Appendix:

Table 1A:
Forecast Error Variance Decomposition Results for the period from 2005 to 2007

This table reports the results of forecast error variance decomposition (percentage points) among volatilities of US security bond, stock markets and commodities from 2005 to 2007. The variance decomposition is based on the directed graph on innovations given in Figure 1A. VIX is the Chicago Board Option Exchange (CBOE)'s S&P500 volatility index. MOVE is the Bank of America Merrill Lynch's Treasury Option Volatility Estimate Index. "German VIX" (VDAX) is the Deutsche Borse's DAX-30 volatility index. "French VIX" (VCAC) is the Euronext-Paris' CAC-40 volatility index. "UK VIX" (VFTSE) is the Euronext's FTSE100 volatility index. "Swiss VIX" (VSMI) is the SWX Swiss Exchange's SMI volatility index. "Japan VIX" (VXJ) is the Nikkei 225 volatility index. "Korea VIX" (VKOSPI) is the KOSPI200 volatility index. "HKVIX" (VHSI) is Hong Kong's Hangseng volatility index. Oil and Gold VIX indices are excluded because those indices do not extend back far enough.

Day	VIX	German VIX	UK VIX	Swiss VIX	French VIX	Korean VIX	Japanese VIX	HK VIX	MOVE
Variance of MOVE explained by shocks to the implied volatilities									
0	6.15	2.64	0.10	0.07	0.26	0.00	0.01	0.00	90.77
1	9.33	3.20	0.06	0.05	0.67	0.24	0.51	0.00	85.94
2	9.07	3.44	0.68	0.10	0.67	1.03	0.52	0.00	84.50
3	8.69	3.70	1.11	0.48	0.64	1.00	1.08	0.33	82.98
12	9.56	5.59	1.53	0.99	0.78	1.71	2.01	1.38	76.45
30	9.60	5.66	1.71	1.05	0.83	1.92	2.05	1.43	75.73
Variance of VIX explained by shocks to the implied volatilities									
0	66.67	28.57	1.06	0.73	2.84	0.04	0.07	0.03	0.00
1	59.22	31.11	1.60	0.63	4.89	1.15	0.17	1.09	0.14
2	57.66	28.41	1.56	0.65	4.38	5.37	0.17	1.34	0.46
3	56.03	27.87	1.61	0.72	4.75	5.51	1.69	1.32	0.50
12	52.08	15.68	2.48	1.13	4.81	5.77	4.10	1.97	1.98
30	51.30	25.34	2.58	1.20	4.97	5.77	4.23	2.17	2.42
Variance of German VIX explained by shocks to the implied volatilities									
0	0.00	100	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	9.35	89.33	0.05	0.00	0.38	0.01	0.42	0.32	0.14
2	12.89	82.48	0.05	0.01	0.52	1.36	0.42	1.03	1.24
3	12.62	80.37	0.06	0.23	0.72	2.27	1.37	10.2	1.34
12	12.42	73.28	1.45	1.07	0.99	2.66	3.22	2.07	2.84
30	12.40	72.34	1.61	1.16	1.07	2.67	3.45	2.15	3.13
Variance of UK VIX explained by shocks to the implied volatilities									
0	0.00	55.36	28.53	5.34	9.84	0.12	0.40	0.42	0.00
1	11.01	53.26	20.14	4.17	10.49	0.17	0.40	0.28	0.07
2	15.60	48.49	18.41	3.86	9.54	2.38	0.38	0.76	0.59
3	15.03	46.73	17.80	4.46	10.25	2.73	1.10	0.73	1.16
12	14.96	41.66	17.64	5.27	9.30	2.79	3.20	2.29	2.89
30	14.95	41.18	17.47	5.32	9.25	2.77	3.45	2.43	3.18
Variance of French VIX explained by shocks to the implied volatilities									
0	0.00	77.22	0.00	2.79	19.41	0.25	0.31	0.02	0.00
1	10.42	70.04	0.33	2.28	15.93	0.18	0.33	0.48	0.02
2	13.75	63.77	0.72	2.23	14.68	1.88	0.36	1.45	1.16
3	13.33	62.08	0.71	2.90	14.56	2.60	0.99	1.42	1.41
12	13.18	54.84	2.89	3.86	12.85	2.67	3.46	2.20	4.05
30	13.14	54.05	3.01	3.91	12.69	2.66	3.66	2.36	4.53

Table 1A (continued)

Day	VIX	German VIX	UK VIX	Swiss VIX	French VIX	Korean VIX	Japanese VIX	HK VIX	MOVE
Variance of Swiss VIX explained by shocks to the implied volatilities									
0	0.00	51.63	0.00	46.28	0.00	0.00	2.09	0.00	0.00
1	10.50	56.43	0.55	29.19	1.94	0.00	0.87	0.35	0.17
2	18.40	48.27	0.63	24.99	2.33	1.51	0.72	1.27	1.88
3	17.61	46.24	0.70	24.69	2.38	3.44	0.99	1.32	2.64
12	16.32	41.94	2.70	23.40	2.55	3.43	3.25	2.67	3.75
30	16.30	41.44	2.90	23.12	2.69	3.39	3.39	2.81	3.95
Variance of Korean VIX explained by shocks to the implied volatilities									
0	0.00	0.45	0.00	0.40	0.00	78.08	13.91	7.16	0.00
1	6.72	8.47	0.97	0.24	0.30	65.79	11.60	5.90	0.01
2	10.47	11.17	2.95	0.30	0.53	57.46	11.06	5.69	0.37
3	10.69	11.16	2.92	0.31	0.63	56.79	10.97	5.77	0.75
12	10.70	10.24	4.70	1.82	0.83	49.20	11.24	7.09	4.19
30	10.76	10.26	4.72	1.88	0.94	48.44	11.48	7.03	4.49
Variance of Japanese VIX explained by shocks to the implied volatilities									
0	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00
1	7.79	9.42	0.35	0.12	1.50	0.06	80.60	0.00	0.18
2	11.78	13.82	1.26	0.22	2.83	0.11	68.92	0.43	0.63
3	11.48	13.13	1.21	0.28	2.70	1.44	66.35	0.42	2.99
12	10.67	12.01	2.88	1.85	3.44	3.49	56.75	3.54	5.39
30	10.57	12.05	2.89	1.98	3.52	3.64	56.25	3.65	5.44
Variance of Hong Kong VIX explained by shocks to the implied volatilities									
0	0.00	5.57	0.00	5.00	0.00	0.00	0.23	89.20	0.00
1	6.58	11.25	0.83	6.41	1.14	0.05	0.46	73.28	0.00
2	10.11	11.12	1.50	6.24	1.94	0.15	1.05	67.40	0.50
3	9.94	11.69	1.47	6.38	2.10	0.77	1.21	65.20	1.24
12	10.00	12.05	3.79	6.28	2.63	1.72	3.41	58.15	1.98
30	9.99	12.04	3.84	6.40	2.84	1.77	3.70	57.40	2.02

Table 2A: Spillover Intensity Matrix

This table reports spillover intensity (in percentage points). Panel A is based on Table 2 for the period from 2008 to 2013 while Panel B is based on Table 1A for the period from 2005 to 2007. In the upper-left 11×11 submatrix in Panel A and 9×9 submatrix in Panel B, diagonal elements are zeros and the off-diagonal elements are 12-day-ahead pairwise volatility spillover intensity. The last row shows market-wide total spillover to all others from column *j*, which is column sum of the off-diagonal pairwise spillovers (Diebold and Yilmaz, 2014).

Panel A: the period from 2008 to 2013

	VIX	MOVE	UK VIX	German VIX	French VIX	Swiss VIX	Japanese VIX	HK VIX	Korean VIX	Gold VIX	Oil VIX
VIX	0	4.3	0.2	1.5	1.9	0.8	0.0	1.8	2.7	0.6	0.0
MOVE	1.9	0	0.3	1.7	1.2	1.3	0.2	0.4	0.1	0.0	0.0
UK VIX	47.4	2.8	0	17.0	1.9	3.8	0.0	0.7	2.9	0.4	0.0
German VIX	57.5	3.2	0.1	0	0.5	1.3	0.2	0.8	3.1	0.8	0.0
French VIX	41.8	2.9	3.1	19.2	0	0.8	0.0	0.5	1.9	1.1	0.3
Swiss VIX	52.2	2.4	0.1	22.8	1.4	0	0.0	1.2	2.3	0.4	0.0
Japanese VIX	22.7	1.7	0.7	2.1	1.7	1.1	0	8.6	5.6	0.0	0.0
HK VIX	32.1	4.5	1.1	2.6	5.6	0.6	0.1	0	0.9	1.0	0.2
Korean VIX	35.6	2.6	0.9	7.5	2.7	1.2	0.0	10.5	0	0.7	0.0
Gold VIX	18.7	4.9	0.2	0.4	0.1	1.4	0.4	0.6	0.7	0	0.1
Oil VIX	23.2	1.6	0.1	4.4	0.0	0.9	0.0	1.4	2.7	2.6	0
Spillover	**333.1**	**30.9**	**6.8**	**79.2**	**17.1**	**13.1**	**1.0**	**26.5**	**23.0**	**7.6**	**0.7**

Panel B: the period from 2005 to 2007

	VIX	MOVE	UK VIX	German VIX	French VIX	Swiss VIX	Japanese VIX	HK VIX	Korean VIX
VIX	0	1.98	2.48	25.68	4.81	1.13	4.10	1.97	5.77
MOVE	9.56	0	1.53	5.59	0.78	0.99	2.01	1.38	1.71
UK VIX	14.96	2.89	0	41.66	9.30	5.27	3.20	2.29	2.79
German VIX	12.42	2.84	1.45	0	0.99	1.07	3.22	2.07	2.66
French VIX	13.18	4.05	2.89	54.84	0	3.86	3.46	2.20	2.67
Swiss VIX	16.32	3.75	2.70	41.94	2.55	0	3.25	2.67	3.43
Japanese VIX	10.67	5.39	2.88	12.01	3.44	1.85	0	3.54	3.49
HK VIX	10.00	1.98	3.79	12.05	2.63	6.28	3.41	0	1.72
Korean VIX	10.70	4.19	4.70	10.24	0.83	1.82	11.24	7.09	0
Spillover	97.81	27.07	22.42	204.01	25.33	22.44	33.89	23.21	24.24

Table 3A: Network Centrality for the period from 2005 to 2007

This table reports network centrality of each market for the period from 2005 to 2007. Compared with Table 3, Oil and Gold VIX indices are excluded because those indices do not extend back far enough. The upper-left 9×9 submatrix is adjacency matrix in which diagonal elements are zeros and the off-diagonal elements are 12-day-ahead total pairwise volatility spillover intensity (in percentage points). For example, the total spillover intensity between VIX and MOVE is 11.54%, which is the sum of the VIX spillover to MOVE, 9.56%, and the MOVE spillover to VIX, 1.98%, in Panel B of Table 2A. The second last row shows degree centrality, which is simply the average of column sum of the off-diagonal total pairwise spillovers. The last row of the matrix shows eigenvector centrality, defined as the principal eigenvector of the network's adjacency matrix. Intuitively, a market is considered more central if it is connected to other markets are themselves central (Ahern and Harford, 2014).

	VIX	MOVE	UK VIX	German VIX	French VIX	Swiss VIX	Japanese VIX	HK VIX	Korean VIX
VIX	0	11.54	17.44	38.1	17.99	17.45	14.77	11.97	16.47
MOVE	11.54	0	4.42	8.43	4.83	4.74	7.4	3.36	5.9
UK VIX	17.44	4.42	0	43.11	12.19	7.97	6.08	6.08	7.49
German VIX	38.1	8.43	43.11	0	55.83	43.01	15.23	14.12	12.9
French VIX	17.99	4.83	12.19	55.83	0	6.41	6.9	4.83	3.5
Swiss VIX	17.45	4.74	7.97	43.01	6.41	0	5.1	8.95	5.25
Japanese VIX	14.77	7.4	6.08	15.23	6.9	5.1	0	6.95	14.73
HK VIX	11.97	3.36	6.08	14.12	4.83	8.95	6.95	0	8.81
Korean VIX	16.47	5.9	7.49	12.9	3.5	5.25	14.73	8.81	0
Degree centrality	18.22	6.33	13.10	28.84	14.06	12.36	9.64	8.13	9.38
Eigenvector centrality	0.40	0.14	0.34	0.58	0.39	0.32	0.21	0.18	0.20

Table 4A: Robustness Check of Network Centrality for the period from 2008 to 2013

This table checks the robustness of network centrality of each market from 2008 to 2013. Compared with Table 3, French VIX and German VIX are replaced with the EU VIX (Eurex STOXX50 volatility index). The upper-left 10×10 submatrix is adjacency matrix in which diagonal elements are zeros and the off-diagonal elements are 12-day-ahead total pairwise volatility spillover intensity (in percentage points), estimated in a way similar to those in Tables 3 and 3A. The second last row shows degree centrality, which is simply the average of column sum of the off-diagonal total pairwise spillovers. The last row of the matrix shows eigenvector centrality, defined as the principal eigenvector of the network's adjacency matrix. Intuitively, a market is considered more central if it is connected to other markets are themselves central (Ahern and Harford, 2014).

	VIX	MOVE	EU VIX	UK VIX	Swiss VIX	Japanese VIX	HK VIX	Korean VIX	Gold VIX	Oil VIX
VIX	0.00	6.51	60.21	49.65	51.20	24.19	37.81	38.95	20.10	23.63
MOVE	6.51	0.00	4.41	3.02	4.34	2.05	5.75	2.71	4.90	1.74
EU VIX	60.21	4.41	0.00	15.92	11.26	1.74	6.16	5.26	1.44	1.95
UK VIX	49.65	3.02	15.92	0.00	12.01	2.04	3.64	8.64	0.88	1.79
Swiss VIX	51.20	4.34	11.26	12.01	0.00	1.21	2.28	2.13	2.07	1.63
Japanese VIX	24.19	2.05	1.74	2.04	1.21	0.00	8.82	5.41	0.43	0.02
HK VIX	37.81	5.75	6.16	3.64	2.28	8.82	0.00	11.02	1.60	1.61
Korean VIX	38.95	2.71	5.26	8.64	2.13	5.41	11.02	0.00	1.50	2.85
Gold VIX	20.10	4.90	1.44	0.88	2.07	0.43	1.60	1.50	0.00	2.59
Oil VIX	23.63	1.74	1.95	1.79	1.63	0.02	1.61	2.85	2.59	0.00
Degree centrality	34.69	3.94	12.04	10.84	9.79	5.10	8.74	8.72	3.95	4.20
Eigenvector centrality	0.65	0.09	0.39	0.35	0.33	0.16	0.25	0.26	0.12	0.14

Table 5A: Network Centrality for the period from 2011 to 2012

This table reports network centrality of each market from 2011 to 2012. As in Table 4A, French VIX and German VIX are replaced with the EU VIX (Eurex STOXX50 volatility index). The upper-left 10×10 submatrix is adjacency matrix in which diagonal elements are zeros and the off-diagonal elements are 12-day-ahead total pairwise volatility spillover intensity (in percentage points), estimated in a way similar to those in Tables 3, 3A and 4A. The second last row shows degree centrality, which is simply the average of column sum of the off-diagonal total pairwise spillovers. The last row of the matrix shows eigenvector centrality, defined as the principal eigenvector of the network's adjacency matrix. Intuitively, a market is considered more central if it is connected to other markets are themselves central (Ahern and Harford, 2014).

	VIX	MOVE	EU VIX	UK VIX	Swiss VIX	Japanese VIX	HK VIX	Korean VIX	Gold VIX	Oil VIX
VIX	0.00	10.92	15.84	34.52	27.80	3.91	32.33	34.52	11.70	34.11
MOVE	10.92	0.00	1.03	2.20	1.60	3.32	3.01	3.55	0.86	3.31
EU VIX	15.84	1.03	0.00	37.53	56.24	9.57	9.21	11.25	17.43	4.03
UK VIX	34.52	2.20	37.53	0.00	7.14	2.25	0.44	3.31	0.46	1.25
Swiss VIX	27.80	1.60	56.24	7.14	0.00	2.70	3.90	3.37	2.25	2.17
Japanese VIX	3.91	3.32	9.57	2.25	2.70	0.00	11.68	4.90	1.79	2.73
HK VIX	32.33	3.01	9.21	0.44	3.90	11.68	0.00	16.79	1.72	0.66
Korean VIX	34.52	3.55	11.25	3.31	3.37	4.90	16.79	0.00	2.68	8.22
Gold VIX	11.70	0.86	17.43	0.46	2.25	1.79	1.72	2.68	0.00	2.04
Oil VIX	34.11	3.31	4.03	1.25	2.17	2.73	0.66	8.22	2.04	0.00
Degree centrality	22.85	3.31	18.01	9.90	11.91	4.76	8.86	9.84	4.55	6.50
Eigenvector centrality	0.51	0.09	0.47	0.35	0.40	0.12	0.26	0.29	0.15	0.21

Table 6A: Additional Tests for Determinants of Daily VIX Aggregate Spillovers

This table reports the results of the following daily regressions: $AS_{t,\mathrm{H}} = \beta_0 + \beta_1 QE_t + Controls + \varepsilon_t$, where $AS_{t,H}$ is the daily H-step-ahead aggregate volatility spillover index from VIX to other VIXs, which is the sum of the shares of recursive forecast error variance of other VIXs explained by VIX. QE_t is the proxy of US quantitative easing, the cumulative net purchase of US Treasury and agency mortgage-backed securities. Controls include the following variables. $SHORT_t$ is the US short rate. ΔUSD_t is the log difference of the trade-weighted US dollar index. $TERM_t$ is term spread defined as the difference between the 10-year and 3-month Treasury yields. DEF_t is the default spread defined as the difference between BAA corporate bond and 10-year Treasury yields. TED_t is the spread between 3-month LIBOR based on US dollars and 3-month Treasury yield. $\Delta ADSBCI_t$ is the change of Aruoba, Diebold, and Scotti's business condition index. $\Delta CESG10_t$ is the change of Citigroup's Economic Surprise Index for the G10. $\Delta CESEM_t$ is the change of Citigroup's Economic Surprise Index for the Emerging Markets. $USRET_t$ is US stock market excess return. $USSMB_t$ is US size premium, which is excess return of US small caps over big caps. $USHML_t$ is US value premium, which is excess return of US value stocks over growth stocks. $USMOM_t$ is US stock momentum factor. WDRET_t is the world stock excess return. WDHML_t is the world value premium. ΔVIX_t is the first difference of VIX_t. ΔEPU_t is the first difference of US economic policy uncertainty index developed by Baker, Bloom and Davis. The coefficient estimates are reported with *, **, ***, denoting significance at 10%, 5%, and 1% respectively. The robust standard errors are reported in parentheses below.

	1-day ahead VIX aggregate spillover				3-day ahead VIX aggregate spillover				12-day ahead VIX aggregate spillover			
QE_t	0.45***	0.45***	0.45***	0.45***	1.05***	1.05***	1.06***	1.06***	0.79***	0.79***	0.80***	0.80***
	(0.13)	(0.13)	(0.13)	(0.13)	(0.15)	(0.15)	(0.15)	(0.15)	(0.16)	(0.16)	(0.16)	(0.16)
$SHORT_t$	-18.23***	-18.21***	-18.02***	-18.02***	-22.00***	-22.03***	-21.89***	-21.89***	-24.37***	-24.43***	-24.22***	-24.22***
	(6.31)	(6.32)	(6.32)	(6.32)	(7.22)	(7.22)	(7.23)	(7.23)	(7.78)	(7.79)	(7.79)	(7.79)
ΔUSD_t	-1.85**	-1.87	-2.08	-2.08	-2.22**	-2.73*	-2.89*	-2.89*	-2.39**	-3.00*	-3.23*	-3.23*
	(0.84)	(1.40)	(1.42)	(1.42)	(0.96)	(1.61)	(1.62)	(1.62)	(1.04)	(1.73)	(1.74)	(1.75)
$TERM_t$	-9.37***	-9.37***	-9.33***	-9.33***	-12.95***	-12.94***	-12.91***	-12.91***	-12.07***	-12.07***	-12.02***	-12.02***
	(1.04)	(1.04)	(1.04)	(1.04)	(1.19)	(1.19)	(1.19)	(1.19)	(1.28)	(1.28)	(1.28)	(1.28)
DEF_t	9.35***	9.37***	9.39***	9.39***	9.36***	9.38***	9.39***	9.39***	12.25***	12.25***	12.27***	12.27***
	(1.03)	(1.03)	(1.03)	(1.03)	(1.17)	(1.18)	(1.18)	(1.18)	(1.26)	(1.27)	(1.27)	(1.27)
TED_t	-37.95***	-37.98***	-38.11***	-38.11***	-49.26***	-49.29***	-49.38***	-49.38***	-55.42***	-55.43***	-55.57***	-55.57***
	(1.87)	(1.88)	(1.88)	(1.88)	(2.14)	(2.15)	(2.15)	(2.15)	(2.30)	(2.31)	(2.32)	(2.32)

$\Delta ADSBCI_t$	-64.60***	-64.79***	-64.45***	-64.45***	-68.51***	-68.72***	-68.47***	-68.47***	-74.08***	-74.18***	-73.80***	-73.80***
	(11.97)	(12.02)	(12.02)	(12.03)	(13.70)	(13.75)	(13.76)	(13.77)	(14.76)	(14.82)	(14.82)	(14.84)
$\Delta CESG10_t$	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
	(0.09)	(0.09)	(0.09)	(0.09)	(0.10)	(0.10)	(0.10)	(0.10)	(0.11)	(0.11)	(0.11)	(0.11)
$\Delta CESEM_t$	-0.06	-0.06	-0.06	-0.06	-0.01	-0.01	-0.00	-0.00	-0.03	-0.03	-0.02	-0.02
	(0.10)	(0.10)	(0.10)	(0.10)	(0.11)	(0.11)	(0.11)	(0.11)	(0.12)	(0.12)	(0.12)	(0.12)
$USRET_t$	-0.44*	-0.41	-0.69	-0.69	-0.43	-0.15	-0.36	-0.36	-0.51	-0.20	-0.51	-0.51
	(0.26)	(0.61)	(0.66)	(0.66)	(0.30)	(0.70)	(0.75)	(0.75)	(0.32)	(0.76)	(0.81)	(0.81)
$USSMB_t$	1.34***	1.36***	1.44***	1.44***	1.30**	1.29**	1.35**	1.35**	1.34**	1.32**	1.40**	1.40**
	(0.49)	(0.51)	(0.51)	(0.51)	(0.56)	(0.58)	(0.58)	(0.58)	(0.60)	(0.62)	(0.63)	(0.63)
$USHML_t$	-0.17	-0.26	-0.29	-0.29	-0.19	-0.32	-0.35	-0.35	-0.09	-0.18	-0.22	-0.22
	(0.57)	(0.71)	(0.71)	(0.71)	(0.66)	(0.81)	(0.81)	(0.81)	(0.71)	(0.87)	(0.87)	(0.88)
$USMOM_t$	-0.52*	-0.49	-0.57*	-0.57*	-0.63*	-0.61	-0.67*	-0.67*	-0.68*	-0.68*	-0.77*	-0.77*
	(0.31)	(0.33)	(0.34)	(0.34)	(0.36)	(0.38)	(0.39)	(0.39)	(0.38)	(0.41)	(0.42)	(0.42)
$WDRET_t$		-0.04	-0.21	-0.21		-0.41	-0.54	-0.54		-0.47	-0.67	-0.67
		(0.85)	(0.87)	(0.87)		(0.98)	(0.99)	(0.99)		(1.05)	(1.07)	(1.07)
$WDHML_t$		0.26	0.36	0.36		0.36	0.44	0.44		0.22	0.34	0.34
		(1.30)	(1.30)	(1.30)		(1.48)	(1.49)	(1.49)		(1.60)	(1.60)	(1.60)
ΔVIX_t			-0.28	-0.28			-0.21	-0.21			-0.31	-0.31
			(0.24)	(0.24)			(0.27)	(0.27)			(0.29)	(0.29)
ΔEPU_t				0.00				-0.00				0.00
				(0.00)				(0.01)				(0.01)
adj. R^2	0.710	0.710	0.710	0.710	0.823	0.822	0.822	0.822	0.783	0.783	0.783	0.783

Table 7A: Additional Tests for Determinants of Daily VIX Spillovers from rolling and combined estimates

This table reports the result of the following daily regressions: $S^{'i}_{t,12} = \beta_0 + \beta_1 QE_t + Controls + \varepsilon_t$, where $S^{'i}_{t,12}$ is daily rolling or combined 12-day-ahead aggregate VIX spillover index defined above. QE_t is the proxy of US quantitative easing, the cumulative net purchase of US Treasury and agency mortgage-backed securities. $SHORT_t$ is the US short rate proxied by 1-month Treasury yield. ΔUSD_t is the change of foreign currency per US dollar. ΔUSD_t is the log difference of the trade-weighted US dollar index. Controls include the following variables. $TERM_t$ is term spread defined as the difference between the 10-year and 3-month Treasury yields. DEF_t is the default spread defined as the difference between BAA corporate bond and 10-year Treasury yields. TED_t is the spread between 3-month LIBOR based on US dollars and 3-month Treasury yield. $\Delta ADSBCI_t$ is Aruoba, Diebold, and Scotti's business condition index. $\Delta CESG10_t$ is Citigroup's Economic Surprise Index for the G10. $\Delta CESEM_t$ is Citigroup's Economic Surprise Index for the Emerging Markets. The coefficient estimates are reported with *, **, ***, denoting significance at 10%, 5%, and 1% respectively. The robust standard errors are reported in parentheses below.

Panel A: dependent variables are rolling VIX spillover estimates

Rolling	**60-day rolling window**			**70-day rolling window**			**80-day rolling window**			**90-day rolling window**		
QE_t	1.66***	1.08***	0.99**	1.74***	1.32***	1.45***	1.90***	1.62***	1.79***	1.86***	1.65***	1.82***
	(0.33)	(0.38)	(0.40)	(0.31)	(0.36)	(0.39)	(0.30)	(0.35)	(0.37)	(0.29)	(0.34)	(0.36)
$SHORT_t$		-97.91***	-269.17***		-68.12**	-209.72***		-39.38	-159.46***		-32.61	-145.36***
		(33.56)	(43.54)		(32.38)	(42.22)		(31.19)	(40.85)		(29.83)	(39.06)
ΔUSD_t		-0.78	-3.66		-2.93	-5.23		-4.58	-6.01		-4.57	-5.71
		(5.66)	(5.63)		(5.46)	(5.46)		(5.26)	(5.28)		(5.03)	(5.05)
Controls	NO	NO	YES	NO	NO	YES	NO	NO	YES	NO	NO	YES
adj. R^2	0.022	0.027	0.058	0.026	0.027	0.051	0.033	0.031	0.050	0.035	0.033	0.056

Panel B: dependent variables are combination of recursive and rolling VIX spillover estimates

Combine	**recursive & 60-day rolling**			**recursive & 70-day rolling**			**Recursive & 80-day rolling**			**Recursive & 90-day rolling**		
QE_t	2.09***	1.49***	1.58***	2.13***	1.62***	1.81***	2.21***	1.76***	1.98***	2.19***	1.78***	2.00***
	(0.18)	(0.20)	(0.22)	(0.17)	(0.20)	(0.21)	(0.17)	(0.19)	(0.21)	(0.16)	(0.19)	(0.20)
$SHORT_t$		-103.07***	-132.33***		-88.18***	-102.61***		-73.81***	-77.48***		-70.42***	-70.43***
		(18.16)	(23.78)		(17.70)	(23.17)		(17.20)	(22.53)		(16.63)	(21.71)
ΔUSD_t		-1.87	-2.50		-2.94	-3.29		-3.77	-3.68		-3.76	-3.53
		(3.06)	(3.07)		(2.99)	(3.00)		(2.90)	(2.91)		(2.81)	(2.81)
Controls	NO	NO	YES	NO	NO	YES	NO	NO	YES	NO	NO	YES
adj. R^2	0.109	0.130	0.145	0.119	0.134	0.151	0.022	0.027	0.058	0.026	0.027	0.051

Table 8A: Additional Tests for Determinants of VIX Spillovers with Real Short Rate

This table reports the results of the following weekly regressions: $S_{t,\mathrm{H}} = \beta_0 + \beta_1 QE_t + Controls + \varepsilon_t$, where $S_{t,\mathrm{H}}$ is the daily or weekly (Friday) aggregate or individual VIX spillover index defined earlier. QE_t is the US QE proxy, the sum of US Treasury, agency and mortgage-backed securities holdings on the Fed balance sheet. Controls include the following variables. $SHORT^*_t$ is the US real short rate, defined as 1-month Treasury yield minus inflation rate. ΔUSD_t is the change of foreign currency per US dollar. At the aggregate level, ΔUSD_t is the log difference of the trade-weighted US dollar index. In the case of two commodity markets, ΔUSD_t is the log difference of oil and gold prices per US dollar. $SWAP_t$ is the dollar amount foreign central banks draw from liquidity swaps with the Federal Reserve. $TERM_t$ is term spread defined as the difference between the 10-year and 3-month Treasury yields. DEF_t is the default spread defined as the difference between BAA corporate bond and 10-year Treasury yields. TED_t is the spread between 3-month LIBOR based on US dollars and 3-month Treasury yield. $\Delta ADSBCI_t$ is the change of Aruoba, Diebold, and Scotti's business condition index. $\Delta CESG10_t$ is the change of Citigroup's Economic Surprise Index for the G10. $\Delta CESEM_t$ is the change of Citigroup's Economic Surprise Index for the Emerging Markets. The coefficient estimates are reported with *, **, ***, denoting significance at 10%, 5%, and 1% respectively. The robust standard errors are reported in parentheses below. "N" is the number of observations used in each regression.

Panel A: daily 12-day-ahead volatility spillover

Dependent variable	All other markets	German stocks	France stocks	UK stocks	Swiss stocks	Japanese stocks	Korean stocks	Hong ong stocks	Oil	Gold
QE_t	0.88***	0.218***	0.279***	0.196***	0.202***	-0.576***	-0.039*	0.114***	0.285***	0.219***
	(0.17)	(0.033)	(0.017)	(0.023)	(0.033)	(0.030)	(0.023)	(0.025)	(0.016)	(0.012)
$SHORT^*_t$	-2.21*	-0.992***	0.025	-1.323***	-0.963***	3.721***	-1.499***	-1.669***	0.519***	0.148
	(1.32)	(0.255)	(0.135)	(0.181)	(0.255)	(0.231)	(0.177)	(0.195)	(0.125)	(0.092)
ΔUSD_t	-2.10**	-0.224**	-0.084*	-0.116*	-0.022	0.196**	0.011	0.723	-0.064***	-0.025
	(0.93)	(0.094)	(0.050)	(0.068)	(0.087)	(0.089)	(0.052)	(1.596)	(0.019)	(0.019)
$TERM_t$	-11.17***	-1.527***	-1.930***	-1.803***	-0.709***	-1.093***	-0.477***	-0.292	-2.462***	-0.735***
	(1.26)	(0.242)	(0.128)	(0.173)	(0.243)	(0.221)	(0.168)	(0.186)	(0.120)	(0.088)
DEF_t	12.70***	2.638***	0.551***	1.555***	3.068***	2.468***	2.068***	1.713***	-1.951***	0.718***
	(1.40)	(0.270)	(0.143)	(0.192)	(0.270)	(0.245)	(0.187)	(0.206)	(0.134)	(0.097)
TED_t	-59.54***	-12.948***	-5.817***	-9.219***	-12.559***	-6.439***	-6.006***	-5.715***	0.429**	-1.185***
	(1.93)	(0.374)	(0.198)	(0.268)	(0.375)	(0.341)	(0.259)	(0.287)	(0.192)	(0.135)
$\Delta ADSBCI_t$	-77.86***	-16.754***	-6.246***	-8.750***	-18.382***	-4.744*	-10.130***	-8.431***	0.174	-4.914***
	(14.89)	(2.883)	(1.526)	(2.053)	(2.886)	(2.625)	(1.999)	(2.210)	(1.430)	(1.045)
$\Delta CESG10_t$	0.00	-0.004	0.008	0.002	-0.007	-0.007	0.004	-0.002	0.004	0.000
	(0.11)	(0.020)	(0.011)	(0.015)	(0.020)	(0.019)	(0.014)	(0.016)	(0.010)	(0.007)
$\Delta CESEM_t$	-0.02	0.004	0.001	-0.003	-0.006	0.004	-0.020	-0.014	0.030**	-0.002
	(0.12)	(0.023)	(0.012)	(0.017)	(0.023)	(0.021)	(0.016)	(0.018)	(0.012)	(0.008)
N	1083	1083	1083	1083	1083	1083	1083	1083	1093	1086
Adj. R^2	0.781	0.806	0.918	0.859	0.744	0.797	0.425	0.515	0.929	0.833

Panel B: Weekly 3-day-ahead volatility spillover

Dependent variable	All other markets	German stocks	France stocks	UK stocks	Swiss stocks	Japanese stocks	Korean stocks	Hong Kong stocks	Oil	Gold
QE_t	1.73***	0.545***	0.477***	0.244***	0.500***	-0.625***	0.014	0.030	0.432***	0.188***
	(0.42)	(0.080)	(0.042)	(0.061)	(0.081)	(0.070)	(0.055)	(0.061)	(0.034)	(0.026)
$SHORT^*_t$	-3.26	-1.121**	-0.607**	-1.913***	-0.911*	4.998***	-1.160***	-1.841***	-0.155	-0.247
	(2.59)	(0.493)	(0.259)	(0.373)	(0.501)	(0.435)	(0.340)	(0.375)	(0.204)	(0.157)
ΔUSD_t	-1.96**	-0.180*	-0.118**	-0.128*	0.014	0.032	-0.039	0.041	0.016	-0.039**
	(0.92)	(0.096)	(0.050)	(0.070)	(0.085)	(0.083)	(0.051)	(1.480)	(0.018)	(0.018)
$SWAP_t$	6.20**	1.122**	0.479**	0.550	1.405***	-0.114	1.264***	0.995***	-0.172	0.607***
	(2.39)	(0.455)	(0.239)	(0.345)	(0.463)	(0.403)	(0.315)	(0.348)	(0.191)	(0.147)
$TERM_t$	-12.96***	-0.702	-1.855***	-2.439***	-0.086	-0.908**	-0.744**	-1.843***	-2.217***	-1.654***
	(2.36)	(0.446)	(0.235)	(0.340)	(0.450)	(0.392)	(0.308)	(0.338)	(0.189)	(0.146)
DEF_t	9.73**	4.006***	1.530***	1.009*	3.986***	1.092*	0.829*	-0.629	-0.579*	-0.436*
	(3.83)	(0.724)	(0.381)	(0.554)	(0.721)	(0.627)	(0.497)	(0.542)	(0.310)	(0.231)
TED_t	-59.66***	-14.077***	-6.209***	-8.581***	-14.113***	-6.510***	-6.665***	-5.462***	1.126**	-0.305
	(5.12)	(0.979)	(0.515)	(0.752)	(0.977)	(0.855)	(0.662)	(0.729)	(0.483)	(0.313)
$\Delta ADSBCI_t$	-16.39**	-3.860**	-1.360*	-1.778	-4.400***	-2.429*	-2.517**	-1.245	0.590	0.017
	(7.97)	(1.522)	(0.800)	(1.150)	(1.529)	(1.343)	(1.046)	(1.151)	(0.643)	(0.494)
$\Delta CESG10_t$	-0.08	-0.015	-0.004	-0.011	-0.022	-0.002	-0.010	-0.016	0.001	-0.004
	(0.10)	(0.019)	(0.010)	(0.014)	(0.019)	(0.016)	(0.013)	(0.014)	(0.008)	(0.006)
$\Delta CESEM_t$	0.10	0.013	0.014	0.010	0.008	0.010	0.004	0.016	0.018**	0.007
	(0.11)	(0.022)	(0.011)	(0.017)	(0.022)	(0.019)	(0.015)	(0.017)	(0.009)	(0.007)
N	217	217	217	217	217	217	217	217	220	219
Adj. R^2	0.817	0.831	0.939	0.871	0.770	0.794	0.459	0.642	0.956	0.887

Figure 1A: Contemporaneous Causal Flow Patterns among Changes of Implied Volatilities for the period from 2005 to 2007

This figure shows the contemporaneous causal flow patterns among changes of implied volatilities for the period from 2005 to 2007. VIX is the Chicago Board Option Exchange (CBOE)'s S&P500 volatility index. MOVE is the Bank of America Merrill Lynch's Treasury Option Volatility Estimate Index. "French VIX" (VCAC) is the Euronext-Paris' CAC-40 volatility index. "UK VIX" (VFTSE) is the Euronext's FTSE100 volatility index. "Swiss VIX" (VSMI) is the SWX Swiss Exchange's SMI volatility index. "Japanese VIX" (VXJ) is the Nikkei 225 volatility index. "Korean VIX" (VKOSPI) is the KOSPI200 volatility index. "HKVIX" (VHSI) is Hong Kong's Hang Seng volatility index. The VIX indices for oil and gold are excluded because those indices do not extend back far enough. The analysis is conducted using a directed acyclic graph (DAG) with the resulting graph at the conventional 10% significance level.

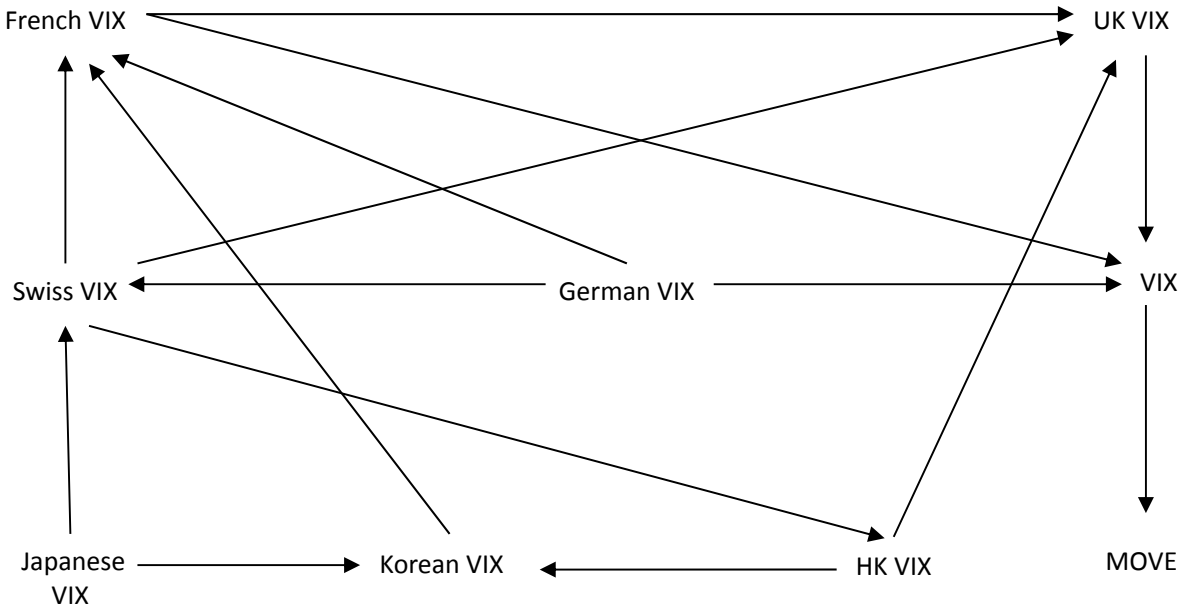
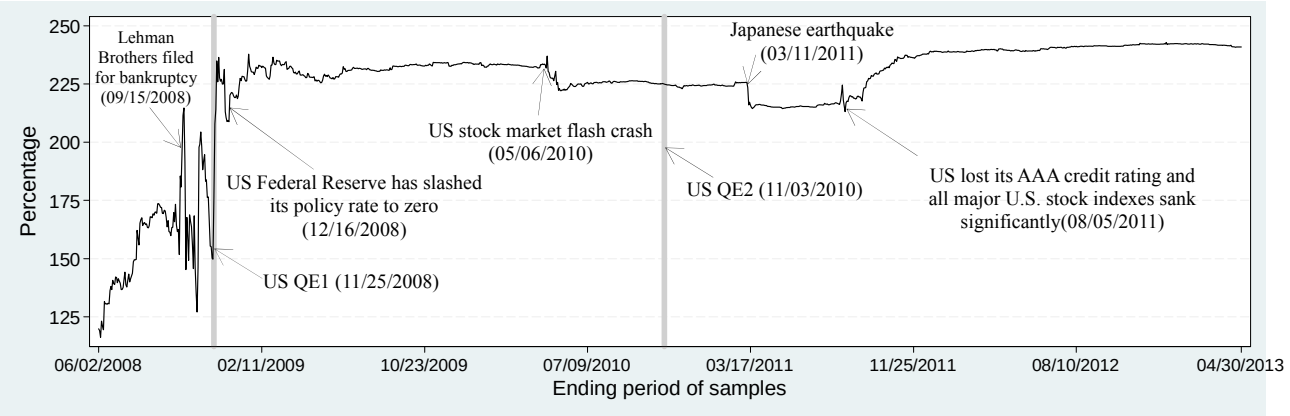


Figure 2A: Aggregate Volatility Spillover index of VIX

This figure plots the aggregate volatility spillover index of VIX, which is the sum of all recursive variance decomposition contributions from VIX to all other VIXs each day at the horizons of 12 days. VIX is the Chicago Board Option Exchange (CBOE)'s S&P500 volatility index. In Panel A, other VIXs include the following. "German VIX" (VDAX) is the Deutsche Borse's DAX-30 volatility index. "French VIX" (VCAC) is the Euronext-Paris' CAC-40 volatility index. "UK VIX" (VFTSE) is the Euronext's FTSE100 volatility index. "Swiss VIX" (VSMI) is the SWX Swiss Exchange's SMI volatility index. "Japan VIX" (VXJ) is the Nikkei 225 volatility index. "Korea VIX" (VKOSPI) is the KOSPI200 volatility index. "HKVIX" (VHSI) is Hong Kong's Hangseng volatility index.



Note: The initial sample period is January 2, 2008– June 2, 2008, and the variance decompositions are estimated recursively each day with an expanding sample. The final sample period is January 2, 2008–April 30, 2013.