Dynamic Relation between Volatility Risk Premia of Stock and Oil Returns

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1. Motivation, focus, and findings

Motivation（1）

Volatility Risk Premium（$\mathrm{VRP_t}$）

Reward for bearing future volatility risk:

$$\mathrm{VRP_t} \equiv \mathrm{E_t^Q}[\sigma_{t+T}] - \mathrm{E_t^P}[\sigma_{t+T}]$$

Q: risk neutral probability, P: original probability,

Empirical approximation of VRP:

$$\mathbf{VRP_t \equiv IV_t - RV_t}$$

$\mathrm{IV_t}$: implied volatility, $\mathrm{RV_t}$: realized volatility

Motivation (2)

Volatility Risk Premium (VRP_t)

Regarded as investors' sentiment (i.e., aversion of future uncertainty)

Investors' sentiment gets worse.
=> Current asset prices are lower
=> Future asset returns become higher.

We can expect high VRP predicts high future returns of assets.

Motivation（3）

Return-predictability of VRP:

Many papers have found predictive power of VRPs on returns of many different assets.

- Bollerslev, Tauchen, and Zhou (2009):
  U.S. aggregate stock market returns (S&P500)

- Bollerslev, Marrone, Xu, and Zhou (2009):
  Returns of stock indices in other advanced countries

- Della Corte, Ramadorai, and Sarno (2016)
  Londono and Zhou (2017) :
  Exchange rates

- Ornelas and Mauad (2017):
  Commodity currencies, stocks, bonds, gold, and oil

Focus of this paper

Dynamic relation between VRP's of different assets

Interpreted to represent how investors' sentiment is transmitted from one asset market to another over time.

This point is important especially between stock and oil because of the *financialization* of commodities.

=> We investigate dynamic relation between VRP's of stock and oil using daily data.

Motivation（4）

Relation among IV's and RV's (and returns):

- Liu, Ji, and Fan (2013):
  Dynamic relation among IV's (VIX, OVX, GVZ, and EVZ)
  VIX strongly Granger causes OVX. (Spillover is from stock to oil.)
  Shocks in IV's have only temporary effects on each other.

- Robe and Wallen (2016):
  Regress oil IV on a number of explanatory variables.
  VIX has significant explanatory power on oil IV.

- Christoffersen and Pan (2018):
  Oil IV predicts RV of stock market and returns of individual stocks .
  Increases in oil IV predict tightening funding constraints of fin. Intermediaries.

Motivation (5)

Dynamic relation among stock VRP's:

- Hattori, Shim, and Sugihara (2018)

Spillovers from US and Euro VRP's to the other countries' VRP's are evident during the post-GFC period.

Increase of US VRP tends to reduce (weekly) equity fund flow to all other advanced and emerging economies. (<= Possible cause of spillover.)

Findings of this paper

Spillover exists between oil VRP and stock VRP after GFC.

Before GFC:

No dynamic relation is found between stock and oil VRP's.

After GFC:

Oil VRP has, though small, positive and long-lasting effect on stock VRP.

Stock VRP has limited and short-lived effect on oil VRP.

=> Spillover of sentiment is from oil market to stock market!

2. Data

Data (1)

$\mathrm{VRP}_{\mathrm{sp}_t}$: Daily VRP of S&P500 (stock VRP)

$$\mathrm{VRP}_{\mathrm{sp}_t} \equiv \mathrm{IV}_{\mathrm{sp}_t} - \mathrm{RV}_{\mathrm{sp}_t}$$

$\mathrm{IV}_{\mathrm{sp}_t}$: Daily IV of S&P 500

VIX published by the Chicago Board of Trade (CBOE).

$\mathrm{RV}_{\mathrm{sp}_t}$: Daily RV of S&P 500

provided by the Oxford-Man Institute of Quantitative Finance

Data (2)

$\mathrm{VRP}_{\mathrm{oil}_t}$: Daily VRP of USO (oil VRP)

$$\mathrm{VRP}_{\mathrm{oil}_t} \equiv \mathrm{IV}_{\mathrm{oil}_t} - \mathrm{RV}_{\mathrm{oil}_t}$$

$\mathrm{IV}_{\mathrm{oil}_t}$: Daily IV of USO

OVX published by the Chicago Board of Trade (CBOE), which measures the 30-day implied volatility of crude oil prices calculated from option prices of the United States Oil Fund (USO).

Data (3)

$\mathrm{RV}_{\mathrm{oil}_\mathrm{t}}$: Daily RV of USO (estimated by the following SV model)

$$\mathrm{r}_\mathrm{t} = \mu_{oil} + \beta_{oil}\left(e^{\frac{h_t}{2}} - IV_t\right) + e^{\frac{h_t}{2}}\epsilon_t,$$

$$h_t = \mu_h + \beta_h(h_{t-1} - \mu_h) + \sigma_h \eta_t,$$

$$\epsilon_t \equiv \sqrt{\frac{\nu-2}{\nu}}\frac{\xi_t}{\sqrt{\zeta_t}}, \quad \zeta_t \sim \Gamma\left(\frac{\nu}{2},\frac{\nu}{2}\right), \begin{pmatrix}\xi_t \\ \eta_t\end{pmatrix} \sim N\left(\begin{bmatrix}0\\0\end{bmatrix},\begin{bmatrix}1 & \rho \\ \rho & 1\end{bmatrix}\right)$$

$$\boldsymbol{RV}_{\boldsymbol{oil}_\mathbf{t}} = \mathbf{e}^{\frac{\boldsymbol{h_t}}{\mathbf{2}}}$$

Data (4)

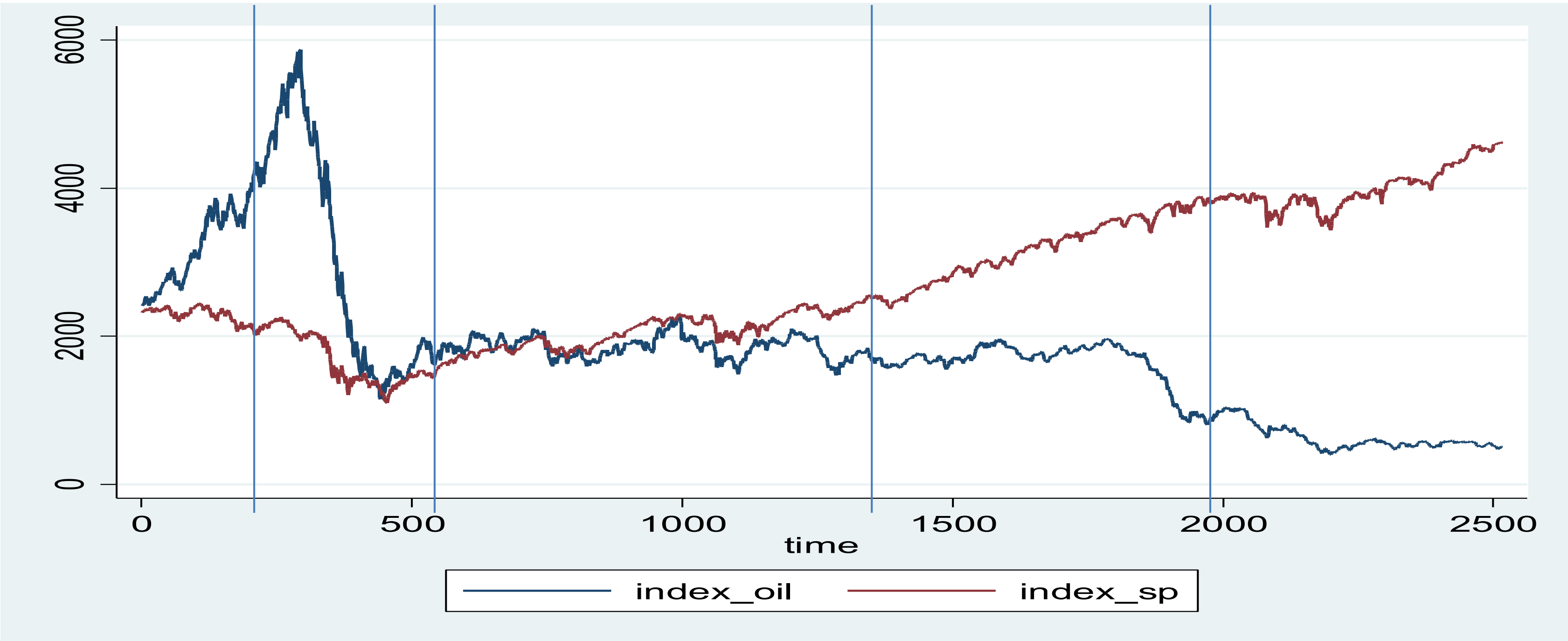
1st : t=1 (070510) ~ t=266 (080530) pre-crisis period

2nd : t=267 (080601) ~ t=533 (090630) crisis outbreak period

3rd : t=534 (090701) ~ t=1311 (120731) post-crisis recovery period 1

4th : t=1312 (120801) ~ t=1855 (140930) post-crisis recovery period 2

5th : t=1856 (141001) ~ t=2516 (170516) plunging oil price period



Data (5)

1st : *t*=1 (070510) ~ *t*=266 (080530) pre-crisis period

2nd : *t*=267 (080601) ~ *t*=533 (090630) crisis outbreak period

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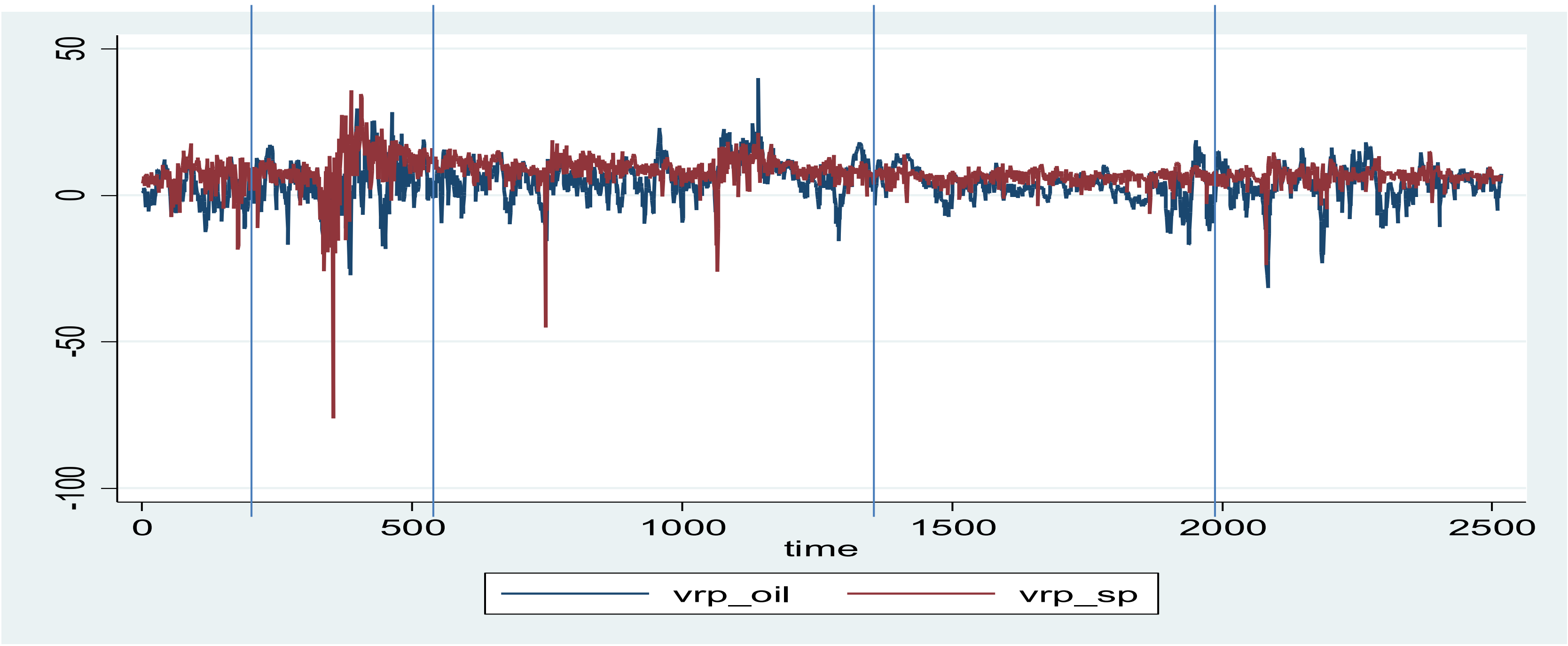


Descriptive statistics

		Whole	Before 1st	Outbreak 2nd	Recover1 3rd	Recover2 4th	Oil Plunge 5th
Mean	VRP_{oil_t}	4.202	2.529	3.623	5.846	4.231	3.151
	VRP_{sp_t}	7.785	6.509	9.583	9.536	6.441	6.616
S.D.	VRP_{oil_t}	6.627	5.842	9.754	6.317	4.619	6.724
	VRP_{sp_t}	4.891	4.794	10.148	4.168	2.115	2.801
Corr.		0.273	0.097	0.344	0.278	0.212	0.222

Stock VRP is large during Crisis outbreak period and Crisis recovery period 1.
S.D. of both VRP's are large during Crisis outbreak period.
Corralation between oil and stock VRP's is small before GFC.

Stationarity

VRP_{sp} and VRP_{oil}:

Augmented Dickey–Fuller test
Phillips–Perron test
GLS detrended augmented Dickey–Fuller test

All tests reject the null hypothesis (Existence of Unit Root) at 1 % level significance in all periods.

=> VRP_{sp} and VRP_{oil} are stationary in the whole and all sub-periods.

3. VAR analysis

VAR model

$$\mathrm{VRP_t} = \alpha + \sum_{i=1}^{P} \mathrm{A_i VRP_t} + \mathrm{e_t}$$

$$\text{where } \mathrm{VRP_t} = (\mathrm{VRP_{oil_t}}, \mathrm{VRP_{sp_t}})'$$

Optimal *P* (lag #):		*P* (lag #) used:
Whole period: 18 (AIC), 5 (HQIC), 2 (SBIC)	=>	5
1st period: 1 (AIC, HQIC, SBIC)	=>	1
2nd period: 2 (AIC, HQIC, SBIC)	=>	2
3rd period: 3 (AIC, HQIC, SBIC)	=>	3
4th period: 2 (AIC, HQIC, SBIC)	=>	2
5th period: 7 (AIC), 2 (HQIC, SBIC)	=>	2

We redo all with lag # = 9, and get the similar results.

AIC: Akaike information criterion

HQIC: Hannan and Quinn information criterion

SBIC: Schwartz's Bayesian information criterion

Granger causality (order: oil, sp)

Null hypothesis	Period	Chi 2	# of lags
VRP_{sp} does not GC VRP_{oil} Stock => Oil	Whole	21.174***	5
	Period 1	1.214	1
	Period 2	1.011	2
	Period 3	35.073***	3
	Period 4	1.439	2
	Period 5	4.786*	2
VRP_{oil} does not GC VRP_{sp} Oil => Stock	Whole	26.076***	5
	Period 1	0.024	1
	Period 2	6.861**	2
	Period 3	27.029***	3
	Period 4	18.452***	2
	Period 5	9.066**	2

No GC before GFC.

Stronger GC from oil VRP to stock VRP after GFC.

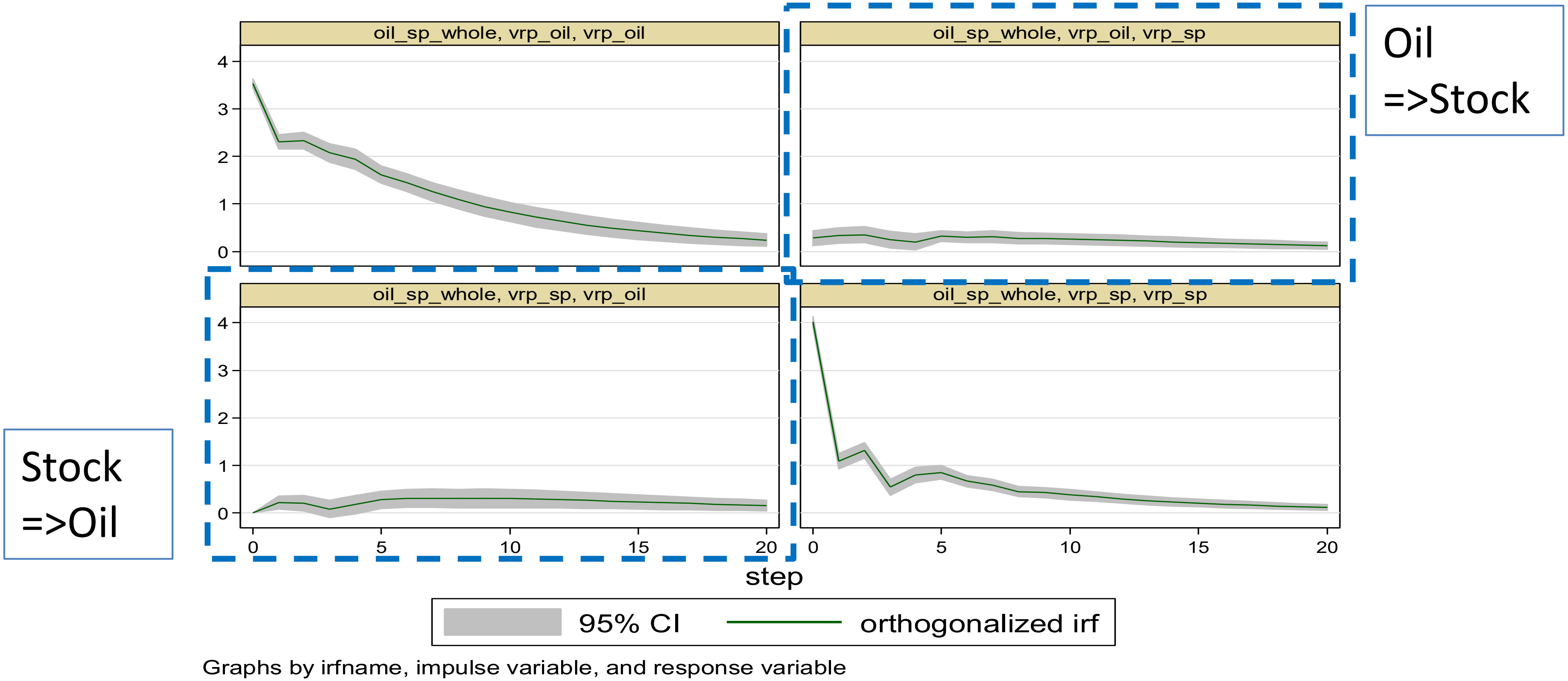
IRF

Significantly positive,
Long-lasting effects

Significantly positive,
Short-lived effects

No effects

Whole: t=1 (070510) ~ t=2516 (170516) (order: oil, sp)



Shocks in both VRP_{sp} and VRP_{oil} have significantly positive effects on each other for most of all 20 trading days after the shock.

Whole: t=1 (070510) ~ t=2516 (170516) (order: oil, sp)

Impulse	VRP_{oil}	VRP_{sp}	VRP_{oil}	VRP_{sp}
Response	VRP_{oil}		VRP_{sp}	
1	1	0	0.005	0.995
5	0.996	0.004	0.020	0.980
10	0.986	0.014	0.037	0.963
15	0.977	0.023	0.048	0.952
20	0.973	0.027	0.052	0.948

Stock =>Oil   Oil =>Stock

At date 20,

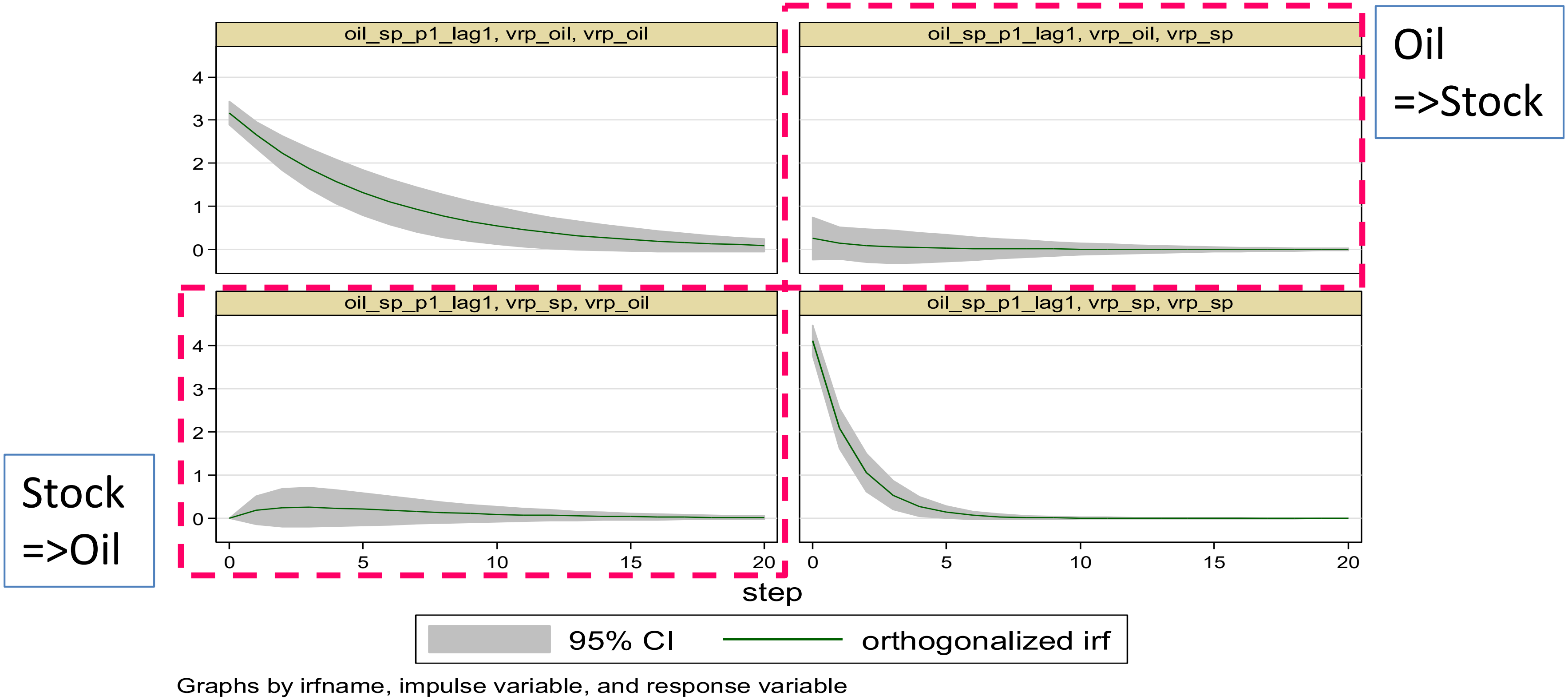
2.7% of FEV of VRP_{oil} is explained by innovations in VRP_{sp}.

5.2% of FEV of VRP_{sp} is explained by innovations in VRP_{oil}.

VRP's of stock and oil have similar effects on each other.

1st : *t*=1 (070510) ~ *t*=266 (080530) **pre-crisis** period

(order: oil, sp)



No significant effects between stock VRP and oil VRP.

1st : t=1 (070510) ～ t=266 (080530) **pre-crisis** period

(order: oil, sp)

Impulse	VRP_{oil}	VRP_{sp}	VRP_{oil}	VRP_{sp}
Response	VRP_{oil}		VRP_{sp}	
Period1				
1	1	0	0.004	0.996
5	0.992	0.008	0.005	0.995
10	0.989	0.011	0.005	0.995
15	0.989	0.011	0.005	0.995
20	0.989	0.011	0.005	0.995

Stock=>Oil

Oil =>Stock

At date 20,

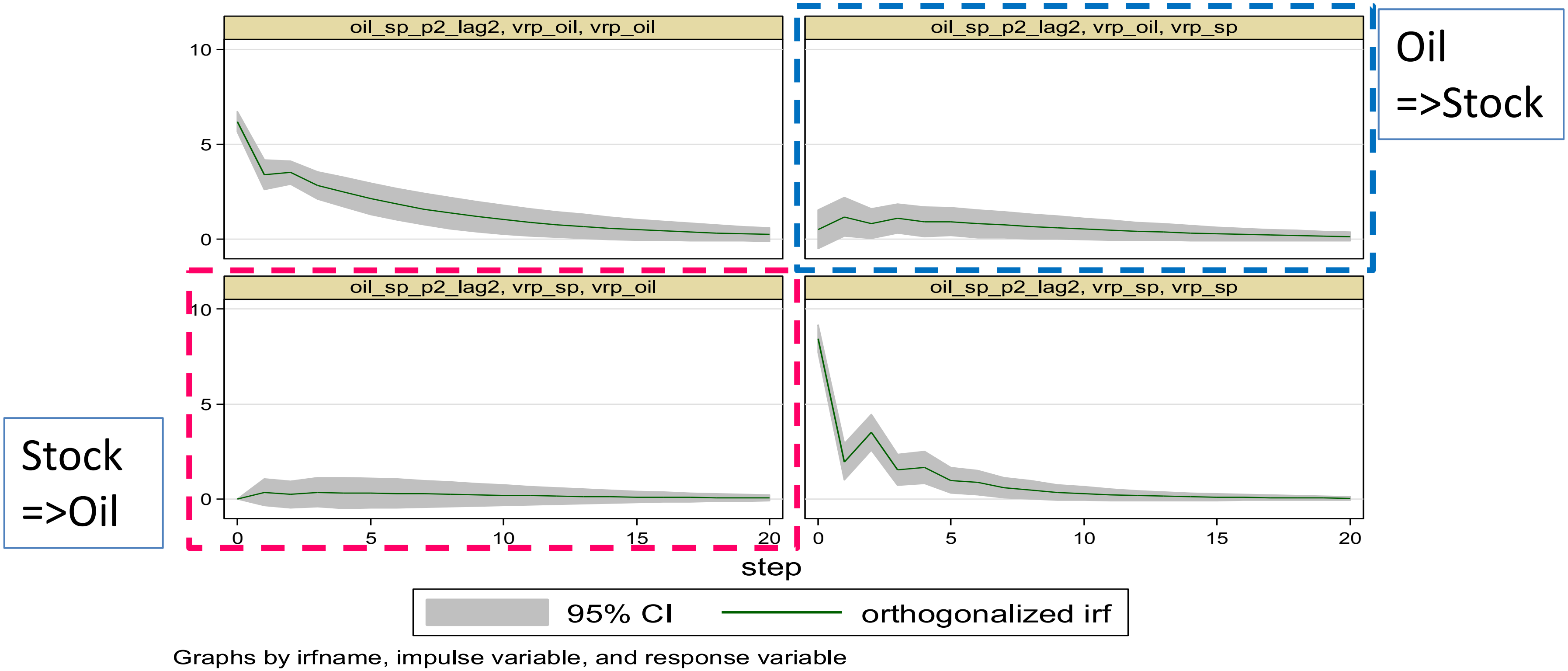
1.1% of FEV of VRP_{oil} is explained by innovations in VRP_{sp}.

0.5% of FEV of VRP_{sp} is explained by innovations in VRP_{oil}.

VRP's of stock and oil have little effects on each other before GFC.

2^{nd} : t=267 (080601) ~ t=533 (090630) **crisis outbreak** period

(order: oil, sp)



VRP_{oil} has significantly positive effect on VRP_{sp} from the 1st to the 8th trading days after the shock.

VRP_{sp} has no effect on VRP_{oil}.

2nd : t=267 (080601) ～ t=533 (090630) **crisis outbreak** period

(order: oil, sp)

Impulse	$\mathrm{VRP}_{\mathrm{oil}}$	$\mathrm{VRP}_{\mathrm{sp}}$	$\mathrm{VRP}_{\mathrm{oil}}$	$\mathrm{VRP}_{\mathrm{sp}}$
Response	$\mathrm{VRP}_{\mathrm{oil}}$		$\mathrm{VRP}_{\mathrm{sp}}$	
Period2				
1	1	0	0.004	0.996
5	0.995	0.005	0.044	0.956
10	0.992	0.008	0.070	0.930
15	0.991	0.009	0.078	0.922
20	0.991	0.009	0.080	0.920

Stock=>Oil

Oil =>Stock

At date 20,

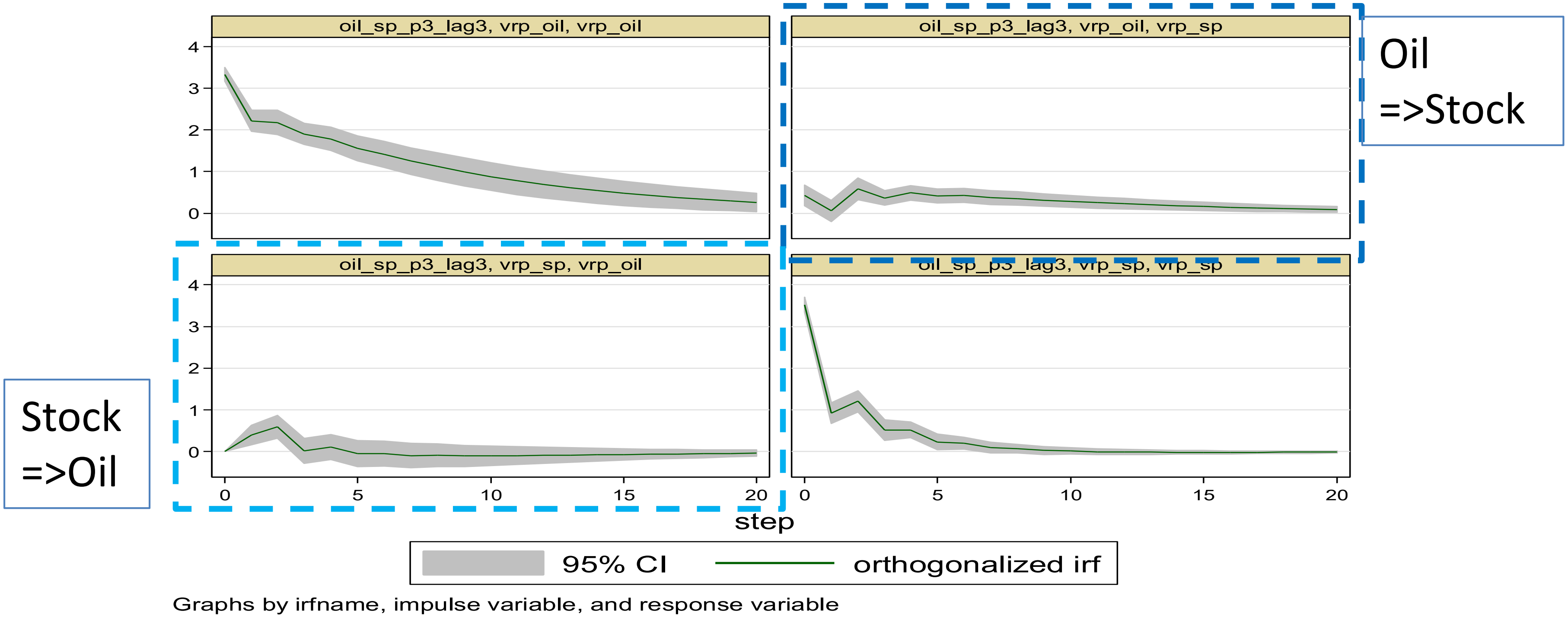
0.9% of FEV of $\mathrm{VRP}_{\mathrm{oil}}$ is explained by innovations in $\mathrm{VRP}_{\mathrm{sp}}$.

8.0% of FEV of $\mathrm{VRP}_{\mathrm{sp}}$ is explained by innovations in $\mathrm{VRP}_{\mathrm{oil}}$.

$\mathrm{VRP}_{\mathrm{oil}}$ has stronger effect on $\mathrm{VRP}_{\mathrm{sp}}$ than $\mathrm{VRP}_{\mathrm{sp}}$ has on $\mathrm{VRP}_{\mathrm{oil}}$.

3^{rd} : t=534 (090701) ~ t=1311 (120731) **post-crisis recovery** per. 1

(order: oil, sp)



VRP_{oil} has significantly positive effect on VRP_{sp} after the 2nd day.

VRP_{sp} has significantly positive effect on VRP_{oil} up to the 2nd day.

3rd : t=534 (090701) ～ t=1311 (120731) **post-crisis recovery** per. 1

(order: oil, sp)

Impulse	VRP_{oil}	VRP_{sp}	VRP_{oil}	VRP_{sp}
Response	VRP_{oil}		VRP_{sp}	
Period3				
1	1	0	0.015	0.985
5	0.981	0.019	0.056	0.944
10	0.985	0.015	0.095	0.905
15	0.985	0.015	0.110	0.890
20	0.985	0.015	0.114	0.886

Stock=>Oil

Oil =>Stock

At date 20,

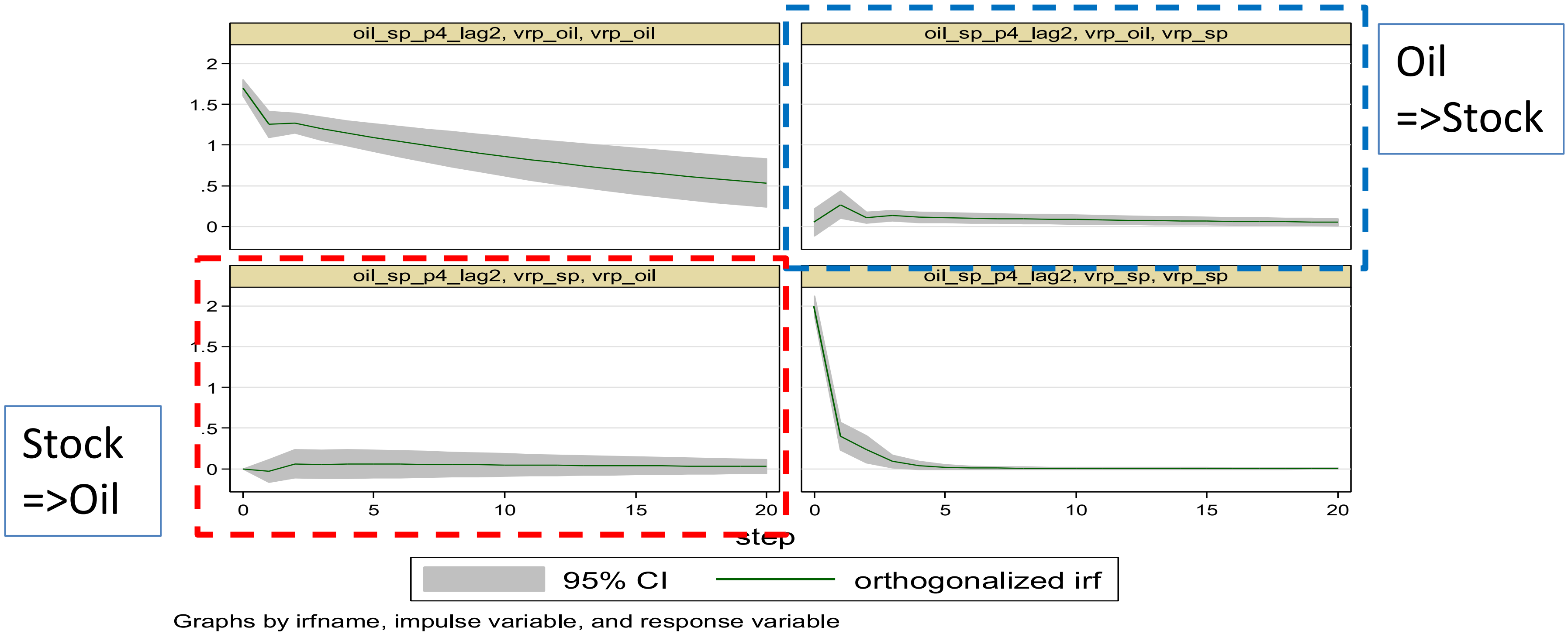
1.5% of FEV of VRP_{oil} is explained by innovations in VRP_{sp}.

11.4% of FEV of VRP_{sp} is explained by innovations in VRP_{oil}.

VRP_{oil} has stronger effect on VRP_{sp} than VRP_{sp} has on VRP_{oil}.

4^{th} : t=1312 (120801) ~ t=1855 (140930) **post-crisis recovery** per. 2

(order: oil, sp)



VRP_{oil} has significantly positive effect on VRP_{sp} in all trading days after the shock.

VRP_{sp} has no effect on VRP_{oil}.

4th : t=1312 (120801) ~ t=1855 (140930) **post-crisis recovery** per. 2

(order: oil, sp)

Impulse	VRP_{oil}	VRP_{sp}	VRP_{oil}	VRP_{sp}
Response	VRP_{oil}		VRP_{sp}	
Period4				
1	1	0	0.001	0.999
5	0.999	0.001	0.027	0.973
10	0.998	0.002	0.037	0.963
15	0.998	0.002	0.044	0.956
20	0.998	0.002	0.048	0.952

Stock=>Oil

Oil =>Stock

At date 20,

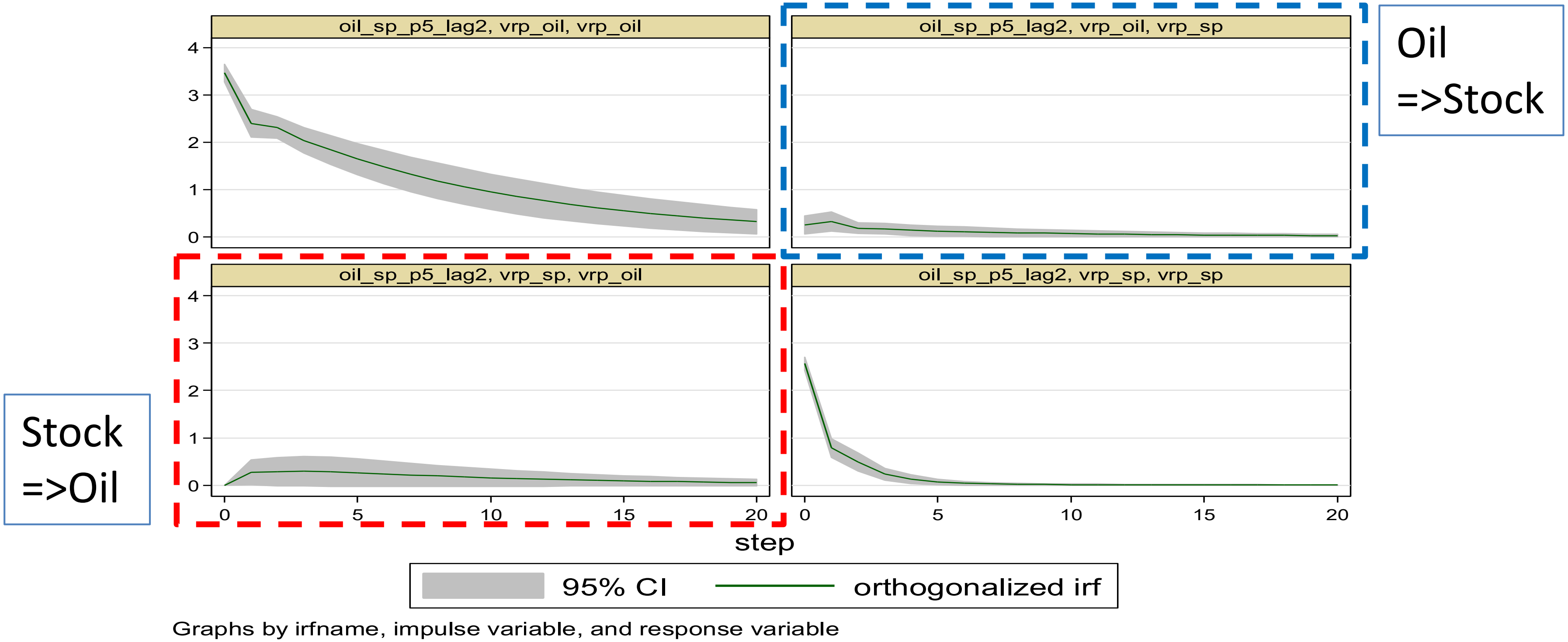
0.2% of FEV of VRP_{oil} is explained by innovations in VRP_{sp}.

4.8% of FEV of VRP_{sp} is explained by innovations in VRP_{oil}.

VRP_{oil} has stronger effect on VRP_{sp} than VRP_{sp} has on VRP_{oil}.

5th : t=1856 (141001) ~ t=2516 (170516) **plunging oil price** period

(order: oil, sp)



VRP_{oil} has significantly positive effect on VRP_{sp} up to the 7th day.

VRP_{sp} has no effect on VRP_{oil}.

5th : t=1856 (141001) ～ t=2516 (170516) **plunging oil price** period

(order: oil, sp)

Impulse	VRP_{oil}	VRP_{sp}	VRP_{oil}	VRP_{sp}
Response	VRP_{oil}		VRP_{sp}	
Period5				
1	1	0	0.009	0.991
5	0.990	0.010	0.032	0.968
10	0.986	0.014	0.037	0.963
15	0.985	0.015	0.039	0.961
20	0.985	0.015	0.040	0.960

Stock=>Oil

Oil =>Stock

At date 20,

0.15% of FEV of VRP_{oil} is explained by innovations in VRP_{sp}.

4.0% of FEV of VRP_{sp} is explained by innovations in VRP_{oil}.

VRP_{oil} has stronger effect on VRP_{sp} than VRP_{sp} has on VRP_{oil}.

4. Summary of results

GC and IRF

(order: oil, sp)

GC	Whole	1st	2nd	3rd	4th	5th
VRP_{oil} --> VRP_{sp}	GC***	-	GC**	GC***	GC***	GC**
VRP_{sp} --> VRP_{oil}	GC***	-	-	GC***	-	GC*

IRF	Whole	1st	2nd	3rd	4th	5th
VRP_{oil} --> VRP_{sp}	+	-	+	+	+	+
	(1~20)		(1~8)	(2~20)	(1~20)	(1~7)
VRP_{sp} --> VRP_{oil}	+	-	-	+	-	+
	(1~20)	-	-	(~2)	-	-

Forecast Error Variance（@ 20th day）

(order: oil, sp)

FEV	Whole	1st	2nd	3rd	4th	5th
VRP_{oil} --> VRP_{sp}	5.2%	0.5%	8.0%	11.4%	4.8%	4.0%
VRP_{sp} --> VRP_{oil}	2.7%	1.1%	0.8%	1.5%	0.2%	1.5%

Findings of this paper

Spillover exists between oil and stock VRP's after GFC.

Before GFC:

No dynamic relation is found between stock and oil VRP's.

After GFC:

Spillover effect from oil VRP to stock VRP is stronger, significantly positive (though small), and long-lasting.

Spillover effect from stock VRP to oil VRP is limited and short-lived.

Spillover of investors' sentiment is from oil market to stock market.

5. Remarks

Remarks (1)

(1) Mechanism of VRP spillover:

Hattori, Shim, and Sugihara (2018) find that increase of US VRP tends to reduce equity fund flow to all other advanced and emerging economies.

=> Similar change of fund flow from oil market to stock market?

Christoffersen and Pan (2018) find that increases in oil IV predict tightening funding constraints of financial Intermediaries.

=> Explain direction of spillover: from oil to stock?

Fund flow may be the cause of VRP spillover.

Remarks (2)

(2) Implications for investment and policy:

Need to take account of spillovers between oil and stock VRP's, in addition to the usual comovements of returns and volatilities.

It is important to understand the mechanism of spillover in order to predict how shocks propagate across different markets, and especially how such relation changes over time.

Remarks (3)

(3) Need of updating the data.

(4) Estimation of RV_{oil}:

We estimate RV_{oil} by an SV model.

Daily RV_{oil} can be estimated from high frequency intraday data.

(5) Approximation of $E_t^P[\sigma_{t+T}]$ in $VRP_t \equiv E_t^Q[\sigma_{t+T}] - E_t^P[\sigma_{t+T}]$.

(6) Including other potential explanatory variables.

Structural change (e.g., shale oil/gas, COVID-19 shock),

Macro economic/policy changes (e.g., QQE, green recovery)

Speculation, Day of the week effect, etc.

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Thank you very much!