The Simple Economics of Global Fuel Consumption

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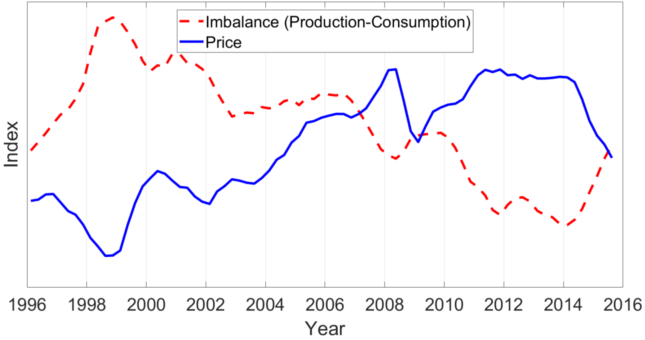
What moves the global oil market?

- Global oil market marked by supply and demand shifts
  - Nature of shocks matters for market participants, macroeconomic impact, monetary policy, environmental policies
- Existing SVAR models vary substantially in terms of
  - Relative contributions of supply and demand shocks
  - Supply elasticity, demand elasticity (Kilian & Murphy 2014: 1.5%, -26%; Baumeister & Hamilton 2017: 15%, -35%; Caldara, Cavallo & Iacoviello 2017: 11%, -13%)
- This paper: crude oil is not consumed directly, its demand is derived from demand for refined products (IEA, EIA, OPEC, BP)
- Goal: Use data on global fuel consumption to provide insights on key quantitative features within a structural framework

Motivation

- Identity: $\text{Production}_t - \text{Consumption}_t = \Delta\text{Inventory}_t$
- Oil price changes typically reflect physical market imbalances



This paper

Structural framework based on global fuel consumption
("Verleger-Hypothesis": Verleger 1982; Baumeister, Kilian & Zhou 2017)

- Stylized theoretical framework to motivate SVAR model based on production, consumption, prices (supply, demand, speculative demand shocks)
- Identification: *simple economics* of markets for storable commodities (Knittel & Pindyck 2016)
  - Empirical evidence on persistence of supply and demand shocks
  - Robustness: sign restrictions

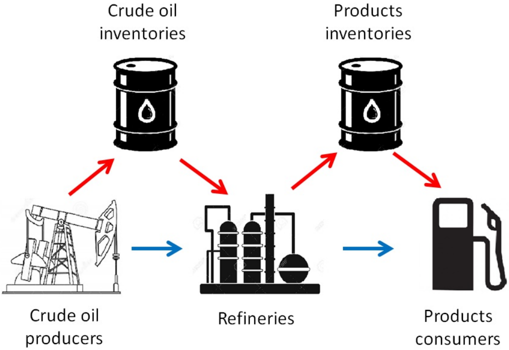
Preview of findings

- Quantitative results
  - Supply elasticity elasticity $\approx$ 1.5%, fuel demand elasticity $\approx$ -2.3%
  - Fuel demand shocks account for majority of oil price fluctuations, but flow supply is more important than suggested by some existing studies (e.g., Kilian 2009, Kilian & Murphy 2014)
  - Cyclical fluctuations in fuel consumption are driven by demand shocks (short run) and supply shocks (long run)
  - Limited impact of oil supply shocks on global economic activity

- Implications
  - Identification of oil demand and supply shocks
  - Understanding quantities in the global oil market
    $\rightarrow$ tax incidence, speculation
  - Differences in macro- and micro-elasticities

Contribution

Overview of the global oil market



- Storage takes place at different stages of the value chain
- Flow consumption determined by fuel demand

A stylized framework of the oil market: Crude oil prices

$$\Delta P_t = \frac{1}{\eta_S - c \cdot \eta_D^g} \cdot [u_t^q - u_t^x + (\Delta I_t^c + \Delta I_t^g)]$$

Crude oil price P_t, supply elasticity η_S, gasoline demand elasticity η_D^g, pass-through coefficient c, demand shifter u_t^q, supply shifter u_t^x, crude oil inventories I_t^c, gasoline inventories I_t^g

- Crude oil and gasoline inventories matter
- Micro-elasticity η_D^g different from macro-elasticity $\eta_D \equiv c \cdot \eta_D^g$
- By identity: $\text{Production}_t - \text{Consumption}_t = (\Delta I_t^c + \Delta I_t^g)$ $\rightarrow$ empirical framework based on production, consumption, crude oil price

Data description

- Global oil production and fuel consumption data collected and published by International Energy Agency (IEA)
  - Quarterly data since 1986 (similar to data from EIA, OPEC, BP)
  - Consumption is measured from production and disappearance from primary and secondary sources
  - Corresponds to official statistics for most advanced countries, estimates for most developing countries Graph Implied Inventories

- Production and consumption are commensurate
  $\rightarrow$ broad definition of oil production that includes crude, condensates, NGLs, oil shale, ... Decomposition

Empirical framework

- VAR model (log variables, 1988Q1-2017Q3, 6 lags)

$$\mathbf{y}_t = \boldsymbol{c} + \sum_{h=1}^{p} \boldsymbol{\Phi}_h \cdot \mathbf{y}_{t-h} + \boldsymbol{\epsilon}_t, \quad \boldsymbol{\epsilon}_t = B \cdot \boldsymbol{u}_t$$

$\mathbf{y}_t = [\text{production}_t,\ \text{consumption}_t,\ \text{real price}_t]'$

- Economic structure

$$\begin{bmatrix} \epsilon_t^x \\ \epsilon_t^q \\ \epsilon_t^p \end{bmatrix} = \underbrace{\begin{bmatrix} 1 & \gamma_D \cdot \eta_S & \eta_S \\ \gamma_S \cdot \eta_D & 1 & \eta_D \\ \gamma_S & \gamma_D & 1 \end{bmatrix}}_{\equiv B} \cdot \begin{bmatrix} u_t^x \\ u_t^q \\ u_t^p \end{bmatrix}$$

supply elasticity η_S, demand elasticity η_D, price impact of supply shocks γ_S, price impact of demand shocks γ_D, u_t^p captures other price shocks, e.g. from shift in inventory demand

Identification

4 structural parameters, 3 equations $\rightarrow$ under-identification

- Existing models often rely on external information on elasticities for identification
  - Zero restrictions (Kilian 2009)
  - Bounds (Kilian & Murphy 2014)
  - Priors (Baumeister and Hamilton 2018)
- Trade-off between supply and demand elasticity Details
  $\rightarrow$ higher demand elasticity is associated with lower supply elasticity and larger price impact of demand shocks

This paper: theory of storage & empirical evidence on expected persistence of price changes Details Intuition

Model robustness: sign restrictions

- Our model is a special case of a more general sign-identified model

Variable / Shock	Flow Supply	Flow Demand	Other
Crude Oil Production	-	+	+
Fuel Consumption	-	+	-
Price	+	+	+

- Some dynamic restrictions to rule out implausible large negative impacts of *Other Shocks* after one quarter
  (similar to Kilian & Murphy 2013; Kilian & Murphy 2014)

Model properties

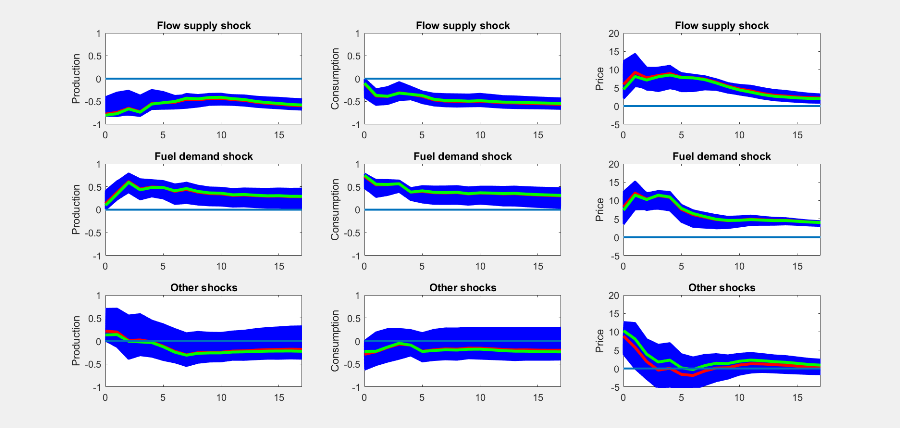
- Structural shocks conistent with established accounts of key episodes, e.g., 1st Gulf War, Financial crisis Shocks IRFs Oil Price Decomposition
- Reaction of inventories consistent with identifying restriction Graph
- Short-run demand elasticity ≈ -2.3 %, supply elasticity ≈ 1.5 %

Corresponds very closely to the median sign-identified model:

- Median demand elasticity ≈ -1.9 % $[-4.63\%; -0.34\%]$
- Median supply elasticity ≈ 1.5 % $[0.27\%; 3.63\%]$

[10 %; 90 %]-quantiles

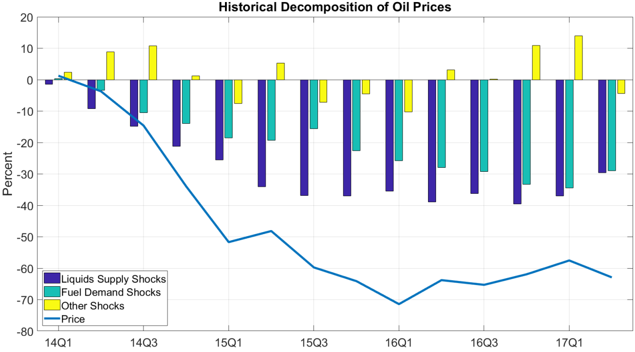
Sign restrictions: comparing IRFs



Model implications

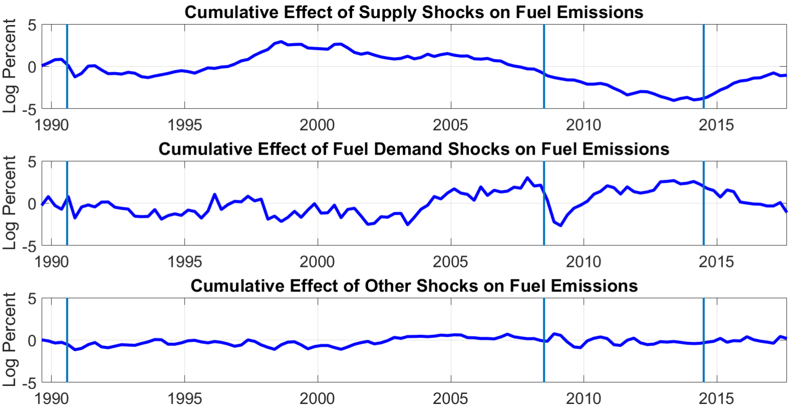
- What caused the 2014-2015 oil price drop?
- What drives quantities in the global oil market?
  - Emissions from global fuel consumption
- What is the effect of oil price shocks on global industrial production?

What caused the 2014-2015 oil price drop?



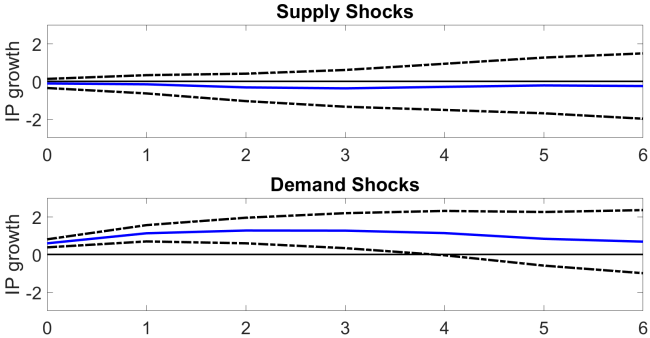
- Initial oil price drop mainly driven by supply side developments, demand became driving factor after 2015

What drives quantities in the global oil market?



- EIA data on global CO2 emissions from fuel
  (assuming exogenous evolution of emission intensity of global fuel mix)

What is the effect of oil price shocks on global industrial production?



- No prior restrictions on the impact of oil supply and demand shocks or dependence on particular measure of global real economic activity (Kilian & Zhou JIMF 2018)

Global fuel demand elasticity w.r.t. crude oil price

- Short-run demand elasticity $\approx$ -2.3 %, supply elasticity $\approx$ 1.5 %
- Existing estimates of demand elasticity tend to be much higher
    - $|$ Crude oil elasticities $|$ often $>$ 25% (Kilian & Murphy 2014)
    - $|$ US gasoline consumption elasticity $|$ $>$ 30 %
      (Coglianese et al. 2016; Levin et al. 2017)
- How plausible is -2.3%?

Low global fuel consumption elasticity consistent with reduced form changes in oil consumption I

Oil prices are volatile

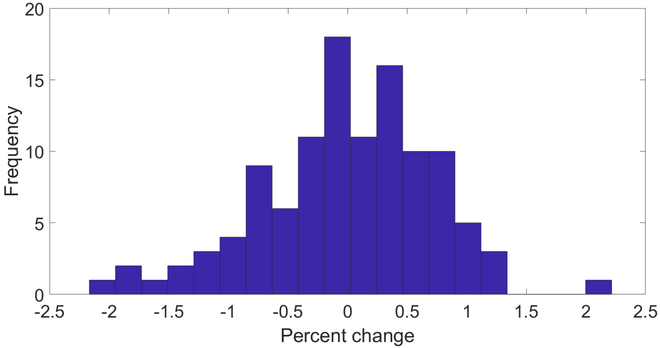
- Standard deviation of oil prices $\approx$ 13%; non-demand shocks key role in some oil price shocks (e.g. near 50% price increase in 1990Q3)

Values of $\eta_D \approx -0.25$ imply large changes in oil consumption

$$\begin{aligned}
\eta_D \cdot \epsilon_t^{p,non-demand} &\approx -0.25 \cdot 0.5 \approx -12.5\% \quad \text{in 1990Q3} \\
\eta_D \cdot \epsilon_t^{p,non-demand} &\approx -0.25 \cdot \pm 0.13 \approx \pm 3.25\% \quad \text{sometimes}
\end{aligned}$$

Low global fuel consumption elasticity consistent with reduced form changes in oil consumption II

- Observed reduced form changes in fuel consumption are small



Imperfect % pass-through from crude oil to fuel prices

- Relationship between global crude oil and local fuel elasticity

$$\eta_D = \eta_D^g \cdot (\Delta\% G_t)/(\Delta\% P_t)$$

- Pass-through estimates for 21 major oil consuming countries

Countries	**Gasoline**	**Diesel**
US	60%	50%
Western Europe, Japan, Korea, India	25%	28%
South Africa, Chile, Singapore	30%	32%
Major Oil Producers	$< 8\%$	$< 8\%$

- Likely to be lower for other fuels (e.g., bunker fuels)

Demand elasticity: Key take-away

Why are micro-estimates different?

- Back-of-the-envelope calculation: % pass-through from global crude oil prices to "average" barrel of fuel could be as low as 20%

- Micro-estimates typically do not measure quantity reaction to global shocks (see e.g., Muehlegger & Sweeny 2017)

  $\rightarrow$ Estimates of the global fuel demand elasticity are (plausibly) low
  (Not due to lack of structural model, see, e.g. Kilian & Murphy 2014)

- Economic implications
  - Measures of speculation depend on elasticities
    (Hamilton 2009; Fattouh, Kilian & Mahadeva 2013; Knittel & Pindyck 2016)
  - Tax incidence

Conclusion

- Existing models of the global oil market vary in terms of key quantitative implications
- A new structural model including global fuel consumption → simple framework based on quantities and prices yields relatively sharp insights
  - Global oil supply and fuel demand are very inelastic in the short run
  - Historical decompositions of prices and *quantities*
    (e.g., global emissions, changing fuel intensity of global growth)
- Differences between micro- and macro-elasticities
- Low elasticities and oil product inventories: re-consider the role of speculation

Appendix

Contribution to the existing literature

1. Relationship between crude oil and product markets (Verleger 1982; Kilian 2011; Baumeister & Kilian 2016; Baumeister, Kilian & Zhou 2017; IEA; EIA; OPEC; BP)
   - Investigate the role of global fuel consumption in a structural dynamic framework that includes refined product inventories
2. Sources of oil price fluctuations and their macroeconomic impact (e.g., Hamilton 2009; Kilian 2009; Kilian & Murphy 2014; Kilian & Lee 2014; Sockin & Xiong 2015; Knittel & Pindyck 2016; Baumeister & Hamilton 2017; Caldara, Cavallo & Iacoviello 2017)
   - New empirical results based on global fuel consumption and simple identification strategy
3. Estimates of fuel demand elasticities (e.g., Coglianese, Davis, Kilian & Stock 2016; Levin, Lewis & Wolak 2017)
   - Clarify and reconcile differences between micro- and macro-estimates

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Decomposition of oil production and consumption

	Global Production			OECD Consumption			
	1987	2016	Average		1987	2016	Average
Crude Oil	91%	76%	87%	Motor Gasoline	30%	31%	30%
Condensate	0%	6%	3%	Diesel	24%	28%	26%
NGLs	8%	13%	10%	Other Products	31%	36%	34%
Nonconventional Oils	1%	4%	2%	Residual Fuel	15%	5%	10%

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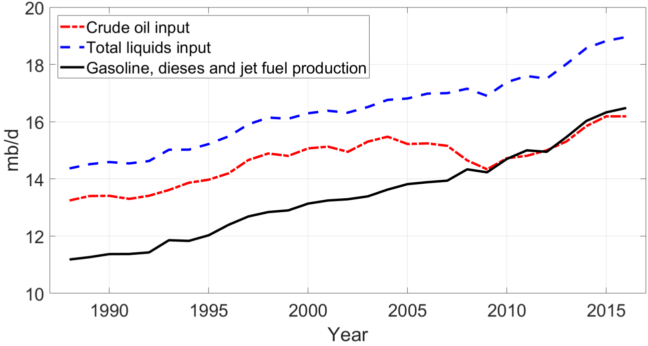
US refinery inputs and outputs



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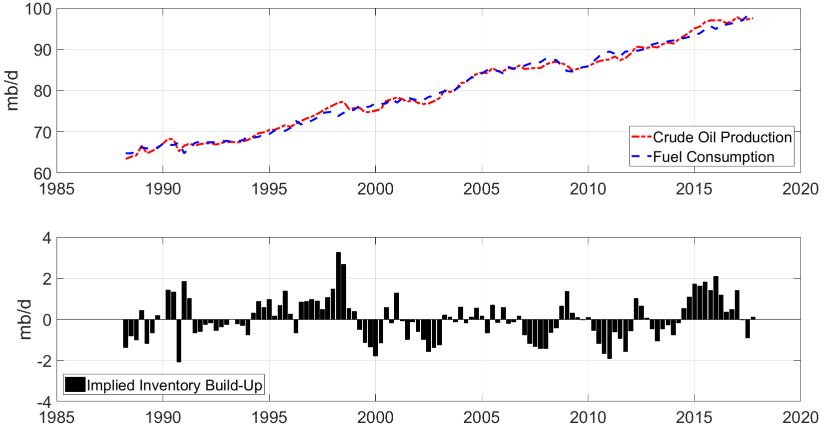
Oil production, consumption and market imbalance



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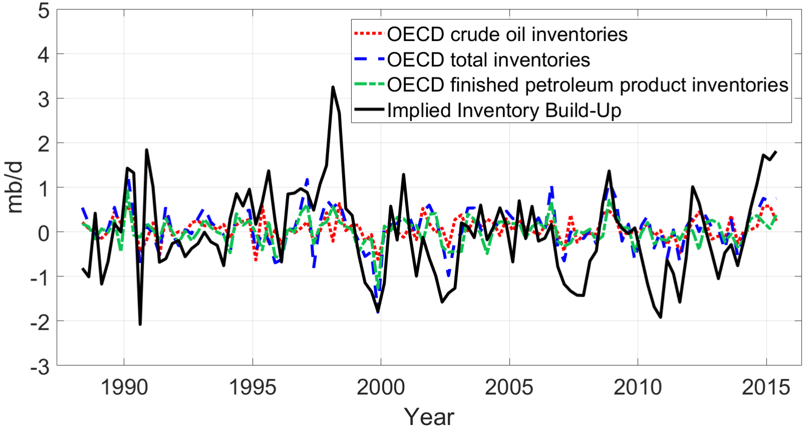
Comparison to other measures of inventory changes



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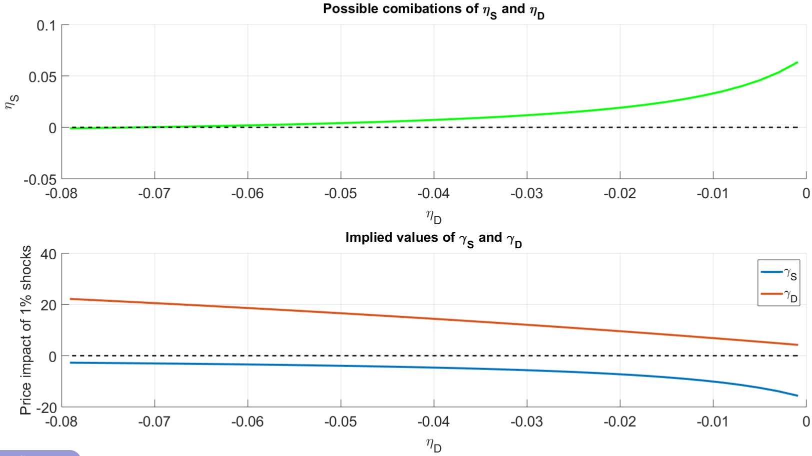
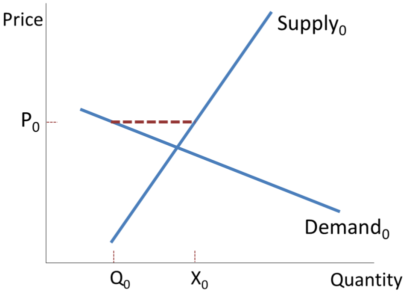
"Trade-off" between supply and demand elasticity

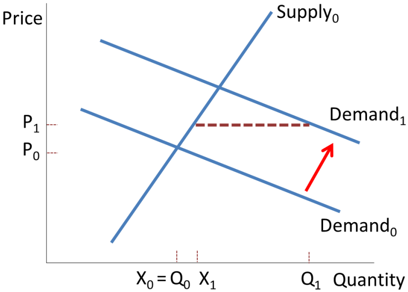
- Demand & supply elasticity key parameters (Caldara et al., 2017)
  Higher demand elasticity → larger estimated impact of demand shocks



Back to identification

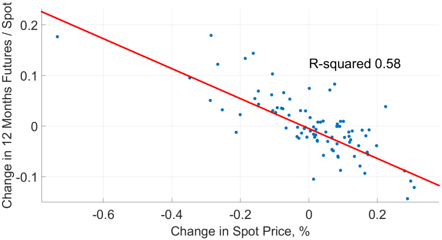
Price impact depends on elasticities and inventories





- Theory of storage: change in inventories depend on changes in expected returns (Knittel & Pindyck 2016)

How persistent are oil price changes expected to be?



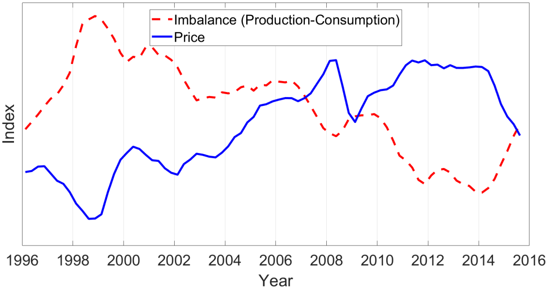
1. Empirical evidence: expected future price change depends on current price impact, but not on the type of shock (*similar expected persistence*)
   Robustness

2. Theory of storage: expected future price changes $\propto \Delta$ inventories

   1.+2. Change in inventories proportional to total price impact for supply, demand shocks
   $\Rightarrow$ additional cross restriction on $\eta_S, \eta_D, \gamma_S, \gamma_D$ Identification Overview

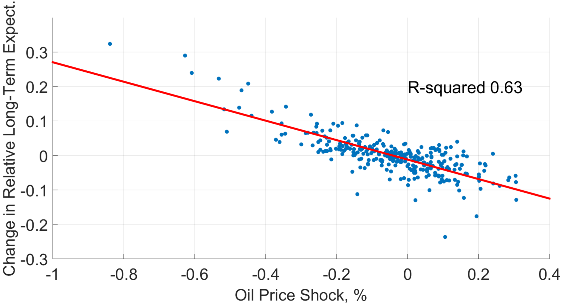
Identification: Intuition

- Oil price changes typically reflect physical market imbalances



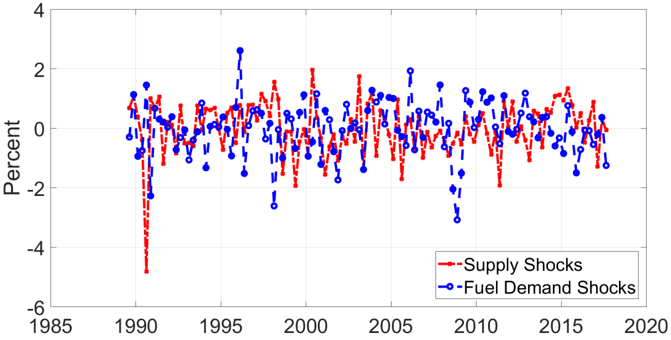
Identification Overview

Robustness: persistence of price impact in the oil market



- Alternative measure of storage incentives: long-term expectations relative to short-term expectations (Baumeister, Ellwanger & Kilian 2017)
- Measures of oil price expectations via term-structure model (Hamilton & Wu 2014; Baumeister & Kilian 2015)
- Here: Unexpected changes in the spot price vs. changes in the ratio of 12-months expectations and 3-months expectations Back to Persistence

Model properties: historical demand and supply shocks



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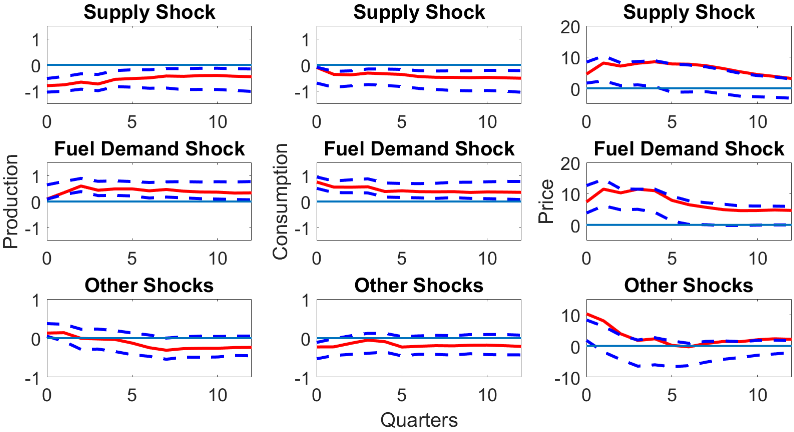
Model properties: impulse response functions



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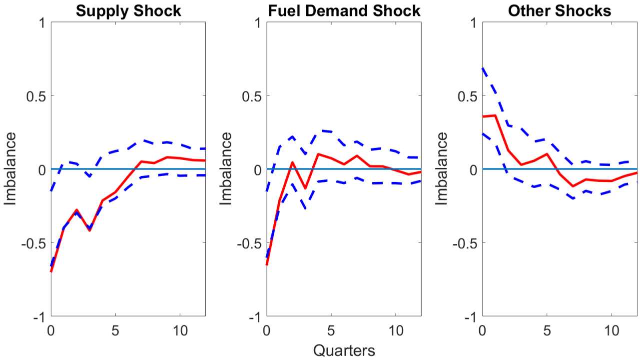
Model properties: inventories



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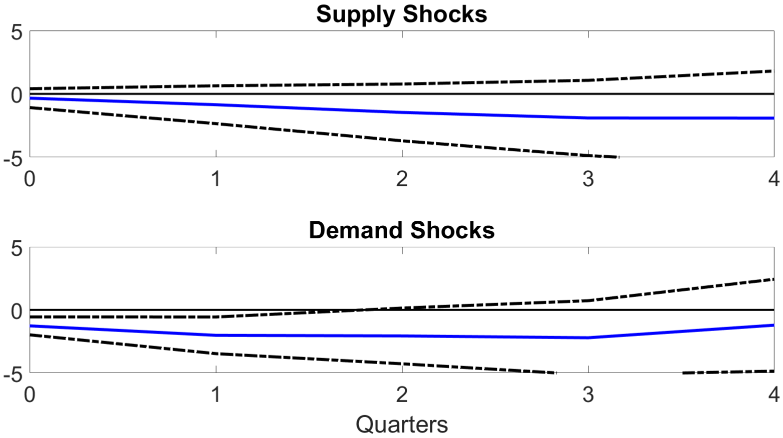
Reaction of oil product inventories (OECD)



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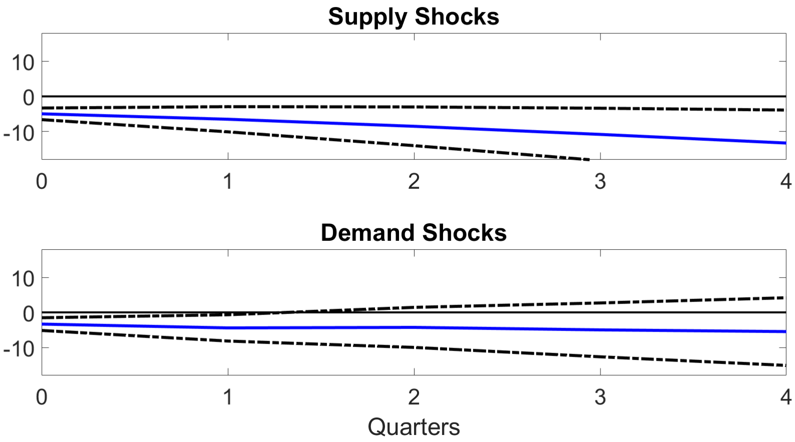
Reaction of total non-OECD inventories



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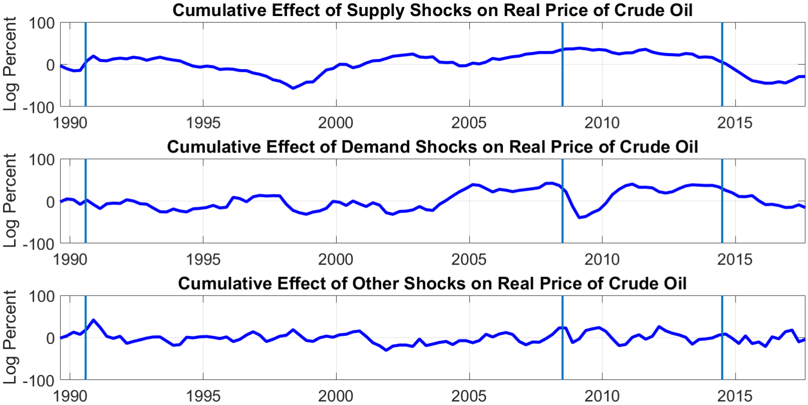
Model implications: historical decomposition of prices



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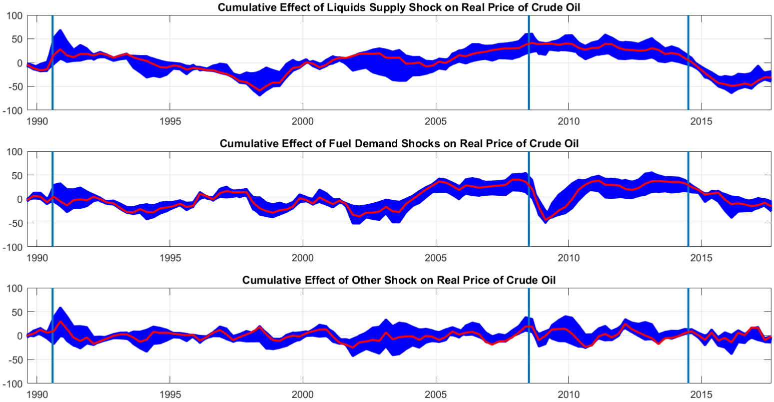
Sign restrictions: historical decomposition



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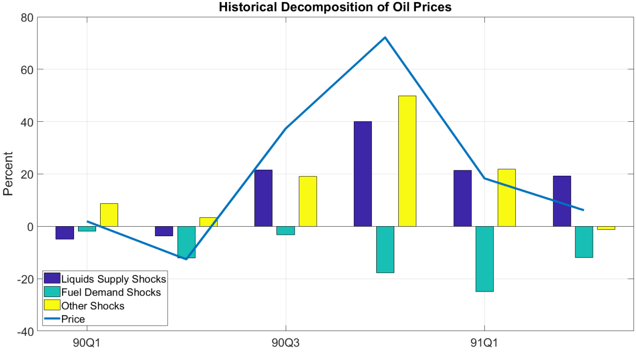
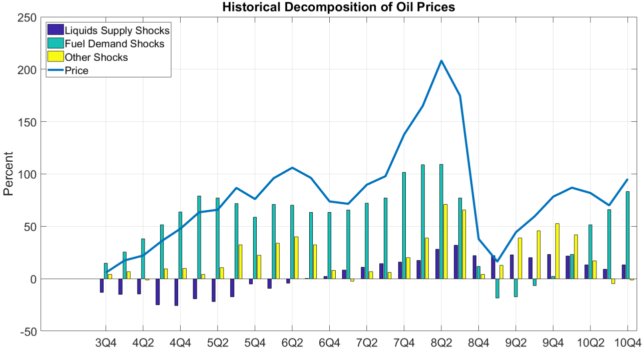
1990-1991 oil price shock



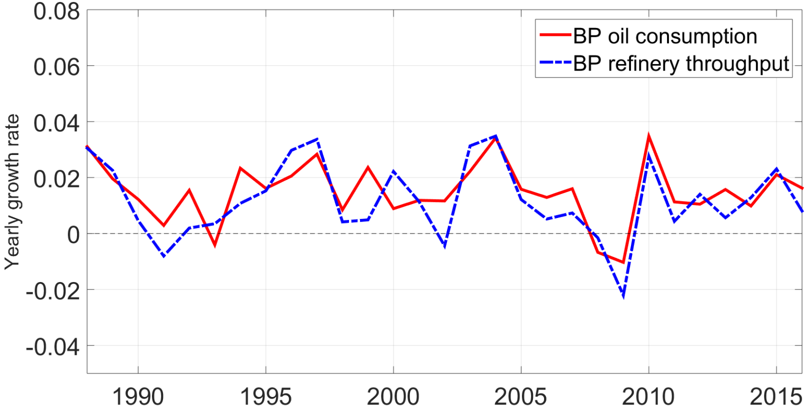
- Impact of supply, speculative demand consistent with historical accounts (e.g., Kilian & Murphy 2014)

Oil prices in the 2000s



- Important role for fuel demand shocks, but little evidence for increased flow consumption driving up prices in 2008Q2

Refinery throughput matches consumption at lower frequencies



Back to demand elasticity