Structural Vector Autoregressions
Demand and Supply - Oil Models

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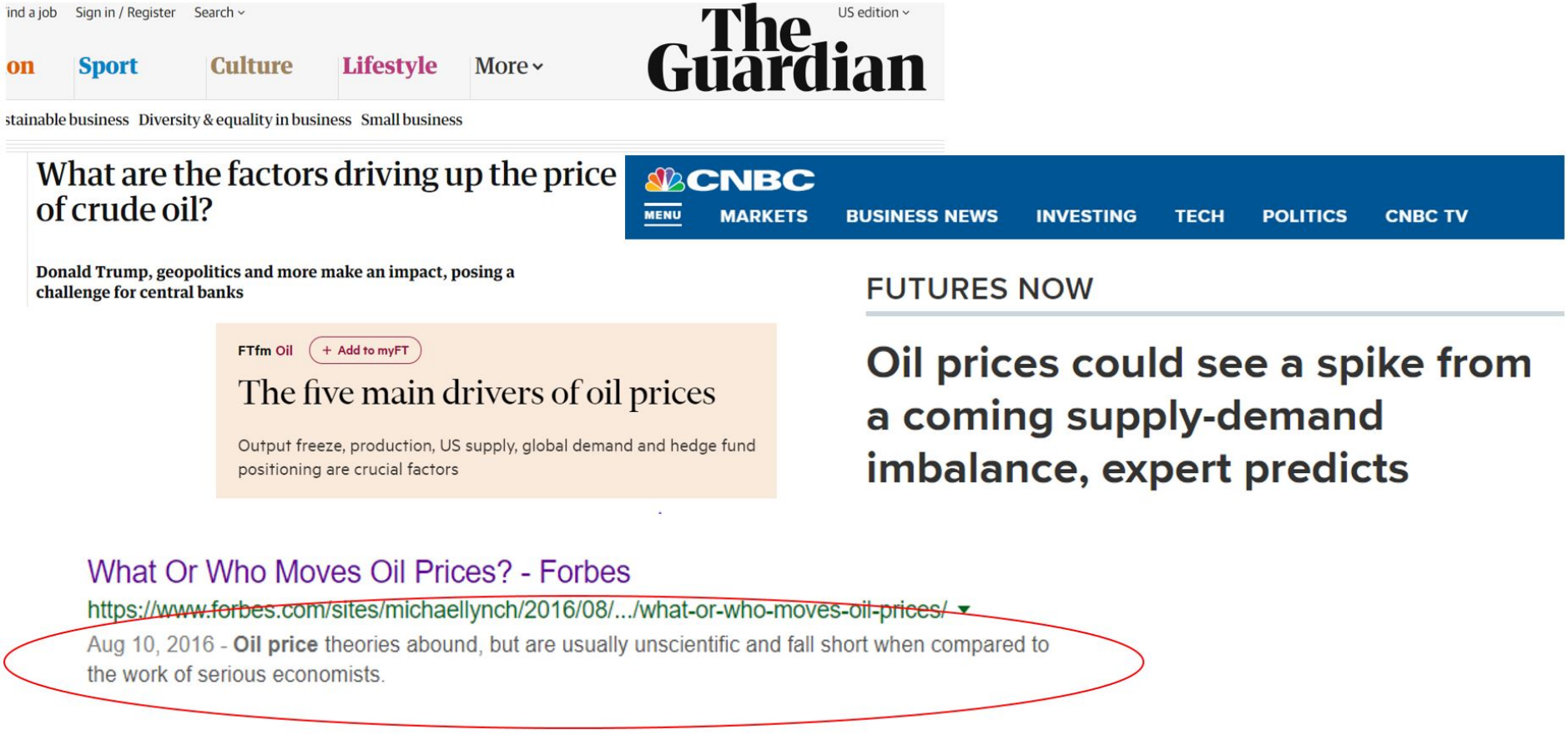
Federal Reserve Board

ECON 597 - Georgetown University

What Moves Oil Prices?



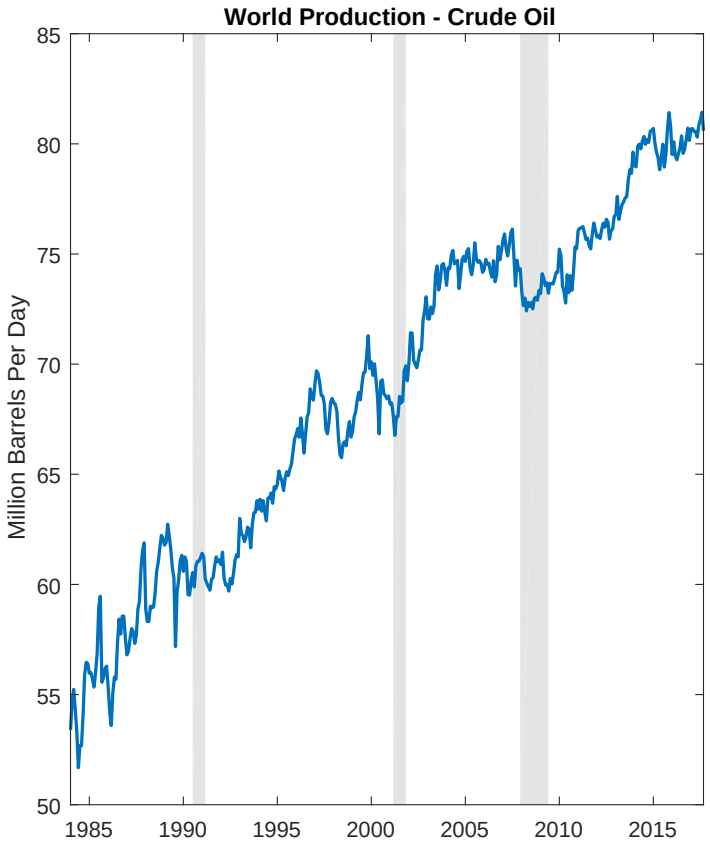
- We can group oil price movements into two broad categories: demand-driven and supply-driven.

Empirical Literature on Oil Prices

- Structural VARs have been widely used to identify drivers of oil prices.

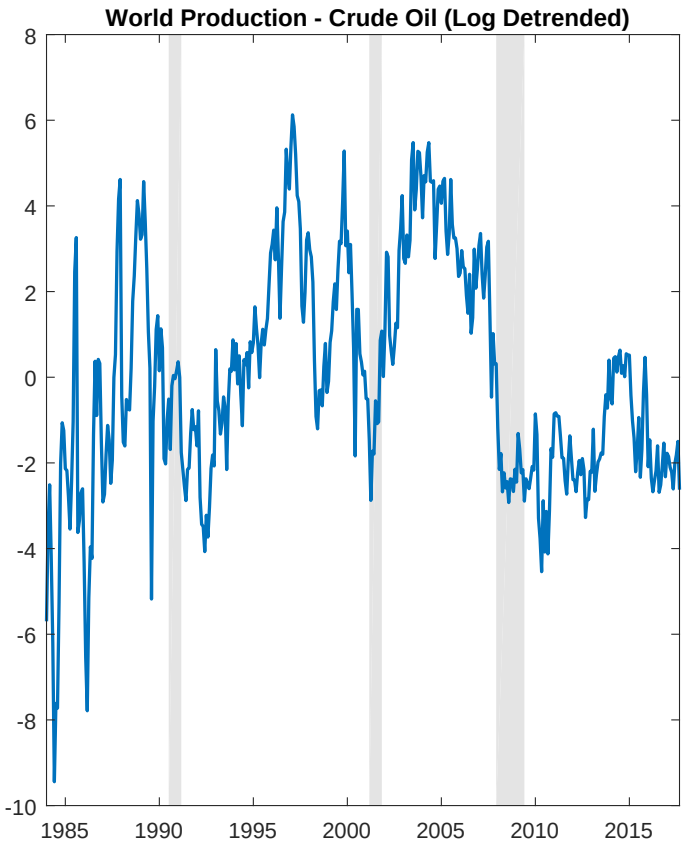
- (Non-exhaustive) reading list:
  - **Kilian, L.**, 2009. "Not All Oil Price Shocks Are Alike: Disentangling Demand and Supply Shocks in the Crude Oil Market," *American Economic Review*, vol. 99(3), pages 1053-1069.
  - **Juvenal, L., and Petrella, I.** , 2015. "Speculation in the Oil Market," *Journal of Applied Econometrics*, vol. 30(4), pages 621-649.
  - **Bjornland, H., Aastveit, K. A., and Thorsrud, L. A.**, 2015 "What drives oil prices? Emerging versus Developed Economies," *Journal of Applied Econometrics*, vol. 30(7), 10131028.
  - **Caldara, D., Cavallo, M., and Iacoviello, M.**, 2018. "Oil Price Elasticities and Oil Price Fluctuations," *Journal of Monetary Economics*, forthcoming.
  - **Baumeister, C. and Hamilton, J.**, 2018 "Structural Interpretation of Vector Autoregressions with Incomplete Identification: Revisiting the Role of Oil Supply and Demand Shocks", Working Paper.

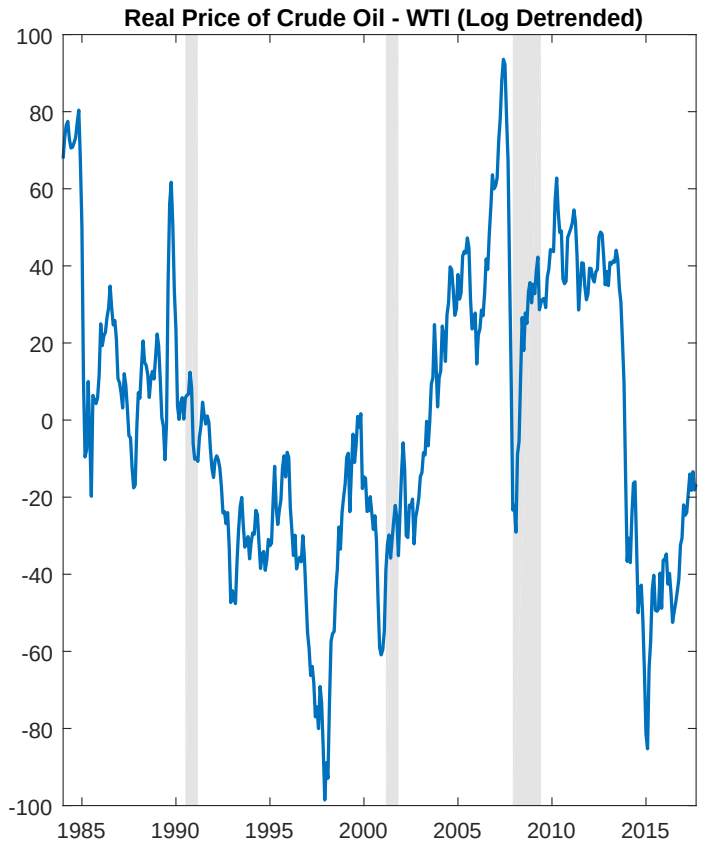
Crude Oil Market: Prices and Production



- Crude oil production: trend and swings.
- Crude oil prices: high volatility.

Transforming the Data





- I removed a linear trend from both series.
- Underlying assumption: we are not writing a model that can explain trend in oil production.

A Simple Model of the Oil Market

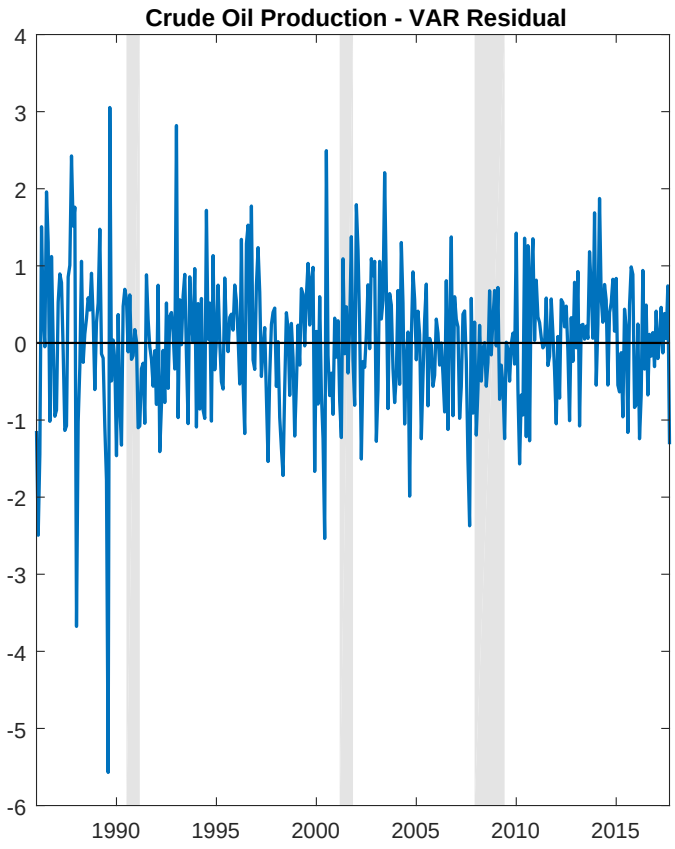
- VAR model with crude oil production (q_t) and crude oil prices (p_t).
- Estimate the following VAR model:

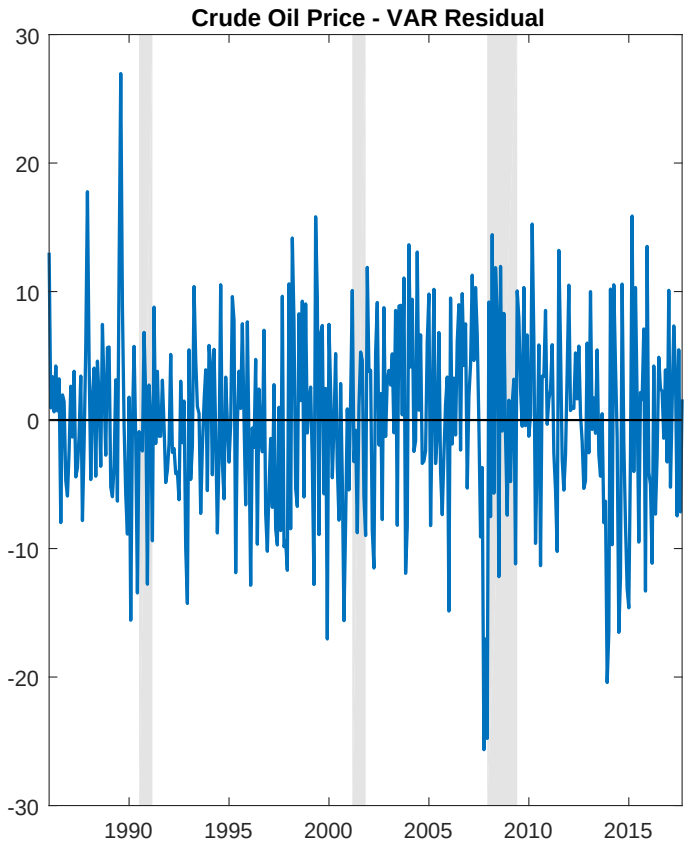
$$y_t = c + A_1 y_{t-1} + \cdots + A_p y_{t-p} + u_t$$

  where $y_t = [q_t, p_t]$, and $p = 24$.

- Sample: 1985:1 - 2018:9.
- Estimation: OLS

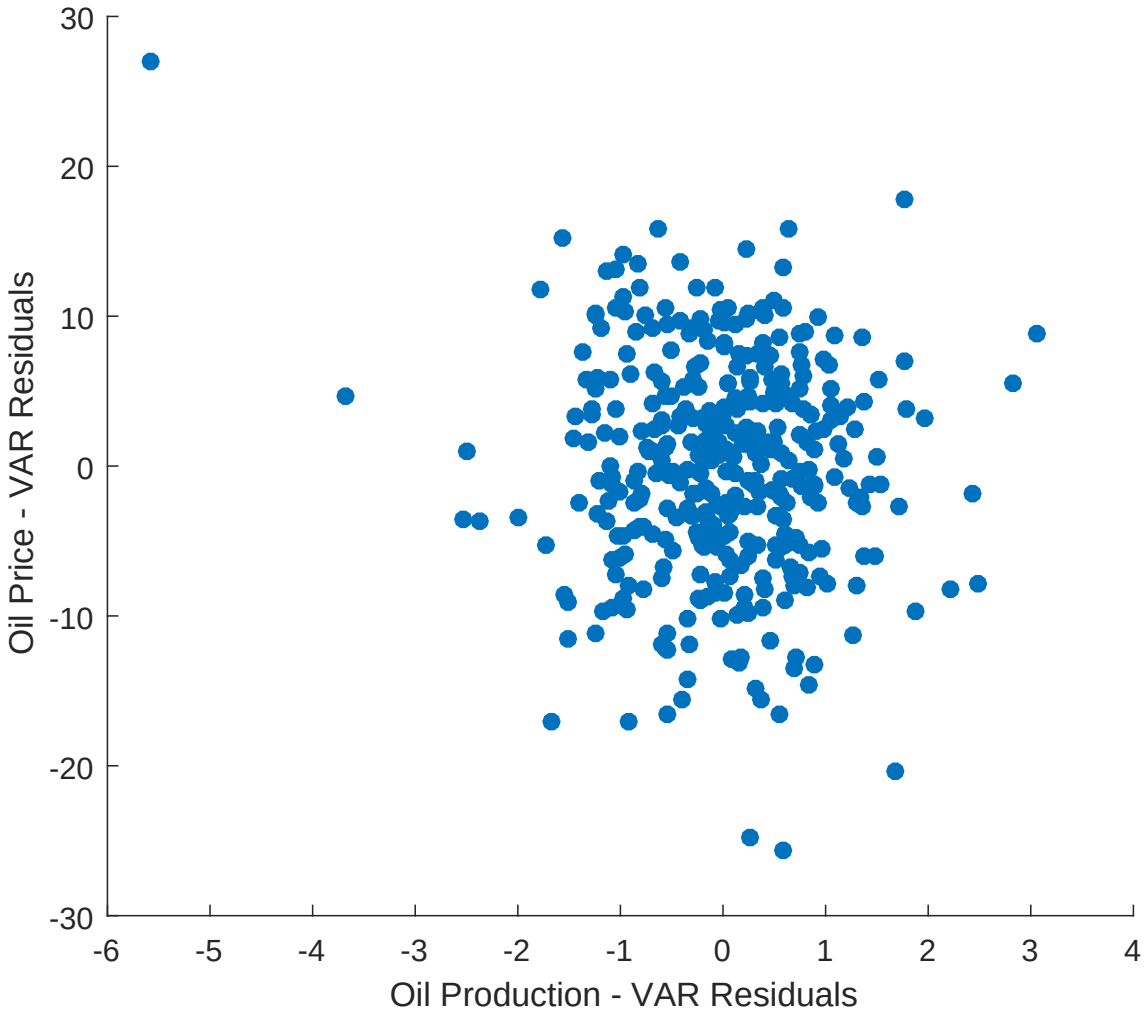
VAR Residuals - Time Series





$$\Sigma_u = \begin{bmatrix} 0.92 & -0.63 \\ -0.63 & 61.25 \end{bmatrix}$$

VAR Residuals - Scatter Plot



- Correlation coefficient between residuals implied by Σ_u: -0.08

Structural VAR of the Oil Market

- Denote by $w_t = [w_{s,t}, w_{d,t}]$ the vector of shocks to the supply of oil ($w_{s,t}$) and demand for oil ($w_{d,t}$).
- The relationship between reduced-form residuals and structural shocks is:

$$u_{q,t} = \psi_s u_{p,t} + \sigma_s w_{s,t} \quad (1)$$

$$u_{q,t} = \psi_d u_{p,t} + \sigma_d w_{d,t} \quad (2)$$

- Equation (1): Supply schedule.
  - ψ_s: Short-run supply elasticity to oil price [$\psi_{12,0}$ in standard notation]
- Equation (2): Demand schedule.
  - ψ_d: Short-run demand elasticity to oil price. [$\psi_{21,0}$ in standard notation.]
- Identification of VAR oil models require making assumptions on either ψ_s or ψ_d.

A Simple Example

- To understand identification, we start from a simple VAR(0):

$$\begin{aligned} q_t &= 0.5p_t + 1.25w_{s,t} \\ q_t &= -0.5p_t + 1.25w_{d,t} \end{aligned}$$

  where $\psi_s = 0.5$, $\psi_d = -0.5$, and $\sigma_d = \sigma_s = 1.25$.
  (zero lags imply that $y_t = u_t$.)

- Write the B_0^{-1} matrix to characterize the response to shocks:

$$\begin{bmatrix} q_t \\ p_t \end{bmatrix} = \begin{bmatrix} 1 & 0.5 \\ -0.5 & 1 \end{bmatrix} \begin{bmatrix} w_t^s \\ w_t^d \end{bmatrix}$$

- This model is such that
  - Supply shocks move production by $q_t = 1$ and prices by $p_t = -0.5$.
  - Demand shocks move production by $q_t = 0.5$ and prices by $p_t = 1$.

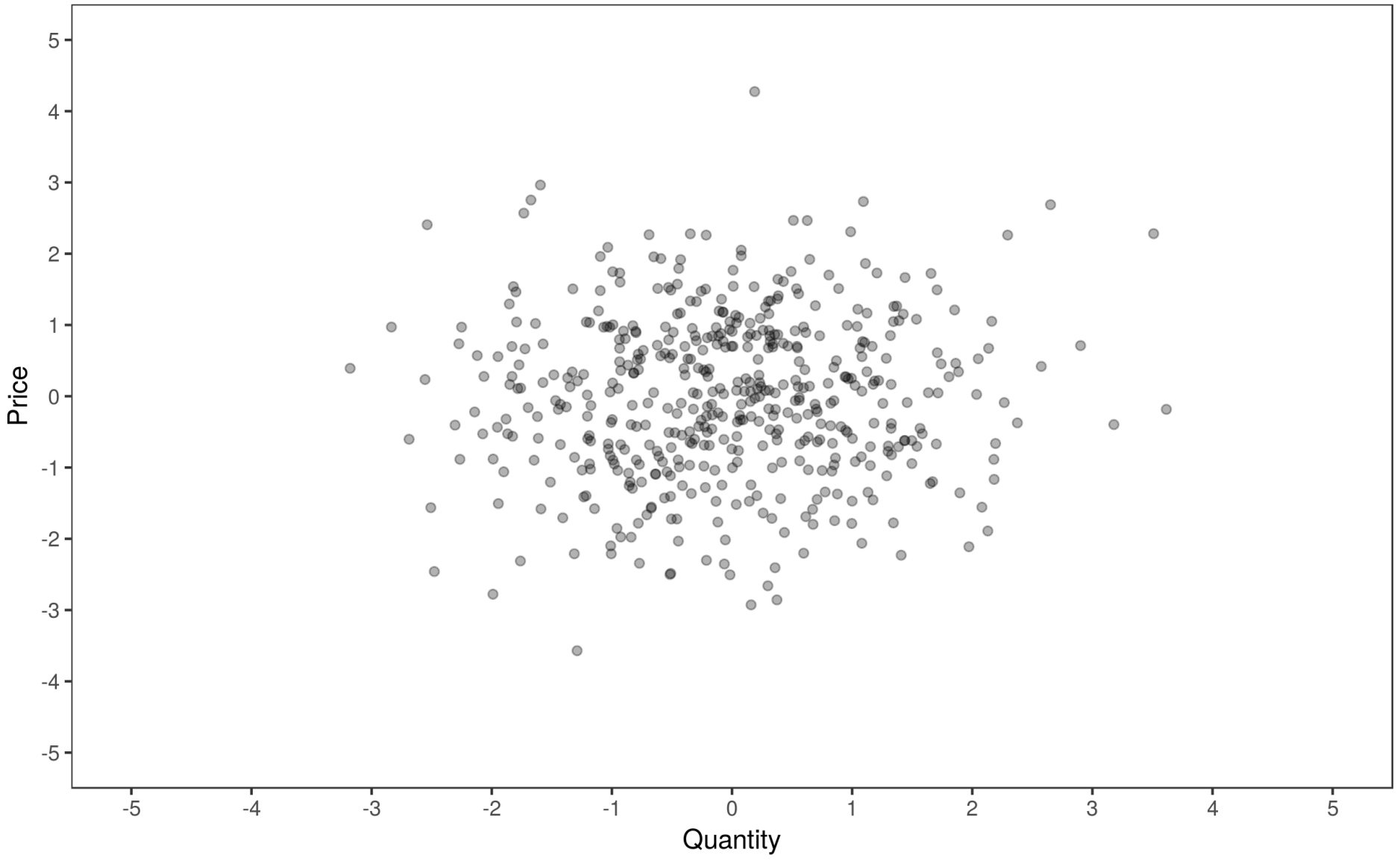
Simple Model

- Assume that our simple structural model is the true model.
- In econometrics jargon, assume that simple model is the data generating process (DGP).
- Simulate 500 observations from the DGP.
  - 500 draws for $w_{s,t}$ and $w_{d,t}$ from $N(0,1)$ distribution.
  - Multiply draws by matrix B_0^{-1} to obtain q_t and p_t.
- Use artificial data for q_t and p_t to estimate a reduced-form VAR model.
- In a VAR(0), we only need to estimate Σ_u:

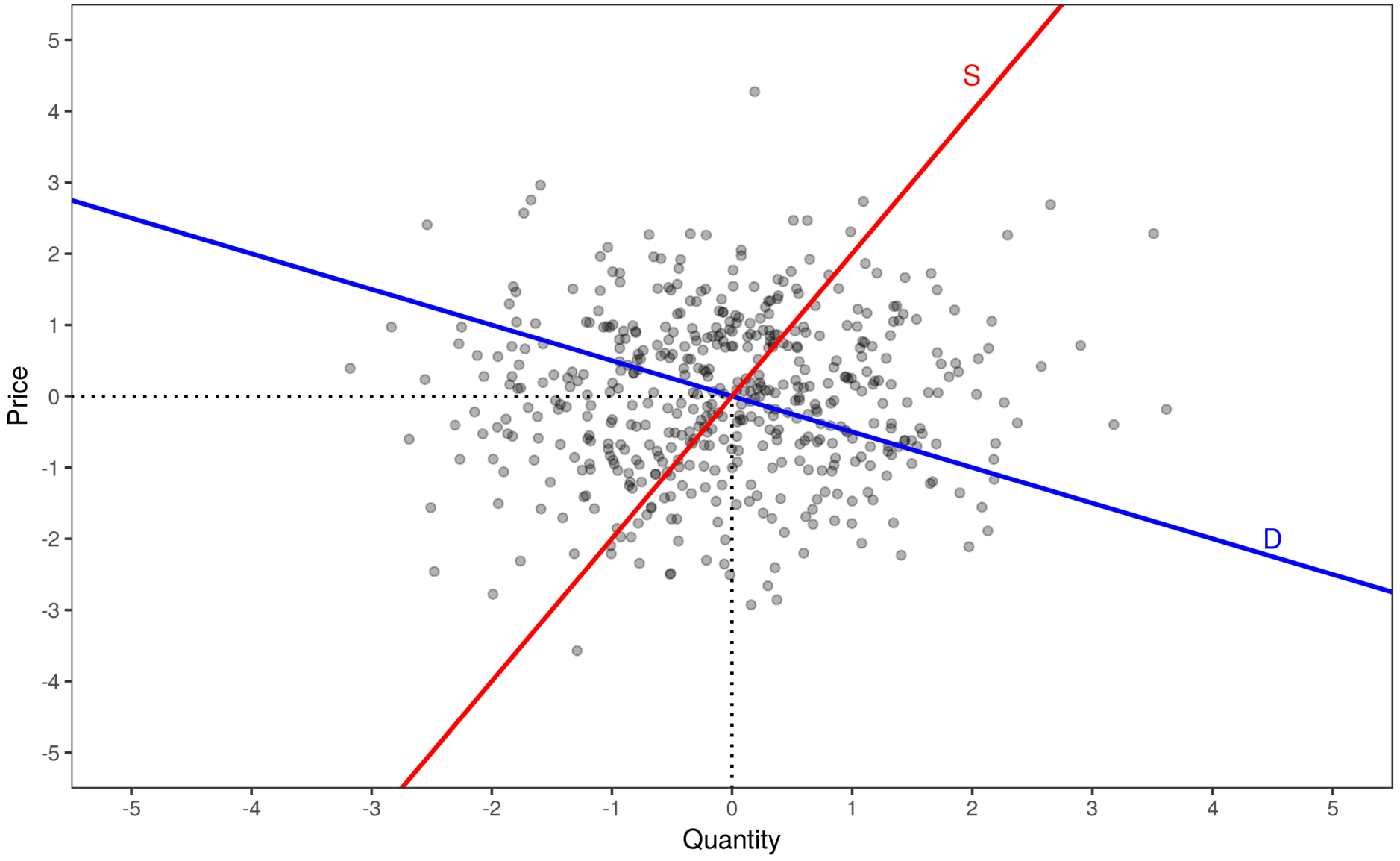
$$\Sigma_u = \begin{bmatrix} 1.25 & 0 \\ 0 & 1.25 \end{bmatrix}$$

- Why are q_t and p_t uncorrelated?

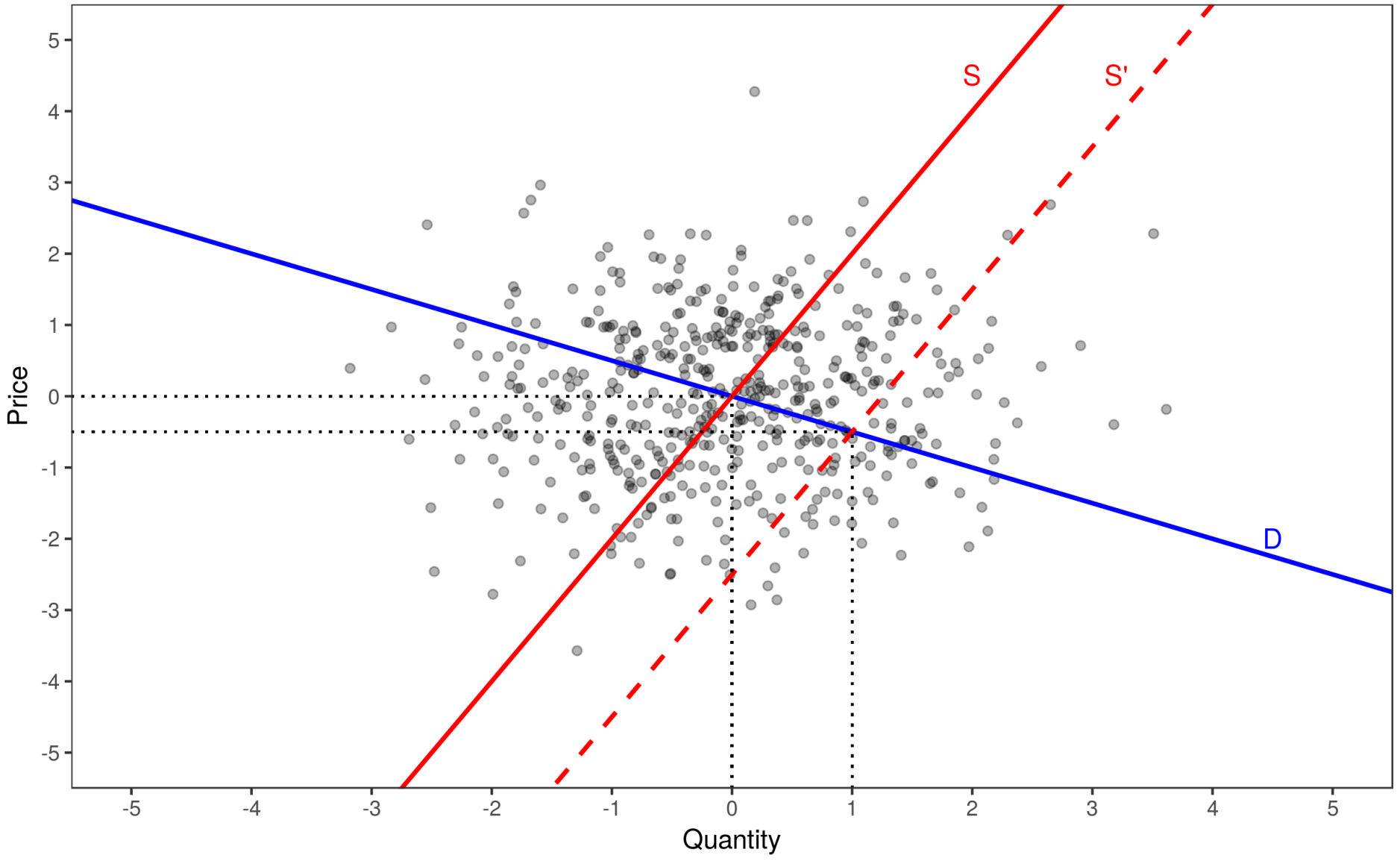
Scatter plot of q_t and p_t



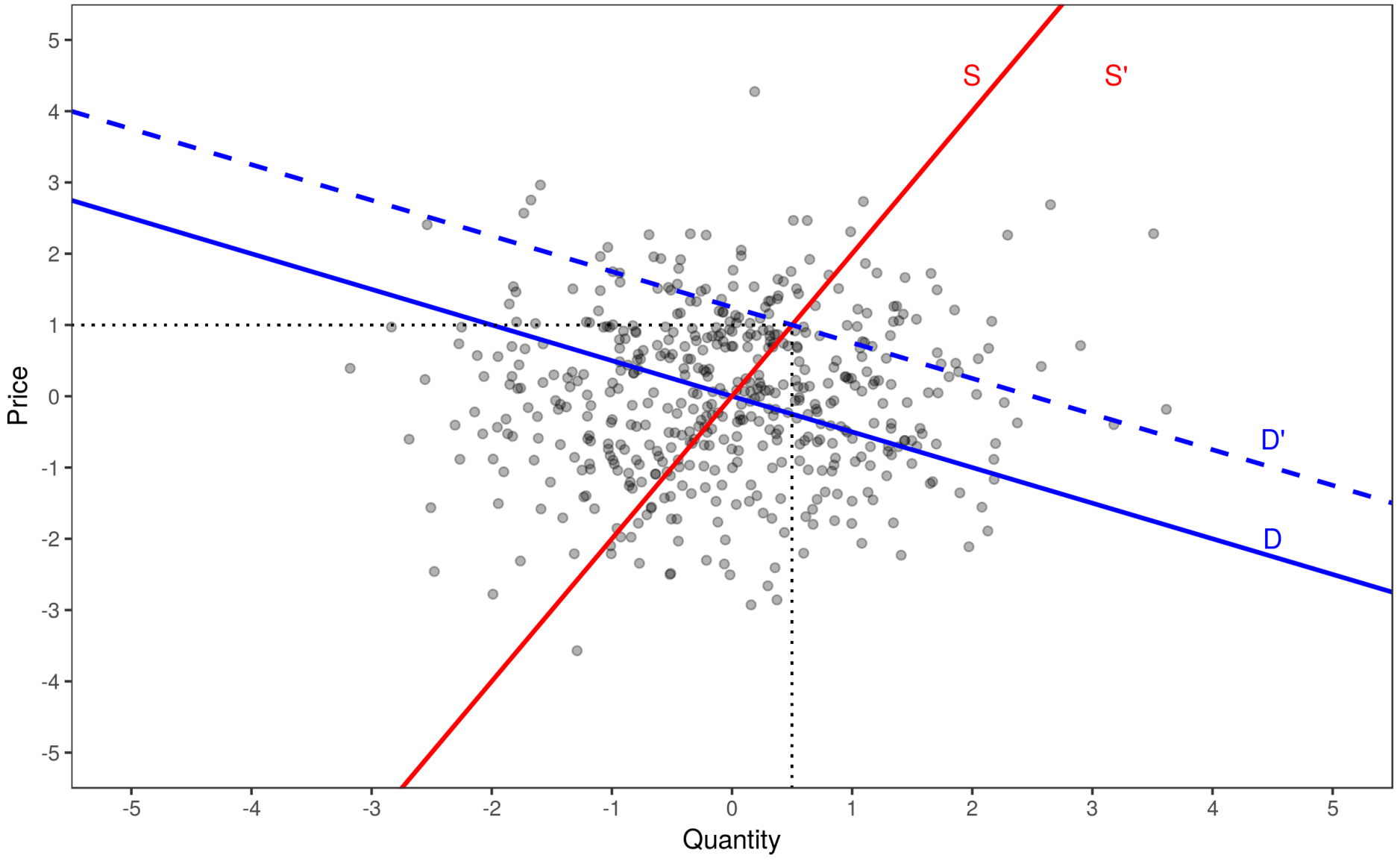
Demand and Supply Curves from DGP



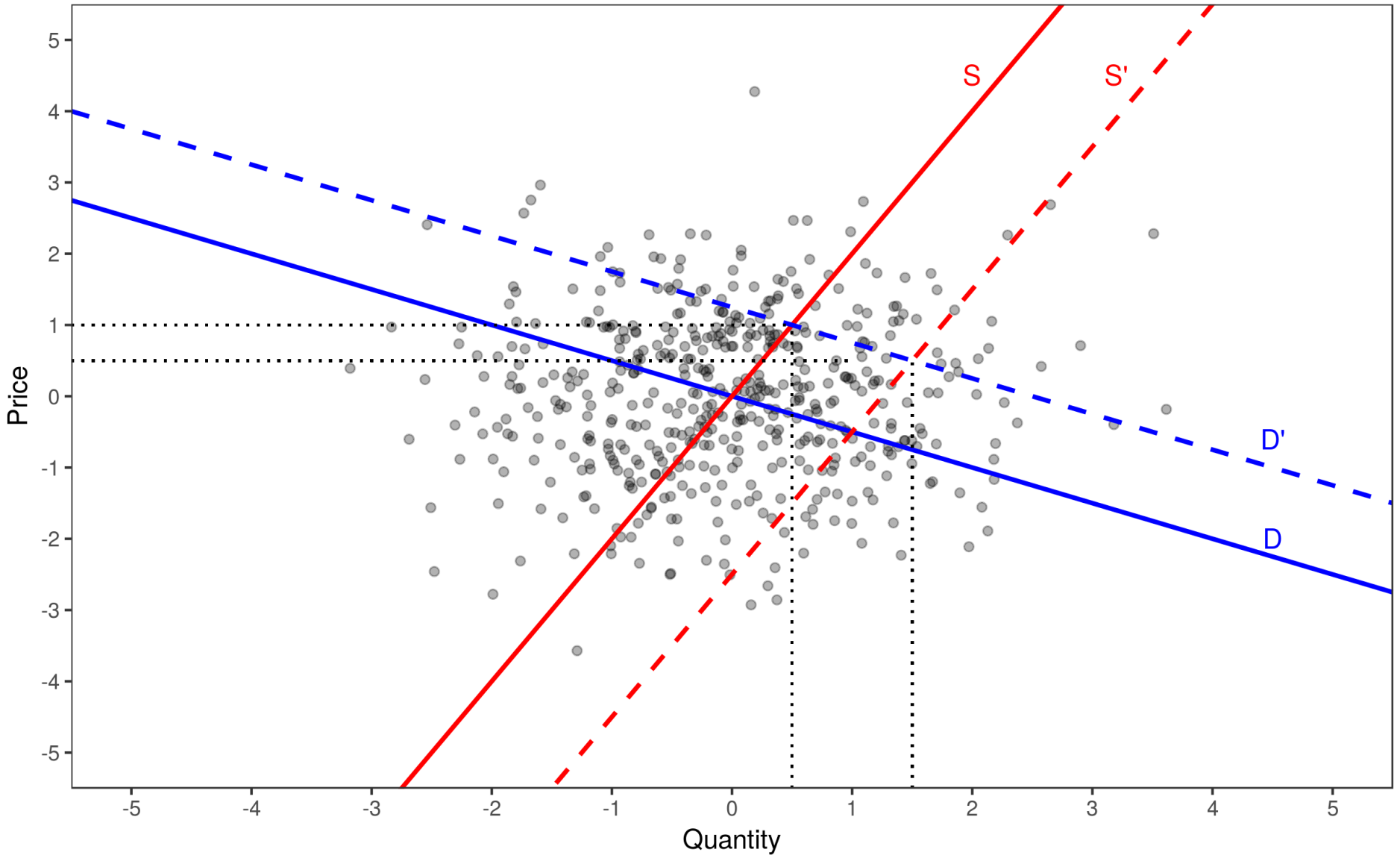
Supply Shocks



Demand Shocks



Supply and Demand Shocks



Identification: Cholesky

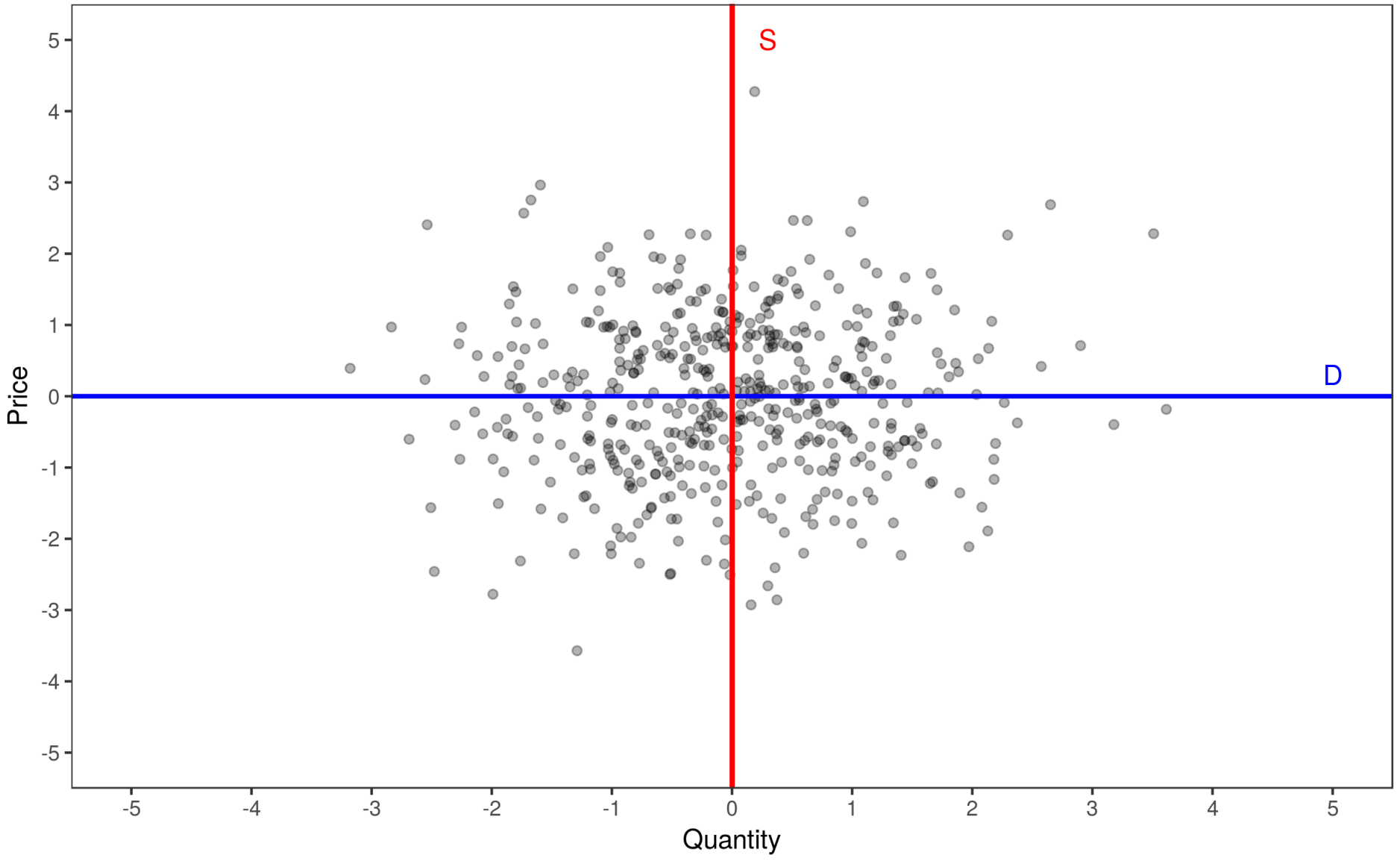
- Assume we do not know the DGP...
- ... but we have data for q_t and p_t. $\Rightarrow$ We can easily estimate Σ_u.
- What could we do?
- We can try a Cholesky identification with ordering $[q_t, p_t]$.
- This ordering assumes that q_t responds only to $w_{s,t}$.

$$y_t = Pw_t; \begin{bmatrix} q_t \\ p_t \end{bmatrix} = \begin{bmatrix} 1.118 & 0 \\ 0 & 1.118 \end{bmatrix} \begin{bmatrix} w_{s,t} \\ w_{d,t} \end{bmatrix}$$

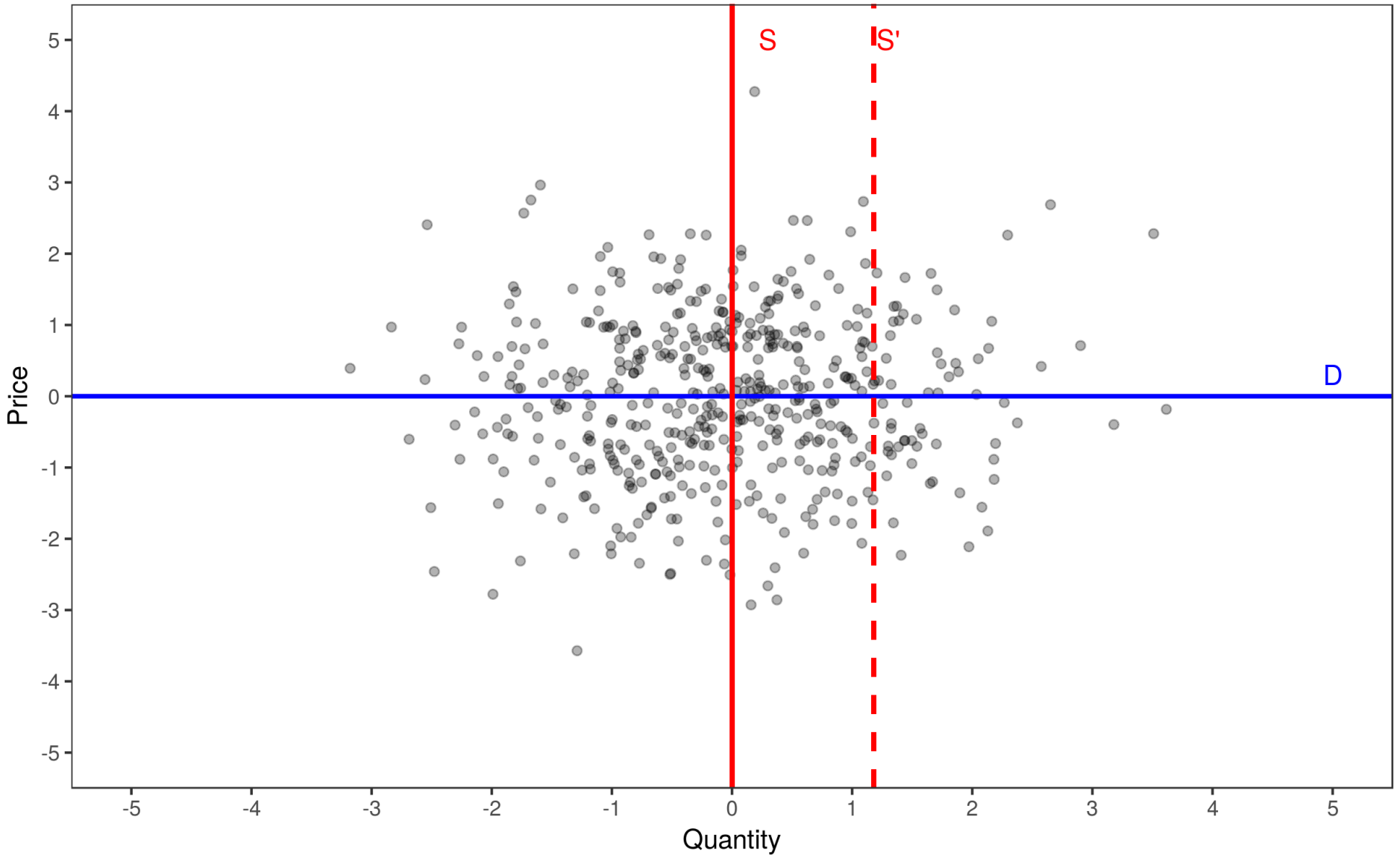
- This ordering implies that p_t only responds to $w_{d,t}$.
- Supply and demand functions implied by Cholesky:

$$\begin{aligned} q_t &= 1.118 w_{s,t} \\ p_t &= 1.118 w_{d,t} \end{aligned}$$

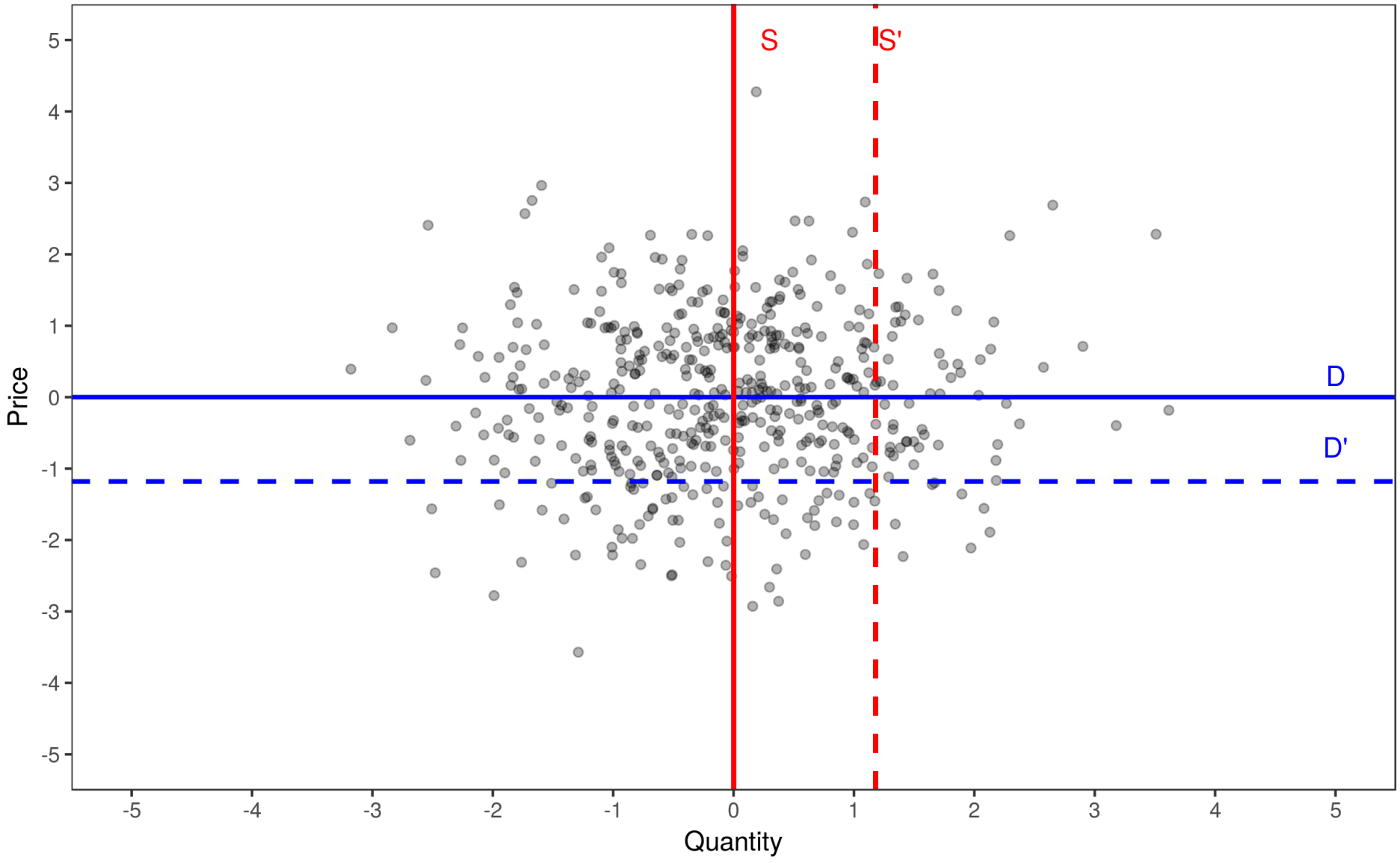
Demand and Supply Curves from Cholesky



Supply Shock from Cholesky



Supply and Demand Shocks from Cholesky



Identification: Taking Stock

- This simple example showed that low (zero) sample correlation between variables cannot justify use of Cholesky.
- The reason is that a structural model with zero restrictions is one of many models that can generate a low (zero) correlation between series.
- What can we do?
  - Identification: Non-zero restrictions.
  - Understand what are the implications of identification restrictions.

Identification: Non-Zero Restrictions

- Remember the nonlinear system of equations used to compute B_0:

$$\mathbb{E}[u_t u_t'] \equiv \Sigma_u = B_0^{-1} B_0^{-1'}$$

- There $K(K+1)/2$ distinct equations, but K^2 coefficients to solve.
- Impose $K(K-1)/2$ restrictions on coefficients in B_0 or B_0^{-1} to solve a system with as many equations as unknown.
- Identifications based on Cholesky impose zero restrictions on coefficients in B_0 or B_0^{-1}.
- Zero restrictions greatly simplify the system of equations:
  - Bivariate model can be solved by hand
  - Multivariate models can be solved using matrix multiplications.

Identification: Non-Zero Restrictions

- Cholesky identification is used to characterize one of many solutions.
- That is, we can solve this system of equations imposing non-zero restrictions on B_0 and B_0^{-1}.
- Example: Our DGP does not have zeros in B_0^{-1}:

$$\begin{bmatrix} q_t \\ p_t \end{bmatrix} = \begin{bmatrix} 1 & 0.5 \\ -0.5 & 1 \end{bmatrix} \begin{bmatrix} w_t^s \\ w_t^d \end{bmatrix}$$

- If I gave you data generated by this model, how could you recover the true structure?

1. Estimate Σ_u
2. Solve $\Sigma_u = B_0^{-1} B_0^{-1\prime}$ restricting either $b_{12,0}^{-1} = 0.5$ or $b_{21,0}^{-1} = -0.5$

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Non-Zero Restrictions: Solution Methods

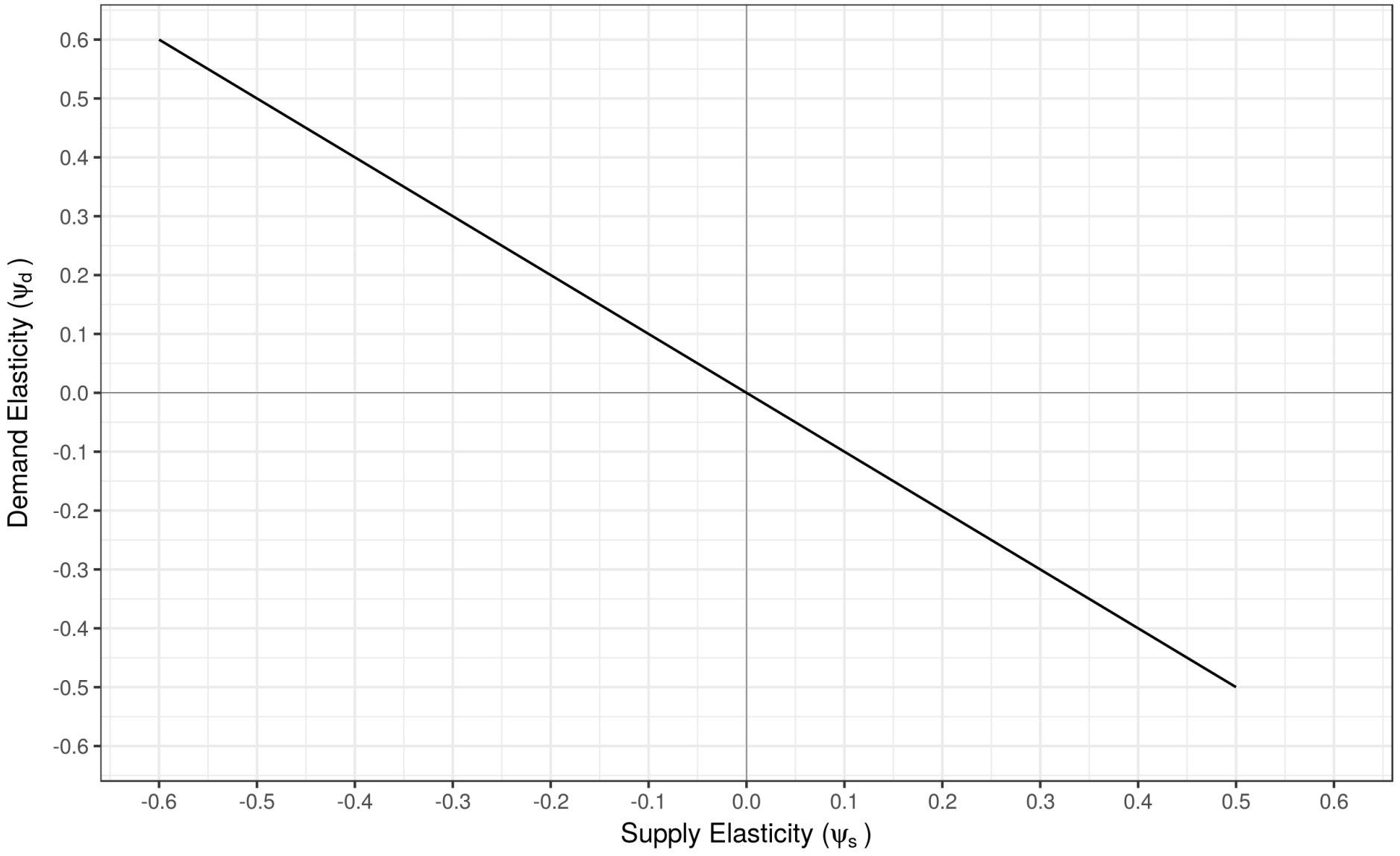
- System $\Sigma_u = B_0^{-1} B_0^{-1'}$ can be solved imposing non-zero restrictions.
- However, solution requires more complicated methods.
  - Nonlinear equation solvers
  - Rubio-Ramirez Waggoner and Zha (2010).
- For two-equation model, there is a closed-form solution.
- Using our oil VAR example:

$$\psi_d = \frac{\psi_s \sigma_q^2 - \sigma_{qp}}{\psi_s \sigma_{qp} - \sigma_p^2}$$

- Similarly, we solve for σ_d and σ_s as a function of ψ_s and Σ_u.

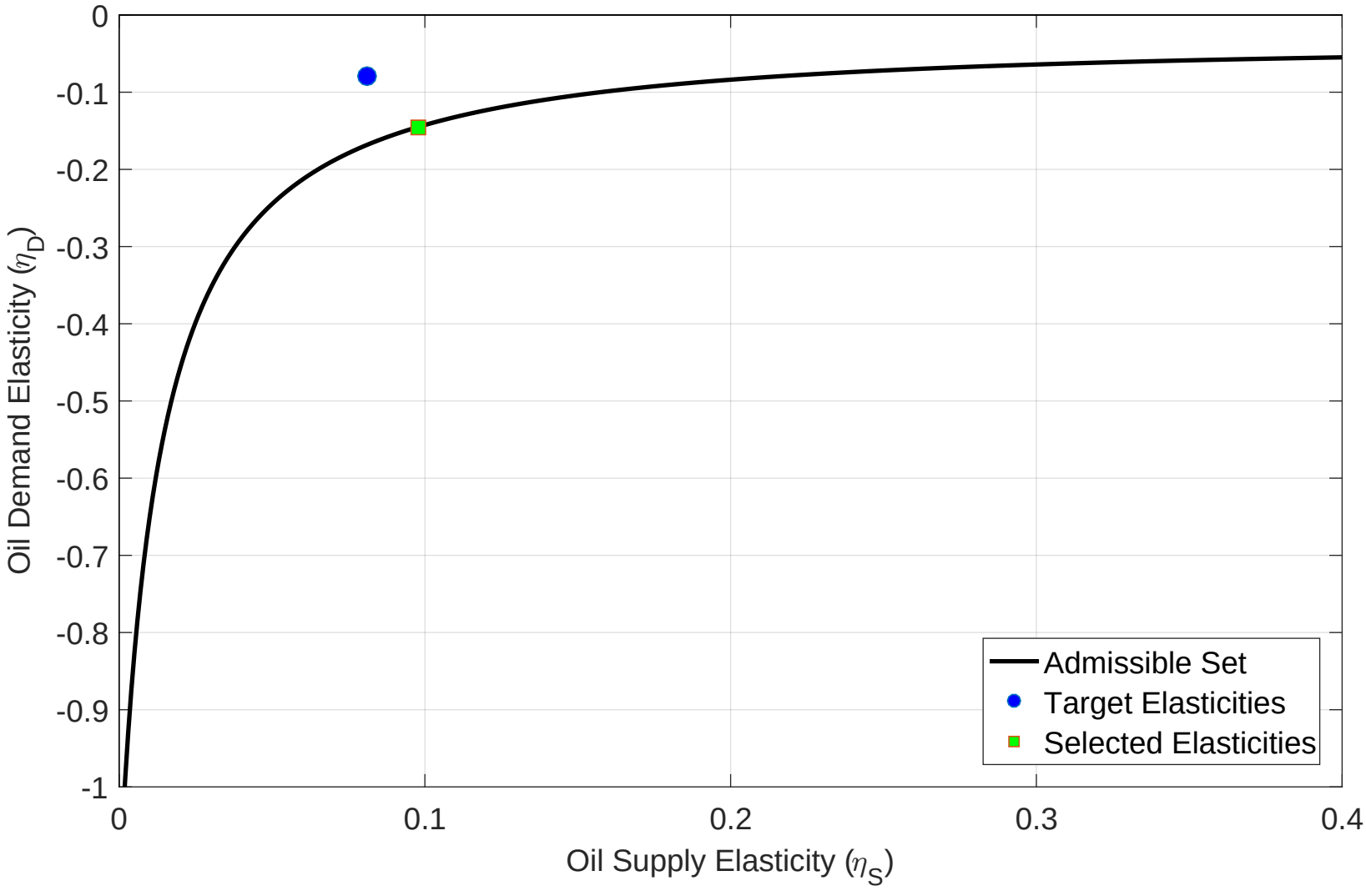
Relationship between ψ_s and ψ_d

Simple Model



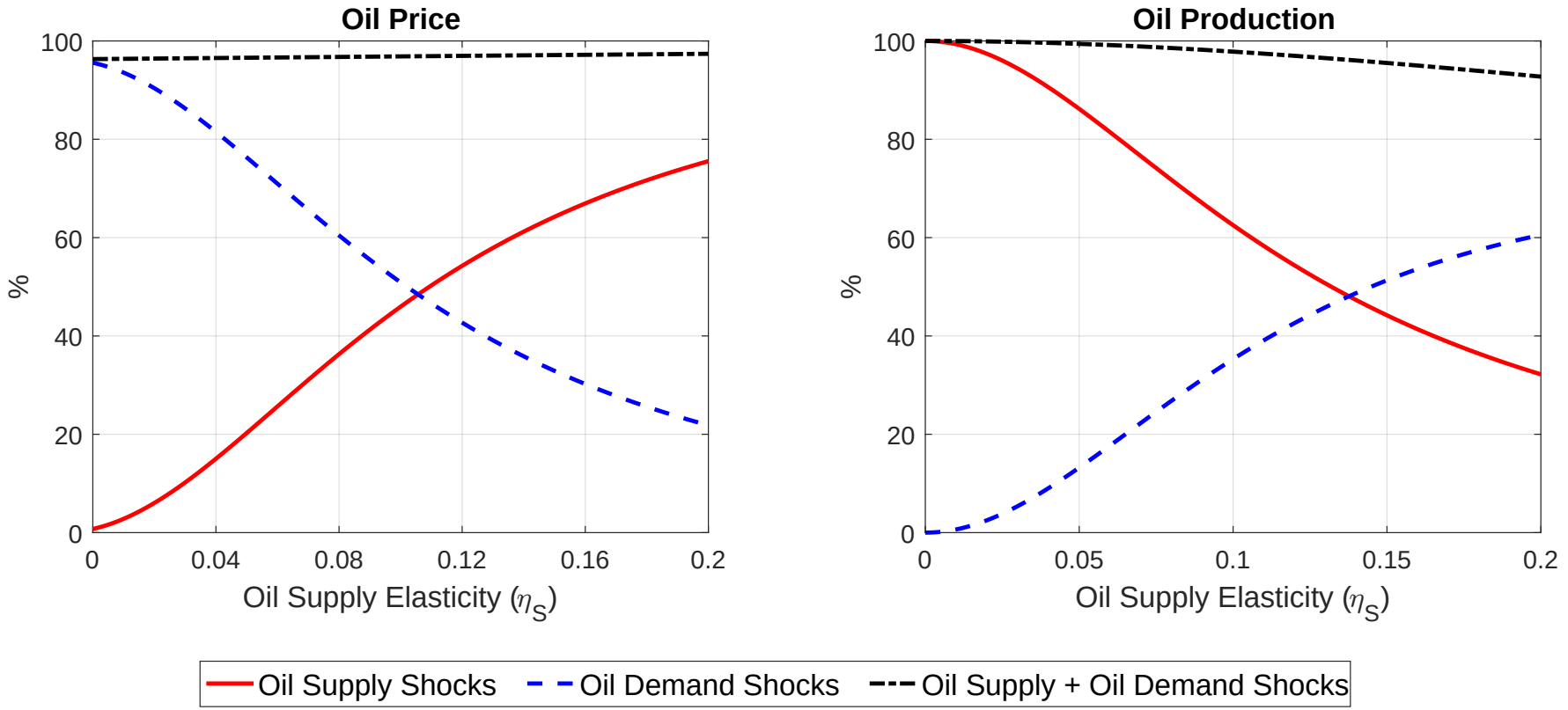
Relationship between ψ_s and ψ_d

From Caldara, Cavallo, and Iacoviello (2018)



Role of Demand and Supply Shocks for Oil Prices

From Caldara, Cavallo, and Iacoviello (2018)



How to Derive (Non-Zero) Restrictions

- Restrictions need to be supported by external/auxiliary evidence.
- One possibility is to formally use economic theory.
  - Impose restrictions that are satisfied in a fully specified DSGE model.
  - Use selective insights from economic theory (information delays, physical constraints...)
- Another possibility is to use parameter estimates derived using alternative frameworks.
- This is the approach we take in Caldara, Cavallo, and Iacoviello (2018)

Using External Information to Estimate Elasticities

- Provide new evidence about ψ_S and ψ_D
- Use external information for a large panel of countries:
  - Revisit Kilian and Murphy (2012)'s event study of Persian Gulf War
  - Generalize analysis of Gulf War to multiple episodes of large, country-specific declines in oil production
  - Narrative analysis to classify episodes as either exogenous or endogenous
  - Country-specific instruments to identify supply and demand curves in global oil market: Sum in each month of all exogenous output drops in other countries
  - Panel IV regressions on oil production and consumption

Stylized Model of Global Oil Market

- Goal: Impose restrictions on the oil supply elasticity ψ_s and on the oil demand elasticity ψ_d.
- Our approach: Estimate instrumental variable (IV) panel regressions.
- A simple model of the global oil market with N countries:

$$\Delta q_{S,i,t} = \psi_S \Delta p_t + w_{S,i,t}, \forall i = 1, ..., n, \quad (3)$$

$$\Delta q_{D,i,t} = \psi_D \Delta p_t + w_{D,i,t}, \forall i = 1, ..., n, \quad (4)$$

$$\sum_{i=1}^{N} \omega_{S,i} \Delta q_{S,i,t} = \sum_{i=1}^{N} \omega_{D,i} \Delta q_{D,i,t}. \quad (5)$$

- Country-specific oil supply and oil demand functions.
- Market clearing condition.

Idea Behind the Instrument

- We can express the change in the equilibrium oil price as follows:

$$\Delta p_t = \sum_{i=1}^{N} c_{S,i} w_{S,i,t} + \sum_{i=1}^{N} c_{D,i} w_{D,i,t},$$

  where the reduced-form coefficients $c_{S,i}$ and $c_{D,i}$ depend on the elasticities η_S and η_D, and on the country weights $\omega_{S,i}$ and $\omega_{D,i}$.

- Key Insight: Running country–specific OLS regressions based on either Equation (3) or Equation (4) would yield biased estimates of ψ_S and ψ_D.

- Intuition: For each country i, the regressor Δp_t is correlated with the shocks $w_{S,i,t}$ and $w_{D,i,t}$.

Idea Behind the Instrument

- What we do: We use large exogenous drops in oil production in *other* countries as instrumental variables for oil prices in Equations (3) and (4).
- Intuition: If events leading to oil supply disruptions in *other* countries are truly exogenous, they should affect oil supply and oil demand in a particular country only through their effect on prices.
- We obtain unbiased estimates of ψ_S and ψ_D by regressing production and consumption in each country against the component of prices that is explained by the exogenous shocks in other countries.

The Gulf War

- Kilian and Murphy (2012)'s event study of Persian Gulf War:
  - August 1990: Oil prices increased 44.3% ...
  - ... allegedly exclusively caused by decline in oil production in Iraq and Kuwait
  - Global production ex. Iraq & Kuwait rose 1.17%
  - $\psi_S = 1.17/44.3 = 0.026$ and should be upper bound.

- Questionable upper bound. U.A.E. also experienced exogenous cut in oil production:
  - Global prod ex. Iraq, Kuwait & UAE rose 1.97%
    $\rightarrow \psi'_S = 1.97/44.3 = 0.045$

Caveat: United Arab Emirates

Business Day

L D1

WEDNESDAY, JULY 18, 1990

The New York Times

BUSINESS Digest

WEDNESDAY, JULY 18, 1990

DOW	DOLLAR	GOLD	BONDS
30 Industrials	vs. Japanese Yen	Comex Spot	30-Year Treasuries
2,999.75	147.80 Yen	$362.00	8.45%
Unchanged	–0.35	–$1.30	+0.01

The Economy

House Democrats will propose a savings and loan enforcement package that will include a bipartisan commission to examine the roots of the savings and loan crisis and new legal weapons to fight crime in the industry. [Page D1.] The Neil Bush case has become a staple of Colorado politics in this election year. [A14.]

The nation's trade deficit rose modestly in May, to $7.73 billion, fueled by heavy reliance on oil imports and foreign cars. [D1.] Industrial production rose four-tenths of a percent in June. [D4.]

Senators approved legislation to curb imports of textiles and apparel, even though similar efforts have failed. [D1.]

A group of American makers of flat screens used in computers filed an anti-dumping petition against Japanese companies. [D4.]

International

Iraq's President threatened to use force against other Arab oil-exporting nations if they do not curb their production. The warning seemed to be aimed at Kuwait and the United Arab Emirates. [D1.]

The World Bank said that its net income topped $1 billion in 1990 and that it would consider reducing its borrowers' costs. [D2.]

Companies

Citicorp earnings fell 37 percent in the second quarter. Chemical Banking reported a 12 percent decline and Manufacturers Hanover's profits plunged 69 percent. Regional banks fared better. [D1.] Earnings rose at Merrill Lynch and Charles Schwab. [D3.]

Coca-Cola said its second-quarter profits rose 18.6 percent, exceeding analysts' expectations. [D5.] Eli Lilly, Pfizer and Upjohn had double-digit gains in profits and sales. [D3.] United Telecom said its earnings fell 55.1 percent. [D5.]

NBC said Brandon Tartikoff had been promoted to a new position, chairman of the NBC Entertainment Group. [D6.]

Nynex said it had dismissed two purchasing employees and disciplined six others in 1988 for improper activities. [D3.]

Wells Fargo agreed to buy the California branch network and other assets of Great Amerian Bank. [D2.] Usinor-Sacilor of France plans to acquire Edgcomb. [D3.]

Markets

The Office of Technology Assessment said it might fail to Congress to lay out a regulatory policy for round-the-clock trading in stocks and futures. [D8.]

The Big Board was set to celebrate, but the Dow Jones industrial average fell back after breaking the 3,000 barrier for a third session. The Dow ended at 2,999.75, unchanged from Monday. [D8.]

Citicorp Posts 37% Drop in Net

Manufacturers and Chemical Also Down

By MICHAEL QUINT

Citicorp, the nation's largest banking company, said yesterday that its earnings fell 37 percent in the second quarter from a year earlier, despite continued growth in its highly profitable consumer banking businesses.

It said the major problems at its Citibank unit were sluggish demand for new loans and slack financing activity among large corporations in the United States and other countries.

Those problems also contributed to a 12 percent decline in earnings at the Chemical Banking Corporation and a 69 percent plunge at the Manufacturers Hanover Corporation, which also made announcements yesterday.

Manufacturers Hanover earnings were also reduced by the $100 million pretax cost of a plan it announced earlier to reduce its staff by 1,400 and cut costs by $125 million annually.

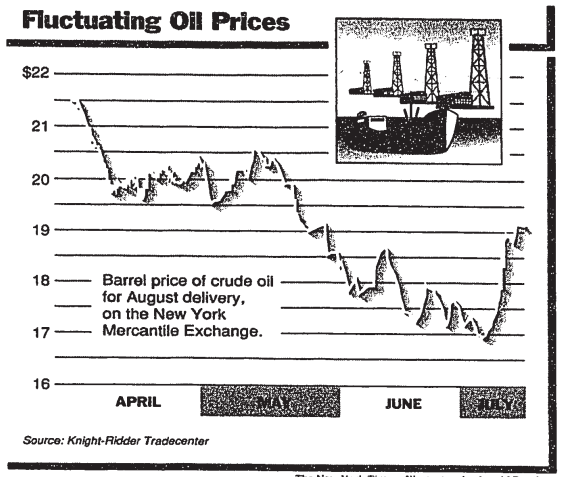
Some regional banking companies, which concentrate on consumer banking and small- to medium-sized businesses, are faring better in the second quarter than are the large New York City banks. At Wells Fargo & Company in San Francisco, for example, profits rose about 58 percent, as it continued to avoid heavy losses on real estate lending.

Cost-Cutting by Mellon

The Pittsburgh-based Mellon National Corporation, which cut costs sharply in its national lending group in the late 1980's, said its profits rose 146 percent. Both Wells Fargo and Mellon also benefited from profits on the sale of subsidiaries.

Citicorp's profit declined to $248 million, or 64 cents a share, from $395 million, or $1.11 a share, a year earlier. But unlike Chemical and Manufacturers Hanover, which have started cutting employees to reduce their costs in the wholesale banking business, Citicorp has not announced such plans.

"Given the imbalance between revenues and costs in their wholesale banking business, it seems inevitable that Citicorp must begin cutting," said James J. McDermott, head of re-



The New York Times; Illustration by Arnold Bombay

Iraq Threatens Emirates And Kuwait on Oil Glut

By YOUSSEF M. IBRAHIM

Special to The New York Times

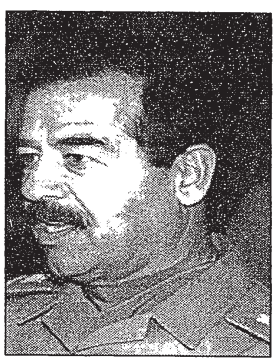
CAIRO, July 17 — President Saddam Hussein of Iraq today openly threatened to use force against Arab oil-exporting nations if they did not curb their excess production, which he said had weakened oil prices and hurt the Iraqi economy.

The Iraqi leader did not mention particular countries by name in his nationally broadcast address today, but his warning was clearly aimed at Kuwait and the United Arab Emirates.

In the last few weeks, the Iraqi oil minister, Issam Abdul-Rahim al-Chalaby, has frequently singled out the two Arab nations, which have been producing oil at rates far above the quotas mandated by the Organization of Petroleum Exporting Countries, as the main culprits in the steep fall of oil prices in recent months.

American Influence Seen

President Hussein charged that the oil production policies of Kuwait and the United Arab Emirates had been the result of American influence.



Agence France-Presse

President Saddam Hussein of Iraq, who warned yesterday that the breaking of OPEC oil production quotas hurt Arab interests.

Savings Crime Bill Is Proposed

Democrats in House Seek Commission, Enforcement Effort

By DAVID JOHNSTON

Special to The New York Times

WASHINGTON, July 17 — Democrats in the House of Representatives will propose a savings and loan enforcement package on Wednesday that will include a bipartisan national commission to examine the roots of one the nation's worst financial crisis as well as new legal weapons to fight crime in the savings and loan industry, Congressional aides said today.

Absent from the package, an amalgam of Democratic and Republican recommendations, are some of the far-reaching proposals tossed up in recent days as Democrats and Republicans hammered at each other in a heated debate over the blame for the crisis. The Democrats are apparently trying to incorporate Republican suggestions to achieve some cooperation to increase the chances for passage of the legislation.

Serious, Not Partisan

"We are trying to find out in a serious and not partisan way what really happened, and if Government is doing all it can to prevent it from happening again," said Representative Charles E. Schumer, Democrat of Brooklyn and chairman of a House Judiciary subcomittee that is preparing the savings and loan legislation.

Some of the most hotly debated Democratic suggestions, like measures to reorganize the Justice Department to create a financial crimes division and a plan to enlist the Secret Service in the savings and loan investigations, were omitted.

Some proposals, like the commission, were originally suggested in slightly different forms by Republicans. Chalmers P. Wylie, an Ohio Republican who brought the commission idea forward, said, "I think the political rhetoric can be laid aside, if it's not reported out just as a Democratic proposal."

To Uncover Crimes

Mr. Schumer, who declined to dis-

Caveat (Continued): United Arab Emirates

The New York Times

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Senator David Durenberger after he was denounced for bringing "dishonor and disrepute" to the Senate through his financial dealings.

Iraq Said to Prevail in Oil Dispute With Kuwait and Arab Emirates

By YOUSSEF M. IBRAHIM
Special to The New York Times

GENEVA, July 25 — Iraq appeared today to have won a political victory, forcing Kuwait and the United Arab Emirates to reduce oil production and pushing the Organization of Petroleum Exporting Countries to raise oil prices.

The Iraqis' apparent success at the meeting of OPEC nations that began today came as tension in the Persian Gulf region seemed to diminish consid-

their chronic overproduction of oil has been the main reason for dropping oil prices. Then on the weekend, Iraq moved troops to its border with Kuwait. [A senior Bush Administration official in Washington said that Iraq had enlarged the border force from 30.000 to 100,000 men in recent days.]

But at the OPEC meeting today, senior OPEC officials said, the United

Caldara, Cavallo, and Iacoviello (2018)

Construction of the Instrument - Quantitative Criteria

- We generalize this example using data on oil production for 21 countries for the sample from 1985 to 2015.
- Using two quantitative criteria to detect episodes of large drops in oil production.
- First criterion: oil production in country i during month t drops by more than 2 percent of global oil production.
- Second criterion defines multiple thresholds calibrated to select a larger set of drops in a country's oil production.
- These drops are either large relative to a country's own past production, or relative to global production.
- Example: Domestic oil production in month t drops by: (1) more than 0.66 percent of global oil production, and (2) more than 19.5 percent and (3) more than 4 standard deviations.

Caldara, Cavallo, and Iacoviello (2018)

Construction of the Instrument - Quantitative Criteria

Table 1: Large Country-Specific Drops in Crude Oil Production

Date	Country	Event	Exogenous?	% of Global Oil Prod.	% of Domestic Oil Prod.	Narrow Crit.[a]	Broad Crit.[b]
Jan 1985	Iran	War	✓	-1.03	-22.32		✓
May 1985	Saudi Arabia	OPEC		-1.62	-25.36		✓
Jun 1985	Nigeria	OPEC		-0.67	-24.15		✓
Jan 1986	Nigeria	OPEC		-0.79	-27.28		✓
Apr 1986	Norway	Strike	✓	-0.97	-62.36		✓
Apr 1986	Qatar	N\A		-0.28	-48.46		✓
Jul 1986	Egypt	OPEC		-0.26	-20.13		✓
Sep 1986	Nigeria	OPEC		-0.79	-26.35		✓
Sep 1986	Saudi Arabia	OPEC		-2.64	-25.09	✓	✓
Oct 1986	Egypt	OPEC		-0.21	-12.71		✓
Jan 1987	Saudi Arabia	OPEC		-2.06	-22.46	✓	✓
Mar 1987	Ecuador	Earthquake	✓	-0.40	-82.56		✓
Sep 1987	Iran	War	✓	-0.97	-22.24		✓
Jan 1988	U.A.E.	OPEC		-0.81	-28.63		✓
Jan 1989	Saudi Arabia	OPEC		-2.82	-26.10	✓	✓
Aug 1990	Iraq	War	✓	-4.03	-70.59	✓	✓
Aug 1990	Kuwait	War	✓	-2.90	-94.59	✓	✓
Aug 1990	U.A.E.	Geopolitics	✓	-0.66	-19.51		✓
May 1992	Russia	Anticipated		-0.86	- 6.32		✓
Oct 1995	Mexico	Hurricanes	✓	-1.37	-30.37		✓
Jun 1997	Iraq	Geopolitics	✓	-1.07	-54.33		✓
Dec 2000	Iraq	Geopolitics	✓	-2.07	-51.87	✓	✓
Jun 2001	Iraq	Geopolitics	✓	-2.61	-61.96	✓	✓
Apr 2002	Iraq	Geopolitics	✓	-1.95	-51.69		✓
Dec 2002	Venezuela	Geopolitics	✓	-2.83	-65.68	✓	✓
Apr 2003	Iraq	War	✓	-1.88	-96.14		✓
Sep 2005	U.S.A.	Hurricane	✓	-1.33	-18.94		✓
Sep 2008	U.S.A.	Hurricane	✓	-1.39	-20.51		✓
Mar 2011	Libya	Civil War	✓	-1.38	-77.61		✓

Caldara, Cavallo, and Iacoviello (2018)

Construction of the Instrument - Narrative Analysis

Table 2: Exogenous Drops in Oil Production Included in the Instruments

Date	Country	Event	% of global Oil Prod.	Narrow Instrument[a]	Broad Instrument[b]
Jan 1985	Iran	Iran-Iraq War	-1.03		✓
Apr 1986	Norway	Strike	-0.97		✓
Mar 1987	Ecuador	Earthquake	-0.40		✓
Sep 1987	Iran	Iran-Iraq War	-0.97		✓
Aug 1990	Iraq+Kuwait+U.A.E.	Gulf War	-7.59	✓	✓
Oct 1995	Mexico	Hurricanes	-1.37		✓
Jun 1997	Iraq	Geopolitics	-1.07		✓
Dec 2000	Iraq	Geopolitics	-2.07	✓	✓
Jun 2001	Iraq	Geopolitics	-2.61	✓	✓
Apr 2002	Iraq	Geopolitics	-1.95		✓
Dec 2002	Venezuela	Political Unrest	-2.83	✓	✓
Apr 2003	Iraq	Iraq War	-1.88		✓
Sep 2005	U.S.A.	Hurricane	-1.33		✓
Sep 2008	U.S.A.	Hurricane	-1.39		✓
Mar 2011	Libya	Civil War	-1.38		✓

IV Estimation of Oil Market Elasticities

- Monthly data from 1985 to 2015 on crude oil production (21 countries) and consumption (8 countries) from U.S. EIA
- First-stage regressions

$$\Delta p_\tau = \pi_i + \gamma \Delta v_{i,\tau} + \epsilon_{i,\tau},$$

- IV Regressions for Supply

$$\Delta q^S_{i,\tau} = \alpha_{S,i} + \psi_S \widehat{\Delta p}_{i,\tau} + w^S_{i,\tau},$$

- IV Regression for Demand

$$\Delta q^D_{i,\tau} = \alpha_{D,i} + \psi_D \widehat{\Delta p}_{i,\tau} + \Psi \mathbf{X}_{i,\tau} + w^D_{i,\tau},$$

- Instrument, $\Delta v_{i,\tau}$, excludes exogenous episodes involving country i
- $E\left(w^K_{i,\tau}, w^K_{j,\tau}\right) = 0$ for $i \neq j$ and $K = S, D$
  - Orthogonality assumption imposed at episode-level

Regression Results

Table 3: Panel Estimates of the Price Elasticity of Crude Oil Supply and Demand

	1. OLS	2. Narrow IV	3. Broad IV
(A.) *Price elasticity of crude oil supply*			
η_S	0.021	0.054	0.081
	[0.017]	[0.019]	[0.037]
First-stage F stat.	-	16.25	16.61
Total Obs.	7719	77	293
Countries	21	21	21
Unique Episodes	372	4	15
(B.) *Price elasticity of crude oil demand*			
η_D	-0.017	-0.031	-0.080
	[0.036]	[0.037]	[0.079]
First-stage F stat.	-	16.25	16.61
Total Obs.	2976	32	118
Countries	8	8	8
Unique Episodes	372	4	15

- $\hat{\psi}_S^{\text{IV}}$ in line with Baumeister and Hamilton (2017); Three times larger than Kilian and Murphy (2012)
- If August 1990 U.A.E. endogenous $\rightarrow \hat{\eta}_S^{\text{IV}} = 0.056$
- ψ_D^{IV} within range of existing empirical evidence.

Structural VAR Model

VAR model of interaction b/w oil market and global activity

- Oil market block:
  - Log of Brent price of crude oil (deflated by U.S. CPI)
  - Log of global supply of crude oil
- Global activity block:
  - Log of IP for advanced economies
  - Log of IP for emerging economies
  - Log of IMF metals price index

Sample from 1985m1 to 2015m12

Measuring global demand for oil

Coincident and Leading Indicators

- Capture key features of global business cycle
- Construct IP indexes for 19 advanced and 33 emerging economies (90% global GDP):
  - Widely available business cycle indicator
  - Advanced economies net oil importers
  - Emerging economies use more oil and oil independent
- IMF Metals Price Index:
  - Metals crucial inputs in many industrial sectors
  - Captures shifts in current and expected global activity
    Pindyck & Rotemberg (1990); Barsky & Kilian (2001); Arezki and Blanchard (2014)

Identification of VAR

Interaction b/w Oil Market and Global Economy and Exclusion Restrictions

- Global Economy $\rightarrow$ Oil Market (Oil Market Block)
- Oil Market $\rightarrow$ Global Economy (Global Activity Block)

$$\underbrace{\begin{bmatrix} 1 & -\psi_S & 0 & 0 & 0 \\ 1 & -\psi_D & -\psi_A & -\psi_E & 0 \\ -\psi_{31} & 0 & 1 & 0 & 0 \\ -\psi_{41} & 0 & -\mu_{43} & 1 & 0 \\ -\psi_{51} & \psi_{52} & -\psi_{53} & -\psi_{54} & 1 \end{bmatrix}}_{\mathbf{B_0}} \underbrace{\begin{bmatrix} q_t \\ p_t \\ ya_t \\ ye_t \\ m_t \end{bmatrix}}_{\mathbf{X_t}} = \sum_{j=1}^{p} \mathbf{B}_j \mathbf{X}_{t-j} + \underbrace{\begin{bmatrix} w_{S,t} \\ w_{D,t} \\ w_{A,t} \\ w_{E,t} \\ w_{M,t} \end{bmatrix}}_{\mathbf{w_t}}$$

- VCV matrix of VAR residuals, Σ_u, zero restrictions in $\mathbf{A}$ and value for either ψ_S or ψ_D deliver necessary and sufficient conditions for identification

Identification of Oil Market Block

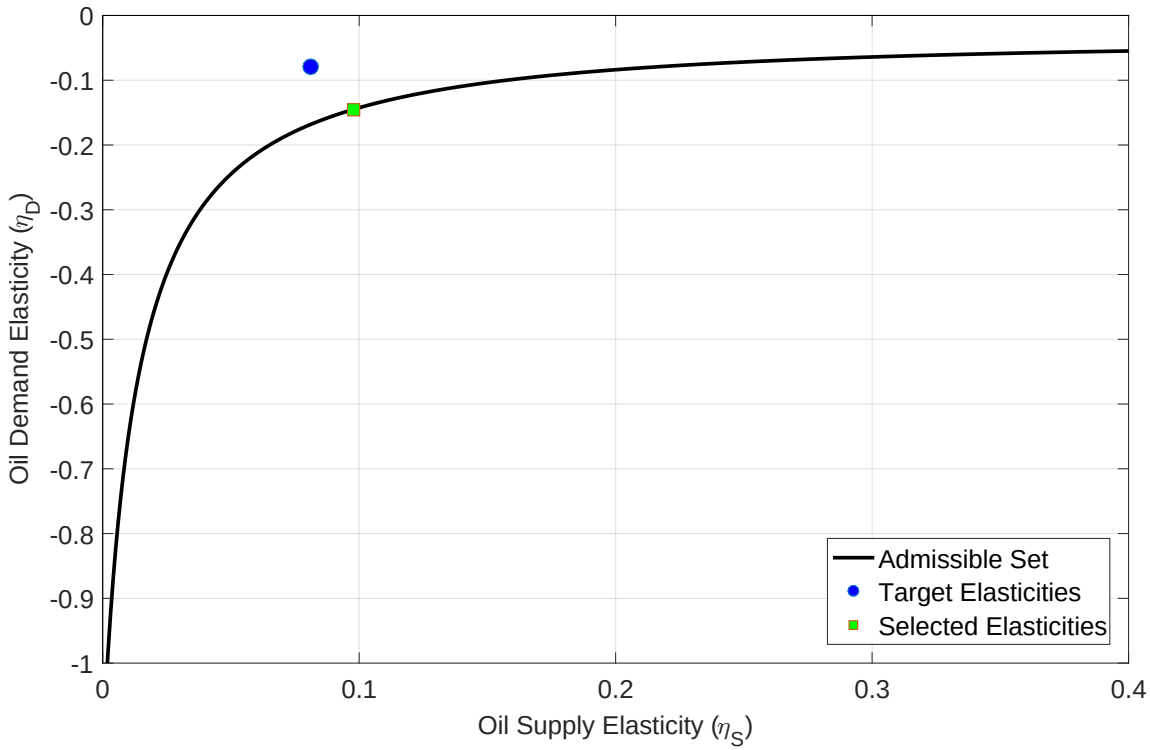
Use External Information to Discipline Supply and Demand Elasticities

- Estimate $\hat{\psi}_S$ and $\hat{\psi}_D$ through external information
  - Based on country-specific IV regressions: $\hat{\psi}_S = 0.08$ and $\hat{\psi}_D = -0.08$
- Joint restrictions on oil supply and demand elasticities
  - Striking Balance b/w external information and VAR Model
  - Minimize Euclidean distance between elasticities consistent with cross-equation restrictions inherent in VAR and estimated elasticities:

$$\min_{\psi_S} \begin{bmatrix} \psi_S - \hat{\psi}_S \\ \psi_D\left(\psi_S; \Sigma\right) - \hat{\psi}_D \end{bmatrix}' V^{-1} \begin{bmatrix} \psi_S - \hat{\psi}_S \\ \psi_D\left(\psi_S; \Sigma\right) - \hat{\psi}_D \end{bmatrix}$$

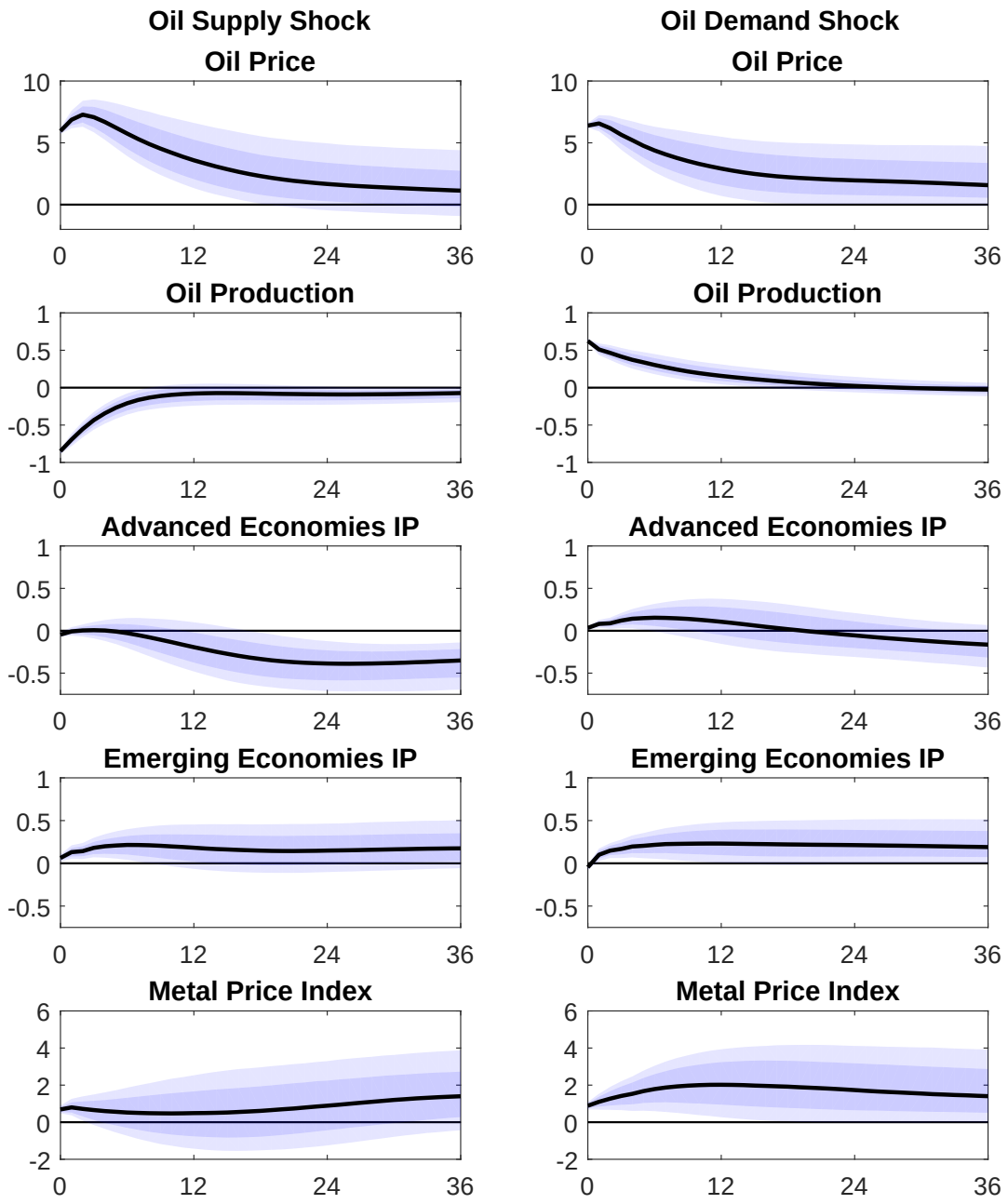
Identification of Oil Market Block

Striking Balance b/w External Information and VAR Model

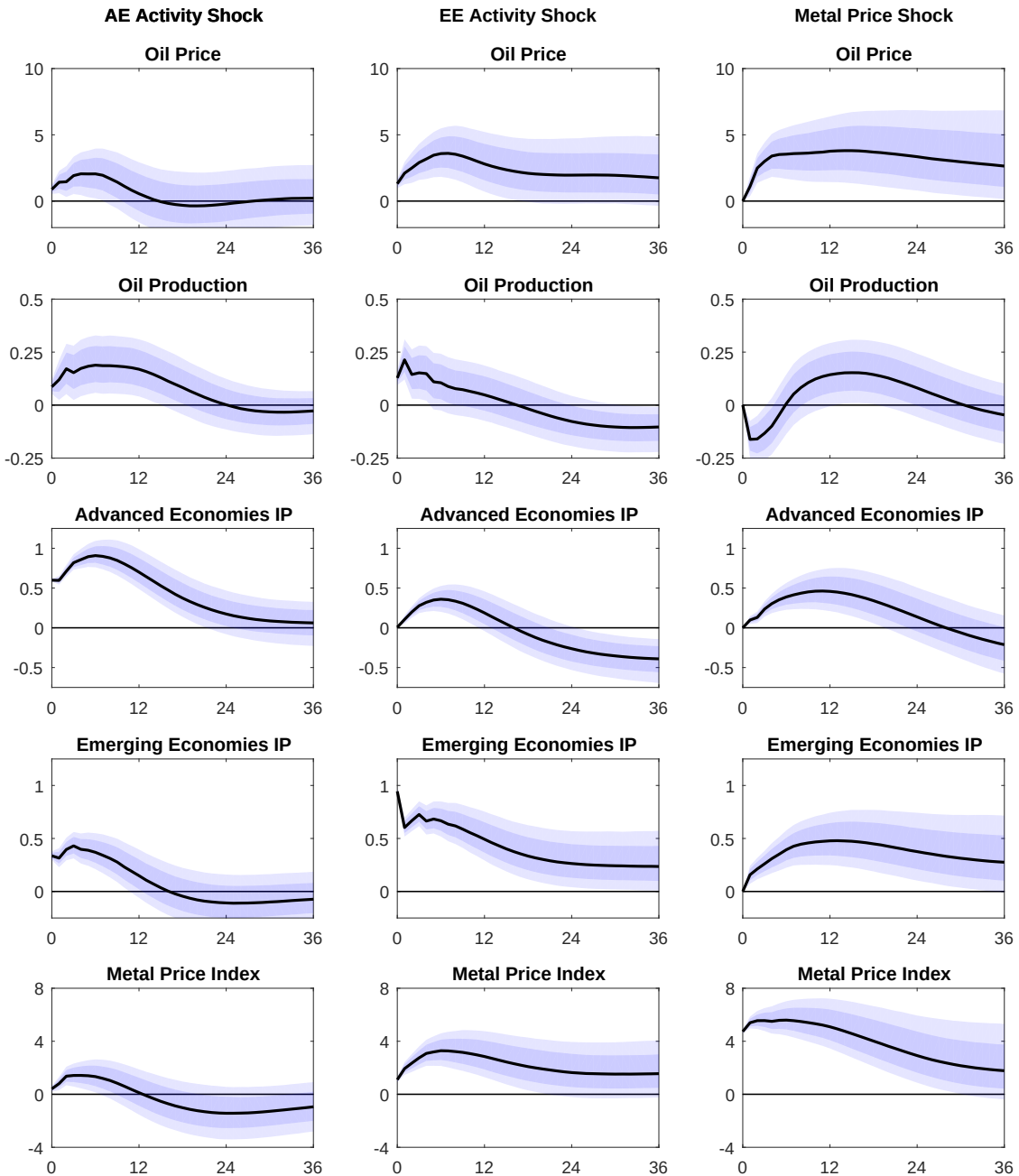


- Minimizing distance b/w VAR-admissible elasticities (Black Curve) and estimated (target) elasticities (Blue Dot)
- Selection: Supply elasticity: 0.11; Demand elasticity: -0.13.

Impulse Responses to Oil Market Shocks



Impulse Responses to Global Activity Shocks



Forecast Error Variance Decomposition

Table 4: Forecast Error Variance Decomposition of Selected Variables
24-Month Ahead

Shock	Oil Supply	Oil Demand	AE Activity	EE Activity	Metal Prices
Oil Prices	36.6	26.5	2.5	13.1	21.3
	[24.3; 46.7]	[16.6; 36.2]	[1.7; 7.7]	[5.9; 22.8]	[9.9; 32.8]
Oil Production	42.6	36.0	9.8	4.1	7.6
	[32.1; 49.5]	[25.8; 42.2]	[4.7; 17.5]	[2.8; 9.3]	[3.9; 15.5]
AE Activity	8.1	1.4	64.2	7.6	18.8
	[2.4; 18.1]	[0.9; 6.8]	[48.0; 70.9]	[5.1; 13.3]	[8.7; 29.9]
EE Activity	5.1	7.5	10.4	48.7	28.3
	[1.5; 13.6]	[2.0; 16.5]	[7.0; 16.6]	[34.1; 59.0]	[14.9; 39.6]

Summing Up Findings

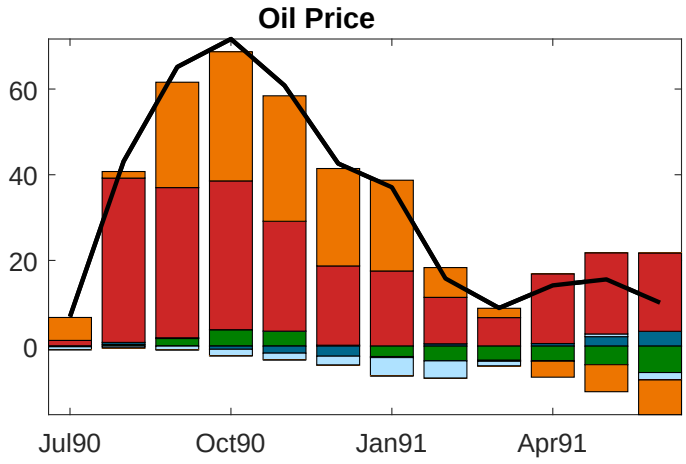
- Negative supply shock: Prices up; Depresses IP advanced; Raises IP emerging
- Positive demand shock: Prices and production up; Small effects on IPs
- Positive global activity shocks: Raise oil prices and production

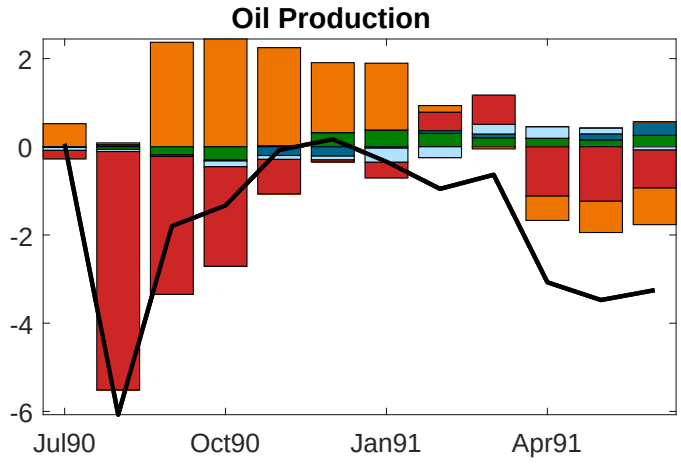
Oil price fluctuations:

- Supply shocks account for nearly 40 percent
- Demand shocks for about 20 percent
- IP emerging and metals prices account for about 35 percent
- Little role for IP advanced economies

Historical Decomposition

Persian Gulf War

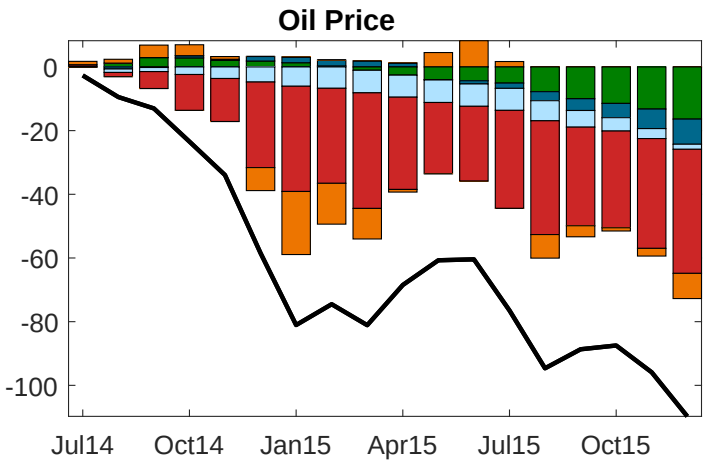


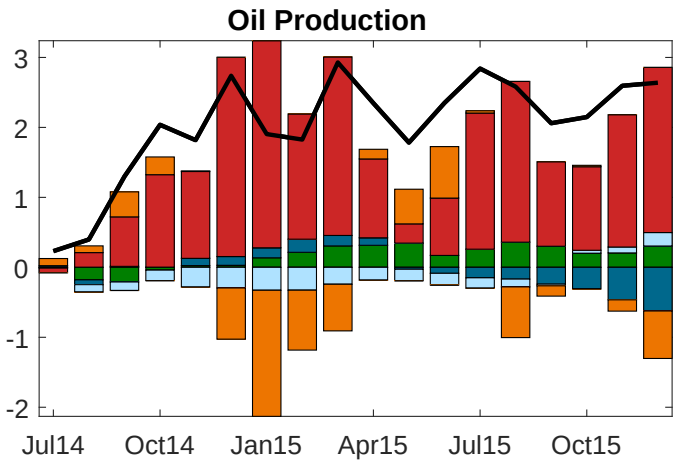


- Most of initial increase attributed to supply shocks
- Oil-specific demand shocks kicking in starting in September 1990.
- Negligible contribution of global demand shocks.

Historical Decomposition

2014-2015 Oil Price Slump





- Most of decline attributed to supply shocks
- Early 2015: Negative oil-specific demand shocks
- 2015: Negative shocks to (1) IP emerging; (2) expectations of global activity captured by metals prices

Concluding Takeaways

- Studied nature of oil price fluctuations and effects on global economy
- Structural VAR of interaction b/w oil market and global economy identified through
  - External information from large panel of countries
  - Imposing joint restrictions on supply and demand elasticities
- Supply shocks main driving force of oil-market movements
  - Account for 35 percent of price and production movements
- Global demand conditions also play important role
  - Account for 35 percent of price fluctuations, 25 percent for production
- Explain muted effects of oil prices on global activity
  - Supply-driven drops in oil prices boosts/depresses activity in advanced/emerging economies.