

A Time-Frequency Decomposition of Systemic Risk in Agricultural Markets: a Graph-Theory Analysis

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MATS Seminar

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The “graph team”

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 - The growing importance of transition metals for market stability
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 - Extreme weather events and futures price returns and volatility
 - Climate risks and price shock propagation
 - Climate risks and electricity futures market

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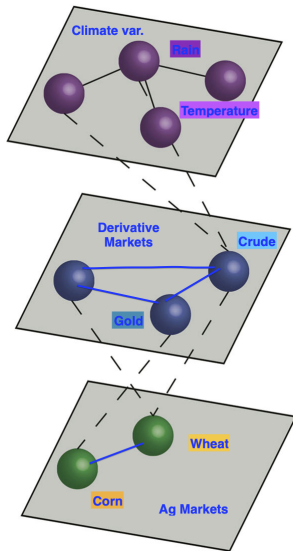
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- Empirical approach (no modeling of systems as complex as climate, financial markets and agriculture)

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- Empirical approach (no modeling of systems as complex as climate, financial markets and agriculture)
- Large database \Rightarrow graph analysis (multilayer networks)

Multilayer networks



Source: Kinsley et al. (2020)

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- No reference of such work in finance
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Technical issues:

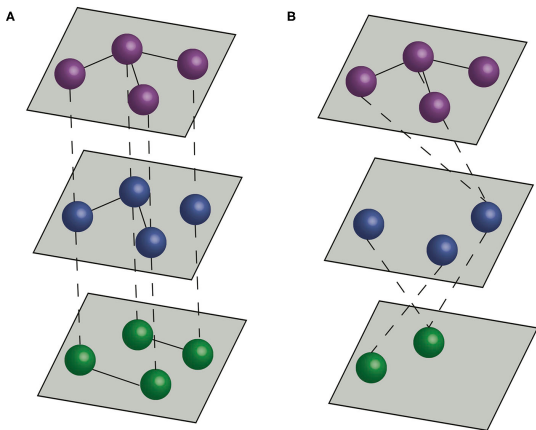
- Choice of the spillover measure for the weights of the links
- VAR estimation / number of observations required / LASSO techniques
- Visualization (too small to see clear clustering/communities, but too big for simple visualization) → filtration
- Directionality of the links / sensitivity of the method to the normalization
- Synthetic measures describing the dynamics, the topology...

Literature

Literature

- Finance:
 - How is climate risk taken into account?
 - Physical risk (Drought index, Putnam et al. (2023)) vs. transition risk (Bastianin, Casoli & Galeotti (2023) Networks & transition metals)
 - Building indexes: Physical Risk Index + Transition Risk Index from Bua et al. (2022)
 - Networks and commodities (Zhou, Wu, Liu, Rognone (2023), use the indexes of Bua et al. (2022))
 - Data: Handbook of Sustainable Finance, Roncalli (2024)
 - Links between macro-level and local-level networks (Meglioli & Gauci, 2021)
- Other fields:
 - Epidemiology: Kinsley et al. (2020)
- Methodology:
 - Minimum Spanning Trees: Lautier & Raynaud (2012), Lautier, Ling, Raynaud (2015)
 - Directionality: Lautier, Raynaud, Robe (2019)
 - Spillovers/Connectedness: Diebold & Yilmaz (2009, 2012), Barunik & Krehlik (2018), Demirer et al. (2018), Calioa et al (2018,19)
 - Multiplex networks (Musmeci et al., 2017), Barigozzi et al. (2022)

Multiplex (left) vs. multilayer (right) networks



Source: Kinsley et al. (2020)

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- “Classical grains” (wheat, soy, corn) + 7 grains eligible to cross-hedging: sorghum, sunflowers seeds, alfalfa meal, corn gluten feed meal, distillers dried grains, corn gluten feed, wheat middlings (Source: CME, 2015)

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 - Possible extension to transition metals (Connection with Polina ?)

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Methodology : weights and direction of the links

Caloia et al. (2018): improved Diebold & Yilmaz (2012)

- Vector AutoRegression VAR(p) model

$$X_t = A_1 X_{t-1} + A_2 X_{t-2} + \cdots + A_p X_{t-p} + \epsilon_t \quad \epsilon_t \sim N(0, \Sigma)$$

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$$X_t = \Psi_0 \epsilon_t + \Psi_1 \epsilon_{t-1} + \dots$$

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- ⇒ Generalized Forecast Error Variance Decomposition (GFEVD)

$$\theta_{ij}^H = \frac{\sigma_{jj}^{-1} \sum_{k=0}^H (\Psi_k \Sigma)_{ij}^2}{\max_i \sum_{j=1}^n \left[\sigma_{jj}^{-1} \sum_{k=0}^H (\Psi_k \Sigma)_{ij}^2 \right]}$$

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- Decomposing the variance of the forecast error of i into the sum of the variances of all the variables (j): Off-diagonal terms = pairwise connectedness (column $j \rightarrow$ row i)

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- **Normalization by largest variance**

Connectedness table / network adjacency matrix

For a specified horizon H :

	x_1	x_2	\dots	x_N	From Others to i (In-Degrees)
x_1	θ_{11}	θ_{12}	\dots	θ_{1N}	$\sum_{j=2}^N \theta_{1j}$
x_2	θ_{21}	θ_{22}	\dots	θ_{2N}	$\sum_{j=1, j \neq 2}^N \theta_{2j}$
\vdots	\vdots	\vdots	\ddots	\vdots	\vdots
x_N	θ_{N1}	θ_{N2}	\dots	θ_{NN}	$\sum_{j=1}^{N-1} \theta_{Nj}$
To Others from j (Out-Degrees)	$\sum_{i=2}^N \theta_{i1}$	$\sum_{i=1, i \neq 2}^N \theta_{i2}$	\dots	$\sum_{i=1}^{N-1} \theta_{iN}$	$\frac{1}{N} \sum_{i, j=1, i \neq j}^N \theta_{ij}$

$$\theta_{ij} = \theta_{i \leftarrow j} = \text{contribution of } j \text{ to the FEV of } i$$

Empirical results

What we do:

- Analysis of daily returns and volatilities
- Two sets of graphs: spatial versus maturity
- Spatial: 1st maturity of each market \Rightarrow 22 nodes (3 metals, 6 energy products, 4 softs, 3 meats, 6 ags)
- Maturity: one market, different delivery dates.
- Static: one period, full sample / Dynamic: rolling window of 3 years.
- Full graphs: visualization and centrality analysis in the spatial dimension
- Filtered graphs: retain X% of the most important links

In the Appendix:

- Sensitivity to the normalization retained
- Frequency analysis - short-term / long-term connectedness

Full connectivity matrix, in the spatial dimension, full sample

	Gold	Silver	Copper	WTI	Brent	NG.US	NG.UK	Heating.Oil	Gasoil	Cocoa.UK	Cocoa.US	Coffee	Sugar	Cattle.Feeder	Live.Cattle	Lean.Hogs	Cotton	Soy.Meal	Soybean	Soy.Oil	Wheat	Corn	From	
Gold	0.0083	0.0612	0.0061	0.0452	0.0063	0.0028	0.0062	0.0051	0.0025	0.0011	0.0014	0.0021	0.0019	0.0000	0.0000	0.0001	0.0009	0.0009	0.0010	0.0016	0.0022	0.0017	0.1504	
Silver	0.0180	0.3253	0.0323	0.2353	0.0374	0.0157	0.0168	0.0279	0.0164	0.0050	0.0070	0.0124	0.0111	0.0000	0.0004	0.0005	0.0061	0.0056	0.0067	0.0089	0.0105	0.0090	0.4834	
Copper	0.0025	0.0447	0.1239	0.3090	0.0472	0.0138	0.0320	0.0336	0.0221	0.0032	0.0044	0.0090	0.0113	0.0000	0.0005	0.0011	0.0090	0.0060	0.0073	0.0089	0.0090	0.0070	0.5817	
WTI	0.0018	0.0304	0.0348	97.9408	0.7379	0.0517	0.3222	0.4925	0.2206	0.0072	0.0120	0.0190	0.0327	0.0004	0.0008	0.0004	0.0114	0.0091	0.0149	0.0239	0.0123	0.0230	2.0592	
Brent	0.0015	0.0295	0.0273	4.1374	0.6252	0.1011	0.1595	0.4040	0.1771	0.0048	0.0061	0.0128	0.0181	0.0001	0.0006	0.0006	0.0111	0.0070	0.0122	0.0196	0.0172	0.0141	5.1618	
NG.US	0.0003	0.0057	0.0034	0.1284	0.0444	8.0641	0.2242	0.0607	0.0205	0.0011	0.0015	0.0049	0.0038	0.0001	0.0001	0.0004	0.0019	0.0023	0.0032	0.0048	0.0048	0.0048	0.5212	
NG.UK	0.0003	0.0021	0.0038	0.3720	0.0373	0.2772	48.9310	0.0386	0.0307	0.0020	0.0015	0.0039	0.0017	0.0001	0.0001	0.0007	0.0029	0.0018	0.0016	0.0013	0.0071	0.0015	0.7881	
Heating.Oil	0.0012	0.0225	0.0201	2.7872	0.4173	0.1461	0.1744	0.5674	0.1980	0.0032	0.0041	0.0114	0.0149	0.0000	0.0007	0.0006	0.0094	0.0050	0.0106	0.0180	0.0136	0.0158	3.8499	
Gasoil	0.0008	0.0167	0.0159	1.9128	0.2411	0.0723	0.1645	0.2874	0.3578	0.0028	0.0041	0.0086	0.0085	0.0000	0.0001	0.0002	0.0075	0.0036	0.0066	0.0121	0.0075	0.0072	2.7658	
Cocoa.UK	0.0004	0.0067	0.0034	0.0673	0.0084	0.0039	0.0165	0.0054	0.0039	0.1090	0.0888	0.0052	0.0035	0.0000	0.0002	0.0009	0.0020	0.0007	0.0009	0.0012	0.0016	0.0010	0.2217	
Cocoa.US	0.0005	0.0091	0.0041	0.0901	0.0098	0.0064	0.0135	0.0065	0.0052	0.0802	0.1480	0.0071	0.0048	0.0000	0.0001	0.0002	0.0026	0.0008	0.0010	0.0013	0.0024	0.0014	0.2474	
Coffee	0.0006	0.0125	0.0067	0.1268	0.0160	0.0159	0.0153	0.0136	0.0072	0.0037	0.0056	0.2995	0.0168	0.0001	0.0001	0.0007	0.0061	0.0035	0.0039	0.0044	0.0093	0.0061	0.2750	
Sugar	0.0006	0.0113	0.0084	0.2221	0.0231	0.0131	0.0277	0.0184	0.0086	0.0025	0.0037	0.0169	0.2988	0.0000	0.0002	0.0005	0.0074	0.0051	0.0056	0.0048	0.0123	0.0082	4.0004	
Cattle.Feeder	0.0000	0.0000	0.0001	0.0070	0.0004	0.0010	0.0032	0.0003	0.0002	0.0001	0.0001	0.0002	0.0001	0.0059	0.0028	0.0016	0.0000	0.0001	0.0000	0.0000	0.0001	0.0004	0.0176	
Live.Cattle	0.0000	0.0009	0.0009	0.0131	0.0016	0.0062	0.0044	0.0019	0.0006	0.0003	0.0002	0.0003	0.0005	0.0000	0.0001	0.0002	0.0016	0.0002	0.0002	0.0000	0.0003	0.0002	0.0004	0.0298
Lean.Hogs	0.0000	0.0003	0.0006	0.0036	0.0007	0.0034	0.0003	0.0005	0.0002	0.0005	0.0002	0.0002	0.0005	0.0003	0.0005	0.6306	0.0000	0.0006	0.0006	0.0002	0.0010	0.0008	0.0151	
Cotton	0.0003	0.0074	0.0080	0.0989	0.0168	0.0080	0.0184	0.0137	0.0078	0.0015	0.0019	0.0070	0.0087	0.0000	0.0001	0.0000	0.1837	0.0055	0.0057	0.0061	0.0114	0.0080	0.2353	
Soy.Meal	0.0003	0.0069	0.0051	0.0732	0.0103	0.0076	0.0094	0.0081	0.0040	0.0005	0.0006	0.0040	0.0056	0.0000	0.0001	0.0008	0.0053	0.2051	0.0759	0.0117	0.0302	0.0403	0.3000	
Soybean	0.0005	0.0105	0.0083	0.1540	0.0236	0.0142	0.0102	0.0196	0.0094	0.0010	0.0011	0.0057	0.0081	0.0000	0.0002	0.0011	0.0073	0.1001	0.0893	0.0296	0.0323	0.0420	0.4787	
Soy.Oil	0.0008	0.0151	0.0111	0.2720	0.0416	0.0246	0.0082	0.0368	0.0192	0.0015	0.0017	0.0072	0.0079	0.0000	0.0002	0.0005	0.0086	0.0173	0.0330	0.0650	0.0255	0.0251	0.5579	
Wheat	0.0006	0.0102	0.0064	0.0834	0.0213	0.0139	0.0355	0.0160	0.0063	0.0010	0.0016	0.0083	0.0117	0.0000	0.0001	0.0010	0.0092	0.0253	0.0205	0.0146	0.3494	0.0802	0.3672	
Corn	0.0006	0.0111	0.0063	0.1837	0.0217	0.0176	0.0090	0.0161	0.0082	0.0008	0.0011	0.0075	0.0097	0.0001	0.0002	0.0010	0.0082	0.0425	0.0336	0.0181	0.1009	0.1750	0.6492	
To	0.0317	0.3147	0.2132	41.3028	1.7641	0.8106	1.2715	1.4868	0.7689	0.1238	0.1486	0.1540	0.1819	0.0033	0.0085	0.0146	0.1173	0.2437	0.2449	0.1913	0.3116	0.2932	0.9091	

Full connectivity matrix, in the spatial dimension, full sample

	Gold	Silver	Copper	WTI	Brent	NG.US	NG.UK	Heating.Oil	Gasoil	Cocoa.UK	Cocoa.US	Coffee	Sugar	Cattle.Feeder	Live.Cattle	Lean.Hogs	Cotton	Soy.Meal	Soybean	Soy.Oil	Wheat	Corn	From	
Gold	0.0083	0.0612	0.0061	0.0063	0.0062	0.0062	0.0062	0.0062	0.0062	0.0062	0.0062	0.0062	0.0062	0.0062	0.0062	0.0062	0.0062	0.0062	0.0062	0.0062	0.0062	0.0062	0.0062	0.0062
Silver	0.0180	0.3253	0.0323	0.2353	0.0374	0.0157	0.0168	0.0279	0.0164	0.0050	0.0070	0.0124	0.0111	0.0000	0.0004	0.0005	0.0061	0.0056	0.0067	0.0089	0.0105	0.0090	0.4834	
Copper	0.0025	0.0447	0.1239	0.3090	0.0472	0.0138	0.0320	0.0336	0.0221	0.0032	0.0044	0.0090	0.0113	0.0000	0.0005	0.0011	0.0090	0.0060	0.0073	0.0089	0.0090	0.0070	0.5817	
WTI	0.0018	0.0304	0.0348	97.9408	0.7379	0.0517	0.3222	0.4925	0.2206	0.0072	0.0120	0.0190	0.0327	0.0004	0.0008	0.0004	0.0114	0.0091	0.0149	0.0239	0.0123	0.0230	2.0592	
Brent	0.0015	0.0295	0.0273	4.1374	0.6252	0.1011	1.595	0.4040	0.1771	0.0048	0.0061	0.0128	0.0181	0.0001	0.0006	0.0006	0.0111	0.0070	0.0122	0.0196	0.0172	0.0141	5.1618	
NG.US	0.0003	0.0057	0.0034	1.284	0.0444	8.0641	0.2242	0.0607	0.0205	0.0011	0.0015	0.0049	0.0038	0.0001	0.0001	0.0004	0.0019	0.0023	0.0032	0.0048	0.0048	0.0048	0.5212	
NG.UK	0.0003	0.0021	0.0038	3.720	0.0373	0.2772	48.9310	0.0386	0.0307	0.0020	0.0015	0.0039	0.0017	0.0001	0.0001	0.0007	0.0029	0.0018	0.0016	0.0013	0.0071	0.0015	0.7881	
Heating.Oil	0.0012	0.0225	0.0201	4.173	0.1461	0.1744	0.5674	0.1980	0.0332	0.0041	0.0114	0.0149	0.0000	0.0000	0.0007	0.0006	0.0094	0.0058	0.0106	0.0180	0.0136	0.0188	3.8499	
Gasoil	0.0008	0.0167	0.0159	1.9128	0.2411	0.0723	0.1645	0.2874	0.3578	0.0028	0.0041	0.0086	0.0085	0.0000	0.0001	0.0002	0.0075	0.0036	0.0066	0.0121	0.0075	0.0072	2.7658	
Cocoa.UK	0.0004	0.0067	0.0034	0.0673	0.0084	0.0039	0.0165	0.0054	0.0039	0.1090	0.0888	0.0052	0.0035	0.0000	0.0002	0.0009	0.0020	0.0007	0.0009	0.0012	0.0016	0.0010	0.2217	
Cocoa.US	0.0005	0.0091	0.0041	0.0901	0.0098	0.0064	0.0135	0.0065	0.0052	0.0802	0.1480	0.0071	0.0048	0.0000	0.0001	0.0002	0.0026	0.0008	0.0010	0.0013	0.0024	0.0014	0.2474	
Coffee	0.0006	0.0125	0.0067	0.1268	0.0160	0.0159	0.0153	0.0136	0.0072	0.0037	0.0056	0.2995	0.0168	0.0001	0.0001	0.0007	0.0061	0.0035	0.0039	0.0044	0.0093	0.0061	0.2750	
Sugar	0.0006	0.0113	0.0084	0.2221	0.0231	0.0131	0.0277	0.0184	0.0086	0.0025	0.0037	0.0169	0.2988	0.0000	0.0002	0.0005	0.0074	0.0051	0.0056	0.0048	0.0123	0.0082	4.004	
Cattle.Feeder	0.0000	0.0000	0.0001	0.0070	0.0004	0.0010	0.0032	0.0003	0.0002	0.0001	0.0001	0.0002	0.0001	0.0059	0.0028	0.0016	0.0000	0.0001	0.0000	0.0000	0.0001	0.0004	0.0176	
Live.Cattle	0.0000	0.0009	0.0009	0.0131	0.0016	0.0062	0.0044	0.0019	0.0006	0.0003	0.0002	0.0003	0.0005	0.0017	0.0259	0.0016	0.0002	0.0002	0.0002	0.0003	0.0002	0.0004	0.0298	
Lean.Hogs	0.0000	0.0003	0.0006	0.0036	0.0007	0.0034	0.0003	0.0005	0.0002	0.0005	0.0002	0.0002	0.0005	0.0003	0.0005	0.0000	0.0000	0.0000	0.0000	0.0002	0.0010	0.0008	0.0151	
Cotton	0.0003	0.0074	0.0080	0.0989	0.0168	0.0080	0.0184	0.0137	0.0078	0.0015	0.0019	0.0070	0.0087	0.0000	0.0001	0.0000	0.1837	0.0055	0.0057	0.0061	0.0114	0.0080	0.2353	
Soy.Meal	0.0003	0.0069	0.0051	0.0732	0.0103	0.0076	0.0094	0.0081	0.0040	0.0005	0.0006	0.0040	0.0056	0.0000	0.0001	0.0008	0.0053	0.2051	0.0759	0.0117	0.0302	0.0403	0.3000	
Soybean	0.0005	0.0105	0.0083	0.1540	0.0236	0.0142	0.0102	0.0196	0.0094	0.0010	0.0011	0.0057	0.0081	0.0000	0.0002	0.0011	0.0073	0.1001	0.0893	0.0296	0.0323	0.0420	0.4787	
Soy.Oil	0.0008	0.0151	0.0111	0.2720	0.0416	0.0246	0.0082	0.0368	0.0192	0.0015	0.0017	0.0072	0.0079	0.0000	0.0002	0.0005	0.0086	0.0173	0.0330	0.0650	0.0255	0.0251	0.5579	
Wheat	0.0006	0.0102	0.0064	0.0834	0.0213	0.0139	0.0355	0.0160	0.0063	0.0010	0.0016	0.0083	0.0117	0.0000	0.0001	0.0010	0.0092	0.0253	0.0205	0.0146	0.3494	0.0802	0.3672	
Corn	0.0006	0.0111	0.0063	0.1837	0.0217	0.0176	0.0090	0.0161	0.0082	0.0008	0.0011	0.0075	0.0097	0.0001	0.0002	0.0010	0.0082	0.0425	0.0336	0.0181	0.1009	0.1750	0.6982	
To	0.0317	0.3147	0.2132	41.3028	1.7641	0.8106	1.2715	1.4868	0.7689	0.1238	0.1486	0.1540	0.1819	0.0033	0.0085	0.0146	0.1173	0.2437	0.2449	0.1913	0.3116	0.2932	0.9091	

	Gold	Silver	Copper	WTI	Brent
Gold	0.0083	0.0612	0.0061	0.0452	0.0063
Silver	0.0180	0.3253	0.0323	0.2353	0.0374
Copper	0.0025	0.0447	0.1239	0.3090	0.0472
WTI	0.0018	0.0304	0.0348	97.9408	0.7379
Brent	0.0015	0.0295	0.0273	4.1374	0.6252

Full connectivity matrix, in the spatial dimension, full sample

	Gold	Silver	Copper	WTI	Brent	NG.US	NG.UK	Heating.Oil	Gasoil	Cocoa.UK	Cocoa.US	Coffee	Sugar	Cattle.Feeder	Live.Cattle	Lean.Hogs	Cotton	Soy.Meal	Soybean	Soy.Oil	Wheat	Corn	From
Gold	0.0083	0.0612	0.0061	0.0063	0.0028	0.0028	0.0028	0.0028	0.0028	0.0014	0.0021	0.0019	0.0000	0.0000	0.0001	0.0009	0.0009	0.0010	0.0016	0.0022	0.0017	0.1504	0.4834
Silver	0.0180	0.3253	0.0323	0.2353	0.0374	0.0157	0.0168	0.0279	0.0164	0.0050	0.0070	0.0124	0.0111	0.0000	0.0004	0.0005	0.0061	0.0056	0.0067	0.0089	0.0105	0.0090	0.5817
Copper	0.0025	0.0447	0.1239	0.3090	0.0472	0.0138	0.0320	0.0336	0.0221	0.0032	0.0044	0.0090	0.0113	0.0000	0.0005	0.0011	0.0090	0.0060	0.0073	0.0089	0.0090	0.0070	0.2092
WTI	0.0018	0.0304	0.0348	97.9408	0.7379	0.0517	0.3222	0.4925	0.2206	0.0072	0.0120	0.0190	0.0327	0.0004	0.0008	0.0004	0.0114	0.0091	0.0149	0.0239	0.0123	0.0230	0.5212
Brent	0.0015	0.0295	0.0273	4.1374	0.6252	0.1011	1.595	0.4040	0.1771	0.0048	0.0061	0.0128	0.0181	0.0001	0.0006	0.0006	0.0111	0.0070	0.0122	0.0196	0.0172	0.0141	5.1618
NG.US	0.0003	0.0057	0.0034	1.284	0.0444	8.0641	0.2242	0.0607	0.0205	0.0011	0.0015	0.0049	0.0038	0.0001	0.0001	0.0004	0.0019	0.0023	0.0032	0.0048	0.0048	0.0048	0.5212
NG.UK	0.0003	0.0021	0.0038	0.3720	0.0373	0.2772	48.9310	0.0386	0.0307	0.0020	0.0015	0.0039	0.0017	0.0001	0.0001	0.0007	0.0029	0.0018	0.0016	0.0013	0.0071	0.0015	0.7881
Heating.Oil	0.0012	0.0225	0.0201	2.7872	0.4173	0.1461	0.1744	0.5674	0.1980	0.0032	0.0041	0.0114	0.0149	0.0000	0.0007	0.0006	0.0094	0.0058	0.0106	0.0180	0.0136	0.0188	3.8499
Gasoil	0.0008	0.0167	0.0159	1.9128	0.2411	0.0723	0.1645	0.2874	0.3579	0.0028	0.0041	0.0086	0.0085	0.0000	0.0001	0.0002	0.0075	0.0036	0.0066	0.0121	0.0075	0.0072	2.7658
Cocoa.UK	0.0004	0.0067	0.0034	0.0673	0.0084	0.0039	0.0165	0.0054	0.0039	0.1090	0.0888	0.0052	0.0035	0.0000	0.0002	0.0009	0.0020	0.0007	0.0009	0.0012	0.0016	0.0010	0.2217
Cocoa.US	0.0005	0.0091	0.0041	0.0901	0.0098	0.0064	0.0135	0.0065	0.0052	0.0802	0.1480	0.0071	0.0048	0.0000	0.0001	0.0002	0.0026	0.0008	0.0010	0.0013	0.0024	0.0014	0.2474
Coffee	0.0006	0.0125	0.0067	0.1268	0.0160	0.0159	0.0153	0.0136	0.0072	0.0037	0.0056	0.2995	0.0168	0.0001	0.0001	0.0007	0.0061	0.0035	0.0039	0.0044	0.0093	0.0061	0.2750
Sugar	0.0006	0.0113	0.0084	0.2221	0.0231	0.0131	0.0277	0.0184	0.0086	0.0025	0.0037	0.0169	0.2988	0.0000	0.0002	0.0005	0.0074	0.0051	0.0056	0.0048	0.0123	0.0082	4.004
Cattle.Feeder	0.0000	0.0000	0.0001	0.0070	0.0004	0.0010	0.0032	0.0003	0.0002	0.0001	0.0001	0.0002	0.0001	0.0059	0.0028	0.0016	0.0000	0.0001	0.0000	0.0000	0.0001	0.0004	0.0176
Live.Cattle	0.0000	0.0009	0.0009	0.0131	0.0016	0.0062	0.0044	0.0019	0.0006	0.0003	0.0002	0.0003	0.0005	0.0017	0.0259	0.0016	0.0002	0.0002	0.0002	0.0003	0.0002	0.0004	0.0298
Lean.Hogs	0.0000	0.0003	0.0006	0.0036	0.0007	0.0034	0.0003	0.0005	0.0002	0.0005	0.0002	0.0002	0.0005	0.0003	0.0005	0.0000	0.0000	0.0006	0.0006	0.0002	0.0010	0.0008	0.0151
Cotton	0.0003	0.0074	0.0080	0.0989	0.0168	0.0080	0.0184	0.0137	0.0078	0.0015	0.0019	0.0070	0.0087	0.0000	0.0001	0.0000	0.1837	0.0055	0.0057	0.0061	0.0114	0.0080	0.2353
Soy.Meal	0.0003	0.0069	0.0051	0.0732	0.0103	0.0076	0.0094	0.0081	0.0040	0.0005	0.0006	0.0040	0.0056	0.0000	0.0001	0.0008	0.0053	0.2051	0.0759	0.0117	0.0302	0.0403	0.3000
Soybean	0.0005	0.0105	0.0083	0.1540	0.0236	0.0142	0.0102	0.0196	0.0094	0.0010	0.0011	0.0057	0.0081	0.0000	0.0002	0.0011	0.0073	0.1001	0.0393	0.0296	0.0323	0.0420	0.4787
Soy.Oil	0.0008	0.0151	0.0111	0.2720	0.0416	0.0246	0.0082	0.0368	0.0192	0.0015	0.0017	0.0072	0.0079	0.0000	0.0002	0.0005	0.0086	0.0173	0.0330	0.0650	0.0255	0.0251	0.5579
Wheat	0.0006	0.0102	0.0064	0.0834	0.0213	0.0139	0.0355	0.0160	0.0063	0.0010	0.0016	0.0083	0.0117	0.0000	0.0001	0.0010	0.0092	0.0253	0.0205	0.0146	0.3494	0.0802	0.3672
Corn	0.0006	0.0111	0.0063	0.1837	0.0217	0.0176	0.0090	0.0161	0.0082	0.0008	0.0011	0.0075	0.0097	0.0001	0.0002	0.0010	0.0082	0.0425	0.0336	0.0181	0.1009	0.1750	0.6982
To	0.0317	0.3147	0.2132	41.3028	1.7641	0.8106	1.2715	1.4868	0.7689	0.1238	0.1486	0.1540	0.1819	0.0033	0.0085	0.0146	0.1173	0.2437	0.2449	0.1913	0.3116	0.2932	0.9091

	Gold	Silver	Copper	WTI	Brent
Gold	0.0083	0.0612	0.0061	0.0452	0.0063
Silver	0.0180	0.3253	0.0323	0.2353	0.0374
Copper	0.0025	0.0447	0.1239	0.3090	0.0472
WTI	0.0018	0.0304	0.0348	97.9408	0.7379
Brent	0.0015	0.0295	0.0273	4.1374	0.6252

• $\theta_{WTI \leftarrow Brent} = 0.7379$

Full connectivity matrix, in the spatial dimension, full sample

	Gold	Silver	Copper	WTI	Brent	NG.US	NG.UK	Heating.Oil	Gasoil	Cocoa.UK	Cocoa.US	Coffee	Sugar	Cattle.Feeder	Live.Cattle	Lean.Hogs	Cotton	Soy.Meal	Soybean	Soy.Oil	Wheat	Corn	From
Gold	0.0083	0.0612	0.0061	0.0063	0.0028	0.0028	0.0028	0.0021	0.0025	0.0014	0.0021	0.0019	0.0000	0.0000	0.0001	0.0009	0.0009	0.0010	0.0016	0.0022	0.0017	0.1504	0.4834
Silver	0.0180	0.3253	0.0323	0.2353	0.0374	0.0157	0.0168	0.0279	0.0164	0.0050	0.0070	0.0124	0.0111	0.0000	0.0004	0.0005	0.0061	0.0056	0.0067	0.0089	0.0105	0.0090	0.5817
Copper	0.0025	0.0447	0.1239	0.3090	0.0472	0.0138	0.0320	0.0336	0.0221	0.0032	0.0044	0.0090	0.0113	0.0000	0.0005	0.0011	0.0090	0.0060	0.0073	0.0089	0.0090	0.0070	0.2092
WTI	0.0018	0.0304	0.0348	97.9408	0.7379	0.0517	0.3222	0.4925	0.2206	0.0072	0.0120	0.0190	0.0327	0.0004	0.0008	0.0004	0.0114	0.0091	0.0149	0.0239	0.0123	0.0230	5.1618
Brent	0.0015	0.0295	0.0273	4.1374	0.6252	0.1011	1.595	0.4040	0.1771	0.0048	0.0061	0.0128	0.0181	0.0001	0.0006	0.0006	0.0111	0.0070	0.0122	0.0196	0.0172	0.0141	0.5212
NG.US	0.0003	0.0057	0.0034	1.284	0.0444	8.0641	0.2242	0.0607	0.0205	0.0011	0.0015	0.0049	0.0038	0.0001	0.0001	0.0004	0.0019	0.0023	0.0032	0.0048	0.0048	0.0048	0.0048
NG.UK	0.0003	0.0021	0.0038	0.3720	0.0373	0.2772	48.9310	0.0386	0.0307	0.0020	0.0015	0.0039	0.0017	0.0001	0.0001	0.0007	0.0029	0.0018	0.0016	0.0013	0.0071	0.0015	0.7881
Heating.Oil	0.0012	0.0225	0.0201	0.4173	0.1461	0.1744	0.5674	0.1980	0.0032	0.0041	0.0114	0.0149	0.0000	0.0000	0.0007	0.0006	0.0094	0.0058	0.0106	0.0180	0.0136	0.0188	3.8499
Gasoil	0.0008	0.0167	0.0159	1.9128	0.2411	0.0723	0.1645	0.2874	0.3579	0.0028	0.0041	0.0086	0.0085	0.0000	0.0001	0.0002	0.0075	0.0036	0.0066	0.0121	0.0075	0.0072	2.7658
Cocoa.UK	0.0004	0.0067	0.0034	0.0673	0.0084	0.0039	0.0165	0.0054	0.0039	0.1090	0.0888	0.0052	0.0035	0.0000	0.0002	0.0009	0.0020	0.0007	0.0009	0.0012	0.0016	0.0010	0.2217
Cocoa.US	0.0005	0.0091	0.0041	0.0901	0.0098	0.0064	0.0135	0.0065	0.0052	0.0802	0.1480	0.0071	0.0048	0.0000	0.0001	0.0002	0.0026	0.0008	0.0010	0.0013	0.0024	0.0014	0.2474
Coffee	0.0006	0.0125	0.0067	0.1268	0.0160	0.0159	0.0153	0.0136	0.0072	0.0037	0.0056	0.2995	0.0168	0.0001	0.0001	0.0007	0.0061	0.0035	0.0039	0.0044	0.0093	0.0061	0.2750
Sugar	0.0006	0.0113	0.0084	0.2221	0.0231	0.0131	0.0277	0.0184	0.0086	0.0025	0.0037	0.0169	0.2988	0.0000	0.0002	0.0005	0.0074	0.0051	0.0056	0.0048	0.0123	0.0082	4.004
Cattle.Feeder	0.0000	0.0000	0.0001	0.0070	0.0004	0.0010	0.0032	0.0003	0.0002	0.0001	0.0001	0.0002	0.0001	0.0059	0.0028	0.0016	0.0000	0.0001	0.0000	0.0000	0.0001	0.0004	0.0176
Live.Cattle	0.0000	0.0009	0.0009	0.0131	0.0016	0.0062	0.0044	0.0019	0.0006	0.0003	0.0002	0.0003	0.0005	0.0017	0.0259	0.0016	0.0002	0.0002	0.0002	0.0003	0.0002	0.0004	0.0298
Lean.Hogs	0.0000	0.0003	0.0006	0.0036	0.0007	0.0034	0.0003	0.0005	0.0002	0.0005	0.0002	0.0005	0.0000	0.0003	0.0005	0.0000	0.0000	0.0000	0.0000	0.0002	0.0010	0.0008	0.0151
Cotton	0.0003	0.0074	0.0080	0.0989	0.0168	0.0080	0.0184	0.0137	0.0078	0.0015	0.0019	0.0070	0.0087	0.0000	0.0001	0.0000	0.1837	0.0055	0.0057	0.0061	0.0114	0.0080	0.2353
Soy.Meal	0.0003	0.0069	0.0051	0.0732	0.0103	0.0076	0.0094	0.0081	0.0040	0.0005	0.0006	0.0040	0.0056	0.0000	0.0001	0.0008	0.0053	0.2051	0.0759	0.0117	0.0302	0.0403	0.3000
Soybean	0.0005	0.0105	0.0083	0.1540	0.0236	0.0142	0.0102	0.0196	0.0094	0.0010	0.0011	0.0057	0.0081	0.0000	0.0002	0.0011	0.0073	0.1001	0.0393	0.0296	0.0323	0.0420	0.4787
Soy.Oil	0.0008	0.0151	0.0111	0.2720	0.0416	0.0246	0.0082	0.0368	0.0192	0.0015	0.0017	0.0270	0.0079	0.0000	0.0002	0.0005	0.0086	0.0173	0.0330	0.0650	0.0255	0.0251	0.5579
Wheat	0.0006	0.0102	0.0064	0.0834	0.0213	0.0139	0.0355	0.0160	0.0063	0.0010	0.0016	0.0083	0.0117	0.0000	0.0001	0.0010	0.0092	0.0253	0.0205	0.0146	0.0349	0.0802	0.3672
Corn	0.0006	0.0111	0.0063	0.1837	0.0217	0.0176	0.0090	0.0161	0.0082	0.0008	0.0011	0.0075	0.0097	0.0001	0.0002	0.0010	0.0082	0.0425	0.0336	0.0181	0.1009	0.1750	0.6492
To	0.0317	0.3147	0.2132	41.3028	1.7641	0.8106	1.2715	1.4868	0.7689	0.1238	0.1486	0.1540	0.1819	0.0033	0.0085	0.0146	0.1173	0.2437	0.2449	0.1913	0.3116	0.2932	0.9091

	Gold	Silver	Copper	WTI	Brent
Gold	0.0083	0.0612	0.0061	0.0452	0.0063
Silver	0.0180	0.3253	0.0323	0.2353	0.0374
Copper	0.0025	0.0447	0.1239	0.3090	0.0472
WTI	0.0018	0.0304	0.0348	97.9408	0.7379
Brent	0.0015	0.0295	0.0273	4.1374	0.6252

$$\bullet \theta_{WTI \leftarrow Brent} = 0.7379$$

$$\bullet \theta_{Brent \leftarrow WTI} = 4.1374$$

Full connectivity matrix, in the spatial dimension, full sample

	Gold	Silver	Copper	WTI	Brent	NG.US	NG.UK	Heating.Oil	Gasoil	Cocoa.UK	Cocoa.US	Coffee	Sugar	Cattle.Feeder	Live.Cattle	Lean.Hogs	Cotton	Soy.Meal	Soybean	Soy.Oil	Wheat	Corn	From
Gold	0.0083	0.0612	0.0061	0.0063	0.0028	0.0028	0.0021	0.0025	0.0014	0.0021	0.0014	0.0021	0.0019	0.0000	0.0000	0.0001	0.0009	0.0009	0.0010	0.0016	0.0022	0.0017	0.1504
Silver	0.0180	0.3253	0.0323	0.2353	0.0374	0.0157	0.0168	0.0279	0.0164	0.0050	0.0070	0.0124	0.0111	0.0000	0.0004	0.0005	0.0061	0.0056	0.0067	0.0089	0.0105	0.0090	0.4834
Copper	0.0025	0.0447	0.1239	0.3090	0.0472	0.0138	0.0320	0.0336	0.0221	0.0032	0.0044	0.0090	0.0113	0.0000	0.0005	0.0011	0.0090	0.0060	0.0073	0.0089	0.0090	0.0070	0.5817
WTI	0.0018	0.0304	0.0348	97.9408	0.7379	0.0517	0.3222	0.4925	0.2206	0.0072	0.0120	0.0190	0.0327	0.0004	0.0008	0.0004	0.0114	0.0091	0.0149	0.0239	0.0123	0.0230	2.0592
Brent	0.0015	0.0295	0.0273	4.1374	0.6252	0.1011	0.1595	0.4040	0.1771	0.0048	0.0061	0.0128	0.0181	0.0001	0.0006	0.0006	0.0111	0.0070	0.0122	0.0196	0.0172	0.0141	5.1618
NG.US	0.0003	0.0057	0.0034	0.1284	0.0444	8.0641	0.2242	0.0607	0.0205	0.0011	0.0015	0.0049	0.0038	0.0001	0.0001	0.0004	0.0019	0.0023	0.0032	0.0048	0.0048	0.0048	0.5212
NG.UK	0.0003	0.0021	0.0038	0.3720	0.0373	0.2772	48.9310	0.0386	0.0307	0.0020	0.0015	0.0039	0.0017	0.0001	0.0001	0.0007	0.0029	0.0018	0.0016	0.0013	0.0071	0.0015	0.7881
Heating.Oil	0.0012	0.0225	0.0201	2.7872	0.4173	0.1461	0.1744	0.5674	0.1980	0.0032	0.0041	0.0114	0.0149	0.0000	0.0007	0.0006	0.0094	0.0058	0.0106	0.0180	0.0136	0.0188	3.8499
Gasoil	0.0008	0.0167	0.0159	1.9128	0.2411	0.0723	0.1645	0.2874	0.3579	0.0028	0.0041	0.0086	0.0085	0.0000	0.0004	0.0002	0.0075	0.0036	0.0066	0.0121	0.0075	0.0072	2.7658
Cocoa.UK	0.0004	0.0067	0.0034	0.0673	0.0084	0.0039	0.0165	0.0054	0.0039	0.1090	0.0888	0.0052	0.0035	0.0000	0.0002	0.0009	0.0020	0.0007	0.0009	0.0012	0.0016	0.0010	0.2217
Cocoa.US	0.0005	0.0091	0.0041	0.0901	0.0098	0.0064	0.0135	0.0065	0.0052	0.0802	0.1480	0.0071	0.0048	0.0000	0.0001	0.0002	0.0026	0.0008	0.0010	0.0013	0.0024	0.0014	0.2474
Coffee	0.0006	0.0125	0.0067	0.1268	0.0160	0.0159	0.0153	0.0136	0.0072	0.0037	0.0056	0.2995	0.0168	0.0001	0.0001	0.0007	0.0061	0.0035	0.0039	0.0044	0.0093	0.0061	0.2750
Sugar	0.0006	0.0113	0.0084	0.2221	0.0231	0.0131	0.0277	0.0184	0.0086	0.0025	0.0037	0.0169	0.2988	0.0000	0.0002	0.0005	0.0074	0.0051	0.0056	0.0048	0.0123	0.0082	0.4004
Cattle.Feeder	0.0000	0.0000	0.0001	0.0070	0.0004	0.0010	0.0032	0.0003	0.0002	0.0001	0.0001	0.0002	0.0001	0.0059	0.0028	0.0016	0.0000	0.0001	0.0000	0.0000	0.0001	0.0004	0.0176
Live.Cattle	0.0000	0.0009	0.0009	0.0131	0.0016	0.0062	0.0044	0.0019	0.0006	0.0003	0.0002	0.0003	0.0005	0.0017	0.0259	0.0016	0.0002	0.0002	0.0002	0.0003	0.0002	0.0004	0.0298
Lean.Hogs	0.0000	0.0003	0.0006	0.0036	0.0007	0.0034	0.0003	0.0005	0.0002	0.0005	0.0002	0.0002	0.0005	0.0003	0.0005	0.0003	0.0000	0.0006	0.0006	0.0002	0.0010	0.0008	0.0151
Cotton	0.0003	0.0074	0.0080	0.0989	0.0168	0.0080	0.0184	0.0137	0.0078	0.0015	0.0019	0.0070	0.0087	0.0000	0.0001	0.0000	0.1837	0.0055	0.0057	0.0061	0.0114	0.0080	0.2353
Soy.Meal	0.0003	0.0069	0.0051	0.0732	0.0103	0.0076	0.0094	0.0081	0.0040	0.0005	0.0006	0.0040	0.0056	0.0000	0.0001	0.0008	0.0053	0.2051	0.0759	0.0117	0.0302	0.0403	0.3000
Soybean	0.0005	0.0105	0.0083	0.1540	0.0236	0.0142	0.0102	0.0196	0.0094	0.0010	0.0011	0.0057	0.0081	0.0000	0.0002	0.0011	0.0073	0.1001	0.0893	0.0296	0.0323	0.0420	0.4787
Soy.Oil	0.0008	0.0151	0.0111	0.2720	0.0416	0.0246	0.0082	0.0368	0.0192	0.0015	0.0017	0.0072	0.0079	0.0000	0.0002	0.0005	0.0086	0.0173	0.0330	0.0650	0.0255	0.0251	0.5579
Wheat	0.0006	0.0102	0.0064	0.0834	0.0213	0.0139	0.0355	0.0160	0.0063	0.0010	0.0016	0.0083	0.0117	0.0000	0.0001	0.0010	0.0092	0.0253	0.0205	0.0146	0.0349	0.0802	0.3672
Corn	0.0006	0.0111	0.0063	0.1837	0.0217	0.0176	0.0090	0.0161	0.0082	0.0008	0.0011	0.0075	0.0097	0.0001	0.0002	0.0010	0.0082	0.0425	0.0336	0.0181	0.1009	0.1750	0.6982
To	0.0317	0.3147	0.2132	41.3028	1.7641	0.8106	1.2715	1.4868	0.7689	0.1238	0.1486	0.1540	0.1819	0.0033	0.0085	0.0146	0.1173	0.2437	0.2449	0.1913	0.3116	0.2932	0.9091

	Gold	Silver	Copper	WTI	Brent
Gold	0.0083	0.0612	0.0061	0.0452	0.0063
Silver	0.0180	0.3253	0.0323	0.2353	0.0374
Copper	0.0025	0.0447	0.1239	0.3090	0.0472
WTI	0.0018	0.0304	0.0348	97.9408	0.7379
Brent	0.0015	0.0295	0.0273	4.1374	0.6252

$$\bullet \theta_{WTI \leftarrow Brent} = 0.7379$$

$$\bullet \theta_{Brent \leftarrow WTI} = 4.1374$$

$$\Rightarrow \text{Net pairwise: (WTI} \rightarrow \text{Brent)} \\ (4.1374 - 0.7379) = 3.3995$$

Full connectivity matrix, in the spatial dimension, full sample

	Gold	Silver	Copper	WTI	Brent	NG.US	NG.UK	Heating.Oil	Gasoil	Cocoa.UK	Cocoa.US	Coffee	Sugar	Cattle.Feeder	Live.Cattle	Lean.Hogs	Cotton	Soy.Meal	Soybean	Soy.Oil	Wheat	Corn	From	
Gold	0.0083	0.0612	0.0061	0.0063	0.0028	0.0028	0.0021	0.0025	0.0014	0.0011	0.0014	0.0019	0.0019	0.0000	0.0000	0.0001	0.0009	0.0009	0.0010	0.0016	0.0022	0.0017	0.1504	
Silver	0.0180	0.3253	0.0323	0.2353	0.0374	0.0157	0.0168	0.0279	0.0164	0.0050	0.0070	0.0124	0.0111	0.0000	0.0004	0.0005	0.0061	0.0056	0.0067	0.0089	0.0105	0.0090	0.4834	
Copper	0.0025	0.0447	0.1239	0.3090	0.0472	0.0138	0.0320	0.0336	0.0221	0.0032	0.0044	0.0090	0.0113	0.0000	0.0005	0.0011	0.0090	0.0060	0.0073	0.0089	0.0090	0.0070	0.5817	
WTI	0.0018	0.0304	0.0348	97.9408	0.7379	0.0517	0.3222	0.0072	0.4925	0.2206	0.0072	0.0120	0.0190	0.0327	0.0004	0.0008	0.0004	0.0114	0.0091	0.0149	0.0239	0.0123	0.0230	2.0592
Brent	0.0015	0.0295	0.0273	4.1374	0.6252	0.1011	1.595	0.4040	0.1771	0.0048	0.0061	0.0128	0.0181	0.0001	0.0006	0.0006	0.0111	0.0070	0.0122	0.0196	0.0172	0.0141	5.1618	
NG.US	0.0003	0.0057	0.0034	0.1284	0.0444	8.0641	0.2242	0.0607	0.0205	0.0011	0.0015	0.0049	0.0038	0.0001	0.0001	0.0004	0.0019	0.0023	0.0032	0.0048	0.0048	0.0048	0.5212	
NG.UK	0.0003	0.0021	0.0038	0.3720	0.0373	0.2772	48.9310	0.0386	0.0307	0.0020	0.0015	0.0039	0.0017	0.0001	0.0001	0.0007	0.0029	0.0018	0.0016	0.0013	0.0071	0.0015	0.7881	
Heating.Oil	0.0012	0.0225	0.0201	0.4173	0.1461	0.1744	0.5674	0.1980	0.0032	0.0041	0.0114	0.0149	0.0000	0.0000	0.0007	0.0006	0.0094	0.0058	0.0106	0.0180	0.0136	0.0108	3.8499	
Gasoil	0.0008	0.0167	0.0159	1.9128	0.0141	0.0723	0.1645	0.0028	0.0041	0.0036	0.0085	0.0005	0.0005	0.0000	0.0004	0.0002	0.0075	0.0036	0.0066	0.0121	0.0075	0.0072	2.7508	
Cocoa.UK	0.0004	0.0067	0.0034	0.0673	0.0084	0.0039	0.0165	0.0054	0.0039	0.1090	0.0888	0.0052	0.0035	0.0000	0.0002	0.0009	0.0020	0.0007	0.0009	0.0012	0.0016	0.0010	0.2217	
Cocoa.US	0.0005	0.0091	0.0041	0.0901	0.0098	0.0064	0.0135	0.0065	0.0052	0.0802	0.1480	0.0071	0.0048	0.0000	0.0001	0.0002	0.0026	0.0008	0.0010	0.0013	0.0024	0.0014	0.2474	
Coffee	0.0006	0.0125	0.0067	0.1268	0.0160	0.0159	0.0153	0.0136	0.0072	0.0037	0.0056	0.2995	0.0168	0.0001	0.0001	0.0007	0.0061	0.0035	0.0039	0.0044	0.0093	0.0061	0.2750	
Sugar	0.0006	0.0113	0.0084	0.2221	0.0231	0.0131	0.0277	0.0184	0.0086	0.0025	0.0037	0.0169	0.2988	0.0000	0.0002	0.0005	0.0074	0.0051	0.0056	0.0048	0.0123	0.0082	0.4004	
Cattle.Feeder	0.0000	0.0000	0.0001	0.0070	0.0004	0.0010	0.0032	0.0003	0.0002	0.0001	0.0001	0.0002	0.0001	0.0059	0.0028	0.0016	0.0000	0.0001	0.0000	0.0000	0.0001	0.0004	0.0176	
Live.Cattle	0.0000	0.0009	0.0009	0.0131	0.0016	0.0062	0.0044	0.0019	0.0006	0.0003	0.0002	0.0003	0.0005	0.0017	0.0259	0.0016	0.0002	0.0002	0.0002	0.0003	0.0002	0.0004	0.0298	
Lean.Hogs	0.0000	0.0003	0.0006	0.0036	0.0007	0.0034	0.0003	0.0005	0.0002	0.0005	0.0002	0.0002	0.0005	0.0003	0.0005	0.0003	0.0000	0.0006	0.0006	0.0002	0.0010	0.0008	0.0151	
Cotton	0.0003	0.0074	0.0080	0.0989	0.0168	0.0080	0.0184	0.0137	0.0078	0.0015	0.0019	0.0070	0.0087	0.0000	0.0001	0.0000	0.1837	0.0055	0.0057	0.0061	0.0114	0.0080	0.2353	
Soy.Meal	0.0003	0.0069	0.0051	0.0732	0.0103	0.0076	0.0094	0.0081	0.0040	0.0005	0.0006	0.0040	0.0056	0.0000	0.0001	0.0008	0.0053	0.2051	0.0759	0.0117	0.0302	0.0403	0.3000	
Soybean	0.0005	0.0105	0.0083	0.1540	0.0236	0.0142	0.0102	0.0196	0.0094	0.0010	0.0011	0.0057	0.0081	0.0000	0.0002	0.0011	0.0073	0.1001	0.0893	0.0296	0.0323	0.0420	0.4787	
Soy.Oil	0.0008	0.0151	0.0111	0.2720	0.0416	0.0246	0.0082	0.0368	0.0192	0.0015	0.0017	0.0072	0.0079	0.0000	0.0002	0.0005	0.0086	0.0173	0.0330	0.0650	0.0255	0.0251	0.5579	
Wheat	0.0006	0.0102	0.0064	0.0834	0.0213	0.0139	0.0355	0.0160	0.0063	0.0010	0.0016	0.0083	0.0117	0.0000	0.0001	0.0010	0.0092	0.0253	0.0205	0.0146	0.0494	0.0802	0.3672	
Corn	0.0006	0.0111	0.0063	0.1837	0.0217	0.0176	0.0090	0.0161	0.0082	0.0008	0.0011	0.0075	0.0097	0.0001	0.0002	0.0010	0.0082	0.0425	0.0336	0.0181	0.0109	0.1750	0.6492	
To	0.0317	0.3147	0.2132	41.3028	1.7641	0.8106	1.2715	1.4868	0.7689	0.1238	0.1486	0.1540	0.1819	0.0033	0.0085	0.0146	0.1173	0.2437	0.2449	0.1913	0.3116	0.2932	0.9091	

	Gold	Silver	Copper	WTI	Brent
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Copper	0.0025	0.0447	0.1239	0.3090	0.0472
WTI	0.0018	0.0304	0.0348	97.9408	0.7379
Brent	0.0015	0.0295	0.0273	4.1374	0.6252

$$\bullet \theta_{WTI \leftarrow Brent} = 0.7379$$

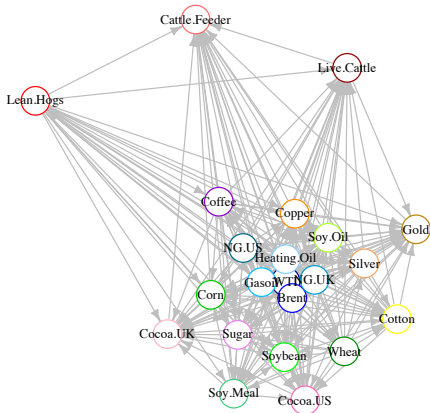
$$\bullet \theta_{Brent \leftarrow WTI} = 4.1374$$

$$\Rightarrow \text{Net pairwise: (WTI} \rightarrow \text{Brent)} \\ (4.1374 - 0.7379) = 3.3995$$

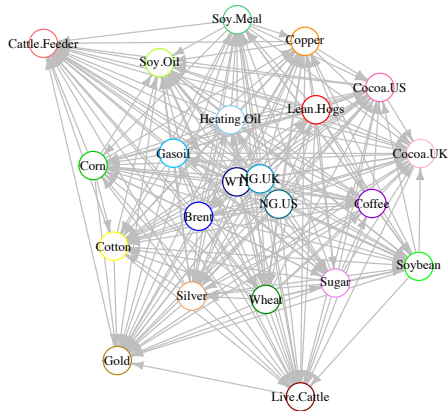
[▶▶ Vol Total Table](#)
[▶▶ Return BK Tables](#)
[▶▶ Return No corr Table](#)
[▶▶ Return Classical DY](#)

Spatial connectedness, full graphs on full sample (static)

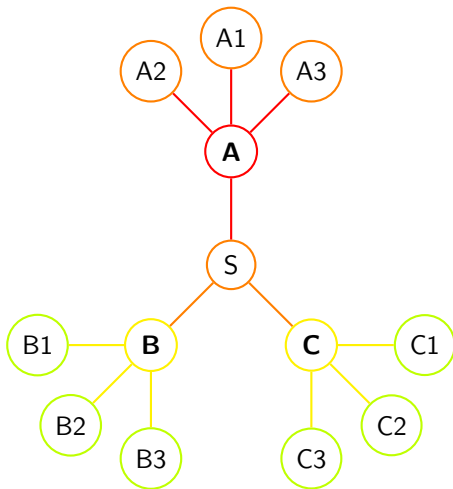
Return DY net pairwise Connectedness



Volatility DY net pairwise Connectedness



Centrality measures



Centrality in the static full graph, spatial dimension: 4 methods

	Out-degree	In-degree
Gold	1	20
Silver	14	7
Copper	6	15
WTI	21	0
Brent	18	3
NG.US	20	1
NG.UK	18	3
Heating.Oil	16	5
Gasoil	12	9
Cocoa.UK	5	16
Cocoa.US	7	14
Coffee	13	8
Sugar	11	10
Cattle.Feeder	0	21
Live.Cattle	2	19
Lean.Hogs	17	4
Cotton	9	12
Soy.Meal	10	11
Soybean	4	17
Soy.Oil	3	18
Wheat	16	5
Corn	8	13

Centrality in the static full graph, spatial dimension: 4 methods

Returns DY	Out-degree	In-degree	Eigenvector		Betweenness	Communicability
			Centrality	Ranking		
Gold	1	20	0.6240	2		
Silver	14	7	0.0014	15		
Copper	6	15	0.0590	7		
WTI	21	0	0.0000	21		
Brent	18	3	0.0002	20		
NG.US	20	1	0	22		
NG.UK	18	3	0.0003	19		
Heating.Oil	16	5	0.0006	17		
Gasoil	12	9	0.0035	13		
Cocoa.UK	5	16	0.0946	6		
Cocoa.US	7	14	0.0368	8		
Coffee	13	8	0.0022	14		
Sugar	11	10	0.0056	12		
Cattle.Feeder	0	21	1	1		
Live.Cattle	2	19	0.3893	3		
Lean.Hogs	17	4	0.0005	18		
Cotton	9	12	0.0143	10		
Soy.Meal	10	11	0.0089	11		
Soybean	4	17	0.1516	5		
Soy.Oil	3	18	0.2429	4		
Wheat	16	5	0.0007	16		
Corn	8	13	0.0230	9		

Centrality in the static full graph, spatial dimension: 4 methods

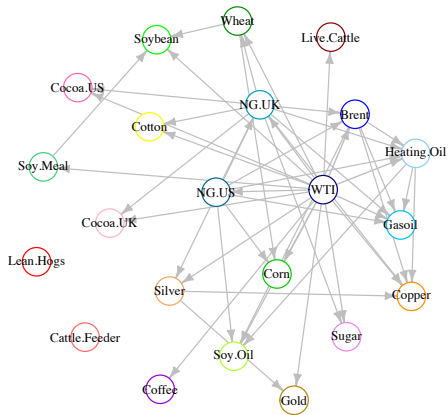
Returns DY	Out-degree	In-degree	Eigenvector		Betweenness		Communicability
			Centrality	Ranking	Centrality	Ranking	
Gold	1	20	0.6240	2	0	6	
Silver	14	7	0.0014	15	0	6	
Copper	6	15	0.0590	7	0	6	
WTI	21	0	0.0000	21	0	6	
Brent	18	3	0.0002	20	0.5	4	
NG.US	20	1	0	22	0	6	
NG.UK	18	3	0.0003	19	3.5	2	
Heating.Oil	16	5	0.0006	17	0.5	4	
Gasoil	12	9	0.0035	13	0	6	
Cocoa.UK	5	16	0.0946	6	0	6	
Cocoa.US	7	14	0.0368	8	0	6	
Coffee	13	8	0.0022	14	0	6	
Sugar	11	10	0.0056	12	0	6	
Cattle.Feeder	0	21	1	1	0	6	
Live.Cattle	2	19	0.3893	3	0	6	
Lean.Hogs	17	4	0.0005	18	6	1	
Cotton	9	12	0.0143	10	0	6	
Soy.Meal	10	11	0.0089	11	0	6	
Soybean	4	17	0.1516	5	0	6	
Soy.Oil	3	18	0.2429	4	0	6	
Wheat	16	5	0.0007	16	3.5	2	
Corn	8	13	0.0230	9	0	6	

Centrality in the static full graph, spatial dimension: 4 methods

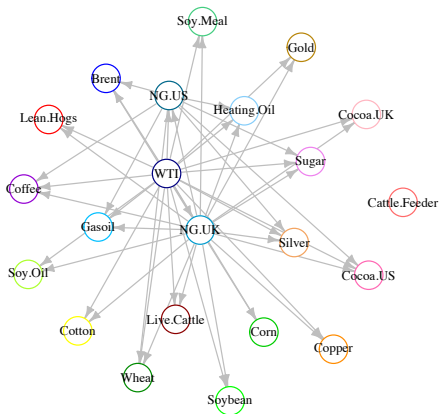
Returns DY	Out-degree	In-degree	Eigenvector		Betweenness		Communicability	
			Centrality	Ranking	Centrality	Ranking	Centrality	Ranking
Gold	1	20	0.6240	2	0	6	1.0000	21
Silver	14	7	0.0014	15	0	6	1.0034	6
Copper	6	15	0.0590	7	0	6	1.0003	15
WTI	21	0	0.0000	21	0	6	1.4213	1
Brent	18	3	0.0002	20	0.5	4	1.0082	4
NG.US	20	1	0	22	0	6	1.0167	3
NG.UK	18	3	0.0003	19	3.5	2	1.0267	2
Heating.Oil	16	5	0.0006	17	0.5	4	1.0066	5
Gasoil	12	9	0.0035	13	0	6	1.0010	9
Cocoa.UK	5	16	0.0946	6	0	6	1.0001	18
Cocoa.US	7	14	0.0368	8	0	6	1.0005	13
Coffee	13	8	0.0022	14	0	6	1.0007	11
Sugar	11	10	0.0056	12	0	6	1.0007	12
Cattle.Feeder	0	21	1	1	0	6	1.0000	22
Live.Cattle	2	19	0.3893	3	0	6	1.0000	19
Lean.Hogs	17	4	0.0005	18	6	1	1.0003	16
Cotton	9	12	0.0143	10	0	6	1.0003	14
Soy.Meal	10	11	0.0089	11	0	6	1.0016	8
Soybean	4	17	0.1516	5	0	6	1.0002	17
Soy.Oil	3	18	0.2429	4	0	6	1.0000	20
Wheat	16	5	0.0007	16	3.5	2	1.0027	7
Corn	8	13	0.0230	9	0	6	1.0008	10

Spatial connectedness filtered network on full sample (static, $X = 20\%$)

Return DY net pairwise Connectedness



Volatility DY net pairwise Connectedness

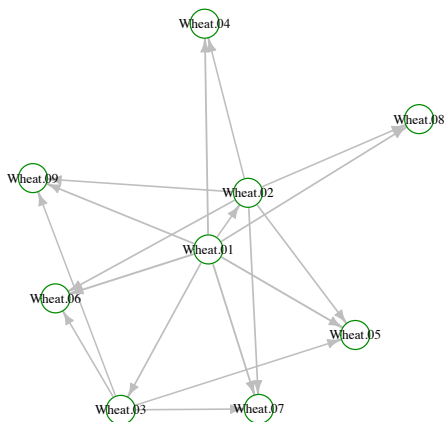


Maturity dimension: Wheat Connectedness matrix, static analysis

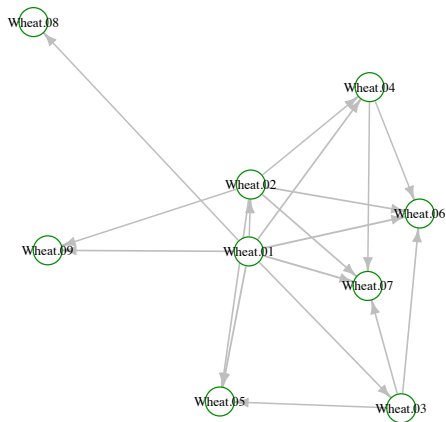
	Wheat.01	Wheat.02	Wheat.03	Wheat.04	Wheat.05	Wheat.06	Wheat.07	Wheat.08	Wheat.09	From
Wheat.01	24.7625	18.3058	14.5824	11.0696	8.5187	6.6689	5.5143	5.6820	4.8959	75.2375
Wheat.02	20.6739	17.1824	13.8635	10.4309	7.8773	6.2281	5.2024	5.2760	4.5669	74.1190
Wheat.03	17.8013	14.9822	13.6222	10.1087	7.2788	5.7428	4.8323	5.0045	4.2707	70.0213
Wheat.04	15.1481	12.6409	11.3363	9.6433	6.8583	5.3531	4.4738	4.6806	4.0589	64.5500
Wheat.05	13.3244	10.9129	9.3313	7.8405	6.4691	5.0569	4.1543	4.3083	3.7108	58.6395
Wheat.06	11.5295	9.5361	8.1369	6.7647	5.5916	4.7949	3.9572	3.9088	3.3799	52.8047
Wheat.07	10.1099	8.4491	7.2645	5.9980	4.8715	4.1965	4.0133	3.6160	3.1792	47.6847
Wheat.08	9.2086	7.5684	6.6437	5.5429	4.4631	3.6618	3.1939	5.8923	3.5602	43.8426
Wheat.09	8.5019	7.0234	6.0833	5.1561	4.1197	3.3914	3.0086	3.9579	4.7748	41.2423
To	106.2976	89.4189	77.2419	62.9114	49.5789	40.2995	34.3369	36.4341	31.6223	58.6824

Wheat connectedness filtered network on full sample (static, $X = 50\%$)

Return DY net pairwise Connectedness



Volatility DY net pairwise Connectedness

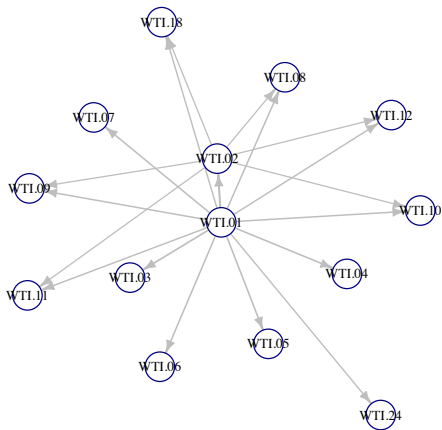


Maturity dimension: example of WTI Connectedness matrix

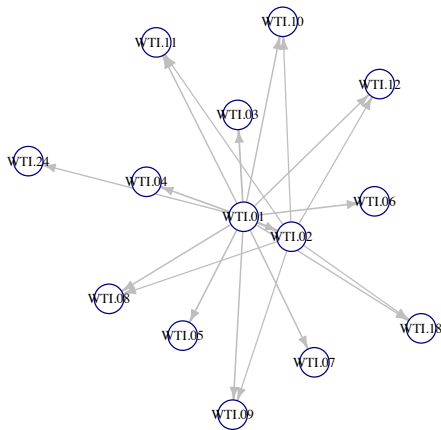
	WTI.01	WTI.02	WTI.03	WTI.04	WTI.05	WTI.06	WTI.07	WTI.08	WTI.09	WTI.10	WTI.11	WTI.12	WTI.18	WTI.24	From
WTI.01	92.3012	1.5102	1.0793	0.8784	0.7363	0.6310	0.5503	0.4855	0.4328	0.3894	0.3511	0.3202	0.1992	0.1351	7.6988
WTI.02	10.0355	1.0183	0.8228	0.6940	0.5997	0.5258	0.4667	0.4182	0.3767	0.3420	0.3117	0.2857	0.1826	0.1256	15.1871
WTI.03	5.7087	0.9090	0.7530	0.6427	0.5594	0.4931	0.4392	0.3947	0.3565	0.3244	0.2962	0.2720	0.1752	0.1212	10.6924
WTI.04	4.8137	0.8281	0.6941	0.5975	0.5230	0.4629	0.4136	0.3726	0.3373	0.3074	0.2811	0.2585	0.1676	0.1165	9.5765
WTI.05	4.2315	0.7638	0.6450	0.5584	0.4910	0.4362	0.3908	0.3528	0.3199	0.2920	0.2674	0.2462	0.1605	0.1121	8.7768
WTI.06	3.8113	0.7101	0.6028	0.5240	0.4625	0.4121	0.3702	0.3349	0.3042	0.2781	0.2550	0.2350	0.1541	0.1080	8.1501
WTI.07	3.4831	0.6647	0.5664	0.4938	0.4370	0.3904	0.3515	0.3186	0.2898	0.2653	0.2436	0.2248	0.1480	0.1042	7.6297
WTI.08	3.2101	0.6254	0.5345	0.4671	0.4143	0.3708	0.3345	0.3037	0.2767	0.2537	0.2332	0.2154	0.1425	0.1007	7.1788
WTI.09	2.9863	0.5901	0.5056	0.4428	0.3934	0.3528	0.3187	0.2898	0.2645	0.2428	0.2234	0.2066	0.1374	0.0974	6.7871
WTI.10	2.7951	0.5591	0.4801	0.4212	0.3748	0.3366	0.3045	0.2773	0.2534	0.2328	0.2145	0.1985	0.1326	0.0944	6.4420
WTI.11	2.6188	0.5308	0.4567	0.4013	0.3575	0.3215	0.2912	0.2655	0.2429	0.2234	0.2061	0.1909	0.1281	0.0915	6.1201
WTI.12	2.4740	0.5055	0.4357	0.3833	0.3420	0.3078	0.2791	0.2547	0.2333	0.2148	0.1983	0.1839	0.1239	0.0888	5.8412
WTI.18	1.8533	0.3913	0.3400	0.3010	0.2700	0.2444	0.2227	0.2042	0.1879	0.1738	0.1611	0.1501	0.1037	0.0759	4.5756
WTI.24	1.4546	0.3131	0.2736	0.2434	0.2193	0.1993	0.1823	0.1678	0.1550	0.1439	0.1339	0.1251	0.0883	0.0660	3.6996
To	49.4761	8.9012	7.4366	6.4515	5.6892	5.0726	4.5638	4.1366	3.7664	3.4508	3.1705	2.9292	1.9400	1.3712	7.7397

WTI connectedness filtered network on full sample (static, $X = 20\%$)

Return DY net pairwise Connectedness



Volatility DY net pairwise Connectedness



Upcoming work in progress

- Looking into the effect of correlations

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- Rely on sparse VAR (LASSO) for estimations, needing less data

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- Analyses of layers 1 and 3
- Multilayer analysis

Additional results

DY (2012) vs. Caloia et al. (2018)

	DY (2012)
Normalization	By row: each row sum = 100%
Advantages	Interpretation: $\theta_{i \leftarrow j}$ = share (%) of FEV of i from j
Disadvantages	Incorrect comparisons of θ_{ij} s

DY (2012) vs. Caloia et al. (2018)

	DY (2012)	Caloia et al. (2018)
Normalization	By row: each row sum = 100%	By max(row sums): largest FEV row sum = 100%
Advantages	Interpretation: $\theta_{i \leftarrow j}$ = share (%) of FEV of i from j	Proper comparisons of elements from different rows
Disadvantages	Incorrect comparisons of θ_{ij} s	Different interpretation: all relative to largest FEV

Spatial Returns GFEVD Connectedness matrix (classical DY)

	Gold	Silver	Copper	WTI	Brent	NG.US	NG.UK	Heating Oil	Gasoil	Cocoa.UK	Cocoa.US	Coffee	Sugar	Cattle Feeder	Live.Cattle	Lean.Hogs	Cotton	Soy.Meal	Soybean	Soy.Oil	Wheat	Com	From
Gold	46.9512	30.0237	5.7720	0.5118	2.0082	0.1662	0.1108	1.7475	1.1855	1.1135	1.1464	1.1077	0.9757	0.0245	0.0644	0.0389	0.6816	0.5971	1.1962	2.3001	1.0193	1.2577	53.0488
Silver	26.1656	40.9403	7.7775	0.6822	3.0538	0.2350	0.0765	2.4248	1.9511	1.3036	1.5003	1.6590	1.4876	0.0511	0.2669	0.0445	1.1334	0.9676	2.0332	3.2838	1.2660	1.2763	59.0597
Copper	5.5522	8.6377	45.6111	1.3722	5.8952	0.3172	0.2222	4.4803	4.0235	1.2943	1.4334	1.8378	2.1303	0.1314	0.5215	0.1321	2.5624	1.5667	3.3388	5.0562	1.6665	2.0373	54.3889
WTI	0.5607	0.8234	1.8020	60.9860	12.9209	0.1658	0.3003	9.1961	5.6255	0.4038	0.5474	0.5432	0.3183	0.1418	0.1238	0.0074	0.4532	0.3356	0.9540	1.8969	0.3192	0.9437	30.0140
Brent	1.3439	2.3317	4.1189	7.4946	31.8497	0.9420	0.4481	21.9523	13.1365	0.7790	0.8152	1.0705	1.5158	0.0954	0.2537	0.0127	1.2875	0.7529	2.2762	4.5296	1.2945	1.6601	68.1503
NG.US	0.2815	0.5061	0.2631	2.5595	0.6478	0.7091	3.7272	1.7249	0.2045	0.2190	0.4668	0.3591	0.1114	0.0238	0.0323	0.2471	0.2858	0.6778	1.2621	0.4084	0.6531	15.3282	
NG.UK	0.1950	0.1137	0.3926	0.4510	1.2772	1.7231	0.8568	1.4107	1.5298	0.2245	0.1382	0.2218	0.0982	0.1018	0.0381	0.0243	0.2224	0.1312	0.2011	0.1689	0.3592	0.1229	9.1432
Heating Oil	1.1265	1.9039	3.2507	5.3697	22.7074	1.4575	0.5342	33.0164	16.7349	0.5565	0.5907	1.0154	1.3303	0.0593	0.3087	0.0322	1.1680	0.6659	2.1109	4.4392	1.9789	1.3669	66.9836
Gasoil	0.9886	1.8365	3.3462	4.8267	17.1128	0.9386	0.6421	20.2388	16.9570	0.6347	0.7589	1.0003	0.9902	0.1638	0.2121	0.0146	1.2082	0.5410	1.7043	3.8980	0.7882	1.1965	63.6436
Cocoa.UK	1.1421	1.5377	1.4845	0.3574	1.2533	0.1074	0.1361	0.8650	0.8522	52.1863	34.6173	1.2633	0.8544	0.1031	0.1972	0.1311	0.6874	0.2058	0.5080	0.8150	0.3563	0.3469	47.8137
Cocoa.US	1.2641	1.8632	1.6106	0.4249	1.3012	0.1556	0.0994	0.9978	1.0086	34.0727	51.2080	1.5445	1.0423	0.0831	0.1370	0.0272	0.7740	0.2222	0.5808	0.8106	0.4758	0.4329	48.7920
Coffee	1.5805	2.6485	2.7126	0.6183	1.1952	0.1377	0.1177	1.9978	1.4355	1.6122	2.0052	66.9630	3.7778	0.2199	0.1463	0.1012	1.8984	1.0209	1.9726	2.7328	1.8804	1.9642	33.0370
Sugar	1.3911	2.2993	3.2592	1.0354	3.0300	0.3151	0.2008	2.5798	1.6477	1.0360	1.2588	3.8274	63.9817	0.0773	0.2735	0.0607	2.2101	1.4102	2.6714	2.8315	2.3831	2.5109	36.0183
Cattle Feeder	0.0402	0.0425	0.2277	0.1534	0.2214	0.1055	0.1035	0.1676	0.1916	0.1897	0.1353	0.2454	0.0985	0.1786	0.1453	0.0963	0.0516	0.0801	0.0620	0.0191	0.1179	0.1348	18.2144
Live.Cattle	0.1112	0.5210	0.9306	0.1713	0.6026	0.0124	0.0876	0.7364	0.3337	0.3127	0.1000	0.1726	0.3326	14.1157	79.1375	0.5765	0.1622	0.1483	0.3175	0.5740	0.0911	0.3625	20.8625
Lean.Hogs	0.0126	0.0756	0.2855	0.0193	0.1012	0.0445	0.0021	0.0811	0.0436	0.2588	0.0773	0.0620	0.1148	1.1463	0.6832	95.7325	0.0051	0.1644	0.3343	0.1707	0.2329	0.3022	4.2675
Cotton	0.9485	1.7906	3.6798	0.5507	2.6309	0.2300	0.1502	2.2975	1.7789	0.7337	0.7973	1.8015	2.2432	0.0492	0.1334	0.0036	65.2280	1.8174	3.2553	4.2924	2.6391	2.9398	34.7720
Soy.Meal	0.5989	1.0706	1.5202	0.2624	1.0414	0.1408	0.0529	0.8769	0.5893	0.1674	0.1517	0.6597	0.9319	0.0176	0.0759	0.0787	1.2128	43.3465	27.9192	5.3170	4.4796	9.4883	56.6555
Soybean	0.8824	1.6648	2.9543	0.5389	2.4131	0.2659	0.0578	2.1364	1.3905	0.3197	0.2886	0.9594	1.3488	0.0145	0.1302	0.1103	1.6788	23.4412	33.3030	13.6663	4.8518	10.0133	66.0961
Soy.Oil	1.8052	2.9388	4.1046	1.2135	5.2228	0.5634	0.0574	4.9290	3.5093	0.6037	0.5680	1.4756	1.6143	0.0066	0.0616	0.0260	4.5524	18.1370	36.8565	4.7139	7.3708	63.1428	
Wheat	1.0263	1.4879	1.7888	0.2803	2.0165	0.2401	0.1853	1.6138	0.8730	0.3118	0.3963	1.2815	1.8119	0.0681	0.0584	0.0664	1.9642	5.0181	7.0086	6.2133	48.5244	17.6754	51.4756
Com	1.0612	1.6831	1.8323	0.6427	2.1418	0.3170	0.0495	1.6639	1.1796	0.2642	0.2759	1.2126	1.5698	0.2593	0.1840	0.1006	1.8375	8.7916	12.0707	8.0352	14.6174	40.1800	59.8200
To	48.7872	66.7891	52.9833	27.2596	91.7693	8.9414	4.3515	86.0824	59.7451	46.3673	47.9111	23.2280	25.7459	17.0235	18.5800	2.6946	20.2000	50.7254	86.2592	72.3118	45.0595	64.9466	64.0783

	Gold	Silver	Copper	WTI	Brent
Gold	46.9512	30.0237	5.7720	0.5118	2.0082
Silver	26.1656	40.9403	7.7775	0.6822	3.0538
Copper	5.5522	8.6377	45.6111	1.3722	5.8952
WTI	0.5607	0.8234	1.8020	60.9860	12.9209
Brent	1.3439	2.3317	4.1189	7.4946	31.8497

- $\theta_{WTI \leftarrow Brent} = 12.9209$
- $\theta_{Brent \leftarrow WTI} = 7.4946$

\Rightarrow Net pairwise: (Brent \rightarrow WTI)
 $(12.9209 - 7.4946) = 5.4263$

Original Return Spatial Connectedness Table

Measuring the importance of a market in the network: centrality (classical DY vs. Caloia et al.)

	Classical DY		Caloia et al.	
	Out-degree	In-degree	Out-degree	In-degree
Gold	12	9	1	20
Silver	14	7	14	7
Copper	13	8	6	15
WTI	8	13	21	0
Brent	21	0	18	3
NG.US	2	19	20	1
NG.UK	3	18	18	3
Heating.Oil	20	1	16	5
Gasoil	16	5	12	9
Cocoa.UK	9	12	5	16
Cocoa.US	10	11	7	14
Coffee	4	17	13	8
Sugar	6	15	11	10
Cattle.Feeder	3	18	0	21
Live.Cattle	3	18	2	19
Lean.Hogs	3	18	17	4
Cotton	6	15	9	12
Soy.Meal	13	8	10	11
Soybean	19	2	4	17
Soy.Oil	18	3	3	18
Wheat	11	10	16	5
Corn	17	4	8	13

Measuring the importance of a market in the network: centrality (classical DY vs. Caloia et al.)

	Classical DY				Caloia et al.			
	Out-degree	In-degree	Communicability		Out-degree	In-degree	Communicability	
			Centrality	Ranking			Centrality	Ranking
Gold	12	9	1.0703	12	1	20	1.0000	21
Silver	14	7	1.4147	5	14	7	1.0034	6
Copper	13	8	1.2381	8	6	15	1.0003	15
WTI	8	13	1.0266	15	21	0	1.4213	1
Brent	21	0	2.1598	1	18	3	1.0082	4
NG.US	2	19	1.0496	14	20	1	1.0167	3
NG.UK	3	18	1.0071	21	18	3	1.0267	2
Heating.Oil	20	1	1.9642	3	16	5	1.0066	5
Gasoil	16	5	1.2764	7	12	9	1.0010	9
Cocoa.UK	9	12	1.0508	13	5	16	1.0001	18
Cocoa.US	10	11	1.0749	11	7	14	1.0005	13
Coffee	4	17	1.0103	18	13	8	1.0007	11
Sugar	6	15	1.0166	17	11	10	1.0007	12
Cattle.Feeder	3	18	1.0074	20	0	21	1.0000	22
Live.Cattle	3	18	1.0226	16	2	19	1.0000	19
Lean.Hogs	3	18	1.0040	22	17	4	1.0003	16
Cotton	6	15	1.0096	19	9	12	1.0003	14
Soy.Meal	13	8	1.1236	9	10	11	1.0016	8
Soybean	19	2	1.9702	2	4	17	1.0002	17
Soy.Oil	18	3	1.5634	4	3	18	1.0000	20
Wheat	11	10	1.1178	10	16	5	1.0027	7
Corn	17	4	1.4056	6	8	13	1.0008	10

Time Frequency Decomposition: Barunik & Krehlik (2018)

- Price shocks may be the sum of shocks at different frequencies
Ex: temperatures have a daily cycle, a yearly cycle, etc.

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- ⇒ Defining frequency bands ⇒ FRF per frequency band. Ex:
 - Short term (1-21 days) vs. long term (21-Inf days)

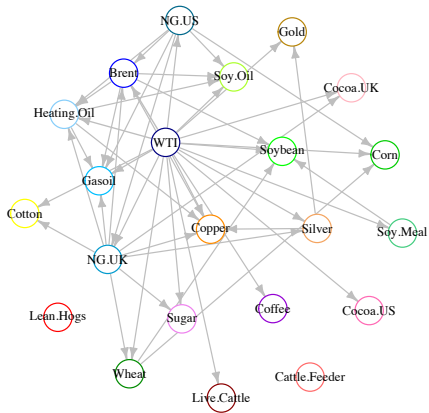
Return BK(1-21, 21-nfd) Connectedness Table

	Gold	Silver	Copper	WTI	Brent	NG.US	NG.UK	Heating Oil	Gasoil	Cocoa.UK	Cocoa.US	Coffee	Sugar	Cattle Feeder	Live.Cattle	Lean.Hogs	Cotton	Soy.Meal	Soy.Oil	Wheat	Corn	From	
Gold	0.0079	0.0582	0.0059	0.0421	0.0099	0.0026	0.0056	0.0049	0.0024	0.0010	0.0013	0.0020	0.0017	0.0000	0.0000	0.0000	0.0000	0.0001	0.0015	0.0020	0.0016	0.1411	
Silver	0.0171	0.3099	0.0308	0.2180	0.0352	0.0146	0.0151	0.0261	0.0155	0.0046	0.0066	0.0116	0.0104	0.0000	0.0004	0.0005	0.0058	0.0053	0.0063	0.0084	0.0098	0.0085	0.4508
Copper	0.0024	0.0428	0.1186	0.2939	0.0452	0.0131	0.0317	0.0321	0.0212	0.0031	0.0042	0.0086	0.0108	0.0000	0.0005	0.0010	0.0086	0.0057	0.0069	0.0085	0.0085	0.0667	0.5582
WTI	0.0003	0.0288	0.0336	94.7899	0.7098	0.0491	0.3137	0.4732	0.2122	0.0070	0.0118	0.0177	0.0315	0.0004	0.0008	0.0004	0.0108	0.0086	0.0142	0.0228	0.0117	0.0222	1.9829
Brent	0.0014	0.0281	0.0261	37.9760	0.5959	0.0952	0.1520	0.3046	0.1684	0.0045	0.0058	0.0120	0.0171	0.0001	0.0006	0.0006	0.0105	0.0067	0.0115	0.0185	0.0163	0.0134	4.8377
NG.US	0.0003	0.0052	0.0000	0.0211	0.0048	0.0027	0.0110	0.0075	0.0193	0.0013	0.0013	0.0046	0.0036	0.0001	0.0003	0.0018	0.0022	0.0046	0.0045	0.0046	0.0046	0.0421	0.2190
NG.UK	0.0003	0.0020	0.0000	0.3539	0.0353	0.2522	46.4052	0.0364	0.0293	0.0019	0.0015	0.0036	0.0017	0.0001	0.0001	0.0007	0.0016	0.0014	0.0010	0.0066	0.0014	0.3738	
Heating.Oil	0.0002	0.0213	0.0198	2.5979	0.3975	0.1380	0.1625	0.5390	0.1879	0.0030	0.0039	0.0106	0.0141	0.0000	0.0006	0.0007	0.0029	0.0055	0.0100	0.0169	0.0128	0.1013	1.6223
Gasoil	0.0007	0.0156	0.0149	1.7580	0.2241	0.0664	0.1531	0.2476	0.3379	0.0026	0.0038	0.0078	0.0079	0.0001	0.0003	0.0002	0.0069	0.0033	0.0061	0.0112	0.0069	0.0067	2.5443
Cocoa.UK	0.0004	0.0063	0.0032	0.0632	0.0080	0.0035	0.0152	0.0052	0.0307	0.1031	0.0839	0.0040	0.0033	0.0000	0.0001	0.0008	0.0018	0.0006	0.0009	0.0011	0.0015	0.0009	0.2086
Cocoa.US	0.0005	0.0085	0.0039	0.0839	0.0093	0.0058	0.0121	0.0061	0.0409	0.0757	0.1405	0.0067	0.0045	0.0000	0.0001	0.0002	0.0023	0.0007	0.0010	0.0013	0.0022	0.0013	0.2310
Coffee	0.0006	0.0118	0.0064	0.1207	0.0153	0.0146	0.0147	0.0129	0.0068	0.0035	0.0054	0.2950	0.0160	0.0001	0.0001	0.0007	0.0057	0.0034	0.0037	0.0041	0.0086	0.0058	0.2606
Sugar	0.0005	0.0109	0.0080	0.1022	0.0221	0.0120	0.0251	0.0176	0.0083	0.0034	0.0035	0.0160	0.2940	0.0000	0.0002	0.0004	0.0071	0.0048	0.0052	0.0045	0.0117	0.0077	0.3783
Cattle Feeder	0.0000	0.0000	0.0001	0.0066	0.0003	0.0009	0.0031	0.0002	0.0002	0.0001	0.0001	0.0002	0.0001	0.0056	0.0226	0.0015	0.0000	0.0001	0.0000	0.0000	0.0001	0.0004	0.0168
Live.Cattle	0.0000	0.0009	0.0008	0.0124	0.0015	0.0002	0.0044	0.0017	0.0006	0.0003	0.0002	0.0003	0.0005	0.0016	0.0246	0.0015	0.0002	0.0002	0.0002	0.0003	0.0002	0.0004	0.0284
Lean.Hogs	0.0000	0.0003	0.0006	0.0034	0.0006	0.0031	0.0003	0.0005	0.0002	0.0005	0.0002	0.0002	0.0004	0.0003	0.0005	0.6035	0.0000	0.0005	0.0005	0.0002	0.0010	0.0008	0.0142
Cotton	0.0003	0.0070	0.0076	0.0930	0.0160	0.0073	0.0174	0.0131	0.0075	0.0014	0.0018	0.0066	0.0083	0.0000	0.0001	0.0000	0.1734	0.0053	0.0054	0.0057	0.0108	0.0076	0.2223
Soy.Meal	0.0003	0.0067	0.0049	0.0713	0.0099	0.0072	0.0085	0.0078	0.0039	0.0005	0.0005	0.0038	0.0063	0.0000	0.0001	0.0007	0.0050	0.1947	0.0720	0.0111	0.0289	0.0384	0.2870
Soy.Oil	0.0005	0.0102	0.0080	0.1488	0.0227	0.0133	0.0093	0.0188	0.0090	0.0009	0.0010	0.0054	0.0077	0.0000	0.0001	0.0010	0.0068	0.0951	0.0850	0.0282	0.0308	0.0401	0.4579
Wheat	0.0008	0.0144	0.0105	0.2569	0.0396	0.0230	0.0079	0.0349	0.0182	0.0014	0.0016	0.0067	0.0074	0.0000	0.0002	0.0005	0.0081	0.0166	0.0313	0.0616	0.0242	0.0239	0.5279
Wheat	0.0006	0.0098	0.0062	0.0814	0.0206	0.0131	0.0341	0.0154	0.0061	0.0010	0.0015	0.0079	0.0111	0.0000	0.0001	0.0010	0.0087	0.0242	0.0196	0.0139	0.3319	0.6765	0.3525
Corn	0.0006	0.0106	0.0061	0.1744	0.0209	0.0164	0.0083	0.0154	0.0078	0.0008	0.0010	0.0070	0.0092	0.0001	0.0002	0.0010	0.0077	0.0404	0.0138	0.0172	0.0060	0.1659	0.4730
To	0.0301	0.2993	0.2038	10.5845	1.6827	0.7516	1.2061	1.4121	0.7334	0.1169	0.1409	0.1442	0.1726	0.0031	0.0080	0.0138	0.1104	0.2316	0.2321	0.1809	0.2953	0.2792	0.8560

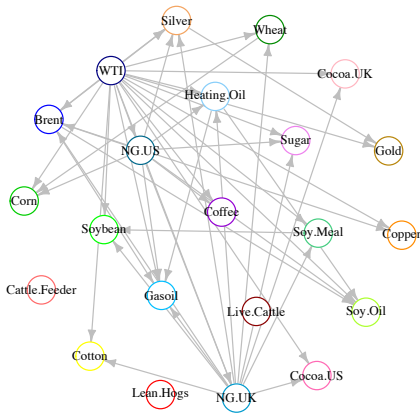
➔ Original Return Spatial Connectedness Table

Frequency decomposition of Return connectedness graphs

Return BK Term 1 (1–21d) net pairwise Connectedness



Return BK Term 2 (21–Inf)d net pairwise Connectedness



Volatility Connectedness Table (Caloia et al.)

	Gold	Silver	Copper	WTI	Brent	NG.US	NG.UK	Heating Oil	Gasoil	Cocoa.UK	Cocoa.US	Coffee	Sugar	Cattle Feeder	Live Cattle	Lean Hogs	Cotton	Soy.Meal	Soybean	Soy.Oil	Wheat	Corn	From
Gold	0.0025	0.0161	0.0033	0.1111	0.0064	0.1316	0.0267	0.0062	0.0026	0.0028	0.0022	0.0035	0.0042	0.0002	0.0006	0.0040	0.0027	0.0080	0.0019	0.0016	0.0048	0.0038	0.2981
Silver	0.0047	0.1015	0.0112	0.3745	0.0201	0.1179	0.2762	0.0187	0.0151	0.0056	0.0075	0.0121	0.0142	0.0008	0.0019	0.0135	0.0097	0.0101	0.0064	0.0053	0.0163	0.0102	0.6528
Copper	0.0014	0.0160	0.0344	0.2724	0.0170	0.0930	0.2215	0.0159	0.0121	0.0049	0.0055	0.0093	0.0106	0.0006	0.0014	0.0103	0.0075	0.0078	0.0052	0.0046	0.0119	0.0078	0.7366
WTI	0.0025	0.0254	0.0143	98.4741	0.2016	0.2677	0.6113	0.1250	0.0696	0.0125	0.0168	0.0234	0.0242	0.0019	0.0041	0.0410	0.0152	0.0135	0.0084	0.0086	0.0246	0.0142	1.5299
Brent	0.0017	0.0181	0.0111	2.7564	0.1581	0.1625	0.4206	0.0911	0.0502	0.0080	0.0090	0.0168	0.0170	0.0014	0.0031	0.0215	0.0116	0.0113	0.0074	0.0078	0.0190	0.0113	3.6570
NG.US	0.0030	0.0327	0.0183	1.0413	0.0515	2.5868	1.1095	0.0597	0.0448	0.0166	0.0192	0.0381	0.0334	0.0021	0.0048	0.0436	0.0241	0.0239	0.0132	0.0135	0.0395	0.0226	2.6554
NG.UK	0.0034	0.0361	0.0232	1.0936	0.0625	0.7834	21.5636	0.0831	0.0726	0.0192	0.0231	0.0421	0.0370	0.0029	0.0053	0.0541	0.0330	0.0292	0.0160	0.0191	0.0556	0.0272	2.5219
Heating Oil	0.0016	0.0166	0.0101	1.7222	0.0942	0.1786	0.5139	0.1384	0.0545	0.0073	0.0083	0.0135	0.0155	0.0012	0.0031	0.0194	0.0114	0.0108	0.0068	0.0075	0.0192	0.0194	2.7292
Gasoil	0.0013	0.0137	0.0080	1.2477	0.0526	0.1528	0.4761	0.0850	0.1299	0.0056	0.0074	0.0134	0.0131	0.0019	0.0024	0.0192	0.0100	0.0093	0.0056	0.0062	0.0162	0.0089	2.1263
Cocoa.UK	0.0008	0.0085	0.0052	0.2037	0.0132	0.0859	0.2080	0.0120	0.0101	0.0294	0.0219	0.0090	0.0101	0.0006	0.0014	0.0116	0.0066	0.0073	0.0044	0.0034	0.0114	0.0071	0.6421
Cocoa.US	0.0009	0.0103	0.0058	0.2285	0.0138	0.0999	0.2386	0.0133	0.0111	0.0203	0.0383	0.0107	0.0114	0.0007	0.0016	0.0138	0.0075	0.0082	0.0049	0.0039	0.0130	0.0079	0.7263
Coffee	0.0011	0.0118	0.0066	0.3157	0.0184	0.1351	0.3048	0.0191	0.0153	0.0064	0.0074	0.0797	0.0142	0.0009	0.0019	0.0169	0.0096	0.0103	0.0061	0.0052	0.0154	0.0096	0.9318
Sugar	0.0012	0.0138	0.0074	0.3039	0.0175	0.1154	0.3099	0.0178	0.0142	0.0063	0.0073	0.0129	0.0833	0.0008	0.0021	0.0153	0.0100	0.0097	0.0059	0.0050	0.0171	0.0107	0.9042
Cattle Feeder	0.0003	0.0024	0.0014	0.0758	0.0048	0.0251	0.0694	0.0045	0.0037	0.0013	0.0015	0.0029	0.0029	0.0023	0.0011	0.0046	0.0019	0.0019	0.0012	0.0011	0.0033	0.0022	0.2134
Live Cattle	0.0003	0.0034	0.0019	1.204	0.0064	0.0336	0.1004	0.0062	0.0043	0.0019	0.0023	0.0034	0.0040	0.0006	0.0152	0.0055	0.0023	0.0023	0.0014	0.0013	0.0039	0.0025	0.2082
Lean Hogs	0.0009	0.0094	0.0050	0.5086	0.0170	0.1005	0.2545	0.0155	0.0127	0.0053	0.0065	0.0104	0.0101	0.0009	0.0020	0.0350	0.0067	0.0079	0.0047	0.0039	0.0117	0.0071	1.0113
Cotton	0.0010	0.0112	0.0062	0.2637	0.0150	0.0966	0.2534	0.0154	0.0122	0.0052	0.0058	0.0109	0.0117	0.0007	0.0014	0.0116	0.0516	0.0084	0.0058	0.0048	0.0139	0.0090	0.7638
Soy.Meal	0.0010	0.0104	0.0057	0.2004	0.0130	0.0932	0.2341	0.0134	0.0114	0.0052	0.0061	0.0107	0.0106	0.0007	0.0013	0.0125	0.0078	0.0687	0.0228	0.0057	0.0150	0.0147	0.6954
Soybean	0.0008	0.0089	0.0050	0.1513	0.0111	0.0676	0.1853	0.0107	0.0087	0.0039	0.0047	0.0081	0.0087	0.0005	0.0010	0.0099	0.0065	0.0299	0.0034	0.0070	0.0126	0.0128	0.5550
Soy.Oil	0.0008	0.0092	0.0056	0.2128	0.0141	0.0790	0.2399	0.0146	0.0120	0.0039	0.0046	0.0088	0.0088	0.0006	0.0012	0.0099	0.0068	0.0090	0.0086	0.0153	0.0118	0.0084	0.6704
Wheat	0.0014	0.0141	0.0083	0.3042	0.0195	0.1327	0.3970	0.0214	0.0166	0.0070	0.0081	0.0142	0.0154	0.0009	0.0019	0.0156	0.0109	0.0141	0.0088	0.0069	0.0019	0.0209	1.0400
Corn	0.0010	0.0108	0.0066	0.2284	0.0139	0.0894	0.2383	0.0139	0.0112	0.0055	0.0062	0.0108	0.0120	0.0007	0.0015	0.0115	0.0084	0.0158	0.0109	0.0057	0.0252	0.0504	0.7277
To	0.0312	0.2990	0.1702	11.7373	0.6836	2.9435	0.7553	0.6324	0.4671	0.1559	0.1811	0.2879	0.2891	0.0208	0.0452	0.3651	0.2101	0.2436	0.1565	0.1280	0.3616	0.2284	1.1997

	Gold	Silver	Copper	WTI	Brent
Gold	0.0025	0.0161	0.0033	0.1117	0.0064
Silver	0.0047	0.1015	0.0112	0.3745	0.0201
Copper	0.0014	0.0160	0.0344	0.2724	0.0170
WTI	0.0025	0.0254	0.0143	98.4741	0.2016
Brent	0.0017	0.0181	0.0111	2.7564	0.1581

- $\theta_{WTI \leftarrow Brent} = 0.2016$

- $\theta_{Brent \leftarrow WTI} = 2.7564$

\Rightarrow Net pairwise: (WTI \rightarrow Brent)
 $(2.7564 - 0.2016) = 2.5548$

[Original Return Spatial Connectedness Table](#)

Preliminary results for extensions

Correlations create artificial connectedness (Barunik & Krehlik, 2018)

	Gold	Silver	Copper	WTI	Brent	NG.US	NG.UK	Heating.Oil	Gasoil	Cocoa.UK	Cocoa.US	Coffee	Sugar	Cattle.Feeder	Live.Cattle	Lean.Hogs	Cotton	Soy.Meal	Soybean	Soy.Oil	Wheat	Corn	From		
Gold	0.0084	0.0001	0.0001	0.0049	0.0001	0.0001	0.0005	0.0000	0.0001	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0064	
Silver	0.0000	0.3300	0.0003	0.0227	0.0000	0.0001	0.0001	0.0000	0.0001	0.0000	0.0002	0.0001	0.0002	0.0000	0.0000	0.0001	0.0000	0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0302
Copper	0.0000	0.0000	0.1255	0.0109	0.0003	0.0007	0.0063	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0013	0.0005	0.0000	0.0000	0.0001	0.0001	0.0000	0.0214
WTI	0.0001	0.0002	0.0008	99.9687	0.0047	0.0007	0.0086	0.0001	0.0000	0.0020	0.0073	0.0031	0.0002	0.0001	0.0001	0.0003	0.0004	0.0003	0.0000	0.0004	0.0003	0.0015	0.0015	0.0015	0.0313
Brent	0.0000	0.0000	0.0001	0.0423	0.6423	0.0023	0.0221	0.0001	0.0002	0.0001	0.0003	0.0001	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0005	0.0002	0.0001	0.0004	0.0004	0.0004	0.5771
NG.US	0.0001	0.0030	0.0001	0.0603	0.0189	0.1582	0.0030	0.0035	0.0016	0.0000	0.0006	0.0005	0.0001	0.0000	0.0000	0.0002	0.0000	0.0002	0.0000	0.0000	0.0000	0.0003	0.0003	0.0003	0.0225
NG.UK	0.0000	0.0001	0.0009	0.0060	0.0014	0.1587	49.4707	0.0006	0.0006	0.0008	0.0011	0.0014	0.0007	0.0000	0.0001	0.0010	0.0000	0.0000	0.0005	0.0000	0.0000	0.0002	0.0001	0.0001	0.1741
Heating.Oil	0.0000	0.0000	0.0000	0.2201	0.0077	0.0004	0.0048	0.5740	0.0004	0.0000	0.0000	0.0003	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0002	0.0002	0.0002	0.0003	0.0003	0.2347
Gasoil	0.0000	0.0000	0.0002	0.1713	0.0013	0.0008	0.0004	0.0666	0.3778	0.0001	0.0001	0.0004	0.0003	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0001	0.0000	0.0002	0.0001	0.0001	0.2420
Cocoa.UK	0.0000	0.0001	0.0000	0.0088	0.0007	0.0011	0.0006	0.0000	0.0000	0.1101	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0002	0.0003	0.0000	0.0000	0.0001	0.0001	0.0001	0.0121
Cocoa.US	0.0000	0.0000	0.0001	0.0094	0.0007	0.0027	0.0014	0.0001	0.0000	0.0021	0.1514	0.0000	0.0001	0.0000	0.0000	0.0001	0.0003	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001	0.0171
Coffee	0.0000	0.0000	0.0001	0.0104	0.0042	0.0019	0.0005	0.0017	0.0000	0.0003	0.0005	0.3030	0.0000	0.0000	0.0000	0.0001	0.0010	0.0010	0.0005	0.0002	0.0001	0.0002	0.0002	0.0002	0.0227
Sugar	0.0000	0.0010	0.0000	0.0092	0.0000	0.0017	0.0209	0.0001	0.0002	0.0000	0.0000	0.0001	0.3021	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0000	0.0001	0.0000	0.0338
Cattle.Feeder	0.0000	0.0001	0.0000	0.0006	0.0007	0.0000	0.0004	0.0010	0.0000	0.0000	0.0000	0.0000	0.0000	0.0060	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0030
Live.Cattle	0.0000	0.0000	0.0000	0.0001	0.0004	0.0000	0.0036	0.0008	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0262	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0055
Lean.Hogs	0.0000	0.0000	0.0001	0.0127	0.0011	0.0023	0.0002	0.0001	0.0004	0.0000	0.0002	0.0000	0.0001	0.0000	0.0000	0.6457	0.0000	0.0004	0.0011	0.0000	0.0000	0.0002	0.0005	0.0194	0.0194
Cotton	0.0000	0.0002	0.0001	0.0162	0.0007	0.0018	0.0000	0.0004	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1860	0.0001	0.0003	0.0001	0.0001	0.0001	0.0000	0.0000	0.0203
Soy.Meal	0.0000	0.0000	0.0001	0.0018	0.0002	0.0000	0.0025	0.0005	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.2075	0.0004	0.0000	0.0003	0.0000	0.0000	0.0001	0.0061
Soybean	0.0000	0.0002	0.0001	0.0004	0.0005	0.0003	0.0014	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0007	0.0002	0.0001	0.0000	0.0000	0.0000	0.0241
Soy.Oil	0.0000	0.0001	0.0000	0.0048	0.0009	0.0005	0.0003	0.0001	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0002	0.0657	0.0000	0.0000	0.0000	0.0001	0.0081
Wheat	0.0000	0.0002	0.0001	0.0006	0.0016	0.0005	0.0004	0.0009	0.0001	0.0004	0.0006	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.3535	0.0001	0.0000	0.0058
Corn	0.0000	0.0001	0.0002	0.0076	0.0015	0.0005	0.0002	0.0001	0.0000	0.0000	0.0000	0.0003	0.0000	0.0000	0.0000	0.0000	0.0001	0.0003	0.0002	0.0000	0.0003	0.1773	0.0001	0.0016	0.0116
To	0.0004	0.0053	0.0036	1.1301	0.0476	0.1772	0.0618	0.0774	0.0043	0.0071	0.0108	0.0069	0.0020	0.0003	0.0005	0.0027	0.0022	0.0055	0.0053	0.0014	0.0038	0.0040	0.0010	0.0010	0.0718

	Gold	Silver	Copper	WTI	Brent
Gold	0.0084	0.0001	0.0001	0.0049	0.0001
Silver	0.0000	0.3300	0.0003	0.0227	0.0000
Copper	0.0000	0.0000	0.1255	0.0109	0.0003
WTI	0.0001	0.0002	0.0008	99.9687	0.0047
Brent	0.0000	0.0000	0.0001	0.5715	0.6423

- $\theta_{WTI \leftarrow Brent} = 0.0047$

- $\theta_{Brent \leftarrow WTI} = 0.5715$

\Rightarrow Net pairwise: (Silver \rightarrow Gold)
 $(0.5715 - 0.0047) = 0.5668$

[▶ Original Return Spatial Connectedness Table](#)