The Correlation of Oil and Equity Prices: The Role of the Zero Lower Bound

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Federal Reserve Board

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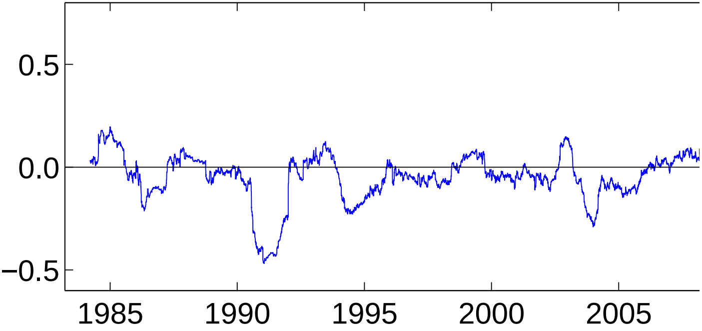
Figure: Oil-Equity Rolling Correlation



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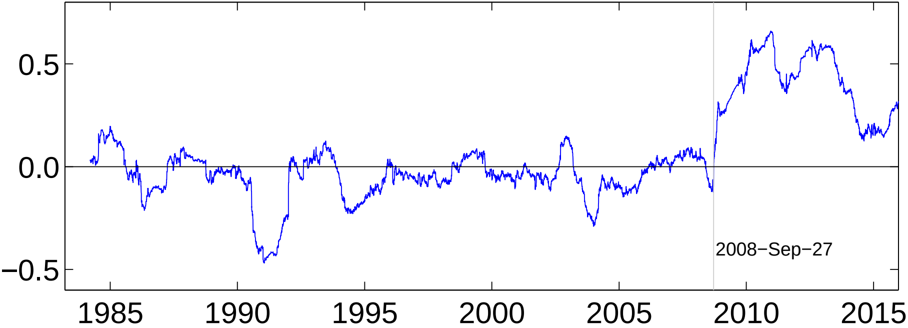
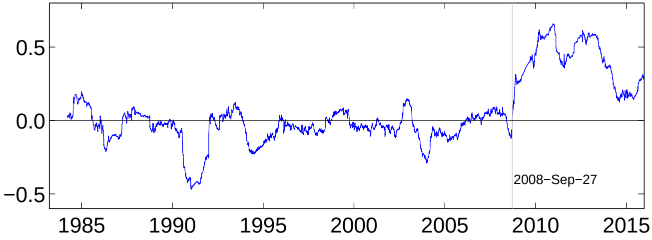


Figure: Oil-Equity Rolling Correlation



- Oil: Nearby futures for WTI (log-differences).
- Equities: Market returns on portfolio of all NYSE, AMEX, and NASDAQ firms (Fama-French).
- Daily correlation: from -0.06 before the break, to 0.41 after the break.
  - Monthly correlation jumped even more sharply: from -0.09 to 0.54.

Outline

1. Document the Increase in the Oil-Equity Correlation
2. Estimate the Responses to Macroeconomic News Surprises
3. Small Scale New-Keynesian Model with Oil:
   Response to Shocks under the ZLB

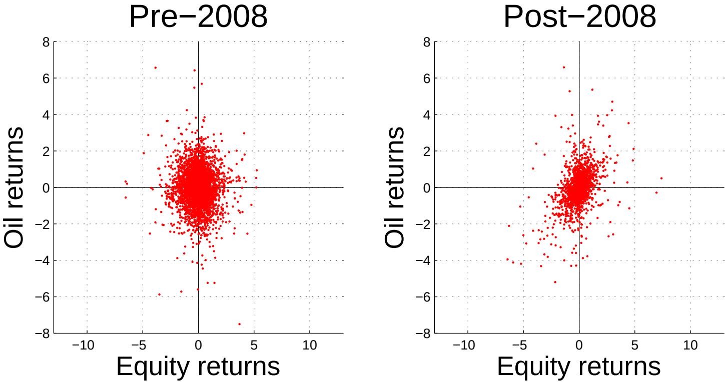

Pre−2008
Post−2008
Oil returns
Equity returns
8
6
4
2
0
−2
−4
−6
−8
−10
−5
0
5
10

Figure: Rolling Equity Beta for Oil

$$Oil_t = \alpha + \beta Equity_t + \varepsilon_t.$$

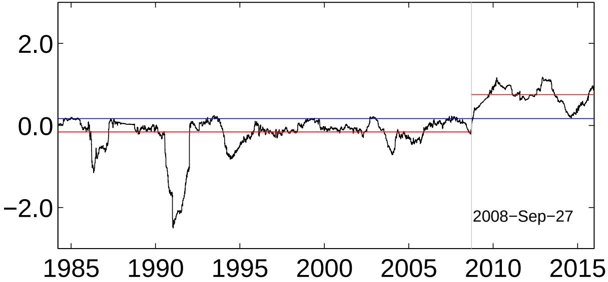


Table: Testing for a Structural Break

	Full Sample		Pre-Break		Post-Break	
	β	t-stat	β	t-stat	β	t-stat
Full equity index	0.17	6.93	-0.16	-5.26	0.75	19.62

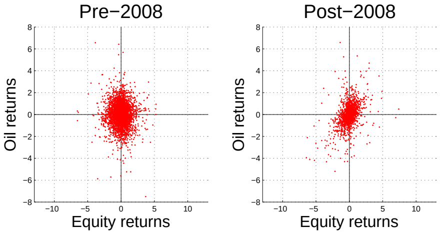
Testing for a Structural Break

		Pre-Break		Post-Break	
Sectors	Break Date	β	t-stat	β	t-stat
Full equity index	2008-Sep-27	-0.16	-5.26	0.75	19.62
Consumer nondurables	2008-Sep-27	-0.3	-9.32	0.87	16.33
Consumer durables	2008-Sep-27	-0.17	-7.31	0.49	17.76
Manufacturing	2008-Sep-27	-0.14	-4.88	0.67	21.06
Energy	2008-Nov-22	0.47	22.88	0.9	31.67
Chemicals	2008-Sep-27	-0.21	-7.41	0.79	19.28
Business equipment	2008-Sep-27	-0.07	-3.84	0.65	17.29
Telecommunications	2008-Sep-27	-0.16	-6.50	0.66	17.29
Utilities	2008-Jul-05	-0.05	-1.44	0.71	16.49
Shops	2008-Sep-27	-0.27	-10.54	0.65	14.13
Health care	2008-Sep-27	-0.21	-8.07	0.63	13.41
Finance	2008-Sep-27	-0.21	-8.53	0.4	15.32
Other	2008-Sep-27	-0.17	-6.32	0.65	18.51

Why should we care?

Perhaps surprisingly, as a way to understand the effects of the Zero Lower Bound.

- Our empirical evidence is that the ZLB is associated with the changing relationship between oil and equity prices.
  We also establish that:
- In a DSGE model where the ZLB is a binding constraint, the correlation between oil and equity prices increases when the ZLB is binding.
- By constrast, a model where the ZLB is not a binding constraint does not imply such a change in the correlation.
- By showing that different rules apply at the ZLB for oil and equity prices, we restrict the set of empirically plausible DSGE models.
- In the model that we find more plausible, fiscal multipliers are larger at the ZLB.
- As such, we contribute to on going debate in the macro literature. (eg Weiland, 2016).



- To test theory, see if responses to shocks changes with the ZLB.
- What shocks to use? We use macroeconomic news surprises.

News is defined as the difference between the actual and expected announcements.

- Expectations are the median response from a survey of financial market institutions and professional forecasters.
- Conducted the Friday before each data release, and reported by Action Economics (successor of Money Market Services).

Estimating Macroeconomic News Responses

For example, on the first Friday of the month, the Bureau of Labor Statistics announces the change in nonfarm payrolls for the previous month.

- In October 2015
  - BLS announced nonfarm payrolls increased 142,000.
  - Analysts had expected 200,000.
  - News surprise is -58,000.
- In January 2013
  - BLS announced nonfarm payrolls increased 155,000.
  - Analysts had expected 155,000.
  - News surprise is 0.

Benefit of Studying News Surprises

- We know the release schedule, which makes reporting and timing of the news exogenous to price events.
- Other events may be much more important for moving prices.
- However, the risk is that reporters ex-post attribute price movements to events that may not have been important.

Many papers on surprises, including Gilbert, Scotti, Strasser, and Vega (2015)

- *The literature is vast and we make no attempt to survey it.*
- ... and then they cite 18 papers.

Most Relevant Papers on Surprises

- Kilian and Vega (REStat 2011): Do Energy Prices Respond to U.S. Macroeconomic News?
  - Studies how oil prices respond to macroeconomic news.
  - Concludes that there is "no compelling evidence of feedback."
  - Data sample ends in spring of 2008.
- Swanson and Williams (AER 2014). Measuring the Effect of the Zero Lower Bound on Medium- and Longer-Term Interest Rates
  - Studies the ZLB effects on longer-term interest rates.
  - 1- and 2-year Treasury yields responded to news (*unconstrained*) in 2008 to 2010.
  - But did not respond to news (*constrained*) starting in 2011.

Theories

Extend on the findings of Kilian and Vega and Swanson and Williams.

- Before 2008, oil prices did not respond to macro surprises.
- However, we have evidence of increased responsiveness thereafter.

Could this be driven by the ZLB?
More formal theory to come, but intuition is:

- In non-ZLB periods, oil prices and equity returns do not respond to news because markets expect monetary policy will offset the news.
- In ZLB period, oil prices and equity returns do respond to news because monetary policy cannot offset the news.

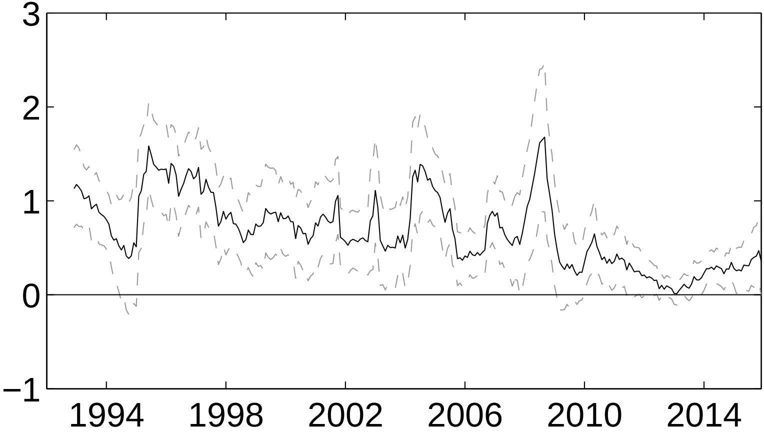
Measuring Time-Varying Sensitivity to News

- First, adopt approach of Swanson and Williams.
- Later, we will present an alternative method.
- For each dependent variable, estimate the following regression for the sample period from $[\tau - (365), \tau]$.

$$Y_t = \alpha^\tau + \delta^\tau \hat{\beta} \boldsymbol{S_t} + \varepsilon_t^\tau$$

- Swanson and Williams estimated δ^τ and β^τ jointly as a nonlinear least squares problem.
- We first estimate $\hat{\beta}$ over a subsample of the data using $Y_t = \alpha + \beta \boldsymbol{S_t} + \varepsilon_t$, and then estimate δ^τ in a rolling regression with $\hat{\beta}$ fixed.

Figure: Interest Rate Response to News (δ^τ)



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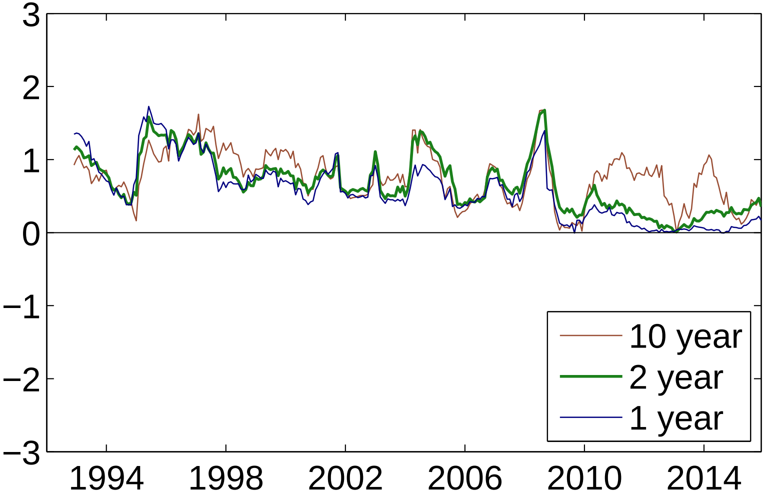
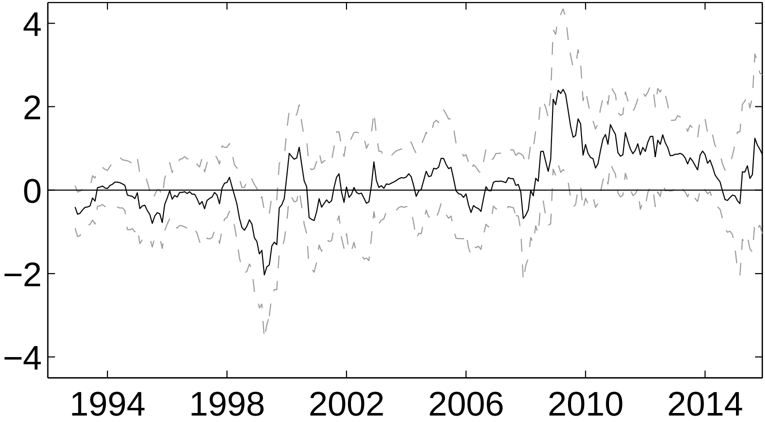


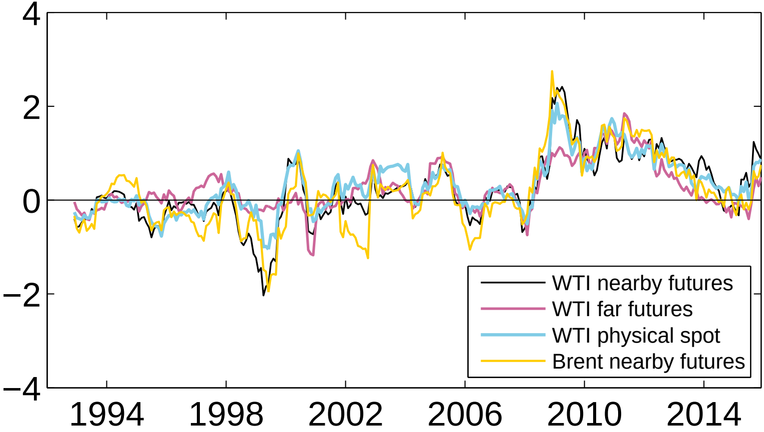
$$Y_t = \alpha^\tau + \delta^\tau \hat{\beta} \boldsymbol{S_t} + \varepsilon_t^\tau$$

Figure: Oil Responses to News (δ^τ)



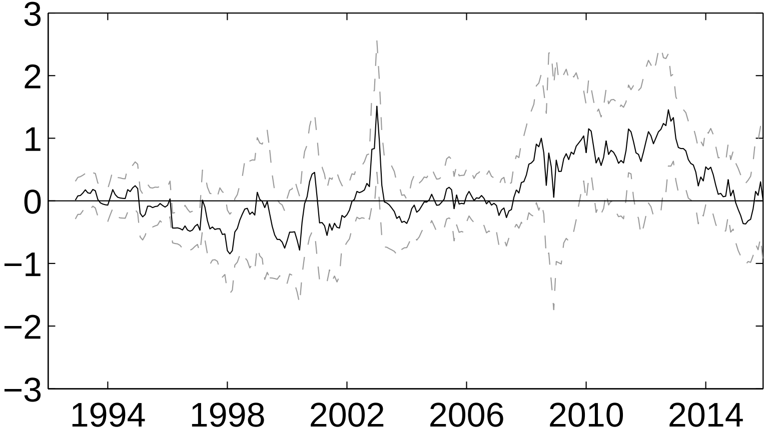
$$Y_t = \alpha^\tau + \delta^\tau \hat{\boldsymbol{\beta}} \boldsymbol{S_t} + \varepsilon_t^\tau$$

Figure: Oil Response to News (δ^{τ})



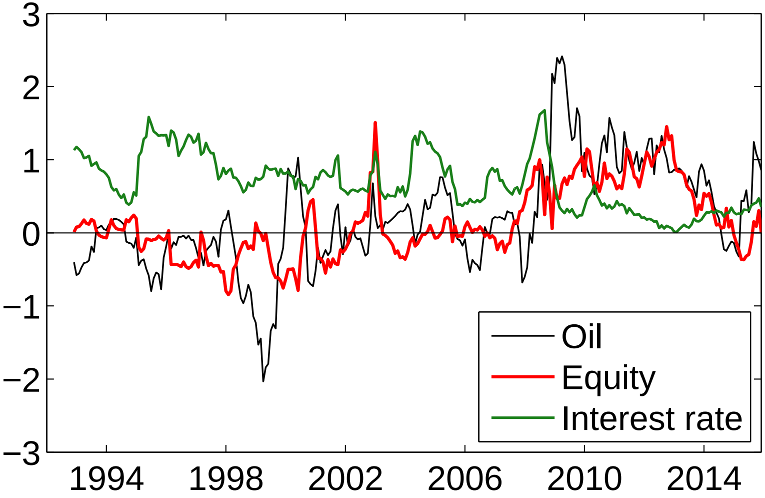
$$Y_t = \alpha^{\tau} + \delta^{\tau} \hat{\beta} \boldsymbol{S_t} + \varepsilon_t^{\tau}$$

Figure: Equity Response to News (δ^{τ})



$$Y_t = \alpha^{\tau} + \delta^{\tau} \hat{\beta} \boldsymbol{S_t} + \varepsilon_t^{\tau}$$

Figure: Responses to News



$$Y_t = \alpha^\tau + \delta^\tau \hat{\beta} \boldsymbol{S_t} + \varepsilon_t^\tau$$

But is it really the ZLB?

We have shown that responsiveness varies over *time*.
Now, we show that the oil-equity correlation and the responsiveness to surprises vary specifically with a *measure of the ZLB*.

- Our ZLB measure: the implied interest rate, Z_k, as the predicted federal funds rate using the modified Taylor rule in Bernanke (2015).
- Return to the regression $Oil_t = \alpha + \beta Equity_t + \varepsilon$.
- Estimate $\Gamma(Z_k) \equiv \{\alpha(Z_k), \beta(Z_k)\}$ by minimizing for each value of Z_k

$$\sum_t \phi\left(\frac{Z_t - Z_k}{h}\right)(Oil_t - \alpha - \beta Equity_t)^2$$

  with respect to (α, β), where ϕ is the pdf for a standard normal distribution.
- Intuition: more weight on observed pairs of (y_t, x_t) when Z_t is close to Z_k.

Figure: Implied Interest Rate

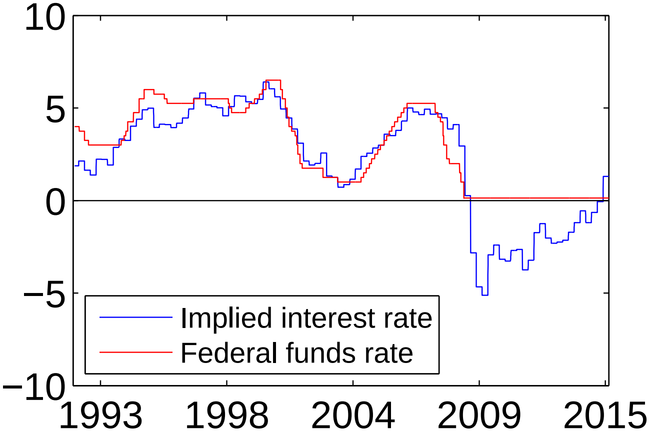


Figure: Explaining the Equity Beta for Oil

$$Oil_t = \alpha(Z_t) + \beta(Z_t) Equity_t + \varepsilon_t$$

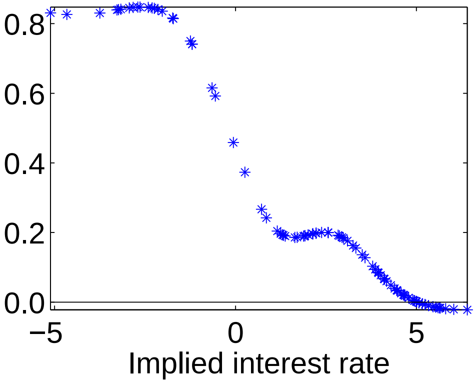
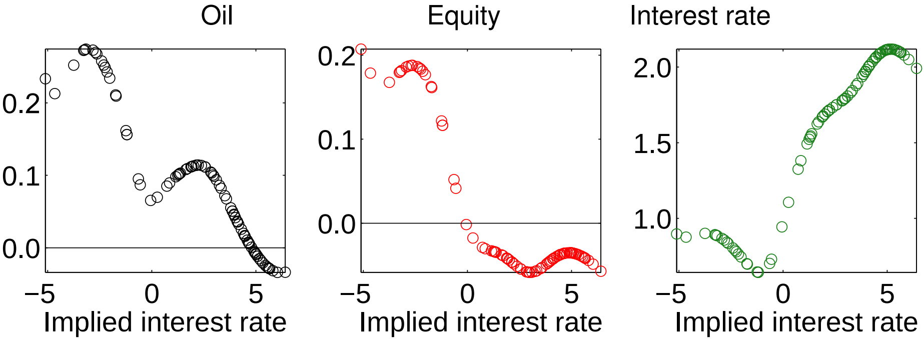


Figure: Explaining the Responsiveness to Surprises



$$Y_t = \alpha(Z_t) + \beta(Z_t)\boldsymbol{S_t} + \varepsilon_t$$

Alternative Hypotheses

Figure: VIX

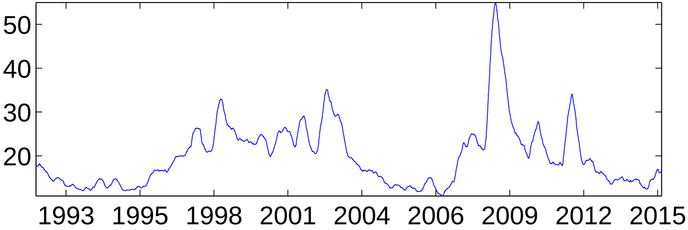
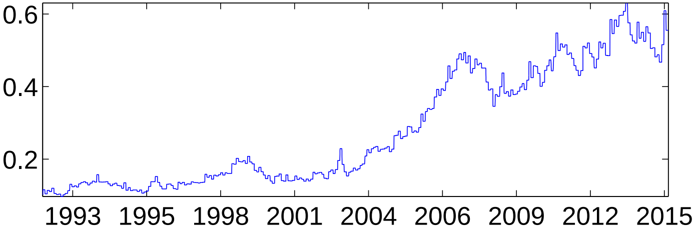


Figure: Open Interest



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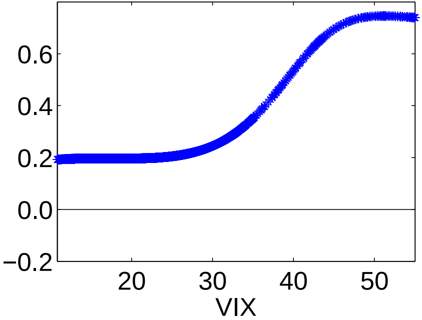
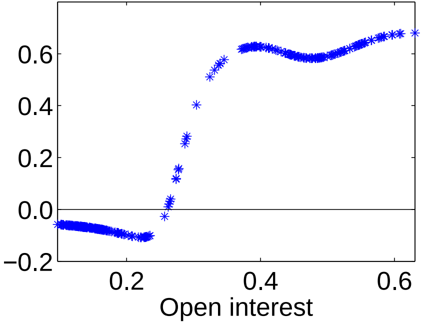
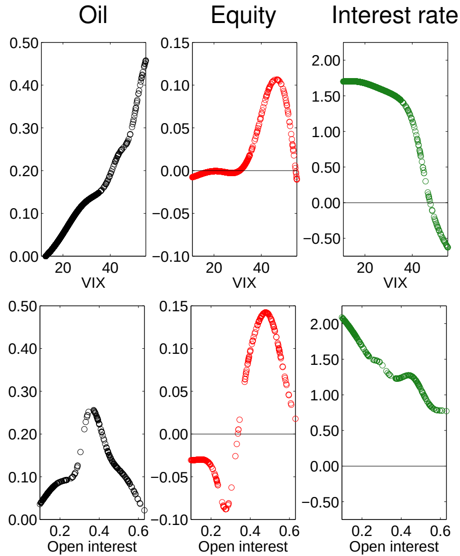




$$Oil_t = \alpha(X_t) + \beta(X_t) Equity_t + \varepsilon_t$$

Figure: Explaining the Responsiveness to Surprises



Testing the Models

To test against the linear model, we use the following procedure.
Calculate the sum of squared residuals for the unrestricted estimated model.

$$SSR(Z) = \sum_t \left(Oil_t - \hat{\alpha}(Z_t) - \hat{\beta}(Z_t) Equity_t \right)^2$$

Calculate the sum of squared residuals for the restricted linear model.

$$SSR = \sum_t \left(Oil_t - \hat{\alpha} - \hat{\beta} Equity_t \right)^2$$

Compute the test statistic.

$$F(Z) = \frac{SSR - SSR(Z)}{SSR(Z)}$$

Need to determine the critical value.

Compute the Critical Value for the Null Hypothesis of the Linear Model

Use a wild bootstrap to create 1000 simulated datasets.
For each simulation i, use the restricted model estimates for $\hat{\alpha}$, $\hat{\beta}$, and $\hat{\varepsilon}_t$ to generate:

$$Y_{it}^{sim} = \hat{\alpha} - \hat{\beta} Equity_t + \nu_{it} * \hat{\varepsilon}_t.$$

- Leave the $Equity_t$ and Z_t variables fixed.
- Scales the residuals $\hat{\varepsilon}_t$ by $\nu_{it} \sim N(0, 1)$

Using these Y_{it}^{sim}, we estimate both the linear model and the unrestricted model and generate the resulting distribution of F-statistics.
Determine how frequently one would observe in this simulated distribution the empirical F-statistic computed using the actual data.

Testing the Alternative Explanations

To test two alternative explanations against each other, we follow a similar process. Estimate an unrestricted model that uses both the implied interest rate Z_t and one of the alternatives, here VIX_t. $\alpha(VIX_t, Z_t)$ and $\beta(VIX_t, Z_t)$ For each explanation, calculate the sum of squared residuals for the unrestricted model.

$$SSR(VIX, Z) = \sum_t \left(Oil_t - \hat{\alpha}(VIX_t, Z_t) - \hat{\beta}(VIX_t, Z_t) Equity_t \right)^2$$

To test whether the implied interest rate Z_t does not contribution to the explanation , calculate the the sum of squared residuals for the model excluding Z_t.

$$SSR(VIX) = \sum_t \left(Oil_t - \alpha(VIX_t) - \beta(VIX_t) Equity_t \right)^2$$

Compute the test statistic.

$$F(Z) = \frac{SSR(VIX) - SSR(VIX, Z)}{SSR(VIX, Z)}$$

Need to determine the critical value.

Compute the Critical Value for the Null Hypothesis that Z is not needed.

Again use a wild bootstrap.
For each simulation i, use the restricted model estimates for $\hat{\alpha}(VIX)$, $\hat{\beta}(VIX)$, and $\hat{\varepsilon}_t$ to generate:

$$Y_{it}^{sim} = \hat{\alpha}(VIX) - \hat{\beta}(VIX)Equity_t + \nu_{it} * \hat{\varepsilon}_t.$$

- Leave the $Equity_t$ and VIX_t and Z_t variables fixed.
- Scales the residuals $\hat{\varepsilon}_t$ by $\nu_{it} \sim N(0, 1)$

Using these Y_{it}^{sim}, we estimate under the restricted and unrestricted models, and generate a distribution of F-statistics.
Determine how frequently one would observe in this simulated distribution the empirical F-statistic computed using the actual data.

Varying responsiveness to surprises

Does the implied interest rate (Z_k) help explain the variation in the responsiveness to surprises?

Table: P-values for testing H_0: Restricted = Unrestricted model

		Dependent Variable (Y_t)		
Unrestricted	Restricted	Oil	Equity	Interest Rate
$\boldsymbol{\Gamma}(Z_k)$	$\boldsymbol{\Gamma}$	0.00 (yes)	0.00 (yes)	0.00 (yes)
$\boldsymbol{\Gamma}(Z_k, VIX_k)$	$\boldsymbol{\Gamma}(VIX_k)$	0.00 (yes)	0.02 (yes)	0.00 (yes)
$\boldsymbol{\Gamma}(Z_k, OI_k)$	$\boldsymbol{\Gamma}(OI_k)$	0.01 (yes)	0.03 (yes)	0.00 (yes)

$$Y_t = \alpha(.) + \boldsymbol{\beta}(.)\boldsymbol{S_t} + \varepsilon_t, \qquad \boldsymbol{\Gamma}(.) = \{\alpha(.), \boldsymbol{\beta}(.)\}$$

Varying responsiveness to surprises

Do the alternatives (VIX_t, OI_t) help explain the variation in the responsiveness to surprises?

Table: P-values for testing H_0: Restricted = Unrestricted model

		Dependent Variable (Y_t)		
Unrestricted	Restricted	Oil	Equity	Interest Rate
$\boldsymbol{\Gamma}(VIX_k)$	$\boldsymbol{\Gamma}$	0.38 (no)	0.61 (no)	0.13 (no)
$\boldsymbol{\Gamma}(Z_k, VIX_k)$	$\boldsymbol{\Gamma}(Z_k)$	0.30 (no)	0.34 (no)	0.09 (yes)
$\boldsymbol{\Gamma}(OI_k)$	$\boldsymbol{\Gamma}$	0.51 (no)	0.30 (no)	0.11 (no)
$\boldsymbol{\Gamma}(Z_k, OI_k)$	$\boldsymbol{\Gamma}(Z_k)$	0.38 (no)	0.30 (no)	0.09 (yes)

$$Y_t = \alpha(.) + \beta(.)\boldsymbol{S_t} + \varepsilon_t, \qquad \boldsymbol{\Gamma}(.) = \{\alpha(.), \beta(.)\}$$

What have we learned?

- Oil prices and equities became more correlated in late 2008.
- Oil prices and equities became more responsive to news in late 2008.
- Provided empirical evidence that different rules apply at the zero lower bound.

We present a New-Keynesian model to build understanding of the relationship between oil prices, equity prices, and the ZLB.

Model: Households

Preferences given by

$$\mathcal{U}_t = E_t \sum_{j=0}^{\infty} \beta^j u\left(C_{t+j}, C^O_{t+j}, L_{t+j}, \frac{B_{t+j}}{P_{t+j}}\right)$$

where C_t is non-oil consumption, C^O_t is oil consumption, L_t are hours worked and $\frac{B_{t+j}}{P_{t+j}}$ are real bond holdings as in Fisher (2014).

The per-period budget constraint is

$$\frac{B_t}{P_t} + \frac{P^O_t}{P_t} C^O_t + C_t + \frac{P^K_t}{P_t} K_{t+1} \leq \frac{W_t}{P_t} L_t + R_{t-1} \frac{B_{t-1}}{P_t} + \frac{R^K_t}{P_t} K_t + T_t + \frac{P^K_t}{P_t} K_t$$

where T_t are taxes, transfers, and profits (lump-sum).

Note that K_t will be fixed in aggregate, P^K_t is the price of capital, and R^K_t is the nominal rental rate of capital.

Model: Final Goods Retailers

Retailers produce final output (with $\epsilon > 1$):

$$Y_t = \left(\int_0^1 Y_t(j)^{\frac{\epsilon-1}{\epsilon}} dj \right)^{\frac{\epsilon}{\epsilon-1}}$$

Implying the demand curve for each intermediate input:

$$Y_t(j) = \left(\frac{P_t(j)}{P_t} \right)^{-\epsilon} Y_t$$

Model: Intermediate Goods Firms

Intermediate goods producers maximize

$$E_t \sum_{m=0}^{\infty} M_{t,t+m} \left[\frac{(1+\tau)P_{t+m}(j) - MC_{t+m}}{P_{t+m}} \left(\frac{P_{t+m}(j)}{P_{t+m}} \right)^{-\epsilon} Y_{t+m} \right.$$
$$\left. - \frac{\phi}{2} \left(\frac{P_{t+m}(j)}{P_{t+m-1}(j)} - 1 \right)^2 \right]$$

where $M_{t,t+k}$ is the household SDF. Their production technology is

$$Y_t = \left((1-\omega_Y)^{\frac{\rho_Y}{1+\rho_Y}} V_t^{\frac{1}{1+\rho_Y}} + (\omega_Y)^{\frac{\rho_Y}{1+\rho_Y}} \left(V_t^O \right)^{\frac{1}{1+\rho_Y}} \right)^{1+\rho_Y},$$

where

$$V_t(j) = K_t(j)^{\alpha} L_t(j)^{1-\alpha}.$$

Policy and Exogenous Processes

Government purchases (G_t), oil supply (O_t^S), and preference shifters (spread shocks, η_t, and oil demand shocks, μ_t) are exogenous and follow the process

$$\log\left(x_t/\bar{x}\right) = \rho_x \log\left(x_t/\bar{x}\right) + \sigma_x \varepsilon_t^x .$$

The difference between a model where the ZLB binds and not binds is determined by the interest rate rule.

ZLB Binding: The monetary authority follows a truncated Taylor rule

$$R_t = \max\left\{1, \frac{1-\eta}{\beta} + \theta_\pi(\pi_t - 1)\right\}$$

ZLB Not Binding: The monetary authority is unconstrained by the ZLB.

$$R_t = \frac{1-\eta}{\beta} + \theta_\pi(\pi_t - 1)$$

Parameters and Functional Forms

Per-period utility is given by

$$u\left(C_t, C_t^O, L_t, \frac{B_t}{P_t}\right) = \log\left[\left((1-\omega_C)^{\frac{\rho_C}{1+\rho_C}} C_t^{\frac{1}{1+\rho_C}} + (\omega_C)^{\frac{\rho_C}{1+\rho_C}} \left(\frac{C_t^O}{\mu_{C^O,t}}\right)^{\frac{1}{1+\rho_C}}\right)^{1+\rho_C}\right] - \frac{\chi}{1+\phi} L_t^{1+\phi} + \Xi_t v\left(\frac{B_t}{P_t}\right).$$

Baseline parameter values

$$\begin{aligned} \beta &= 0.985, \text{ spread} = 0.01 \\ \epsilon &= 7, \ \phi = 200 \\ \alpha &= 1/3, \ \theta_\pi = 1.5 \end{aligned}$$

Oil-specific parameters similar to Bodenstein, Guerrieri, and Gust (2013)

$$\omega_Y = 0.03, \ \omega_C = 0.02$$
$$\rho_Y = -2, \ \rho_C = -2$$

Experiments

Solution Method

- Non-linear solution to accommodate ZLB
- Project decision rules onto Smolyak polynomials

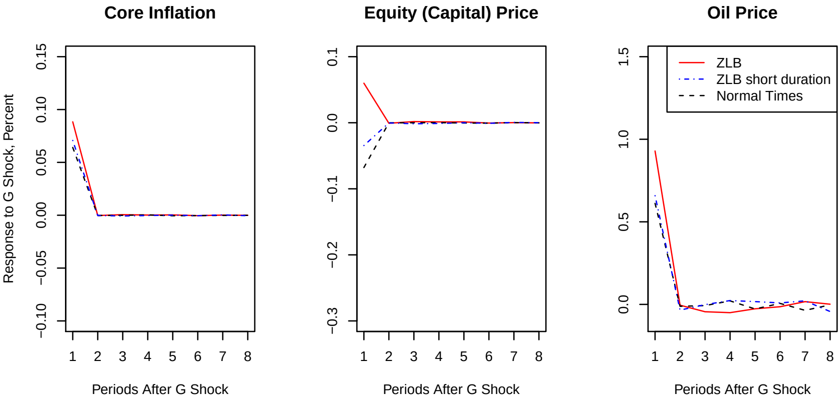
Setup

- A shock causes the spread between riskless and risky assets to be high.
- ZLB binds as a result.
- Consider government demand shocks (G_t), oil demand shocks (μ_t^O), and oil supply shocks (O_t^S).

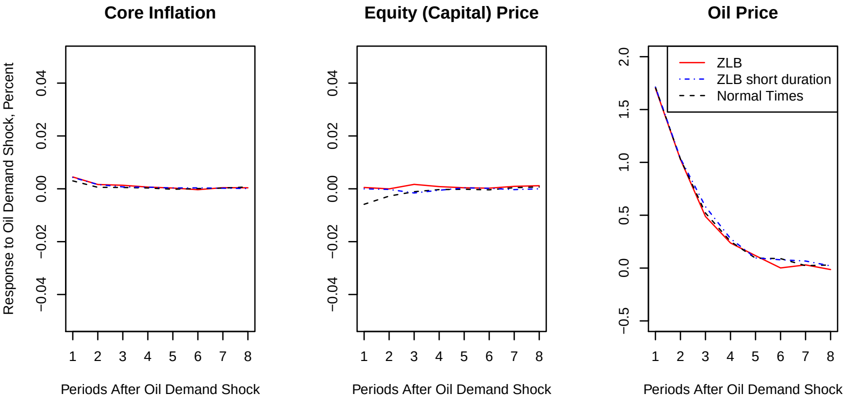
Key takeaways

- In response to the three shocks, the equity and oil prices move in the same direction at the ZLB and opposite directions away from the ZLB.
- Consistent with previous literature, the effect of shocks change when the ZLB binds because the monetary authority does not respond to changes in inflation at the ZLB.

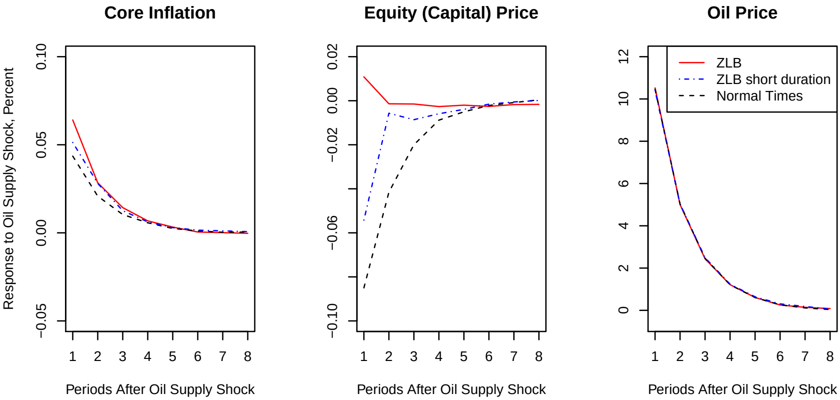
G Shock


Core Inflation
Equity (Capital) Price
Oil Price
Response to G Shock, Percent
0.15
0.10
0.05
0.00
−0.05
−0.10
0.1
0.0
−0.1
−0.2
−0.3
1.5
1.0
0.5
0.0
1 2 3 4 5 6 7 8
Periods After G Shock
Periods After G Shock
Periods After G Shock
ZLB
ZLB short duration
Normal Times

Oil DemandShock



Oil Supply


Core Inflation
Equity (Capital) Price
Oil Price
Response to Oil Supply Shock, Percent
0.10
0.05
0.00
−0.05
0.02
0.00
−0.02
−0.06
−0.10
12
10
8
6
4
2
0
1 2 3 4 5 6 7 8
Periods After Oil Supply Shock
ZLB
ZLB short duration
Normal Times

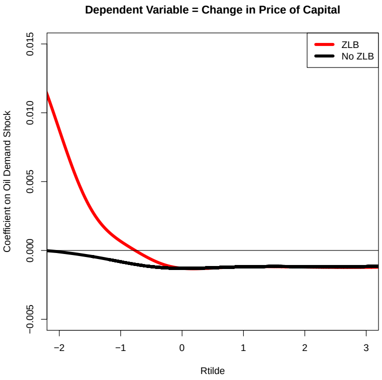
News Regression in A DSGE Model: Demand Shock

Model analogy to news annoucement regressions is the impact responses to structural shocks.

Do this for both the model where the ZLB is binding

$R_t = \max\left\{1, \frac{1-\eta}{\beta} + \theta_\pi(\pi_t - 1)\right\}$

and for the model where the ZLB is not binding. $R_t = \frac{1-\eta}{\beta} + \theta_\pi(\pi_t - 1)$



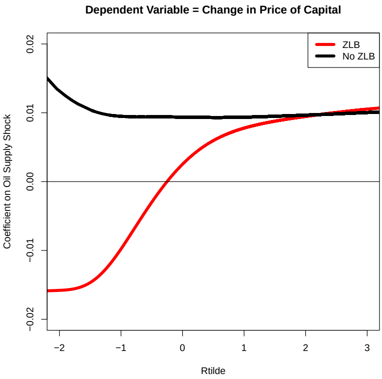
News Regression in A DSGE Model: Supply Shock

Model analogy to news annoucement regressions is the impact responses to structural shocks.

Do this for both the model where the ZLB is binding

$R_t = \max\left\{1, \frac{1-\eta}{\beta} + \theta_\pi(\pi_t - 1)\right\}$

and for the model where the ZLB is not binding. $R_t = \frac{1-\eta}{\beta} + \theta_\pi(\pi_t - 1)$

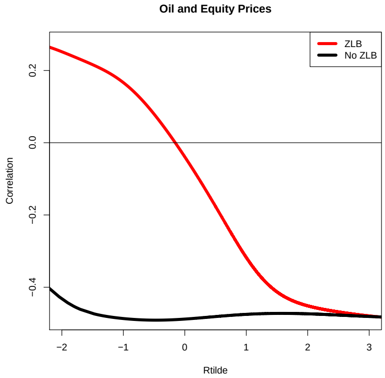


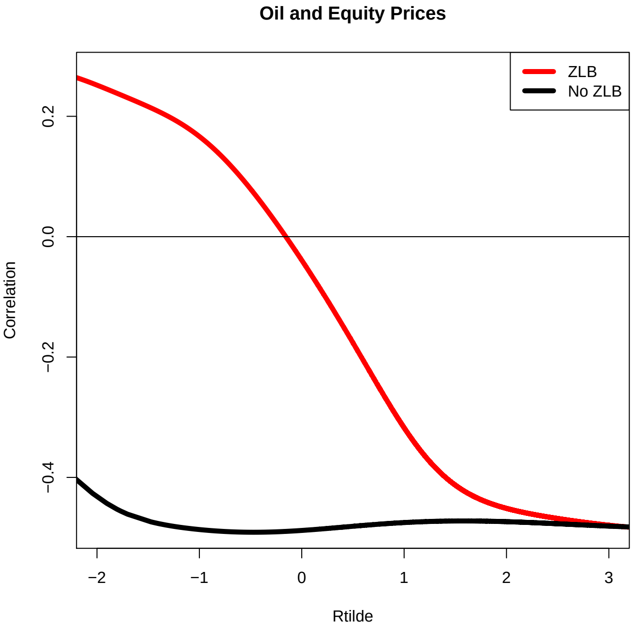
Kernel Regression in A DSGE Model

Simulate data from the model and estimate the same kernel regression as in the empirical section.

$Oil_t = \alpha(Z_t) + \beta(Z_t)Equity_t + \varepsilon_t$

Do this for both the model where the ZLB is binding and for the model where the ZLB is not binding.




Oil and Equity Prices
ZLB
No ZLB
Correlation
0.2
0.0
−0.2
−0.4
−2
−1
0
1
2
3
Rtilde

Conclusion

Oil and equity returns have been positively correlated since September 2008.

- Oil prices and equity returns have become more responsive to macroeconomic news since September 2008, while interest rates have become less responsive.
- Kernel regressions suggest that the variation is due to the ZLB.

Implications for Macroeconomic Modelling

- We show that a standard New-Keynesian model where the ZLB is not a binding constraint would not generate this result.
- Instead, only when the ZLB is a binding constraint, do we find that the correlation varies with the shadow rate.
  - Consistent with previous literature, the effect of shocks changes when the ZLB binds because the monetary authority does not respond to changes in inflation at the ZLB.
  - These models are consistent with literature predicting larger fiscal multipliers at the ZLB.

Is it really ZLB?

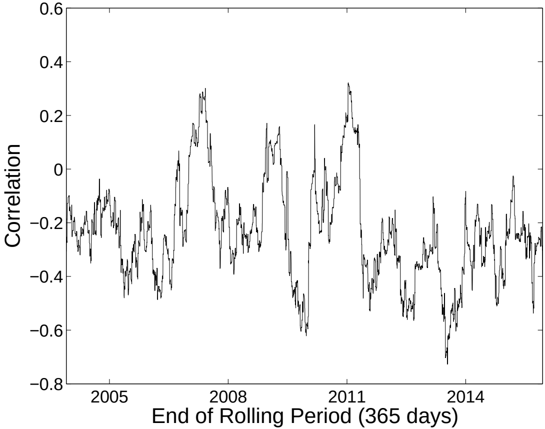
- Have shown that oil and equity prices respond in time varying way to macroeconomic news. The time variation appears to be related to the monetary constraints e.g. ZLB
- Further tests: Do Oil and Equity respond differently to News that is important to the oil market but not to Federal Reserve?
    - News: crude oil inventory surprises. Data is available from 2003-2015

Did Oil Price Move For Different Reasons?- Oil Inventory Story

Look for a structural change, using F-test for statistical significance of the break dates found.

- Oil price:
  - None for surprises series
  - One significant break date on 16Dec2000 using differenced and standardized series for longer sample period
- Equity returns: none

Figure: Oil Price Rolling Correlation with Oil Inventory News



Measuring Sensitivity to News

Table: Inventory Surprises Pre- and Post- Break Regression Results

	Inventory Surprises		Inventory Changes	
	Oil	Equity	Oil	Equity
Oil-specific news	-0.45	0.11	-0.35	-0.03
	-2.80	1.33	-3.90	-0.68
Oil-specific news *Post-break dummy	-0.02	-0.14	-0.02	-0.01
	-0.11	-1.32	-0.09	-0.16
Federal Funds Rate Surprise	-0.02	-0.15	-0.04	-0.15
	-0.10	-1.49	-0.20	-1.65
Post-break Response				
$\beta_1 + \beta_5$	-0.47	-0.03	-0.37	-0.04
F-stat	13.48	0.20	7.01	0.41
p-value	0.00	0.66	0.01	0.52
Observations	778	778	1318	1318

Figure: Oil Price Rolling Beta to Oil Inventory News

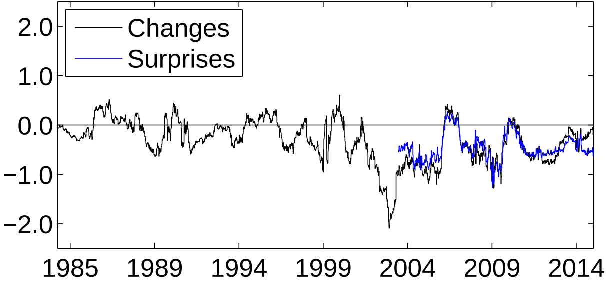


Figure: Equity Ex-energy Rolling Beta to Oil Inventory News