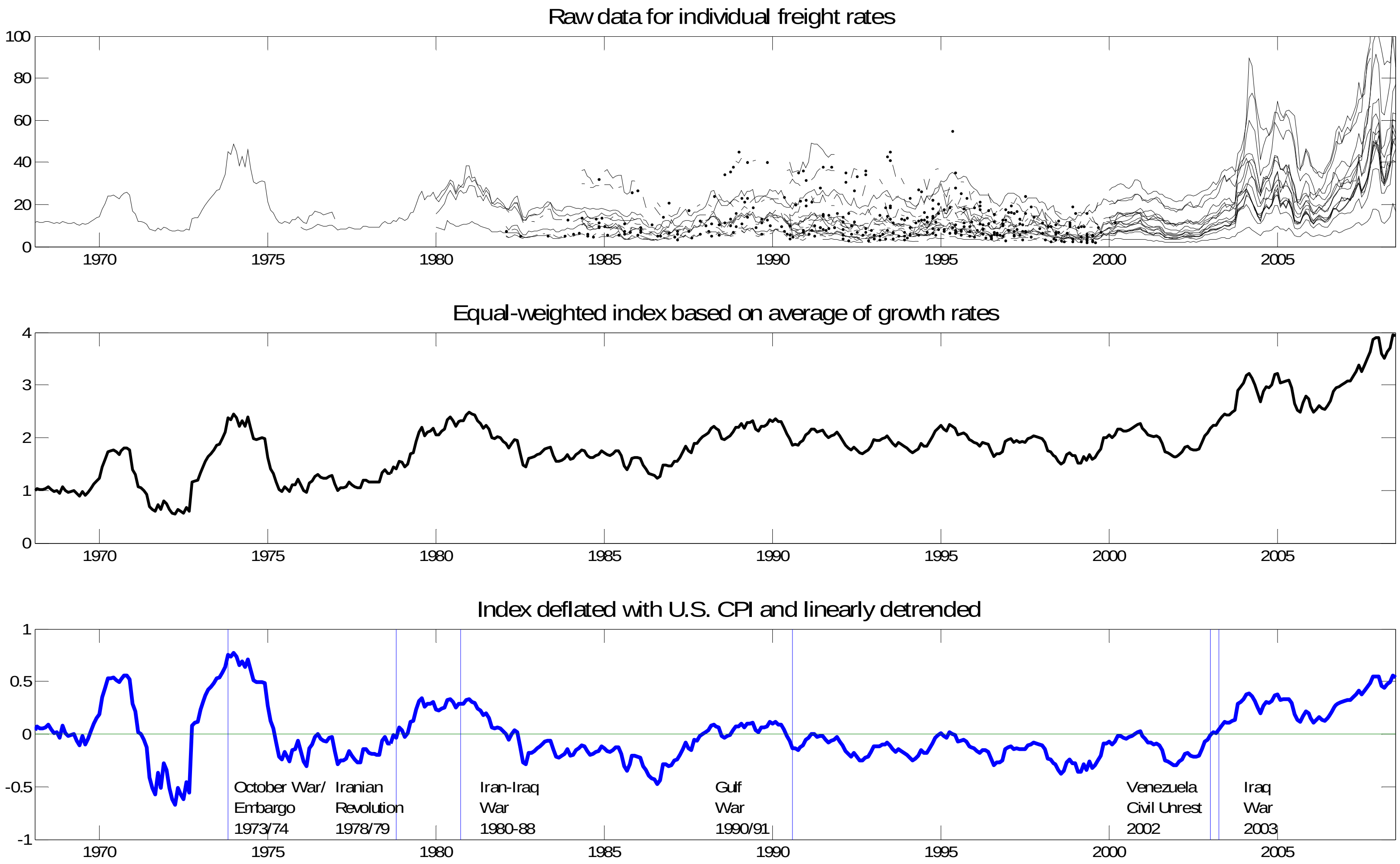
Advantages:

The proposed index is a direct measure of global economic activity that (1) does not require exchange-rate weighting, that (2) automatically aggregates real economic activity in all countries (including, e.g., China, India), and that (3) already incorporates shifting country weights, changes in the composition of real output, and changes in the propensity to import industrial commodities for a given unit of real output.

Construction of the Index in Practice

- Single voyage freight rates
- Only bulk dry cargoes (no substitutability)
- Freight rates are typically quoted in U.S. dollars per metric ton.
- Monthly quotes are provided for different commodities, routes and ship sizes.
- There is no continuous series for the entire sample period.

Index of Global Real Economic Activity based on Dry Cargo Bulk Freight Rates 1968.1-2008.06



Rationale of the Proposed Index (1)

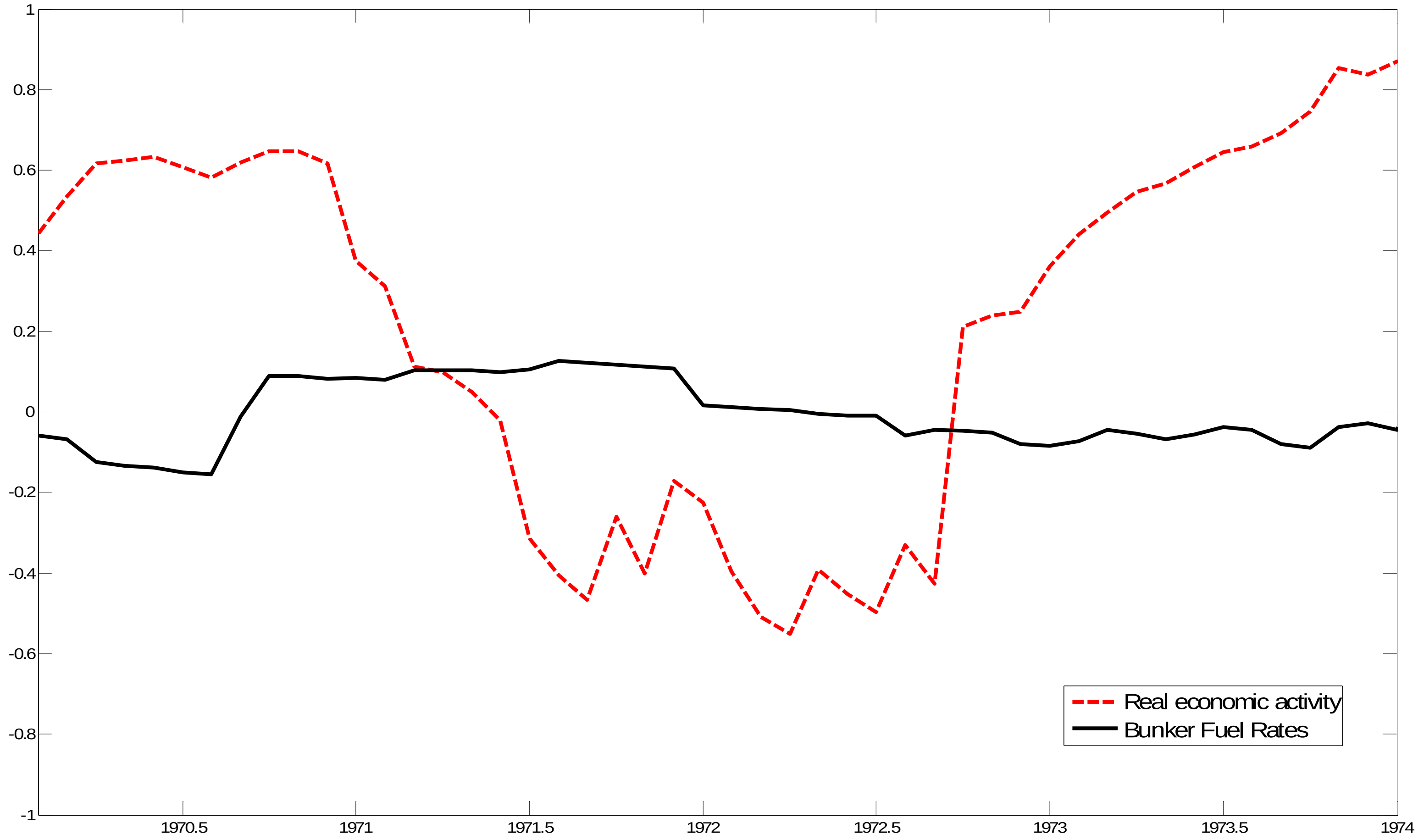
- A concern is that dry cargo freight rates may increase during oil price shocks not because both are driven by higher demand for commodities, but because the provision of shipping services uses bunker fuel oil as an input.

Response:

1. The model below used for the empirical analysis allows for unrestricted lagged feedback from oil prices to freight rates.

2. Data on the real price of bunker fuel from the *Oil and Gas Journal* are consistent with that assumption.

Index of Global Real Economic Activity and Index of Real Bunker Fuel Prices: 1970.1-1973.12



NOTES: The bunker fuel rate data are from the *Oil and Gas Journal*, various issues since 1970. All rates refer to Bunker C fuel, as recorded for the Caribbean, the Gulf Coast and California. The index is based on equal-weighted growth rates, computed using observations for the last week of each month. The real economic activity index is based on Figure 4.

Rationale of the Proposed Index (2)

● Why not include data on crude oil tanker rates available from Drewry's Shipping Monthly?

<u>Response:</u>

Typically these rates strongly co-move with dry cargo rates, but tanker rates at times may be subject to important oil-specific supply shocks, which makes them unsuitable as a measure of real economic activity:

(1) Events such an oil embargo may lower the demand for tankers (and hence tanker rates) simply because there is no oil to be shipped, not because consumers' demand for oil has decreased.

(2) Attacks on shipping in the Persian Gulf may raise the insurance premium for tankers (and hence tanker rates). The same applies to transportation surcharges, as tankers are rerouted.

Rationale of the Proposed Index (3)

- Alternative Measures:
    1. The Baltic Dry Cargo Index (available since 1985) is essentially identical with the freight rate index underlying the proposed measure of global real activity.
    2. Monthly Index of Global Industrial Production?
        - No world industrial production available at monthly frequency
        - OECD industrial production excludes many emerging economies in Asia and misses the demand boom from emerging economies.

<u>Lesson</u>: We need a truly global measure of real activity.

Determinant 3: Expectations Shifts

● So far we have focused on the flow demand and supply of oil. There also may be forward-looking elements in the real price of oil not reflected in past prices and quantities. Examples:

1. Expectations about first moment:

    Supply: New discoveries (Brazilian off-shore oil fields)

    Demand: Global financial crisis

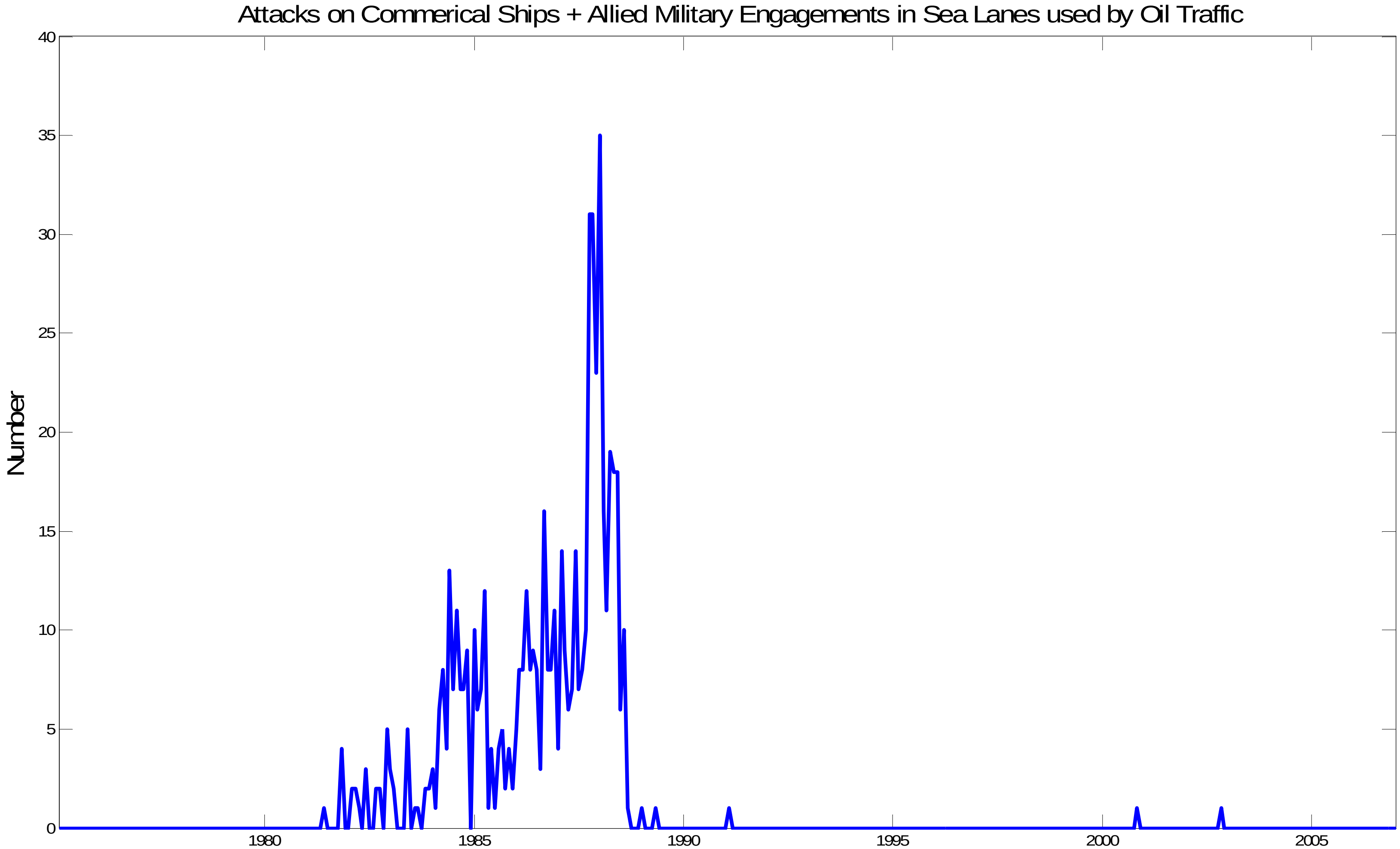
2. Expectations about second moment:

    Uncertainty about future oil supply shortfalls

● Expectations shifts are not directly observable.

● Nonlinear link: Observables → Uncertainty → Demand → Spot price

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



Part 2:
A Simple Structural Model of the Global Crude Oil Market

A Proposal for Solving the Identification Problem

(1) Flow supply of oil based on observable global production of crude oil.

(2) Flow demand for oil driven by global real economic activity.

(3) Additional demand for oil driven by shifts in expectations

New Strategy: Control for (1) and (2) and allow a structural model to pin down the expectations-driven component of the oil price as the residual.

Remarks:

1. If the model correctly captures the conditional expectation of future oil production and global real activity, then the expectations-driven component of demand must reflect shifts in the second moment (uncertainty) by construction.

2. Otherwise the expectations-driven component will be a mixture of all expectations effects.

A VAR Model of the Real Price of Crude Oil

● Structural VAR model based on monthly data for $z_t \equiv (\Delta prod_t, rea_t, rpo_t)'$,

where

$\Delta prod_t$ percent change in global crude oil production,

rea_t index of real activity in global industrial commodity markets,

rpo_t real price of oil.

● Consider the structural representation

$$(1) \qquad A_0 z_t = \alpha + \sum_{i=1}^{24} A_i z_{t-i} + \varepsilon_t ,$$

where ε_t denotes the vector of mutually uncorrelated structural innovations and $e_t = A_0^{-1} \varepsilon_t$:

Identifying Assumptions

$$e_t \equiv \begin{pmatrix} e_t^{\Delta prod} \\ e_t^{rea} \\ e_t^{rpo} \end{pmatrix} = \begin{bmatrix} a_{11} & 0 & 0 \\ a_{21} & a_{22} & 0 \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{pmatrix} \varepsilon_t^{oil\ \mathrm{supply}\ shock} \\ \varepsilon_t^{aggregate\ demand\ shock} \\ \varepsilon_t^{oil-specific\ demand\ shock} \end{pmatrix}$$

● The model postulates a vertical short-run oil supply curve. The short-run demand curve is downward sloping.

● The oil demand curve is being shifted by innovations to the business cycle in global industrial commodity markets as well as by shocks to the demand for crude oil specifically.

● The oil supply curve may be shifted by production disruptions in the Middle East and other exogenous events.

Evidence in Support of the Exclusion Restrictions

● Changing supply is costly.

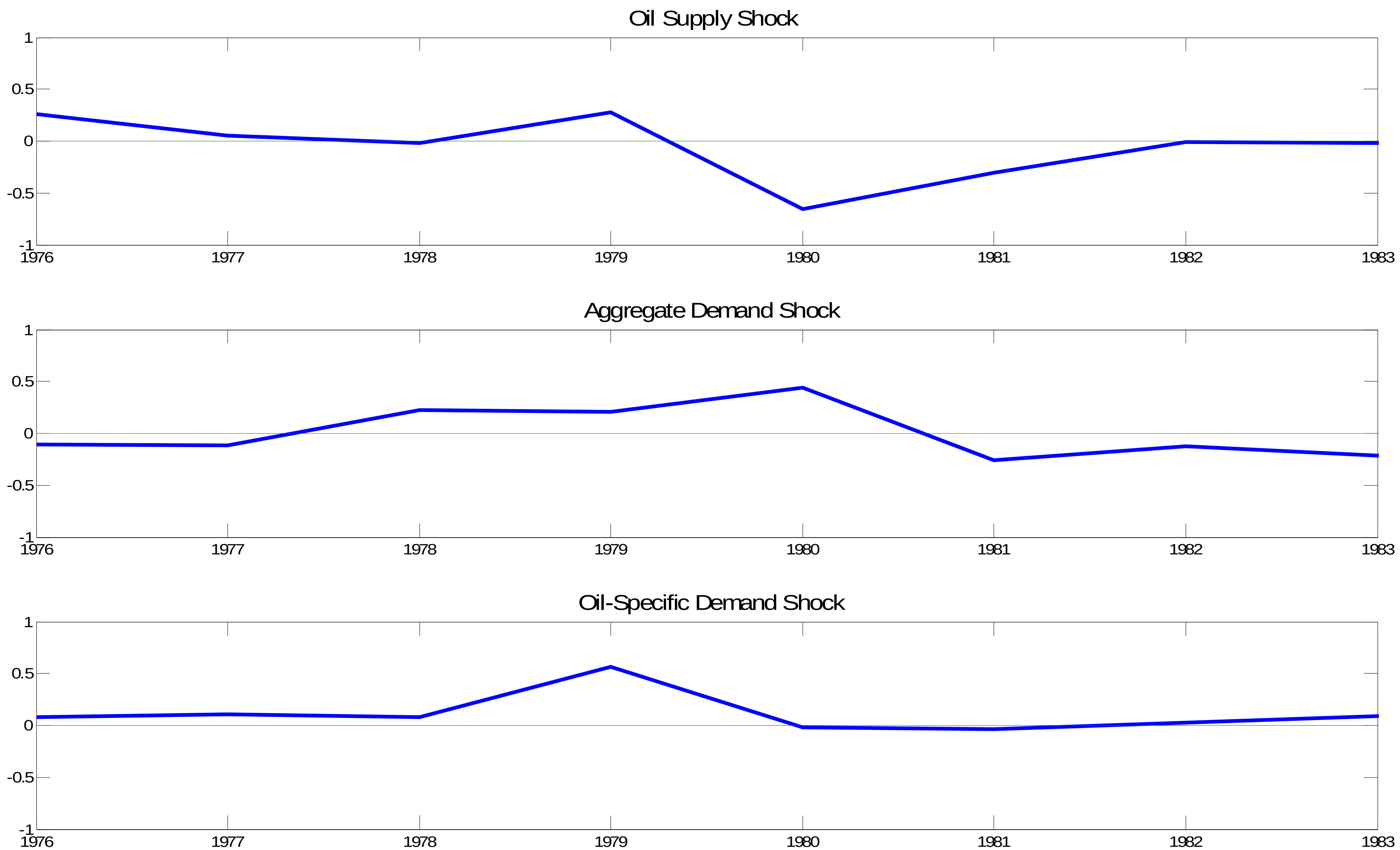
● Supply decisions depend on expected demand growth:

- AARAMCO model of oil demand only updated once a year.
- Evidence that OPEC was slow to respond to world recession in early 1980s.

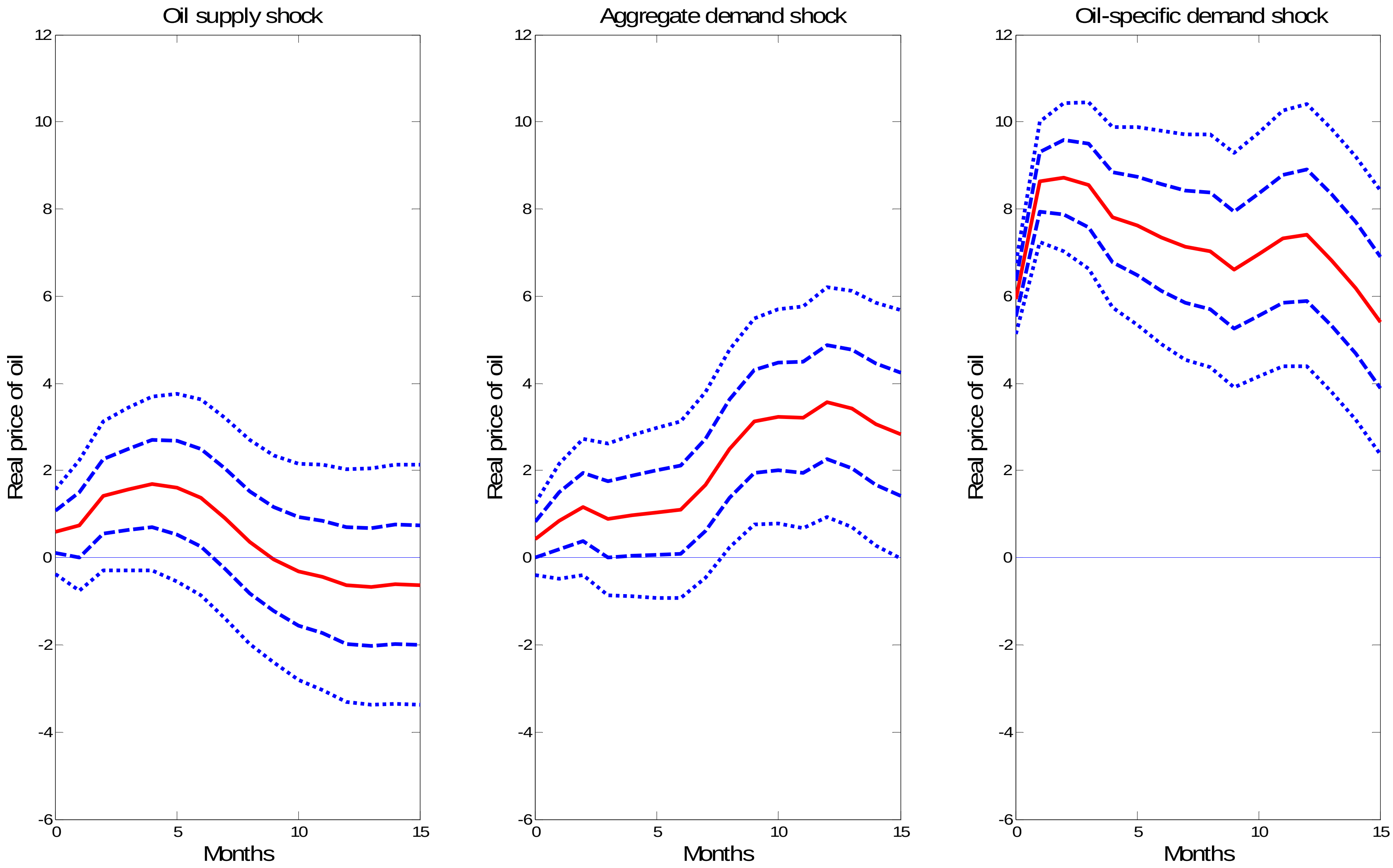
● Oil-specific demand does not affect business cycle in global commodity markets within a month:

- Plausible given delayed reaction of OECD economies to oil price shocks.

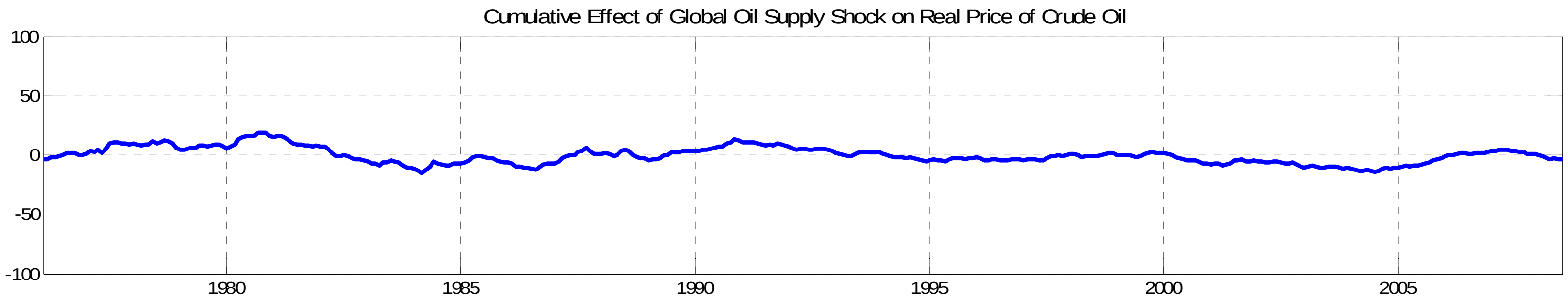
Oil Price Shocks Reflect a Composite of the Underlying Demand and Supply Shocks: Example 1979/80

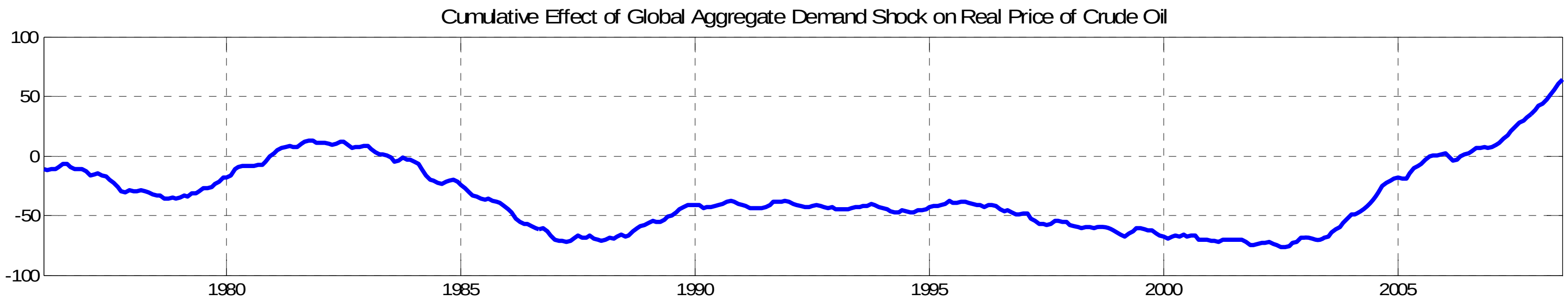


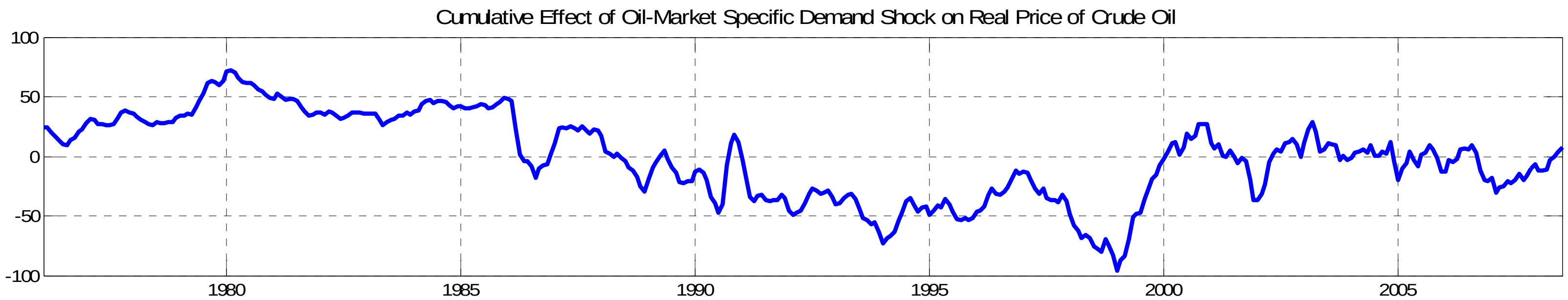
Responses of the Real Price of Crude Oil to One-Standard Deviation Structural Shocks



Historical Decomposition of Real Price of Oil: 1975.2-2008.06







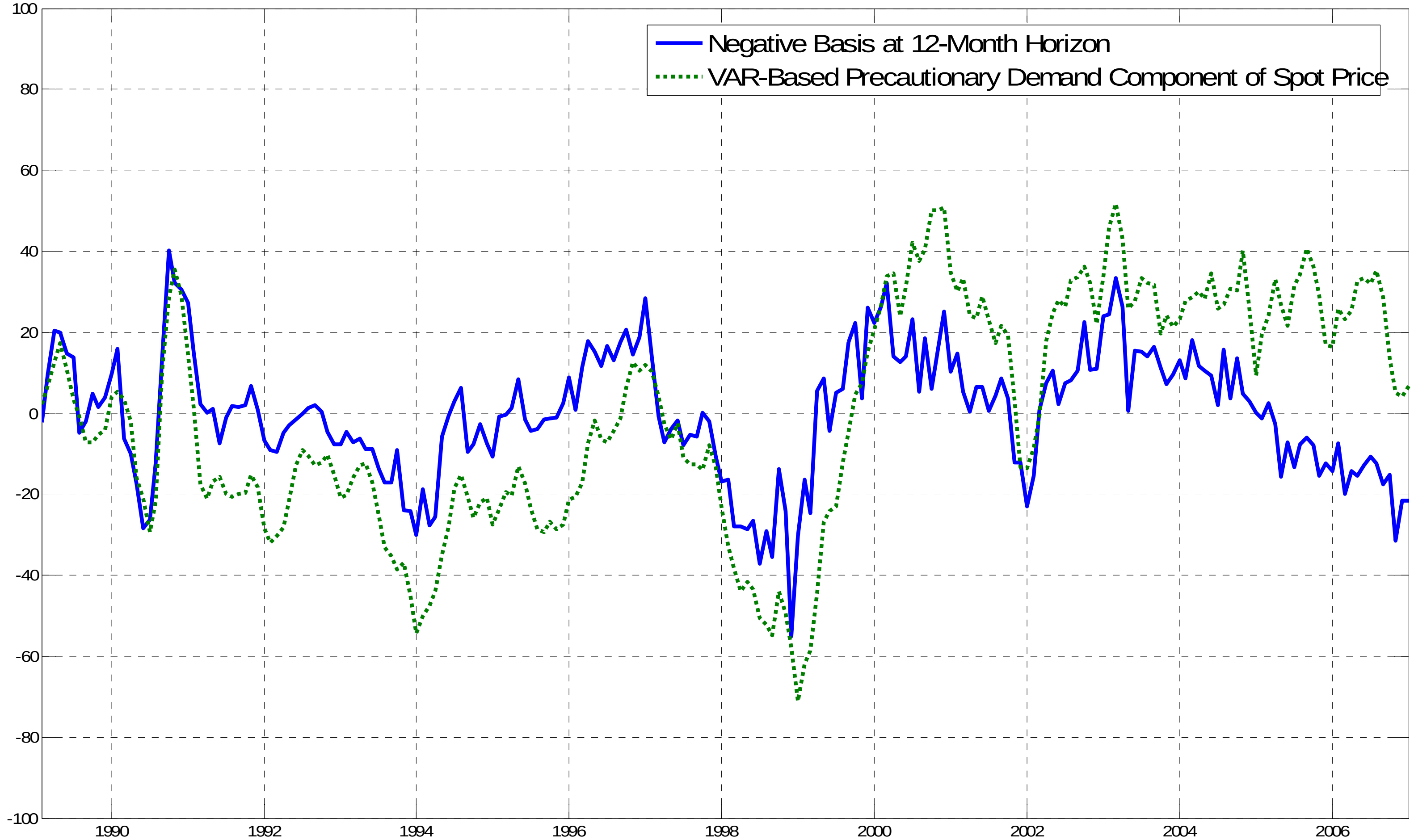
Rationale for Interpreting Oil-Specific Demand Shocks as Precautionary Demand Shocks

● No other plausible candidates (e.g., notion of disproportionately increased preference for oil in China in recent years is inconsistent with VAR evidence).

● The timing of these shocks is consistent with the timing of events that should trigger shifts in precautionary demand.

● Alquist and Kilian (2008) use data on oil futures prices to identify an index of the precautionary demand component of the real price of oil for 1989-2007, which is highly correlated with the VAR-based measure.

Negative *Basis* and VAR-Based Estimate of Precautionary Demand Component of Spot Price
1989.1-2006.12

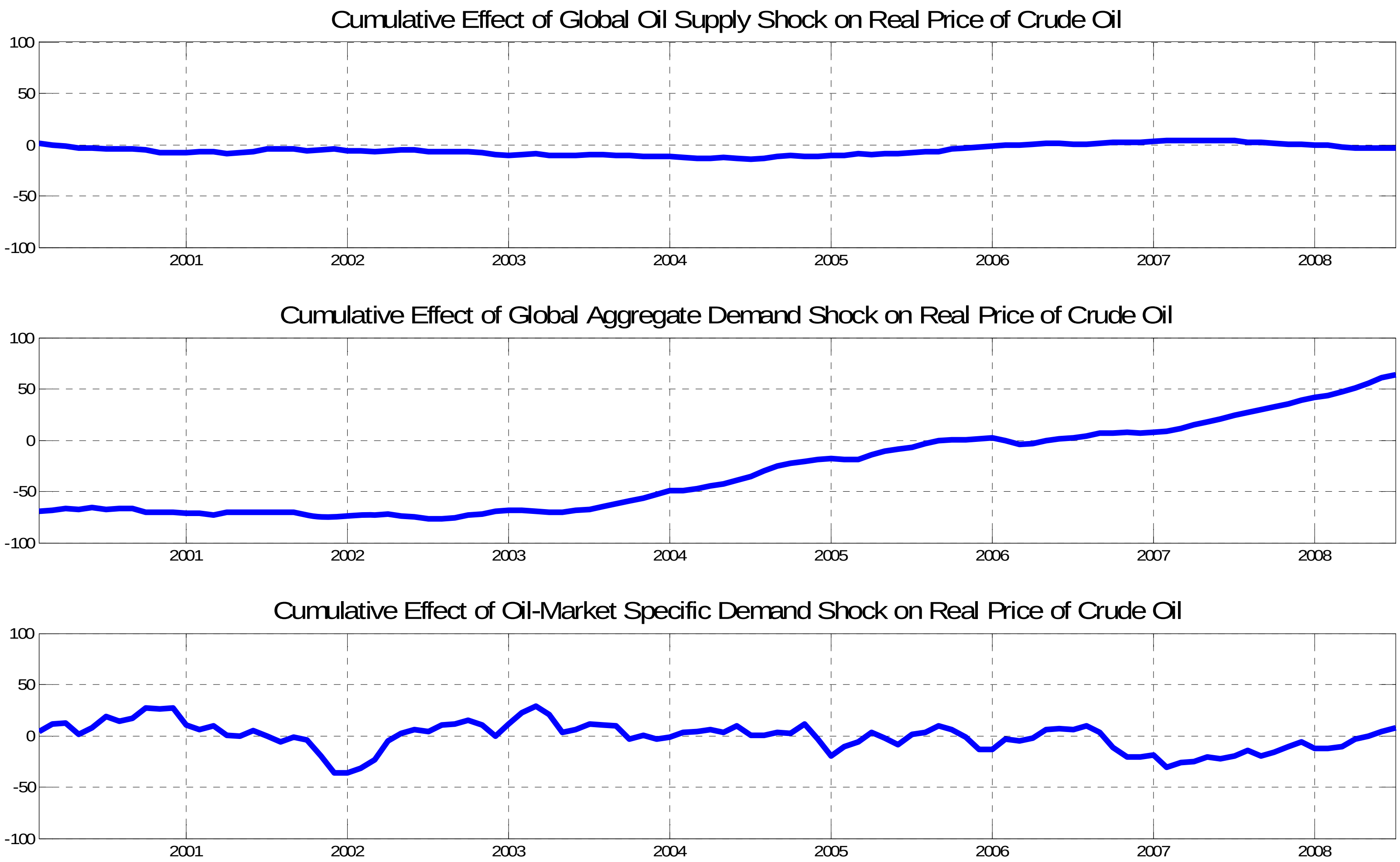


NOTES: The basis has been scaled by -1.5 to improve the readability of the graph. Since the basis is an index that transformation does not involve any loss of generality.

Part 3:
Understanding the Evolution of the Real Price of Oil Since 2000

What has been driving the recent surge in the real price of oil?

Historical decomposition: 2000.1-2008.6



The Role of Oil Supply

Growth Rates of Crude Oil Production in Percent: Selected Periods

	1974.1-1979.12	2001.6-2008.5	2005.6-2008.5
World	14.5	12.5	0.8
Persian Gulf	4.0	23.7	3.1
OPEC	0.6	19.0	2.4
Non-OPEC, Non-U.S.	51.6	11.0	0.3
U.S.	-3.6	-10.4	-5.4

● Key insight: Oil demand rising faster than crude oil supplies

● Demand is driven by strong growth in emerging Asia superimposed on top of steady growth in the OECD.

Alternative 1: Has the recent surge been driven by speculation?

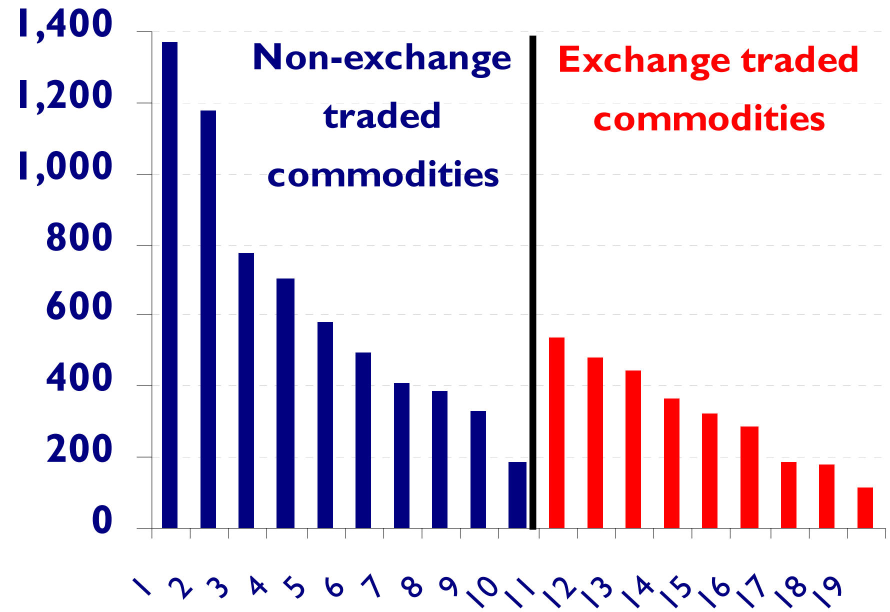
● Speculation could not have been oil market specific or the econometric model would have picked it up as an oil-specific demand shock.

● This leaves the possibility of futures-market driven speculation in many industrial commodity markets.

<u>Problem:</u>

Industrial commodity prices rose similarly in markets for which no futures contracts exist.

Percent Change in Commodity Prices (January 2002-April 2008)



1 Cadmium
2 Molybdenum
3 Rhodium
4 Ferrochrome
5 Manganese
6 Steel
7 Ruthenium
8 Iron ore
9 Rice
10 Cobalt
11 Tin
12 Copper
13 Oil (Brent)
14 Nickel
15 Lead
16 Silver
17 Corn
18 Zinc
19 Aluminium

Source: Bini-Smaghi (2008) based on Bloomberg.

● There was an increase in share of "speculators" in oil futures markets in 2003.

● Suppose that speculators drive up oil futures prices. Why would this matter?

If higher oil futures prices are interpreted as a prediction of higher spot prices, spot traders will buy a barrel of oil and store it with the intention of selling it a year later at a higher price and making a profit.

Problems with this explanation:

1. Evidence suggests that speculators played both sides of the futures markets rather than consistently betting on higher prices.

2. Alquist and Kilian (2008) have shown that oil futures prices are no better predictors of the spot price than no-change forecasts.

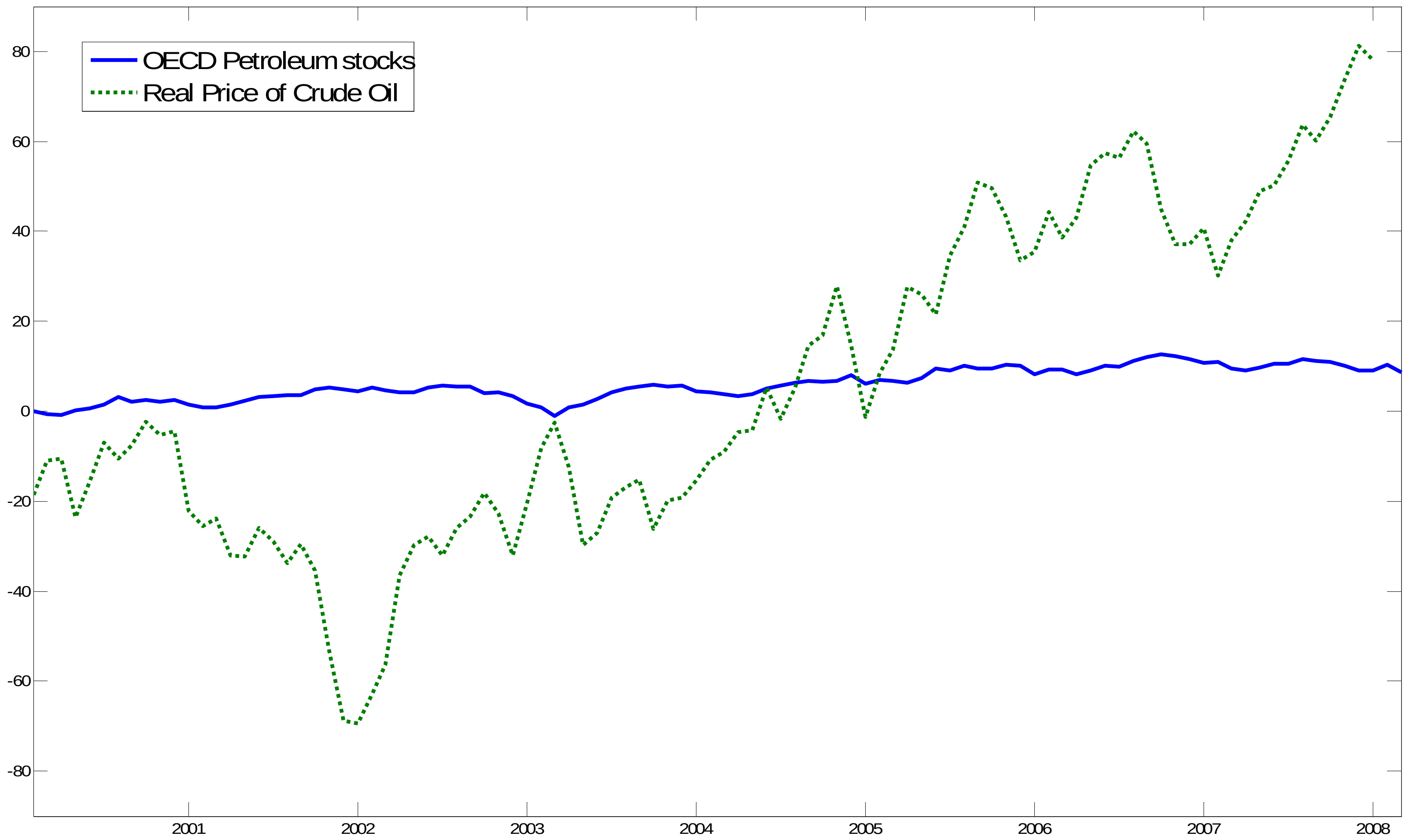
3. Suppose, nevertheless, that spot market traders acted as though oil futures prices predict spot prices:

a. In that case, according to standard economic models, one would expect above-ground oil inventories to have increased sharply relative to trend since 2003.

<u>Problem</u>:
That did not occur in the U.S. and OECD data.

CAVEAT: Not all above-ground oil inventories are monitored adequately.

OECD Petroleum Inventories and the Real Price of Oil since 2000



NOTES: Log-scale. The OECD inventory data have been normalized such that 2000.1is zero.

b. If, for technological reasons, the stock of oil in inventories is fixed, increased speculation in the spot market means that traditional buyers must have received less crude oil.

<u>Problem</u>:
Those traditional buyers are refineries, so their output in the form of gasoline, heating oil, etc. should have fallen since 2003. This again is inconsistent with the data.

Alternative 2: Is U.S. monetary policy to blame?

Expansionary monetary policy played central role in oil price increases (and declines) of the 1970s and early 1980s. It did not play a key role in the 2000s:

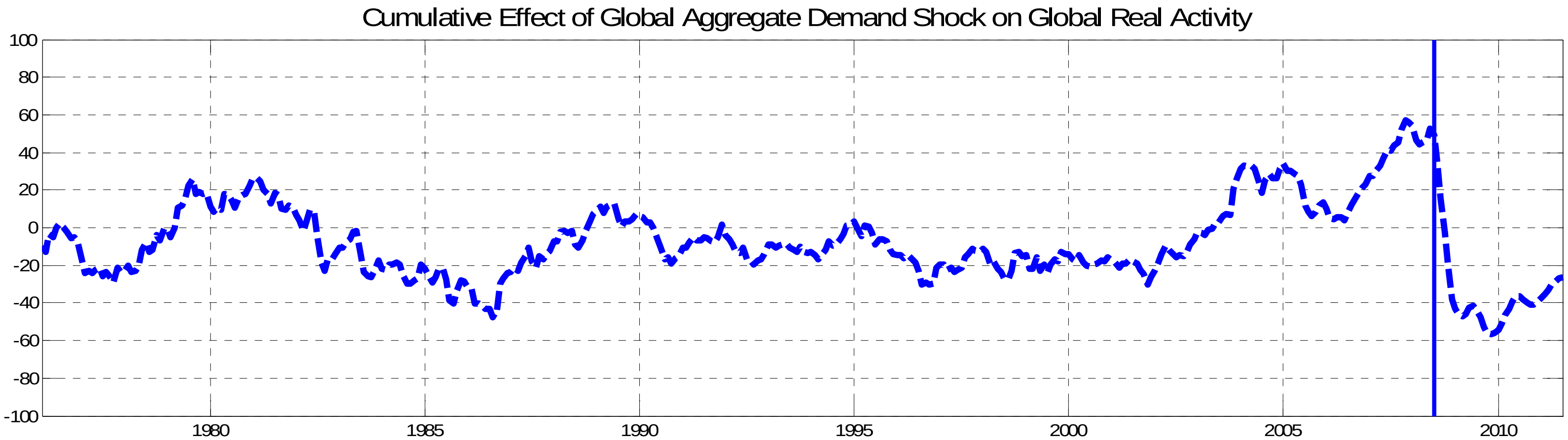
- Openly stimulative U.S. policy only as of late. Can't explain past oil price increases since 2001.
- U.S. monetary expansion since 2001 tempered by concerns about financial stability. Inflation expectations remained anchored.
- No similar monetary expansion elsewhere in the OECD.
- Recent oil price boom driven by emerging Asia rather than the OECD.
- Quantitative importance of the weakening dollar for the demand for oil (and the extent to which it depends on monetary policy) is unclear.

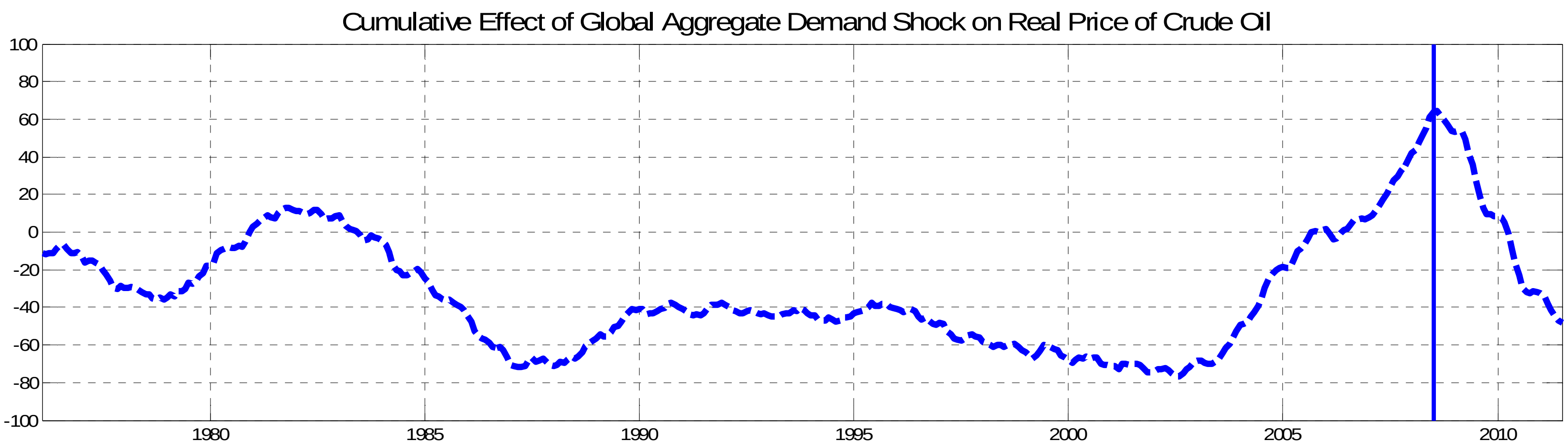
What explains the sharp drop in the price of oil since mid-2008?

Index of Global Real Economic Activity: January 1973-November 2008

Source: This index has been constructed by extrapolating the Kilian (2008) freight rate index of real economic activity based on the Baltic Dry Cargo Index starting in January of 1985. The two indices closely track one another, when both exist.

Projected Real Price of Oil as of 2008.6: 36 Month Horizon
5 Months of Negative Global Aggregate Demand Shocks





Notes: Projections under the counterfactual five large negative global aggregate demand shocks in July 2008-November 2008 of the same magnitude as the largest historically observed demand shocks.

Conclusion

- All the major real oil price increases since the mid-1970s can be traced to increased global aggregate demand and/or increases in precautionary demand for oil.

- The latter demand shifts are consistent with sharp increases in precautionary demand in the wake of exogenous political events in the Middle East.

- Disruptions of crude oil production play a less important role, suggesting that the traditional approach of linking oil price increases to exogenous shortfalls in crude oil production must be re-thought.

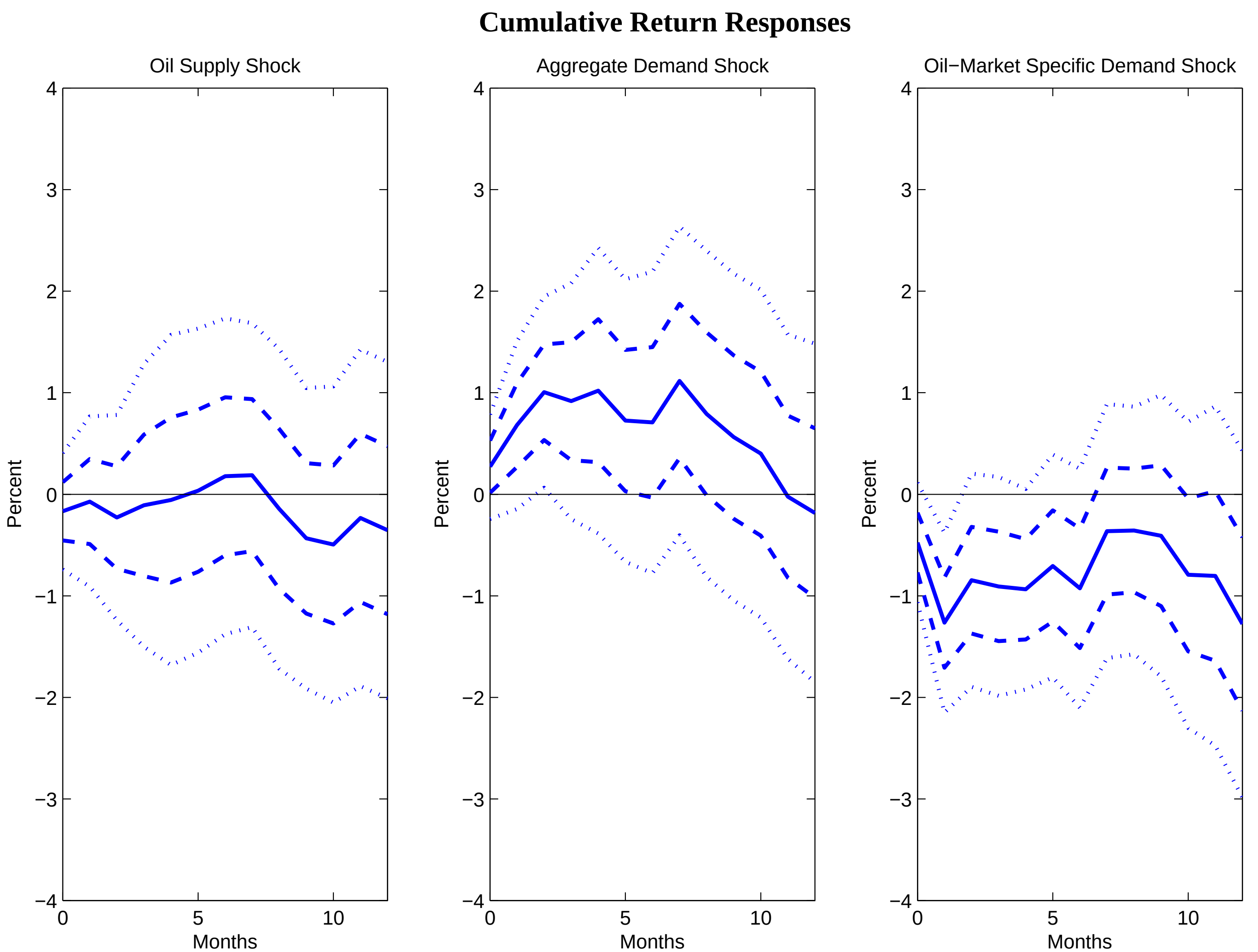
- The rise in the real price of oil since 2002 is accounted for by global aggregate demand pressures; the recent decline reflects weakening global demand as well as forward looking expectations.

Part 4:
The Transmission of Oil Demand and Oil Supply Shocks to the U.S. Economy

a. How do these structural innovations relate to U.S. stock prices?

$$e_t \equiv \begin{pmatrix} e_{1t}^{\Delta\, global\ oil\ production} \\ e_{2t}^{global\ real\ activity} \\ e_{3t}^{real\ price\ of\ oil} \\ e_{4t}^{U.S.\ stock\ returns} \end{pmatrix} = \begin{bmatrix} a_{11} & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \begin{pmatrix} \varepsilon_{1t}^{oil\ \text{supply}\ shock} \\ \varepsilon_{2t}^{aggregate\ demand\ shock} \\ \varepsilon_{3t}^{oil-specific\ demand\ shock} \\ \varepsilon_{4t}^{other\ shocks\ to\ stock\ returns} \end{pmatrix}$$

Why Has the U.S. Stock Market Proved Resilient to High Oil Prices?



SOURCE: Kilian and Park (2008)

Comparison with Traditional Oil Price VAR Models

$$z_t \equiv [real\ \ price\ of\ \ oil_t, U.S.\ stock\ returns_t]$$

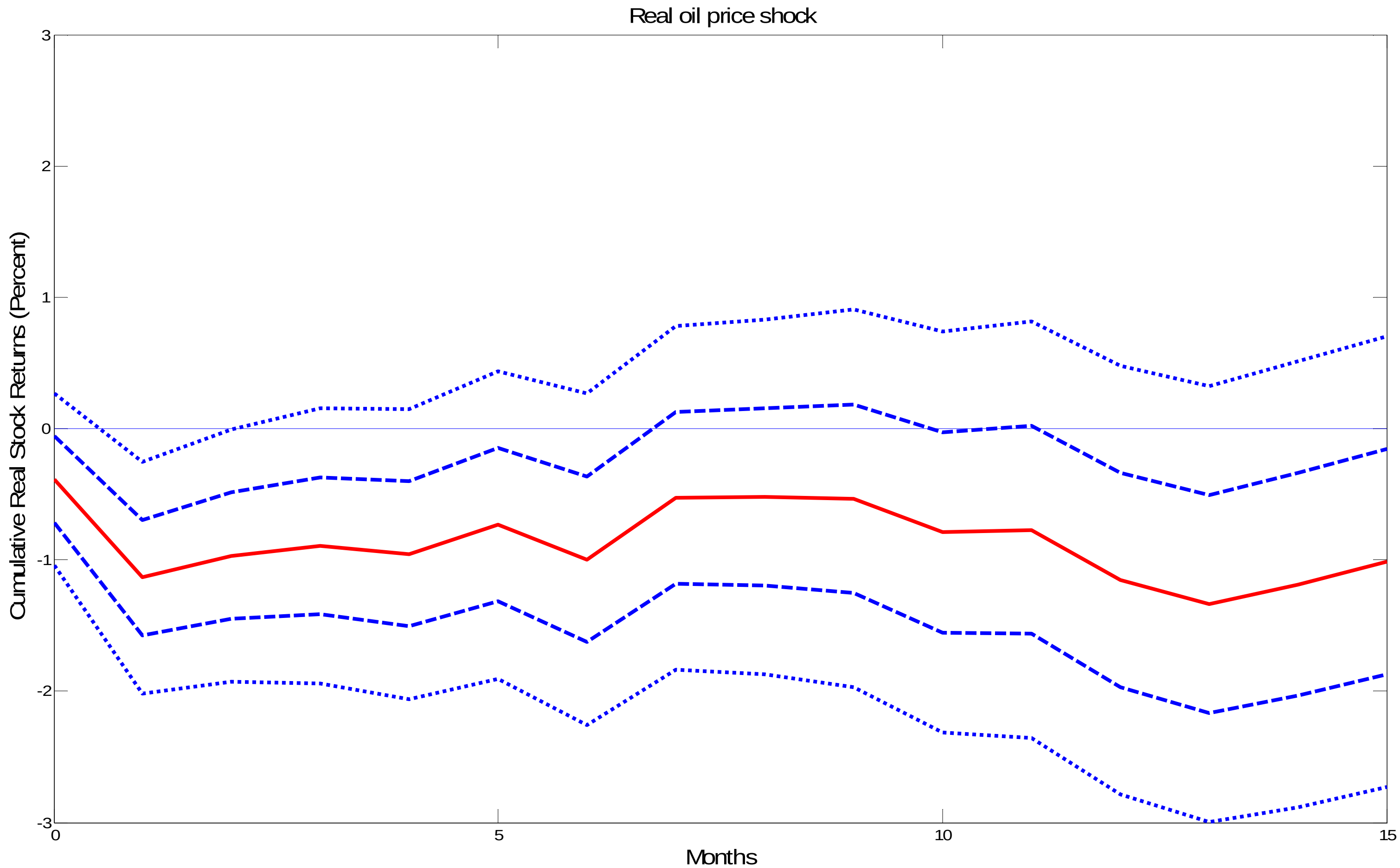
$$A_0 z_t = \alpha + \sum_{i=1}^{24} A_i z_{t-i} + \varepsilon_t \text{, where}$$

$$e_t \equiv \begin{pmatrix} e_{1t}^{real\ \ price\ of\ \ oil} \\ e_{2t}^{U.S.\ stock\ returns} \end{pmatrix} = \begin{bmatrix} a_{11} & 0 \\ a_{21} & a_{22} \end{bmatrix} \begin{pmatrix} \varepsilon_{1t}^{real\ oil\ \ price\ shock} \\ \varepsilon_{2t}^{other\ shocks\ to\ stock\ returns} \end{pmatrix}$$

● Kilian and Vega (2008) provide evidence that the assumption of predetermined oil prices is consistent with the U.S. data.

● The response to an unanticipated oil price shock is by construction a statistical average over the sample period.

Responses of U.S. Real Stock Price to Real Oil Price Innovation with One- and Two-Standard Error Bands



SOURCE: Kilian and Park (2008)

b. How do these structural innovations relate to U.S. real GDP?

Problem: Real GDP is not available at monthly frequency.

Proposal: Average the monthly structural innovations for each quarter:

$$\hat{\zeta}_{jt} = \frac{1}{3}\sum_{i=1}^{3}\hat{\varepsilon}_{j,t,i}, \quad j = 1, 2, 3,$$

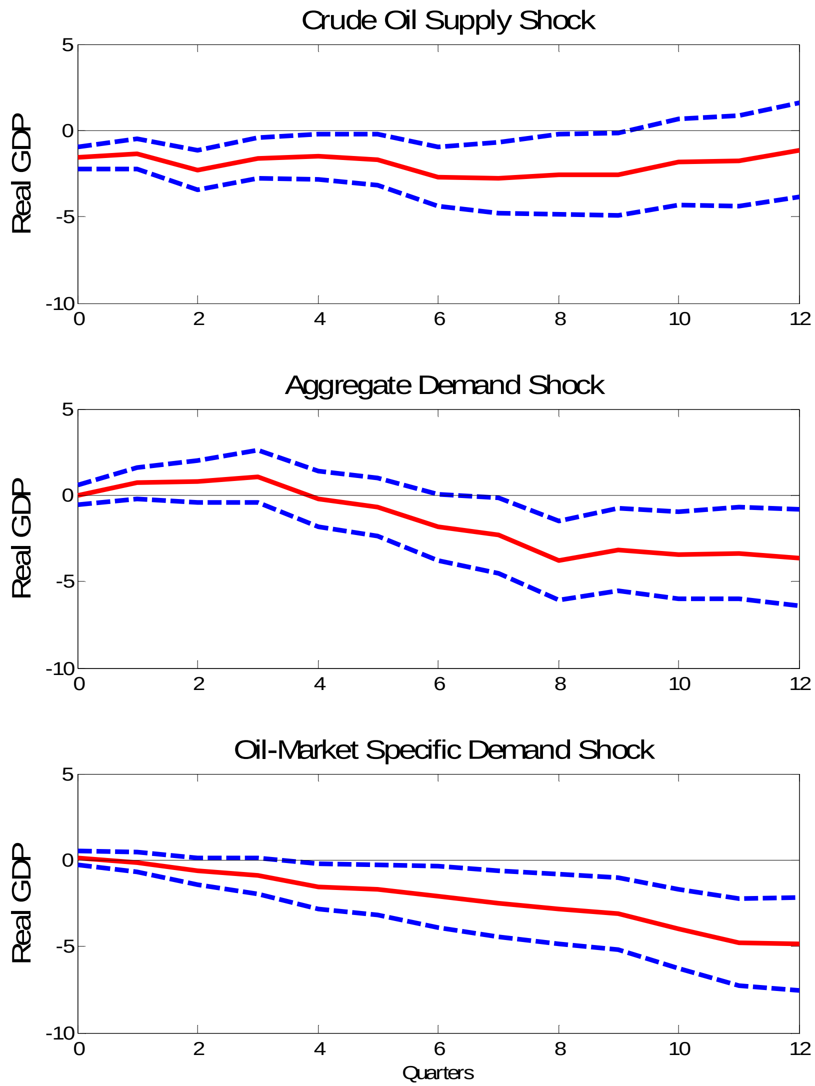
where $\hat{\varepsilon}_{j,t,i}$ refers to the estimated residual for the jth structural shock in the ith month of the tth quarter of the sample.

If these shocks are predetermined with respect to U.S. macro aggregates, we can estimate the response of U.S. real GDP from:

$$\Delta y_t = \alpha_j + \sum_{i=0}^{12}\phi_{ji}\hat{\zeta}_{jt-i} + u_{jt}, \quad j = 1, 2, 3$$

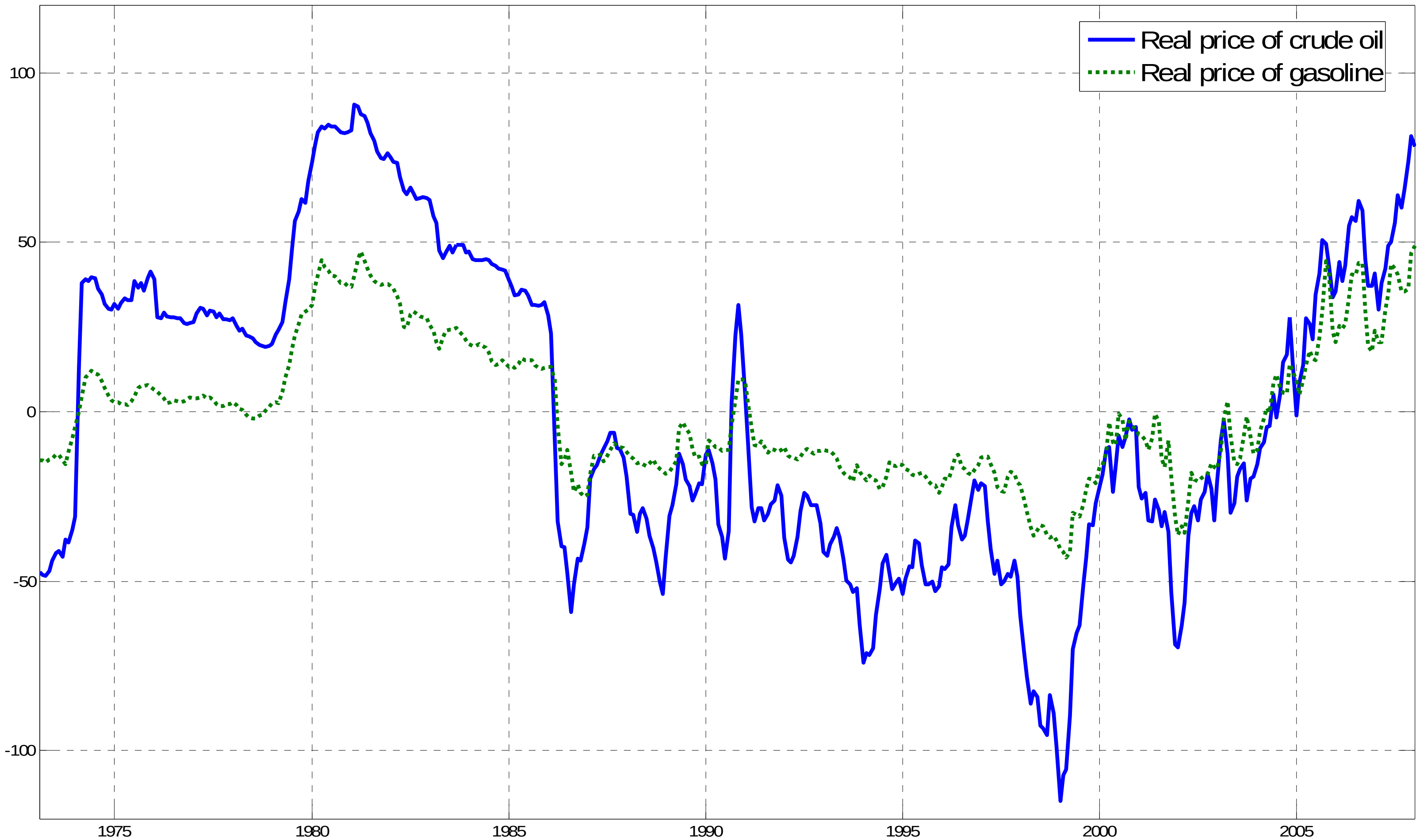
where u_{jt} is a potentially serially correlated error.

Responses of U.S. Real GDP to Oil Demand and Supply Shocks



c. Integrating the Global Crude Oil Market and the U.S. Retail Gasoline Market

Real Price of Imported Crude Oil and Real U.S. Retail Price of Gasoline: 1973.1-2007.12



Identifying Assumptions

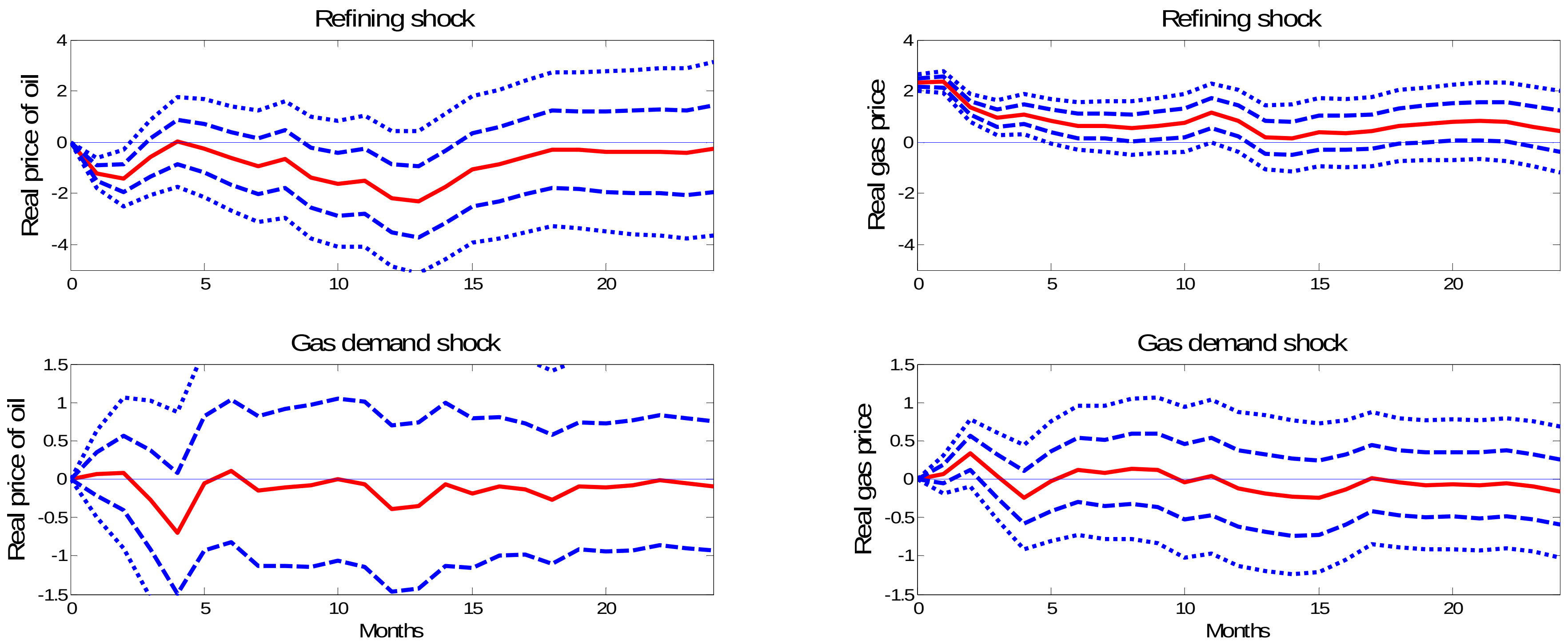
$$e_t \equiv \begin{pmatrix} e_t^{\Delta\ global\ oil\ production} \\ e_t^{global\ real\ economic\ activity} \\ e_t^{real\ price\ of\ crude\ oil} \\ e_t^{real\ U.S.\ price\ of\ gasoline} \\ e_t^{U.S.\ gasoline\ consumption} \end{pmatrix} = \begin{bmatrix} a_{11} & 0 & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} & 0 \\ a_{51} & a_{52} & a_{53} & a_{45} & a_{55} \end{bmatrix} \begin{pmatrix} \varepsilon_t^{oil\ \mathrm{supply}\ shock} \\ \varepsilon_t^{aggregate\ demand\ shock} \\ \varepsilon_t^{oil-market\ specific\ demand\ shock} \\ \varepsilon_t^{refinery\ shock} \\ \varepsilon_t^{gasoline\ demand\ shock} \end{pmatrix}$$

● U.S. retail price of gasoline is effectively set by U.S. refiners. Domestic refiners set retail prices by adding a markup to the price of imported crude oil

● U.S. refiners are price takers in the global crude oil market. Increases in the price of imported crude oil are being passed on by U.S. refiners to the retail price of gasoline within the same month, as are exogenous shocks to the cost of refining.

● The retail supply curve for gasoline is treated as perfectly elastic in the short run.

Price Responses to Structural Shocks in Gasoline Market
Estimates with One and Two-Standard Error Bands



Conclusion

The macroeconomic effects of an increase in the price of oil depend on the underlying cause of that increase. Each oil demand and oil supply shock has its own unique set of effects.

This fact matters:

1. Changes in the composition of “oil price shocks” help explain the instability of regressions of macro aggregates on the price of oil.

2. The distinction between oil demand and oil supply shocks helps explain why the most recent oil price shock has not been associated with a sharp recession.

3. Policy makers should not respond to oil prices as in BGW (1997), but to the structural determinants of oil prices.

4. DSGE models require explicit modeling of oil demand and oil supply (see, e.g., Bodenstein et al. 2007; Nakov and Pescatori 2007)

5. The distinction between crude oil and retail energy prices is important as well.

Part 5:

Implications for DSGE Models of the Transmission of Oil Demand and Supply Shocks

The Channels of Transmission in the Literature

A. Production (or cost) channels:

Direct Effects:

- The transmission of oil price shocks involves moving capital and labor inputs (unlike a technology shock).
- Direct effect is bounded by oil share in production and small (Backus and Crucini 2000). (U.S.: only ~3.5% in 1977, 2005)

Indirect Effects:

Rotemberg and Woodford 1996: Large and time-varying markups

Atkeson and Kehoe 1999: Capital-energy complementarities

Finn 2000: Energy is essential to obtaining service flow from capital

It is unclear whether these models can account for a large share of the business cycle or what their microeconomic support is.

B. Consumption/investment expenditure (or demand) channels:

An increase in energy prices slows economic growth primarily through its effects on consumer spending (Bernanke 2006).

Previous empirical studies:
Lee and Ni (2002) provide survey evidence that oil shocks are viewed as demand rather than supply or cost shocks at industry level.

Kilian and Park (2008) provide complementary evidence in favor of the demand channel based on industry-level stock returns.

Edelstein and Kilian (2007a,b) quantify the energy share in consumption and investment expenditures and the importance of the demand channel.

Problem:
We need some amplifier since the energy share in expenditures is small.

Some DSGE modeling by Hamilton (1988), Dhawan and Jeske (2007).

C. Monetary policy channel:

Bernanke, Gertler, Watson (BPEA 1997):

- Fed creates recession by tightening monetary policy in response to fears that oil price shocks are inflationary.

- Without that policy reaction, the effects of oil price shocks on real output would be more benign.

- Recessions could have been avoided, had the Fed kept interest rates constant.

Problems:

1. It is not clear theoretically why the Fed should respond to oil price shocks (nor how large the effects of such a response would be).

2. It is not clear empirically that the Fed did respond to oil price shocks as presumed by BGW, or that the responses made a large difference.

3. The BGW estimates are weak, not robust, and inconsistent.

D. Real Wage Rigidities/Wage-Price Spirals:

Bruno and Sachs (1985): In the presence of a downward-rigid real wage, unemployment may arise in response to an oil price shock.

Problems:
1. Unions as the ultimate cause? (More plausible for Europe than the U.S.)
2. No direct evidence in support of real wage rigidities for either.
3. In the U.S. the aggregate real wage fell in response to oil price shocks.

E. Oil and the Productivity Slowdown:

Problems:
1. Labor productivity versus total factor productivity.
2. Timing?
3. Causality?
4. Empirical evidence mixed.

Demand Channels of Transmission (1): The Discretionary Income Effect

Higher energy prices are expected to reduce discretionary income, as consumers have less money to spend after paying their energy bills.

The purchasing power gains and losses associated with energy price shocks are approximately the percent change in retail energy prices weighted by the time-varying share of energy expenditures in total expenditures.

All else equal, this *discretionary income effect* will be the larger, the less elastic the demand for energy, but even with perfectly inelastic energy demand the magnitude of the effect of a unit change in energy prices is bounded by the energy share in consumption.

Caveats on the Discretionary Income Effect

1. Implicit is the assertion:

(1) Higher energy prices are primarily driven by higher prices for imported energy goods.

(2) Discretionary income lost from higher prices of imported energy goods is transferred abroad and is not recycled in the form of higher U.S. exports (or returns on foreign asset holdings).

(3) High share of energy in expenditures (U.S.: only ~6.5% in 1970, 2005)

2. In the case of a purely domestic energy price shock (such as a shock to U.S. refining capacity), it is even less obvious that there is an effect on aggregate discretionary income.

The transfer of income to the refiner may be partially returned to consumers in the form of higher wages or higher stock returns on domestic energy companies. Even if the transfer is not returned, higher energy prices simply constitute an income transfer from one consumer to another that cancels in the aggregate.

Demand Channels of Transmission (2): The Uncertainty Effect

Changing energy prices may create uncertainty about the future path of the price of energy, causing consumers to postpone irreversible purchases of consumer durables (see Bernanke 1983, Pindyck 1991).

Unlike the discretionary income effect, this *uncertainty effect* is limited to consumer durables.

Demand Channels of Transmission (3): The Precautionary Savings Effect

Even when purchase decisions are reversible, consumption may fall in response to energy price shocks, as consumers increase their *precautionary savings*.

This response may arise if consumers smooth their consumption because they perceive a greater likelihood of future unemployment and hence future income losses.

It may also reflect greater uncertainty about the prospects of remaining gainfully employed (in which case any change in energy prices would lower consumption).

Demand Channels of Transmission (4): The Operating Cost Effect

Consumption of durables whose operation requires energy will decline, as households delay or forego purchases of energy-using durables.

As the dollar value of such purchases may be large relative to the value of the energy they use, even relatively small changes in energy prices (and hence in purchasing power) can have large effects on expenditures.

This *operating cost effect* is more limited in scope than the uncertainty effect in that it only affects specific consumer durables. It should be most pronounced for motor vehicles.

Demand Channels of Transmission (5): The Reallocation Effect

Shifts in expenditure patterns driven by the uncertainty effect and operating cost effect amount to allocative disturbances that are likely to cause sectoral shifts throughout the economy:

1. Reduced expenditures on energy-intensive durables such as automobiles may cause the reallocation of capital and labor away from the automobile sector (Hamilton 1988).

A similar reallocation may occur within the same sector, as consumers switch toward more energy-efficient durables (Bresnahan and Ramey 1993).

2. In the presence of frictions in capital and labor markets, these reallocations will cause resources to be unemployed, thus causing further cutbacks in consumption and amplifying the effect of energy price shocks on the real economy.

This *reallocation effect* could be much larger than the direct effects listed earlier.

Summary of Demand Channels

	Positive Energy Price Shock	Negative Energy Price Shock
1. Discretionary Income Effect	*Output* $\downarrow$	*Output* $\uparrow$
2. Uncertainty Effect	*Output* $\downarrow$	*Output* $\downarrow$
3a. Precautionary Savings Effect: Smooth Consumption	*Output* $\downarrow$	*Output* $\uparrow$
3b. Precautionary Savings Effect: Increased Uncertainty	*Output* $\downarrow$	*Output* $\downarrow$
4. Operating Cost Effect	*Output* $\downarrow$	*Output* $\uparrow$
5. Reallocation Effect	*Output* $\downarrow$	*Output* $\downarrow$

There is no compelling empirical support for the asymmetric effects 2, 3b, and 5 (Edelstein and Kilian 2007a,b; Kilian and Vigfusson 2009).

Some Key Results from Edelstein and Kilian (2007)

• The decline in residential housing and auto purchases is central in understanding the transmission of retail energy price shocks.

• Despite the absence of a reallocation effect, the effect on real consumption is larger than suggested by the energy share argument:

An unexpected 1% increase in energy prices changes consumption by:

-0.15% (1970-2007)
-0.30% (1970-1987)
-0.08% (1988-2007)

• What does this mean for real GDP?

Suppose that gasoline prices unexpectedly and permanently increase by 25 cents per gallon. Given a share of consumption in GDP of about 72%, this implies that, all else equal, real GDP will have fallen by 0.3% one year after the shock.

Why Have the Effects of Oil Price Shocks Weakened?

<u>Hypothesis 1:</u>
Energy price shocks are not as large as they used to be.

Energy price shocks have not been smaller or less volatile than in the past (Edelstein and Kilian 2007).

<u>Hypothesis 2:</u>
The energy share in expenditures and value added has declined.

A reduced energy share has helped, but the recent energy shares are similar in magnitude to the mid-1970s.

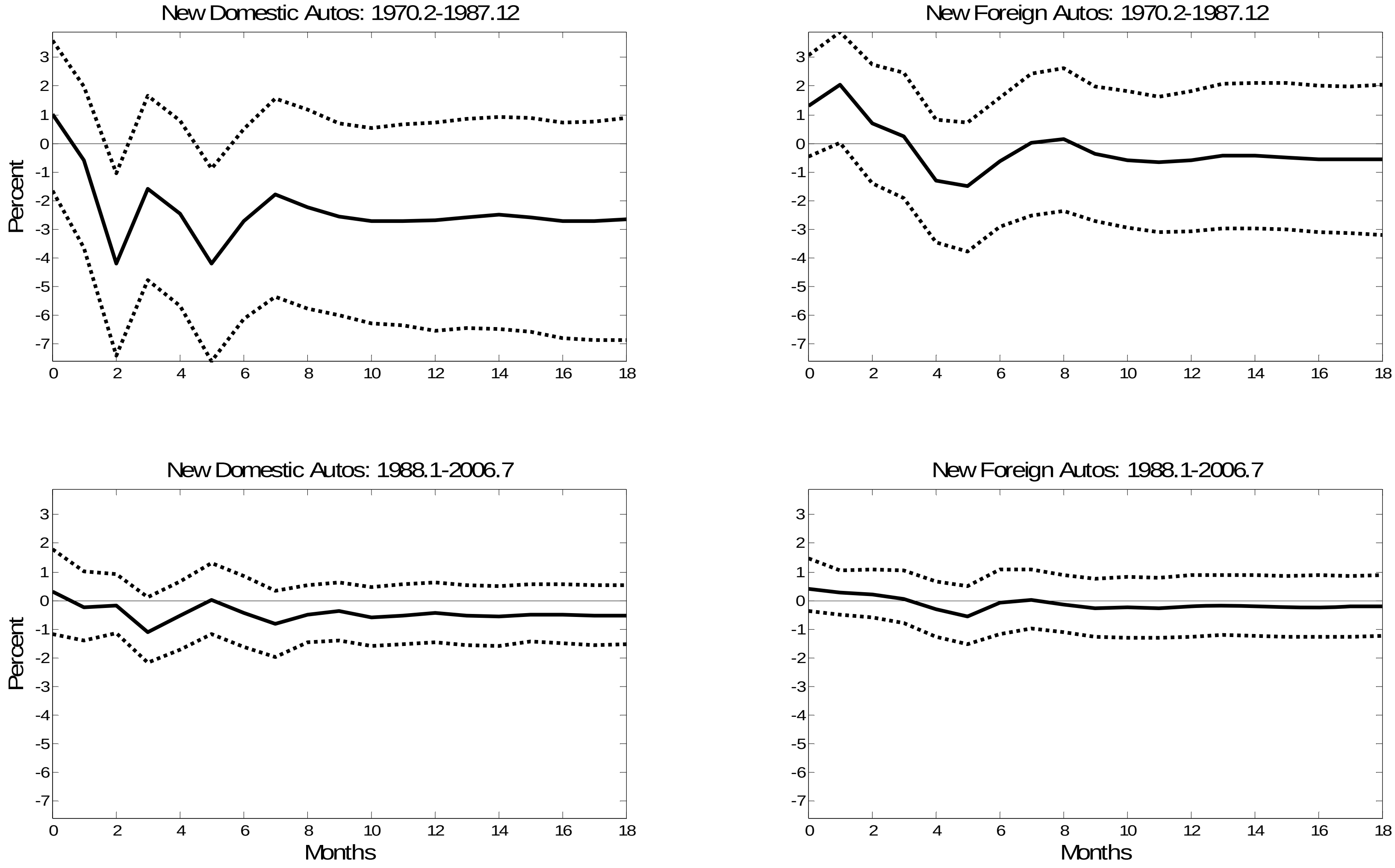
Oil Share in Value Added			
1977	1981	1998	2005
3.3%	5%	1%	3.3%

There is evidence for greatly reduced responses even controlling for energy shares (see Edelstein and Kilian 2007).

Hypothesis 3:
The product mix of the U.S. auto industry has changed.

In the 1970s, the U.S. did not produce small, energy efficient cars, so every auto sale lost to imports caused a reduction in employment. Today, domestic and foreign auto producers are more similar (Edelstein and Kilian 2007).

Response of New Auto Purchases to Purchasing Power Shocks



Source: Edelstein and Kilian (2007a).

<u>Hypothesis 4:</u>
The weight of the U.S. auto industry in U.S. GDP and employment has declined.

Share in:	U.S. Employment
Early 1970s	1.3%
1988	0.9%
2005	0.9%

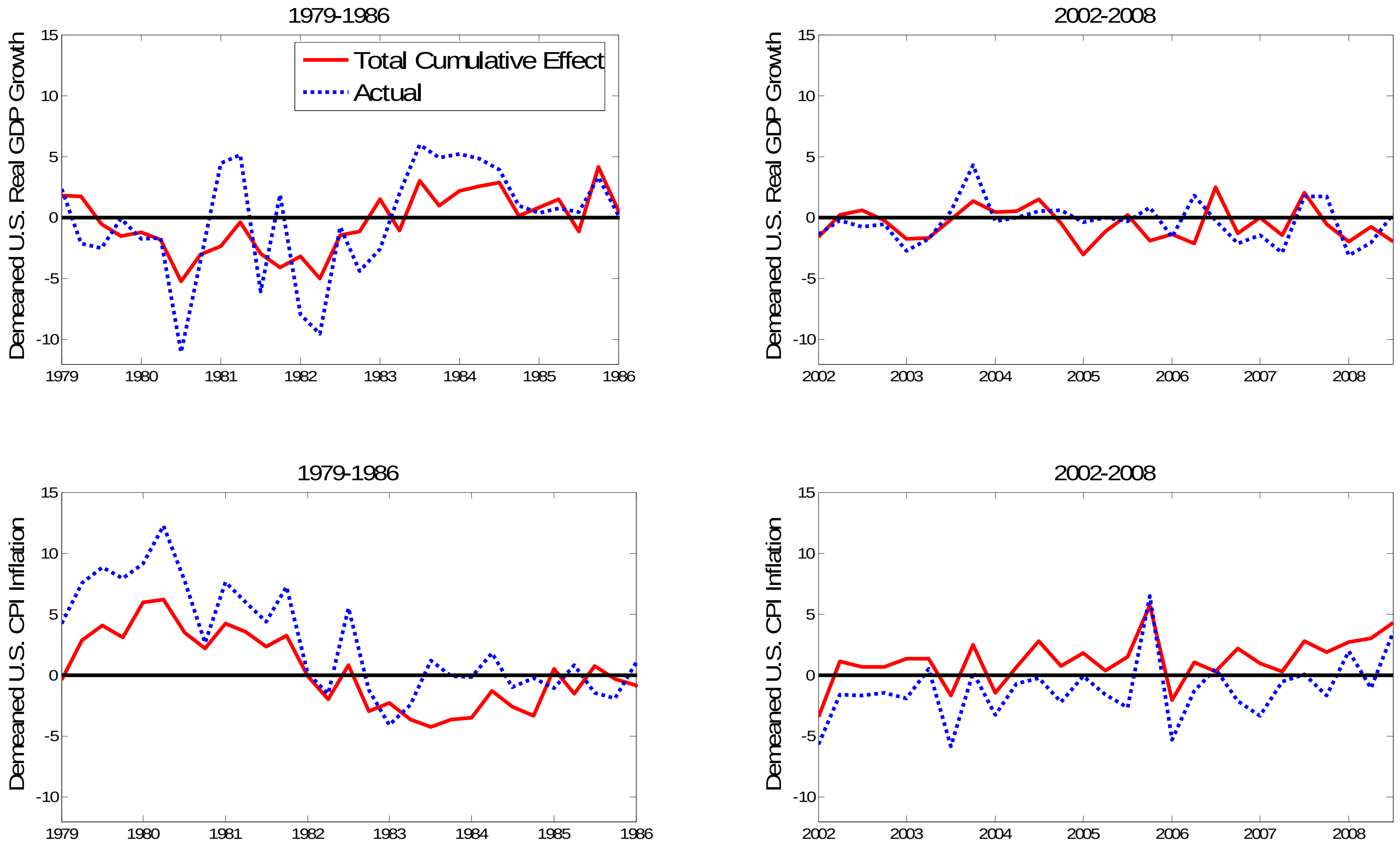
<u>Hypothesis 5:</u>
The composition of oil price shocks has changed.

- The effect of an increase in the price of oil depends on the underlying cause of that increase.

- Each oil demand and oil supply shock has its own unique set of dynamic effects. The net effect depends on the composition of oil demand and supply shocks.

- The distinction between oil demand and oil supply shocks helps explain why the most recent oil price shock has not been associated with a sharp recession.

The Cumulative Effects of All Three Demand and Supply Shocks on the U.S. Economy



NOTES: All estimates are based on the methodology of Kilian (2008, forthcoming: AER).

Implications for DSGE Modeling

1. The real price of oil is endogenous with respect to macroeconomic conditions.

2. We need to model oil demand and oil supply shocks.

3. The oil market is global. We cannot model the price of oil in a closed economy.

4. There is no evidence for asymmetries in the transmission of oil price shocks. As a result, we may abstract from the uncertainty channel and reallocative channel, and a first-order linear approximation to the steady state is likely to be adequate.

5. We need to model both demand and supply channels of transmission. An interesting question is how these channels interact in general equilibrium.

6. We need to model the external transmission of oil demand and supply shocks.

7. It is unclear what role, if any, the monetary policy-reaction function plays.

A Review of Oil Market Models within DSGE Models

Kim and Loungani (JME 1992), Atkeson and Kehoe (AER 1999), Wei (AER 2003):

Exogenous ARMA process for the real price of oil.

Backus and Crucini (JIE 2000):

1. Exogenous AR process for (OPEC) crude oil production.
2. Endogenous response of oil production elsewhere.
3. Demand for oil driven by oil importers' production technology.

→ Endogenous real price of oil. Exogenous OPEC oil supply shocks.

→ Since demand is smooth, major oil price movements are associated with oil supply shocks by construction.

Bodenstein, Erceg and Guerrieri (2007):

1. Oil supply shocks as exogenous shocks to crude oil production as in BC 2000.
2. Oil-market specific demand modeled as a “foreign” preference shock.

   Narrow interpretation: Exogenous oil taste shift in China.
   Loose interpretation: Reduced form for expectation shifts.

Nakov and Pescatori (2008, forthcoming: EJ):

1. OPEC oil supply is endogenous.
2. Dominant oil exporter charges an optimally varying oil price markup.
3. Structural disturbances to oil importers’ productivity, technology in the oil sector, and the capacity of the competitive fringe of oil producers.
4. No oil-market specific demand.

Balke, Brown, and Yücel (2008):

1. Oil supply is endogenous.
2. Reserves are required to produce oil. There are technology shocks to the production of reserves and to the production of oil. Oil producers are oil price takers.
3. Oil-demand shocks mainly arise from domestic and foreign productivity gains plus an "oil wedge" (= energy efficiency) shock.
4. No oil-specific demand shocks.

The Next Generation of Models

1. Calibrated models are of limited usefulness for policy analysis in that they allow for a wide range of responses to oil demand and oil supply shocks. We <u>need to estimate these models</u> to pin down the relevant magnitudes.

This requires more attention to details of the model specification, for estimates are only as credible as the underlying model.

2. Recent DSGE models have focused on selected demand and supply shocks in isolation. We need a model that includes <u>all three types of shocks</u> at the same time. At a minimum, we need oil-specific demand shocks, aggregate demand shocks and oil supply shocks.

3. A case can be made that we need to <u>distinguish further between different sources of aggregate demand shocks</u> (e.g., foreign productivity versus domestic and/or foreign monetary expansion as in the 1970s).

This distinction also matters in that monetary-policy driven demand shocks have purely transitory effects, whereas foreign productivity shocks might have permanent effects on the real price of oil.

4. We need a sufficiently long estimation period to ensure the identification of these oil demand and supply shocks.

5. It is important that we distinguish between retail energy prices (such as the price of gasoline) and the price of crude oil. We need to model both the crude oil market and the refinery market, since crude oil is not consumed directly.

6. We need to allow for both supply/cost/production channels of transmission and demand/consumption channels.

Ultimately, models will have to flesh out the role of the automobile sector and of the residential housing sector. A multi-sector model may be useful in that respect.

7. We need to allow for the evolution of the energy share on the cost and expenditure side.

8. Technology shocks are not a good proxy for shocks to the aggregate demand for industrial commodities.