

Internet Appendix

Network topology of dynamic credit default swap curves of energy firms and the role of oil shocks

Appendix A: Plots of CDS spread curves and DNS factors

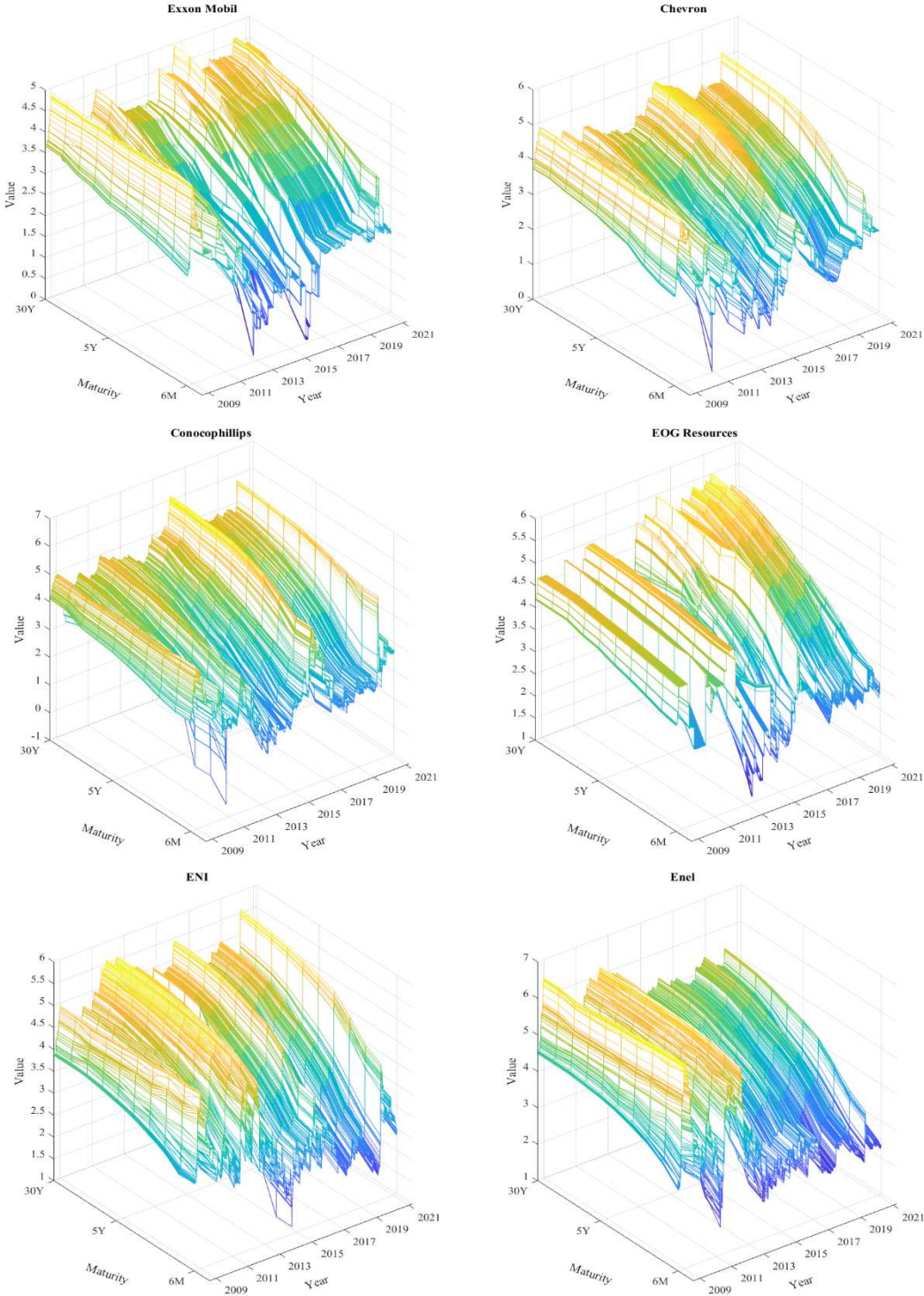
Figure A.1 shows a three-dimensional plot of the CDS spread curves of Exxon Mobil, Chevron ConocoPhillips, EOG Resources, ENI, and Enel¹, which reflects a considerable temporal variation in the level, as well as a commonality that points to the possible existence of credit co-movement and spillovers. For example, there seems to be a simultaneous increase in the credit curve of European energy firms during the ESDC and US energy firms during the oil price shock of 2014-2015, which further motivates our decision to conduct a connectedness analysis across energy firms.

Digging into the behaviour of the three default factors for all energy firms under study, Figure A.2 shows that they display some similarity across firms², especially the level and slope factors, which suggests potential spillover effects. However, the variation in curvature is strong and visible. It appears that the long-term default risk (i.e. level factor) across energy firms increases during the COVID19 outbreak; during the same period, the short-term default risk (i.e. slope factor) decreases, suggesting possible upward slope curves.

¹ The figures for other firms are available upon request from the authors.

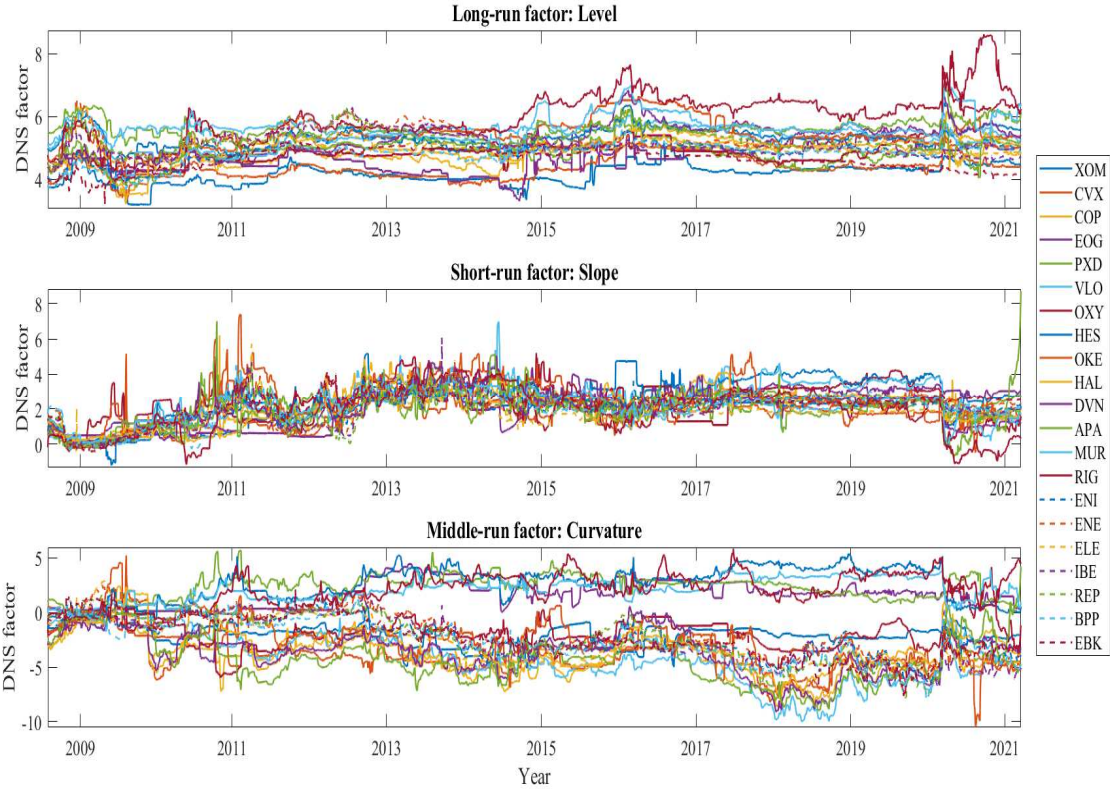
² To visually differentiate between the groups of US and European firms, we feature the default factors of US (European) firms with a solid (dashed) line.

Figure A.1. The CDS spreads data of selected US and European energy firms



Note: (Log) credit default swap spreads from 18 July 2008 to 19 March 2021 with daily data for selected firms across 10 maturities. The data is presented after logarithm transformation.

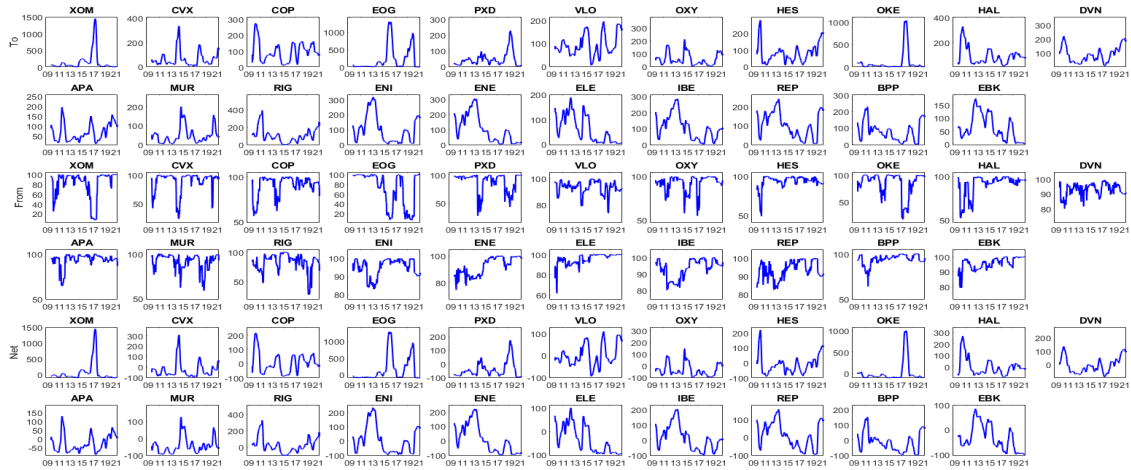
Figure A.2. DNS factors



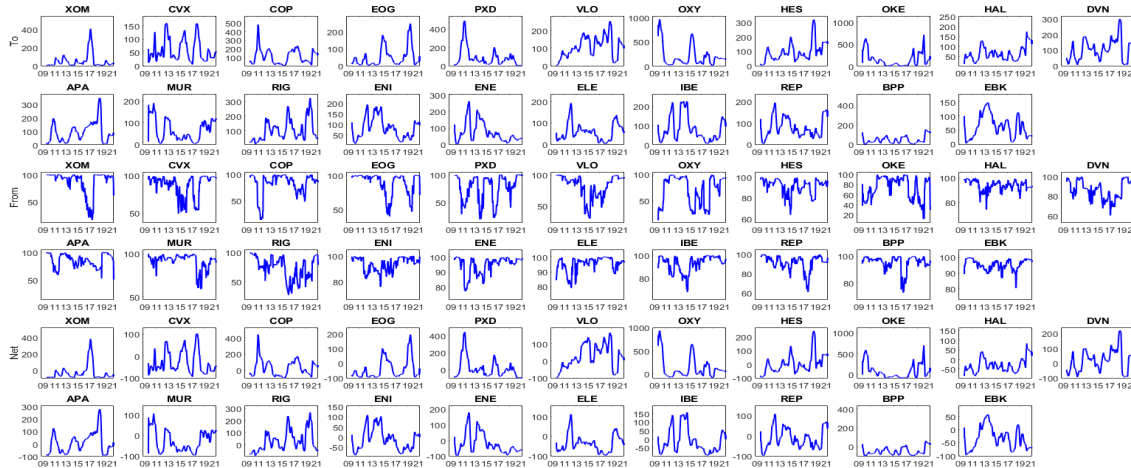
Note. The upper panel shows the level factors, middle panel shows the slope factors, and the bottom panel shows the curvature factors. To visually differentiate between the groups of US and European firms, we show the default factors of US (European) firms with a solid (dashed) line.

Appendix B: Figure B.1. Rolling connectedness

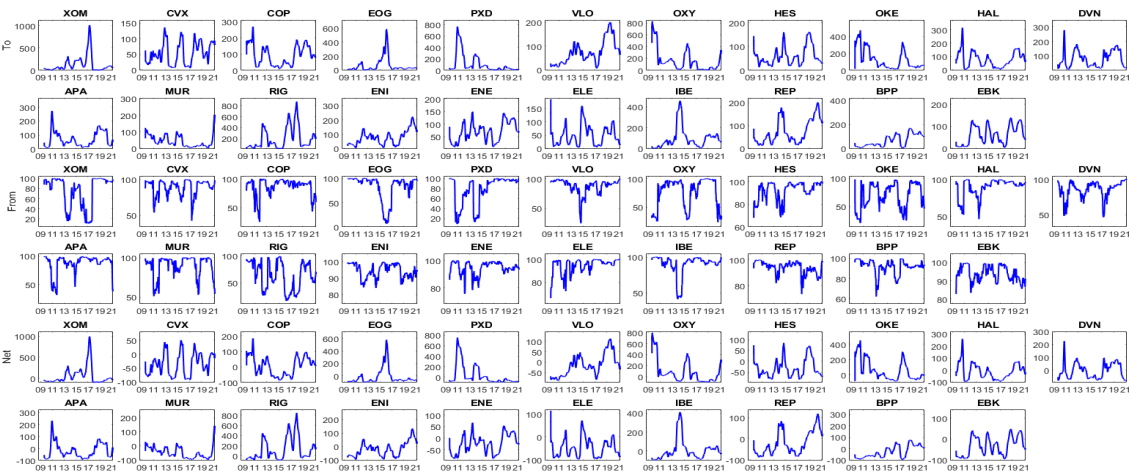
a). Level



b). Slope



c). Curvature



Note: The connectedness measures are computed by one-year rolling window estimation (260 observations). The variance decomposition is performed with a forecast horizon of 12 days.

Appendix C: The cross-quantilogram approach

Following Han et al. (2016), let y_t and x_t be two stationary time series with $y_t = (y_{1t}, y_{2t})^T \in \mathbb{R}^2$ and $x_t = (x_{1t}, x_{2t})^T \in \mathbb{R}^{d_1} \times \mathbb{R}^{d_2}$. We define the conditional distribution function for y_{it} given x_{it} as $F_{(y_i|x_i)}(\cdot | x_{it})$ and the corresponding quantile function as $q_{i,t}(\alpha_i) = \inf \{v : F_{(y_i|x_i)}(v|x_{it}) \geq \alpha_i\}$ for $\alpha_i \in (0,1)$, for $i = 1, 2$. The cross-quantilogram of α quantiles for k lags is formulated as:

$$\rho_\alpha(k) = \frac{E \left[\psi_{\alpha_1} \left(y_{1,t} - q_{1,t}(\alpha_1) \right) \psi_{\alpha_2} \left(y_{2,t-k} - q_{2,t-k}(\alpha_2) \right) \right]}{\sqrt{E \left[\psi_{\alpha_1}^2 \left(y_{1,t} - q_{1,t}(\alpha_1) \right) \right]} \sqrt{E \left[\psi_{\alpha_2}^2 \left(y_{2,t-k} - q_{2,t-k}(\alpha_2) \right) \right]}} \quad (\text{C.1})$$

where, $\psi_\alpha(u) = 1[u < 0] - \alpha$ reflects the quantile-hit process. We test the null-hypothesis of no directional predictability ($H_0: \rho_\alpha(1) = \dots = \rho_\alpha(p) = 0$) against the alternative hypothesis ($H_1: \rho_\alpha(k) \neq 0$) for some $(k, \alpha) \in \{1 \dots \dots p\}$. This can be done under the portmanteau test statistic:

$$\widehat{\rho}_\alpha^{(p)} = T(T+2) \sum_{k=1}^p \frac{\widehat{\rho}_\alpha^2(k)}{T-k} \quad (\text{C.2})$$

We use the stationary bootstrap of Politis and Romano (1994) to construct the confidence interval.

Appendix D: The identification of oil shocks according to Ready (2018).

Ready (2018) argues that the approach of Kilian (2009) to decompose oil price changes is not vigorous because it relies on monthly data, leading to association with contemporaneous or future oil price changes. In contrast, Ready (2018) yields oil shocks at the daily frequency, enabling them to be studied with financial variables available at the daily frequency, in our case the daily interconnectedness of default factors across credit horizons. The new approach of Ready (2018) refines the decomposition of oil price changes into supply shocks (s_t), demand shocks (d_t) and risk shocks (r_t) using information on asset prices. Specifically, the various oil price-driven shocks are identified via a three-dimensional vector $Z_t = (s_t, d_t, r_t)'$ and then mapped with the matrix M into observable variables such as:

$$Z_t = M^{-1}Q_t$$

$$\text{where } M = \begin{bmatrix} 1 & 1 & 1 \\ 0 & m_{22} & m_{23} \\ 0 & 0 & m_{33} \end{bmatrix}, Q_t = \begin{bmatrix} \Delta op_t \\ Prod_t \\ VIX_t \end{bmatrix}$$

In the above, Δop_t , $Prod_t$ and VIX_t , denote oil price changes as measured by the one-month crude oil futures' returns for the second nearest maturity for the NYSE, returns for an index of global oil-producing firms as represented by the World Integrated Oil and Gas Producer Index, and innovations of the CBOE US implied volatility index (VIX), respectively.

Appendix E: Results of the total default connectedness in tables.

Table E.1. Summary of default spillover analysis – Level factors

	Full sample (2008-2021)			Global financial crisis			European sovereign debt crisis			Oil price shock			Covid19 pandemic		
	To	From	Net	To	From	Net	To	From	Net	To	From	Net	To	From	Net
XOM	13.46	87.09	-73.63	56.00	95.42	-39.42	20.34	47.41	-27.07	163.26	69.62	93.64	11.65	99.31	-87.66
CVX	81.69	97.17	-15.48	55.60	96.16	-40.56	12.94	98.20	-85.26	45.00	97.54	-52.54	153.30	92.30	61.00
COP	128.22	85.30	42.91	27.99	89.22	-61.23	101.96	89.55	12.41	28.79	95.16	-66.37	94.16	94.92	-0.76
EOG	19.45	3.81	15.64	58.87	99.58	-40.71	7.87	96.85	-88.98	653.78	22.21	631.57	4.84	99.73	-94.90
PXD	12.90	45.74	-32.83	27.79	97.45	-69.66	9.30	98.45	-89.15	25.92	99.26	-73.34	6.51	99.65	-93.14
VLO	143.06	89.42	53.65	54.01	99.22	-45.21	48.74	98.28	-49.54	136.26	88.02	48.24	165.49	91.45	74.05
OXY	75.22	78.69	-3.47	68.82	98.29	-29.47	24.91	98.94	-74.03	80.32	71.92	8.40	80.99	92.01	-11.02
HES	80.31	84.04	-3.74	61.19	91.82	-30.63	17.14	99.25	-82.11	81.30	98.66	-17.36	196.78	89.90	106.88
OKE	15.08	75.36	-60.28	129.97	62.27	67.70	23.80	94.28	-70.48	1.92	96.38	-94.46	3.08	99.71	-96.63
HAL	54.82	79.88	-25.07	22.99	99.42	-76.42	108.39	65.91	42.48	139.23	93.91	45.32	79.56	95.74	-16.18
DVN	156.92	84.42	72.50	75.15	92.23	-17.08	74.14	81.19	-7.05	108.54	89.53	19.01	187.23	90.55	96.68
APA	116.92	89.79	27.13	83.52	96.03	-12.51	36.13	79.67	-43.55	84.94	94.46	-9.52	89.50	93.24	-3.74
MUR	42.91	46.24	-3.32	47.91	96.42	-48.51	28.41	99.81	-71.41	172.45	76.23	96.22	40.00	99.43	-59.42
RIG	129.10	70.40	58.70	115.71	80.27	35.45	252.58	73.46	179.12	51.16	89.08	-37.92	231.33	83.00	148.33
ENI	133.11	90.41	42.70	163.47	90.74	72.73	135.23	92.99	42.23	5.64	99.80	-94.16	162.57	91.25	71.33
ENE	81.92	89.41	-7.49	189.39	87.77	101.62	201.32	83.99	117.33	2.98	99.97	-96.99	5.89	99.75	-93.86
ELE	51.52	94.78	-43.26	135.23	88.83	46.40	137.22	92.33	44.89	47.21	99.25	-52.05	87.26	95.29	-8.03
IBE	88.11	81.42	6.69	194.52	93.04	101.47	170.34	84.89	85.45	7.02	99.63	-92.62	82.22	96.67	-14.46
REP	101.85	79.94	21.91	159.92	84.72	75.20	166.18	84.41	81.77	16.66	99.93	-83.28	149.11	92.05	57.06
BP	80.48	81.95	-1.47	107.69	94.03	13.66	167.51	70.87	96.64	21.61	99.72	-78.11	156.64	92.96	63.69
EBK	22.43	94.22	-71.79	72.83	75.62	-2.79	79.65	93.35	-13.69	5.91	99.59	-93.68	0.77	100.00	-99.23
Total default connectedness index		77.59			90.88			86.86			89.52			94.71	

Table E.2. Summary of default spillover analysis – Slope factors

	Full sample (2008-2021)			Global financial crisis			European sovereign debt crisis			Oil price shock			Covid19 pandemic		
	To	From	Net	To	From	Net	To	From	Net	To	From	Net	To	From	Net
XOM	14.16	23.20	-9.03	13.08	99.71	-86.63	13.16	98.28	-85.12	16.50	91.91	-75.42	25.64	93.77	-68.13
CVX	36.45	43.24	-6.79	43.64	98.62	-54.98	34.31	50.73	-16.43	76.51	76.56	-0.05	122.99	92.89	30.10
COP	211.76	24.29	187.47	129.25	81.77	47.49	291.49	15.39	276.10	24.13	98.31	-74.18	92.48	90.45	2.02
EOG	1.95	75.42	-73.47	35.26	99.47	-64.21	5.87	99.94	-94.08	64.29	48.98	15.31	67.65	93.51	-25.86
PXD	11.72	94.67	-82.96	40.98	97.97	-56.99	434.75	25.79	408.96	23.52	99.35	-75.83	2.09	99.65	-97.56
VLO	80.07	38.17	41.90	16.30	92.36	-76.06	107.16	53.62	53.54	113.27	41.30	71.97	82.31	95.01	-12.69
OXY	56.24	38.96	17.29	438.69	20.59	418.10	56.39	91.67	-35.29	679.66	23.08	656.58	116.04	91.75	24.29
HES	46.67	79.80	-33.12	18.43	98.53	-80.10	69.81	92.48	-22.67	52.42	83.49	-31.07	190.34	92.32	98.02
OKE	74.31	26.39	47.92	31.07	97.48	-66.42	35.55	84.78	-49.23	25.32	95.68	-70.36	249.03	38.12	210.91
HAL	61.74	84.72	-22.98	71.24	96.09	-24.85	77.71	78.06	-0.35	21.92	86.84	-64.92	156.14	93.78	62.36
DVN	89.89	72.50	17.39	87.44	97.12	-9.68	57.84	79.15	-21.31	26.77	99.02	-72.26	127.71	91.82	35.90
APA	112.35	41.24	71.11	20.94	97.93	-76.99	35.98	83.27	-47.28	35.91	99.33	-63.42	101.95	84.60	17.35
MUR	32.87	99.66	-66.79	36.63	97.79	-61.16	76.08	86.99	-10.92	21.74	96.16	-74.42	145.13	86.59	58.54
RIG	13.13	96.27	-83.14	21.42	98.18	-76.76	32.33	67.91	-35.59	22.76	84.59	-61.83	38.75	95.56	-56.81
ENI	121.70	82.67	39.03	115.82	91.67	24.15	58.07	91.74	-33.67	124.56	96.09	28.47	26.14	99.90	-73.76
ENE	96.93	78.52	18.41	199.43	85.75	113.68	55.38	83.70	-28.32	96.77	85.81	10.96	14.71	99.24	-84.53
ELE	41.23	76.14	-34.91	53.37	80.57	-27.20	39.90	93.83	-53.94	55.61	98.59	-42.97	65.78	95.61	-29.84
IBE	99.30	81.15	18.15	79.78	94.54	-14.76	65.90	89.62	-23.72	90.62	87.53	3.09	93.34	93.98	-0.63
REP	89.42	72.97	16.44	178.40	91.97	86.43	64.27	98.13	-33.87	90.29	78.99	11.30	101.62	93.98	7.64
BP	31.45	75.17	-43.72	119.01	94.00	25.00	20.08	99.24	-79.16	25.88	96.30	-70.42	87.13	95.31	-8.18
EBK	69.59	87.79	-18.20	149.91	87.97	61.94	31.42	99.08	-67.66	72.31	92.84	-20.53	10.52	99.63	-89.11
Total default connectedness index		66.33			90.48			79.21			83.85			91.31	

Table E.3. Summary of default spillover analysis – Curvature factors

	Full sample (2008-2021)			Global financial crisis			European sovereign debt crisis			Oil price shock			Covid19 pandemic		
	To	From	Net	To	From	Net	To	From	Net	To	From	Net	To	From	Net
XOM	8.97	90.93	-81.96	10.82	99.44	-88.63	14.77	87.49	-72.72	193.27	73.19	120.08	99.02	94.10	4.92
CVX	59.84	16.00	43.84	36.98	93.13	-56.15	21.40	30.54	-9.14	8.87	97.62	-88.75	103.68	94.63	9.05
COP	79.41	80.04	-0.63	159.46	85.91	73.55	124.87	24.04	100.83	16.82	89.05	-72.23	38.51	94.47	-55.96
EOG	5.34	75.90	-70.57	22.29	96.98	-74.69	16.59	99.87	-83.28	675.20	8.91	666.29	13.96	97.17	-83.21
PXD	5.01	59.37	-54.36	31.84	99.50	-67.65	613.94	7.79	606.14	30.22	62.68	-32.47	13.70	99.63	-85.93
VLO	94.79	82.13	12.65	50.73	88.43	-37.70	10.79	98.14	-87.34	27.45	95.84	-68.39	116.06	93.40	22.66
OXY	46.87	33.70	13.17	201.75	53.09	148.67	26.20	98.15	-71.95	248.07	30.84	217.23	241.75	49.22	192.54
HES	37.76	33.43	4.33	464.79	43.56	421.23	4.44	99.62	-95.17	18.39	99.25	-80.86	144.21	91.70	52.50
OKE	96.47	12.61	83.87	94.19	94.30	-0.11	10.73	93.33	-82.59	1.91	99.97	-98.06	18.65	93.90	-75.24
HAL	104.32	72.57	31.75	63.89	93.75	-29.86	69.47	47.08	22.39	33.81	98.76	-64.95	79.28	94.74	-15.46
DVN	153.31	76.26	77.05	45.31	77.74	-32.43	41.13	64.05	-22.92	6.65	99.71	-93.06	125.68	95.69	29.99
APA	92.56	76.05	16.51	7.12	98.21	-91.09	21.39	81.52	-60.13	7.67	99.05	-91.38	28.54	79.18	-50.65
MUR	25.83	85.85	-60.03	3.40	99.69	-96.29	19.09	93.00	-73.91	18.97	99.75	-80.78	31.59	99.35	-67.75
RIG	4.38	93.41	-89.03	27.58	73.85	-46.26	60.10	56.66	3.43	23.38	69.12	-45.75	116.06	74.22	41.83
ENI	174.57	81.08	93.49	43.36	91.70	-48.33	44.34	97.52	-53.18	116.76	95.46	21.29	176.30	93.00	83.29
ENE	76.56	88.94	-12.38	91.01	92.36	-1.35	106.17	76.35	29.82	63.45	97.47	-34.02	39.39	96.69	-57.30
ELE	46.09	97.10	-51.02	96.83	62.80	34.03	86.60	75.36	11.24	12.74	99.15	-86.41	73.66	95.01	-21.35
IBE	95.25	86.74	8.50	22.66	98.76	-76.10	103.89	89.03	14.86	88.63	97.86	-9.23	98.85	92.08	6.77
REP	112.67	85.82	26.85	41.61	89.08	-47.47	83.56	94.22	-10.65	78.70	82.56	-3.86	162.84	92.30	70.54
BP	105.66	85.18	20.48	36.55	96.49	-59.94	47.80	55.94	-8.14	49.62	91.74	-42.12	152.50	90.74	61.76
EBK	64.47	77.00	-12.52	214.89	38.33	176.57	42.07	99.65	-57.58	66.04	98.63	-32.59	33.26	96.26	-62.99
Total default connectedness index		70.96			84.15			74.73			85.08			90.83	

References

Han, H., Linton, O., Oka, T., & Whang, Y. J. (2016). The cross-quantilogram: Measuring quantile dependence and testing directional predictability between time series. *Journal of Econometrics*, 193(1), 251-270.

Kilian, L. (2009). Not all oil price shocks are alike: Disentangling demand and supply shocks in the crude oil market. *American Economic Review*, 99(3), 1053-69.

Politis, D. N., & Romano, J. P. (1994). The stationary bootstrap. *Journal of the American Statistical association*, 89(428), 1303-1313.

Ready, R. C. (2018). Oil prices and the stock market. *Review of Finance*, 22(1), 155-176.