

APPENDIX to European Carbon Market Connectedness and Risk  
Contagion: A Study of Return and Volatility Dynamics Between  
Post-Phase II European Union Allowances (EUAs) and Financial Markets  
and their Potential for Portfolio Diversification

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**Abstract**

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## Appendix A. Static Return and Volatility Connectedness Matrix

Table A.1: Static Return and Volatility Connectedness Matrix (Jan 2013 - Jan 2025)

(a) Carbon returns connectedness matrix

	CARBON	EUROSTOXX	BRENT OIL	COAL API	NATGAS	EURSOVER	EURCORP	SPXINDEX	COMEXENG	METALS	DSF (FROM)
CARBON	60.06	4.00	3.80	7.85	10.21	2.48	2.26	3.47	2.76	3.11	<b>39.94</b>
EUROSTOXX	3.28	49.76	5.70	3.33	3.12	3.05	3.67	19.87	5.20	3.03	50.24
BRENT OIL	3.49	6.00	57.40	5.44	3.61	2.68	2.34	7.27	8.29	3.49	42.60
COAL API	6.34	3.77	5.80	56.02	13.78	1.85	2.04	3.84	3.96	2.62	43.98
NATGAS	9.93	3.03	3.88	13.58	58.73	1.80	1.76	2.48	2.56	2.24	41.27
EURSOVER	2.03	2.98	2.68	1.67	1.68	48.35	31.93	2.28	2.05	4.36	51.65
EURCORP	1.97	5.05	2.71	1.75	1.81	30.37	45.49	3.97	2.54	4.35	54.51
SPXINDEX	2.42	17.95	6.82	3.35	2.03	2.30	2.73	53.51	6.40	2.50	46.49
COMEXENG	2.48	5.08	7.44	3.49	2.40	2.16	2.37	6.59	53.07	14.91	46.93
METALS	2.37	3.15	3.10	2.28	2.47	4.83	5.59	2.96	16.14	57.11	42.89
DST (TO)	<b>34.31</b>	51.01	41.93	42.73	41.10	51.52	54.69	52.73	49.89	40.60	460.50
Inc.Own	94.37	100.77	99.33	98.75	99.83	99.87	100.18	106.24	102.96	97.70	<b>TCI</b>
NS (NET)	<b>-5.63</b>	0.77	-0.67	-1.25	-0.17	-0.13	0.18	6.24	2.96	-2.30	<b>46.05</b>

(b) Carbon volatility connectedness matrix

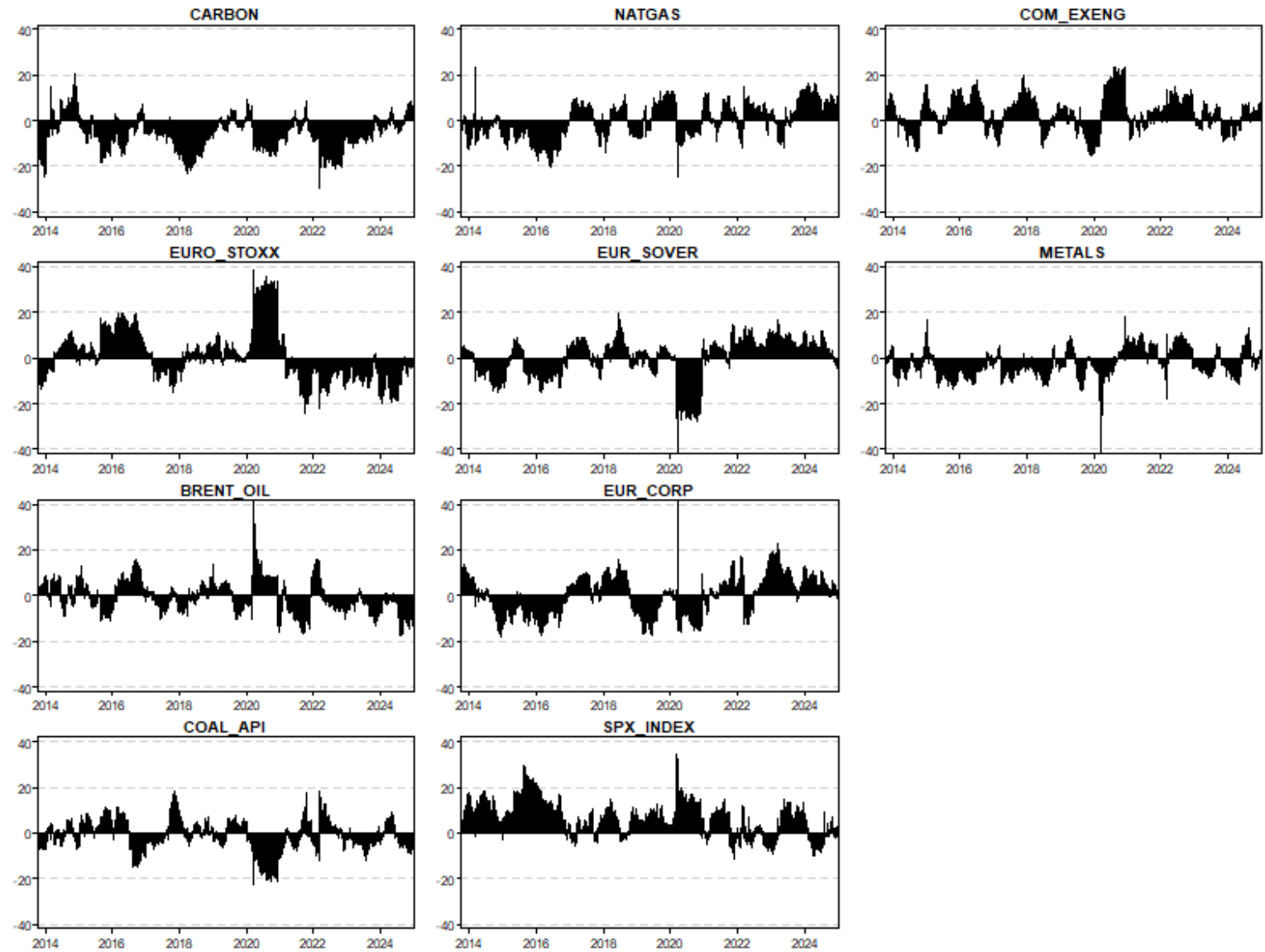
	CARBON	EUROSTOXX	BRENT OIL	COAL API	NATGAS	EURSOVER	EURCORP	SPXINDEX	COMEXENG	METALS	DSF (FROM)
CARBON	55.66	4.60	4.29	7.25	7.13	3.77	3.61	5.06	3.83	4.79	<b>44.34</b>
EUROSTOXX	3.63	47.09	5.17	3.59	3.45	5.12	4.14	16.60	5.25	5.95	52.91
BRENT OIL	4.20	6.54	52.55	4.93	3.59	3.85	4.54	6.49	7.10	6.20	47.45
COAL API	4.67	5.83	4.19	57.95	7.85	3.80	2.71	4.59	3.14	5.26	42.05
NATGAS	4.51	4.64	3.43	8.36	59.40	3.52	3.79	4.82	3.56	3.96	40.60
EURSOVER	2.17	6.27	3.30	2.43	1.86	44.69	25.39	5.60	3.86	4.44	55.31
EURCORP	2.81	5.70	2.52	2.34	2.40	28.32	41.90	5.97	4.70	3.33	58.10
SPXINDEX	3.29	15.44	5.03	3.08	1.71	4.71	3.98	53.15	4.44	5.17	46.85
COMEXENG	2.62	7.96	4.69	3.94	4.00	5.32	5.39	6.71	49.30	10.07	50.70
METALS	3.91	8.31	4.44	3.90	3.85	5.08	6.31	6.26	10.05	47.90	52.10
DST (TO)	<b>31.83</b>	65.30	37.07	39.82	35.85	63.47	59.86	62.11	45.92	49.18	490.40
Inc.Own	87.49	112.39	89.62	97.77	95.25	108.16	101.76	115.27	95.22	97.08	<b>TCI</b>
NS (NET)	<b>-12.51</b>	12.39	-10.38	-2.23	-4.75	8.16	1.76	15.27	-4.78	-2.92	<b>49.04</b>



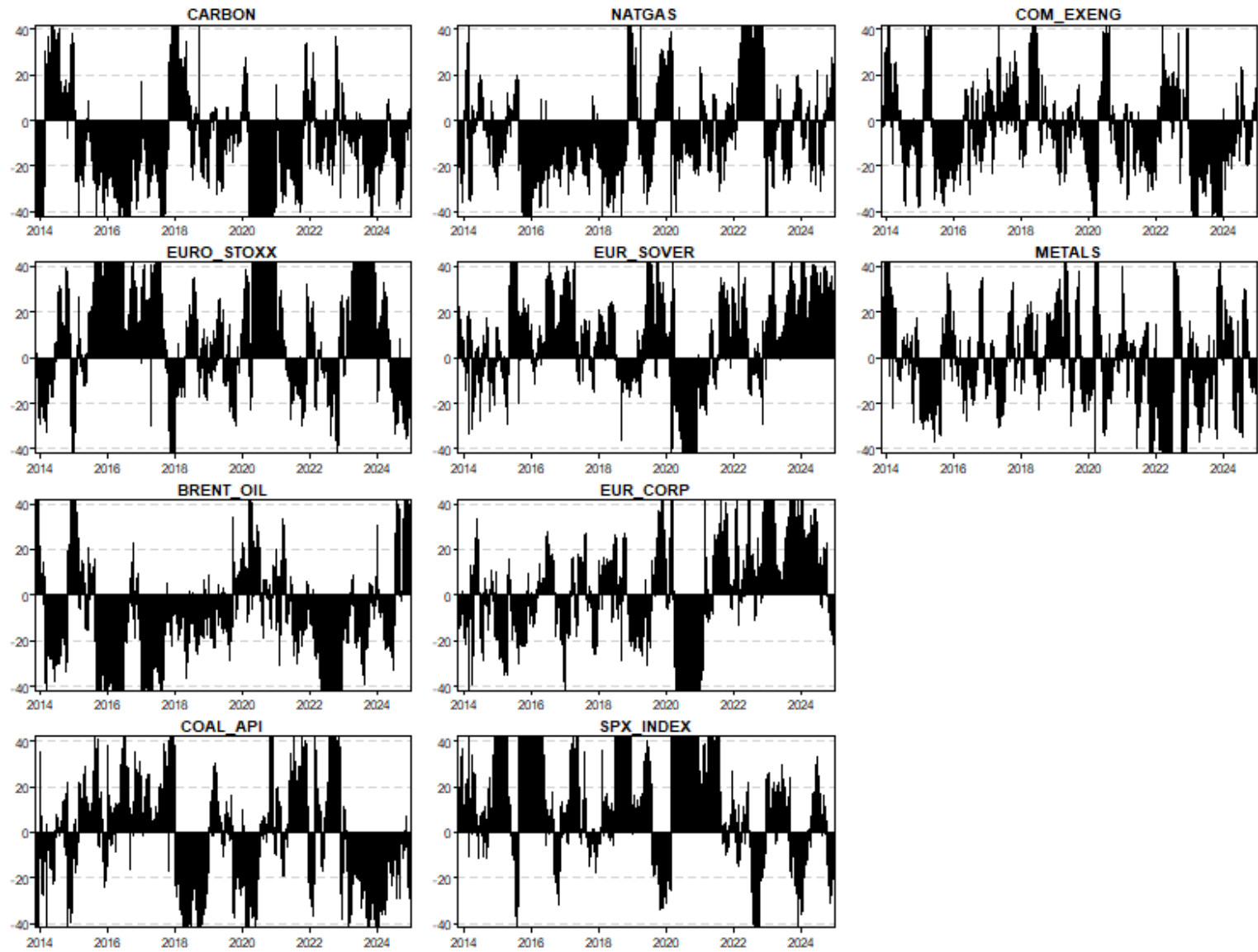
Appendix B. Dynamic Return and Volatility Net Directional Connectedness

Figure B.1: Dynamic Net Directional Connectedness (Jan 2013 – Jan 2025)

(a) Dynamic return net directional connectedness



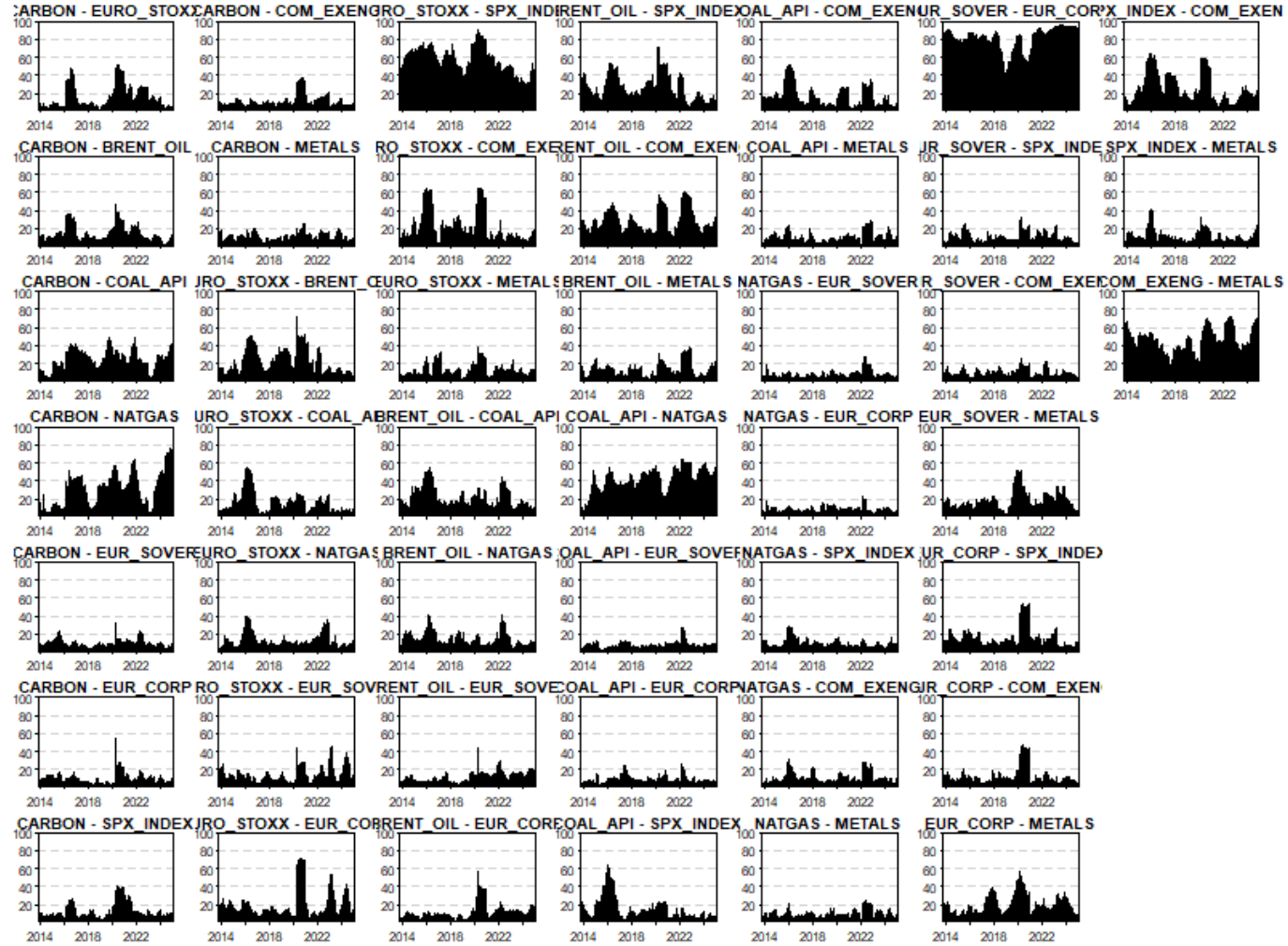
(b) Dynamic volatility net directional connectedness



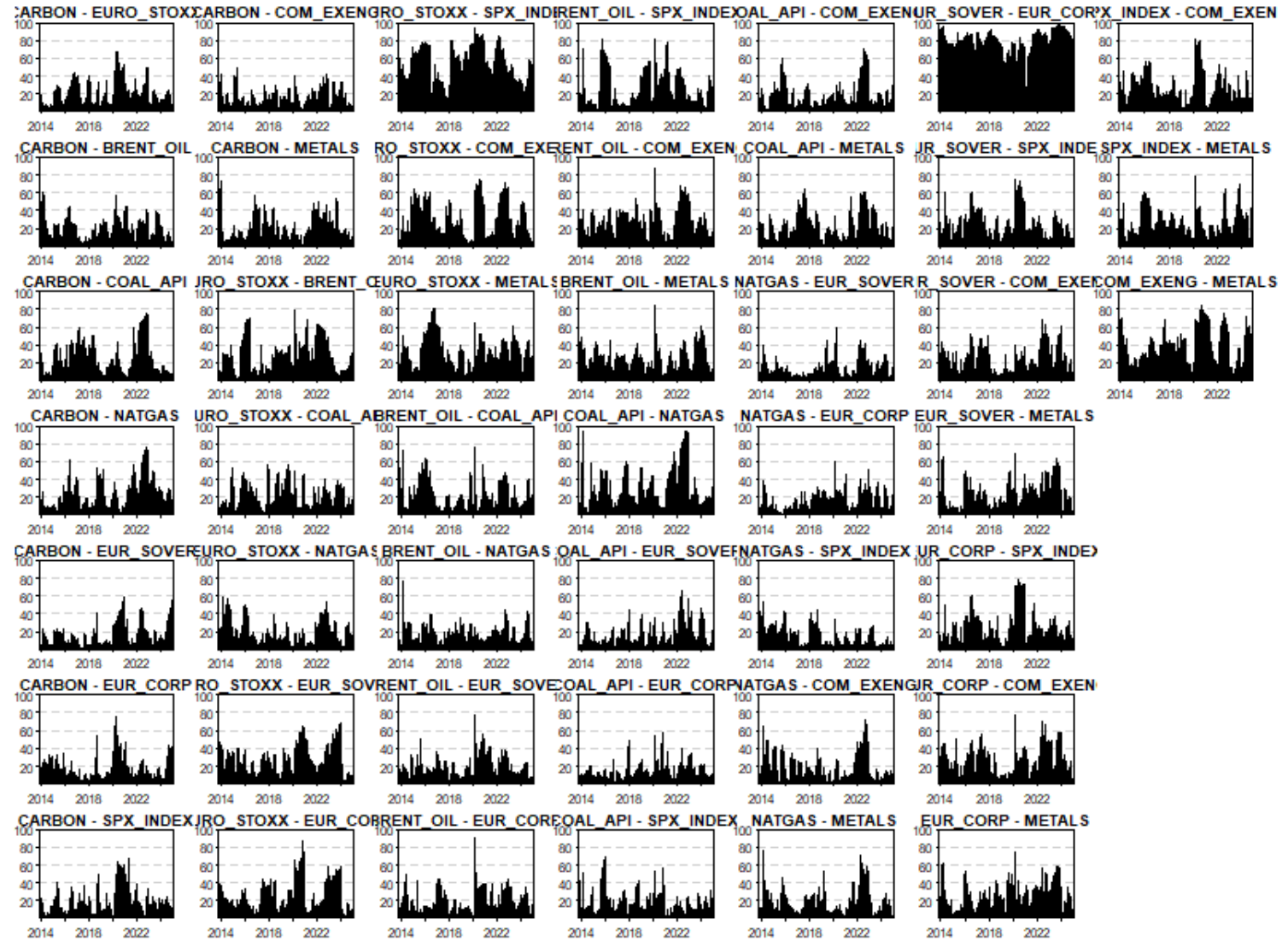
## Appendix C. Dynamic Return and Volatility Pairwise Connectedness Index

Figure C.2: Dynamic Return and Volatility Pairwise Connectedness Index (Jan 2013 – Jan 2025)

(a) Dynamic return PCI



(b) Dynamic volatility PCI



## Appendix D. Robustness Testing of Connectedness Model Parameters

Appendix D.1. 10-period forecast horizon and a rolling window of 180 observations

Appendix D.1.1. Static Return and Volatility Connectedness Matrix

Table D.2: Static Return and Volatility Connectedness Matrix (Jan 2013 - Jan 2025)

(a) Carbon returns connectedness matrix

	CARBON	EUROSTOXX	BRENTOIL	COALAPI	NATGAS	EUROVER	EURCORP	SPXINDEX	COMEXENG	METALS	FROM
CARBON	58.42	4.13	3.95	7.9	10.32	2.75	2.49	3.71	2.96	3.37	41.58
EUROSTOXX	3.42	48.5	5.77	3.45	3.35	3.4	3.94	19.55	5.3	3.32	51.5
BRENTOIL	3.73	6.14	56.08	5.53	3.75	2.88	2.51	7.34	8.26	3.78	43.92
COALAPI	6.47	3.92	5.88	54.74	13.63	2.07	2.25	4.02	4.11	2.91	45.26
NATGAS	10.05	3.24	4.05	13.36	57.16	2.07	1.99	2.76	2.82	2.49	42.84
EUROVER	2.25	3.24	2.94	1.89	1.94	47.16	31.34	2.45	2.3	4.48	52.84
EURCORP	2.18	5.15	2.89	1.98	2.05	29.92	44.6	4.04	2.7	4.48	55.4
SPXINDEX	2.62	17.77	6.93	3.49	2.29	2.53	2.92	52.31	6.39	2.75	47.69
COMEXENG	2.68	5.17	7.47	3.64	2.68	2.41	2.56	6.59	51.98	14.82	48.02
METALS	2.58	3.42	3.38	2.51	2.73	4.92	5.67	3.2	15.94	55.65	44.35
DST(TO)	35.98	52.19	43.28	43.75	42.74	52.95	55.68	53.66	50.79	42.39	473.4
Inc. Own	94.41	100.69	99.36	98.49	99.9	100.11	100.28	105.96	102.76	98.04	cTCI/TCI
NS (NET)	-5.59	0.69	-0.64	-1.51	-0.1	0.11	0.28	5.96	2.76	-1.96	52.60/47.34

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(b) Carbon volatility connectedness matrix

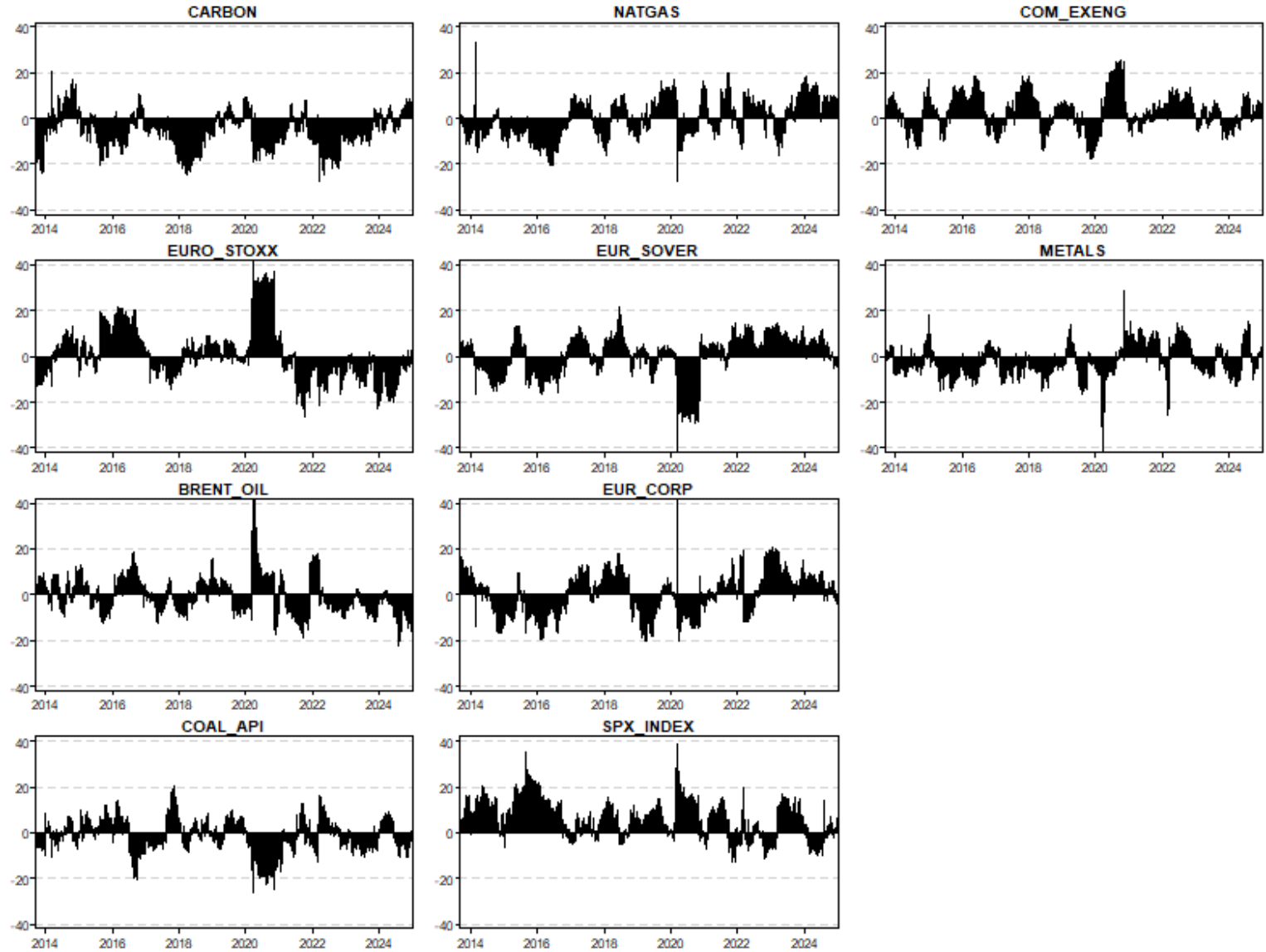
	CARBON	EUROSTOXX	BRENTOIL	COALAPI	NATGAS	EUROVER	EURCORP	SPXINDEX	COMEXENG	METALS	FROM
CARBON	52.95	4.7	4.74	7.16	7.63	4.19	3.79	5.42	4.13	5.3	47.05
EUROSTOXX	4.01	45.08	5.34	4.25	3.87	5.52	4.38	15.91	5.33	6.3	54.92
BRENTOIL	4.76	6.68	49.8	5.09	3.85	4.3	4.99	6.78	7.12	6.64	50.2
COALAPI	4.88	6.1	4.69	54.65	8.24	4.24	3.12	5.11	3.45	5.52	45.35
NATGAS	4.74	4.99	3.73	8.42	56.56	3.94	3.96	5.28	4.05	4.33	43.44
EUROVER	2.49	6.48	3.6	2.86	2.38	42.69	24.76	5.84	4.43	4.47	57.31
EURCORP	3.24	5.76	2.65	2.84	3	27.52	39.98	6.12	5.26	3.63	60.02
SPXINDEX	3.54	15.08	5.4	3.42	2.05	5.22	4.41	50.56	4.69	5.63	49.44
COMEXENG	3.18	7.91	4.75	4.33	4.51	6.08	5.78	7.11	46.34	10	53.66
METALS	4.27	8.4	4.76	4.29	4.33	5.28	6.78	6.91	9.64	45.33	54.67
DST(TO)	35.11	66.11	39.64	42.67	39.87	66.29	61.97	64.48	48.1	51.81	516.05
Inc. Own	88.06	111.19	89.44	97.33	96.43	108.98	101.96	115.04	94.45	97.14	cTCI/TCI
NS (NET)	-11.94	11.19	-10.56	-2.67	-3.57	8.98	1.96	15.04	-5.55	-2.86	57.34/51.60





Figure D.3: Dynamic Net Directional Connectedness (Jan 2013 – Jan 2025)

(a) Dynamic return net directional connectedness



(b) Dynamic volatility net directional connectedness

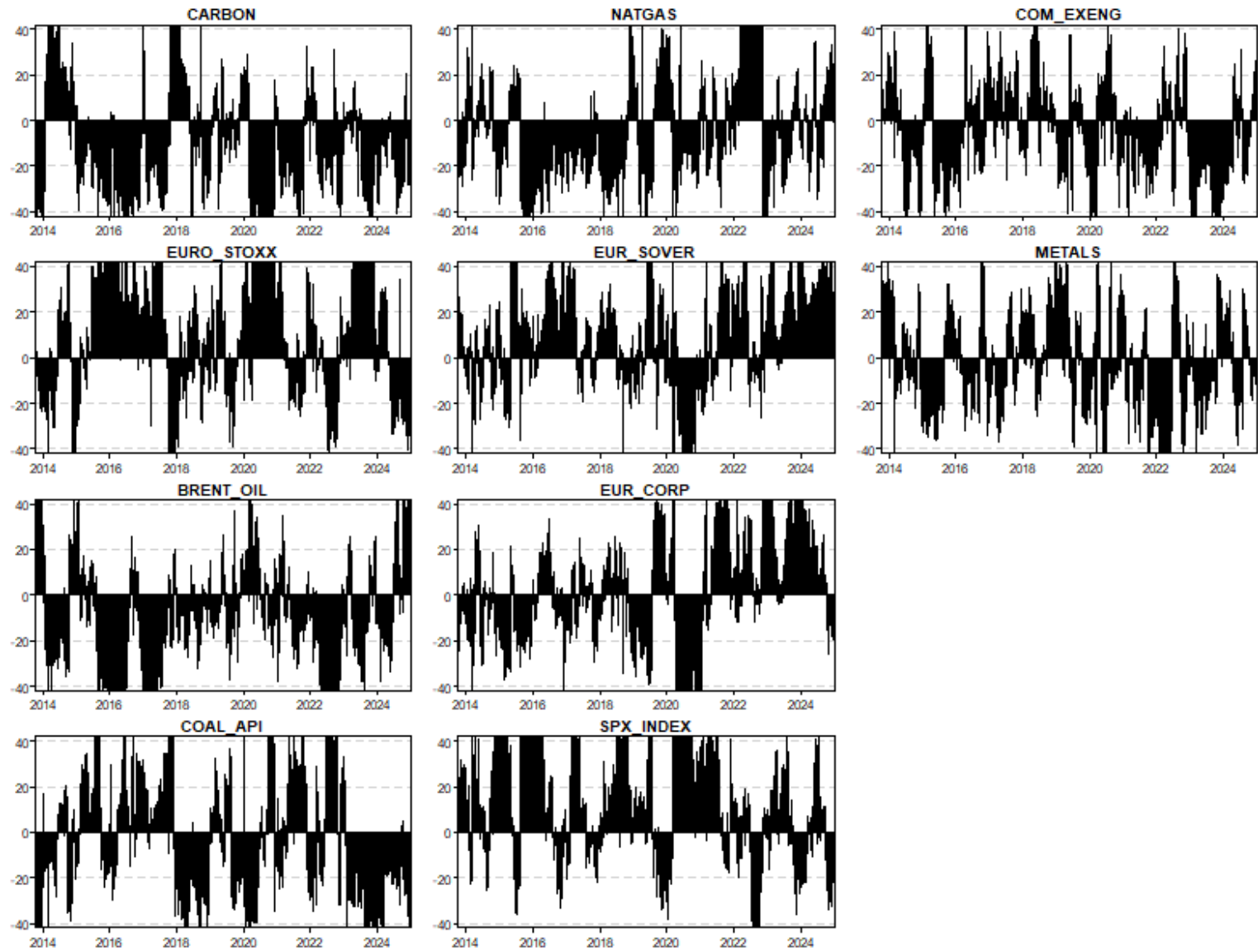
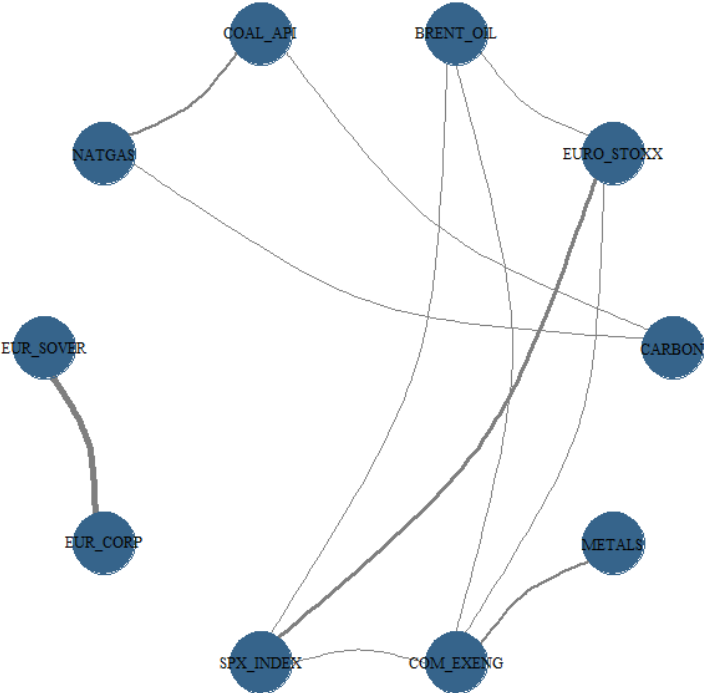
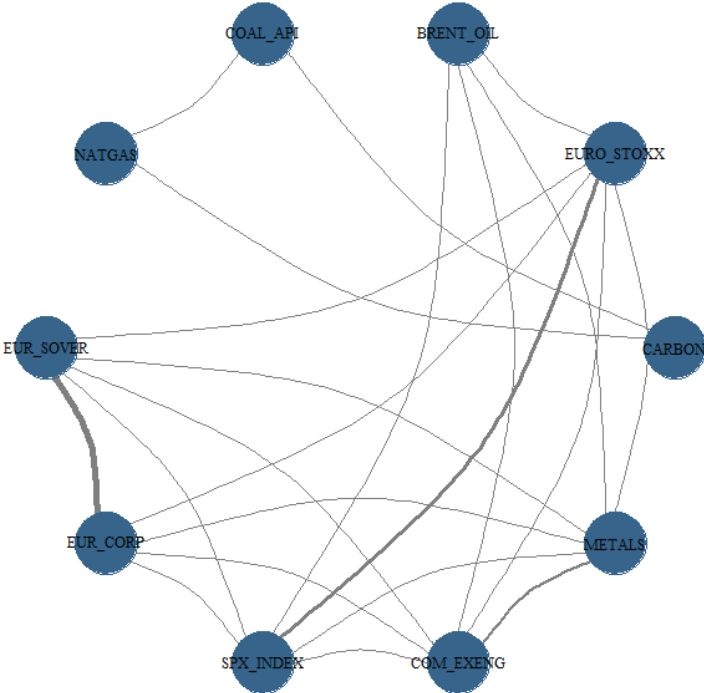


Figure D.4: Network Representation of Pairwise Connectedness Index (Jan 2013 – Jan 2025)

(a) Static Return PCI network



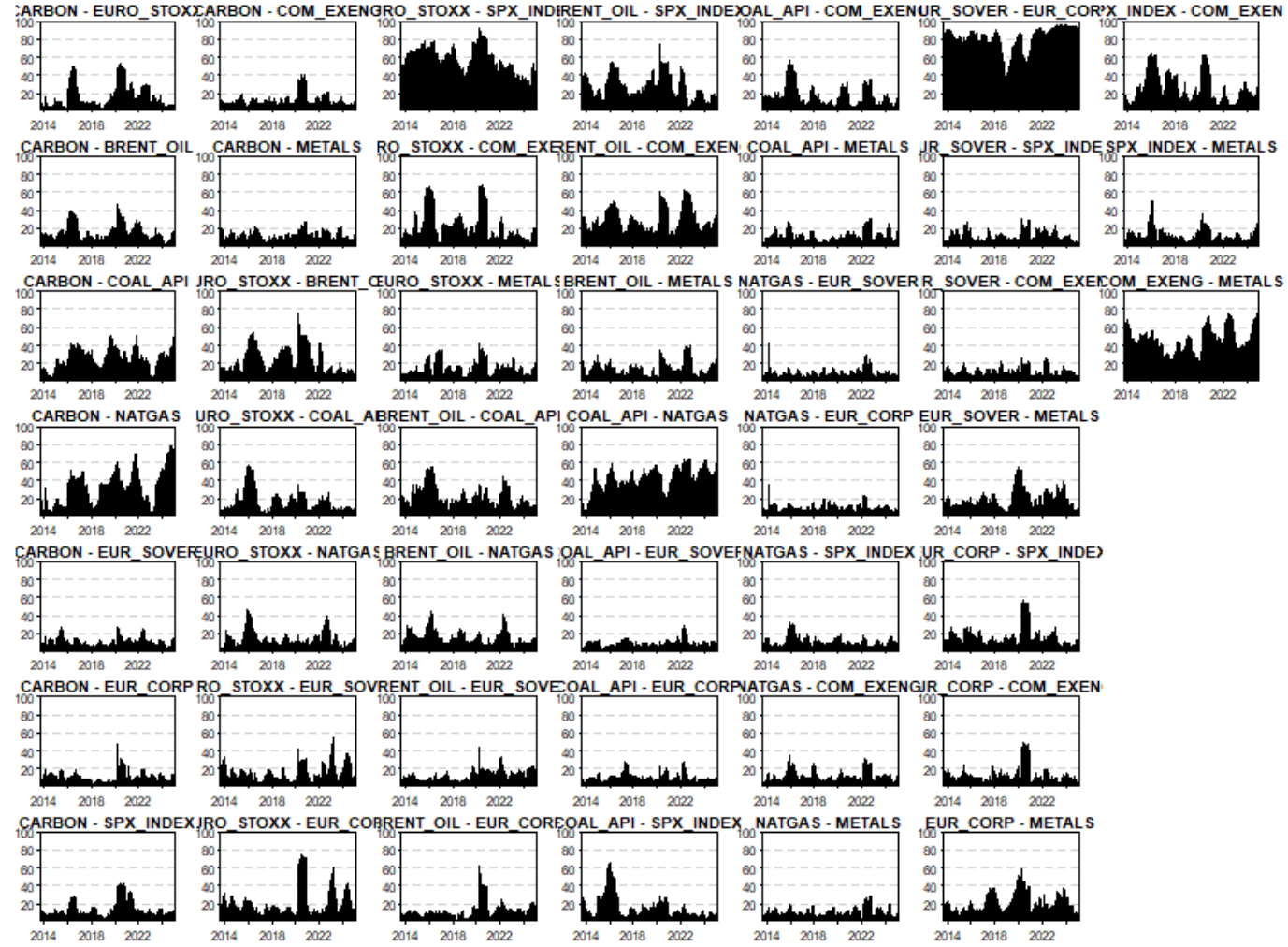
(b) Static Volatility PCI network



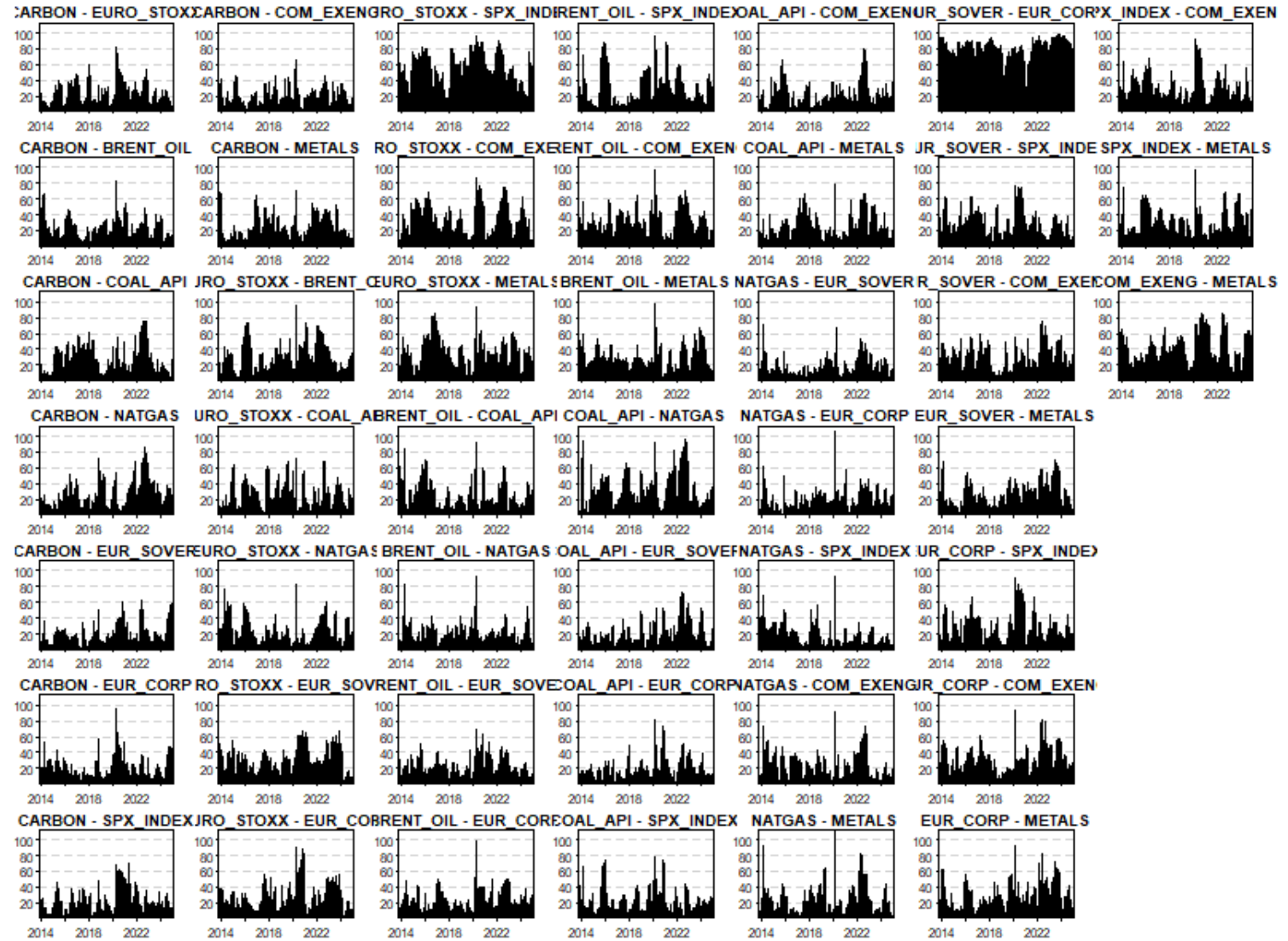
Appendix D.1.4. Dynamic Return and Volatility Pairwise Directional Connectedness

Figure D.5: Dynamic Return and Volatility Pairwise Connectedness Index (Jan 2013 – Jan 2025)

(a) Dynamic return PCI



(b) Dynamic volatility PCI



Appendix D.2. 10-period forecast horizon and a rolling window of 220 observations

Appendix D.2.1. Static Return and Volatility Connectedness Matrix

Table D.3: Static Return and Volatility Connectedness Matrix (Jan 2013 - Jan 2025)

(a) Carbon returns connectedness matrix

	CARBON	EUROSTOXX	BRENTOIL	COALAPI	NATGAS	EUROOVER	EURCORP	SPXINDEX	COMEXENG	METALS	FROM
CARBON	61.35	3.93	3.67	7.77	10.07	2.29	2.12	3.28	2.6	2.91	38.65
EUROSTOXX	3.17	50.79	5.67	3.23	2.94	2.75	3.43	20.12	5.14	2.77	49.21
BRENTOIL	3.31	5.91	58.43	5.38	3.49	2.5	2.22	7.19	8.32	3.25	41.57
COALAPI	6.21	3.65	5.74	57.04	13.87	1.71	1.88	3.69	3.82	2.38	42.96
NATGAS	9.8	2.86	3.74	13.76	59.97	1.62	1.6	2.23	2.37	2.05	40.03
EUROOVER	1.86	2.78	2.47	1.5	1.47	49.32	32.36	2.14	1.84	4.25	50.68
EURCORP	1.83	5	2.6	1.56	1.6	30.68	46.15	3.92	2.43	4.22	53.85
SPXINDEX	2.25	18.12	6.71	3.21	1.8	2.12	2.58	54.48	6.44	2.29	45.52
COMEXENG	2.32	5.03	7.42	3.34	2.17	1.96	2.21	6.63	53.93	14.98	46.07
METALS	2.21	2.9	2.88	2.07	2.24	4.77	5.5	2.76	16.3	58.36	41.64
DST(TO)	32.96	50.19	40.89	41.83	39.66	50.41	53.92	51.95	49.25	39.11	450.17
Inc. Own	94.31	100.98	99.31	98.87	99.63	99.74	100.08	106.43	103.18	97.48	cTCI/TCI
NS (NET)	-5.69	0.98	-0.69	-1.13	-0.37	-0.26	0.08	6.43	3.18	-2.52	50.02/45.02

(b) Carbon volatility connectedness matrix

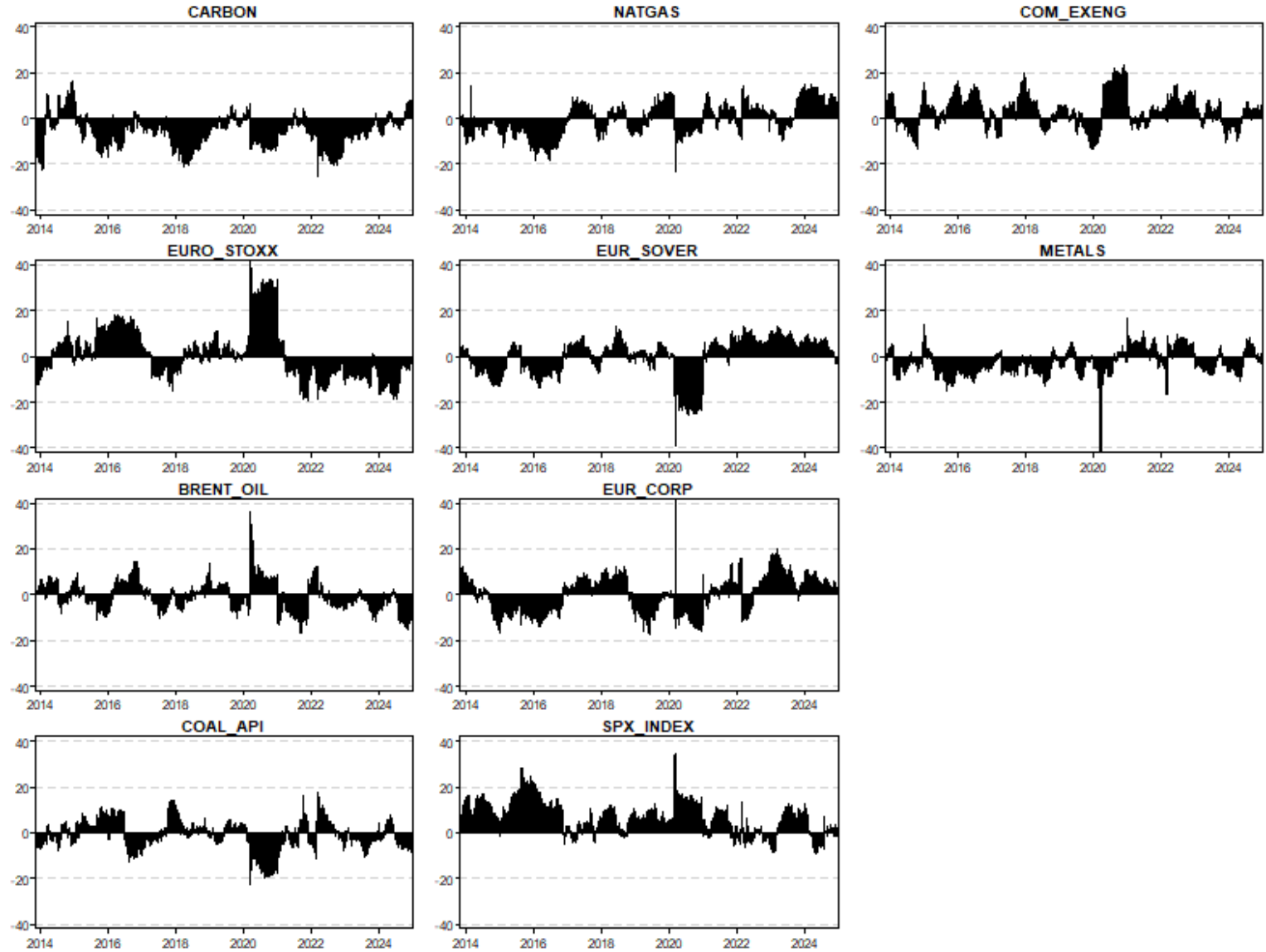
	CARBON	EUROSTOXX	BRENTOIL	COALAPI	NATGAS	EUROOVER	EURCORP	SPXINDEX	COMEXENG	METALS	FROM
CARBON	57.82	4.6	3.99	7.25	6.77	3.43	3.28	4.71	3.77	4.37	42.18
EUROSTOXX	3.26	48.44	4.96	3.2	3.12	4.95	4.06	17.08	5.26	5.68	51.56
BRENTOIL	3.71	6.49	54.56	4.78	3.39	3.48	4.09	6.32	7.29	5.9	45.44
COALAPI	4.61	5.41	3.49	60.67	7.47	3.55	2.54	4.17	3	5.09	39.33
NATGAS	4.33	4.33	3.04	8.15	62.01	3.2	3.63	4.47	3.24	3.6	37.99
EUROOVER	1.88	6.07	3.1	2.09	1.59	46.2	25.84	5.5	3.43	4.3	53.8
EURCORP	2.48	5.69	2.46	1.93	1.95	28.91	43.34	5.93	4.14	3.17	56.66
SPXINDEX	3.03	15.53	4.64	2.83	1.51	4.32	3.72	55.36	4.18	4.88	44.64
COMEXENG	2.16	7.92	4.69	3.69	3.6	4.81	4.93	6.45	51.6	10.15	48.4
METALS	3.68	8.12	4.08	3.63	3.45	4.91	5.83	5.71	10.35	50.22	49.78
DST(TO)	29.15	64.17	34.46	37.57	32.84	61.55	57.91	60.35	44.66	47.14	469.8
Inc. Own	86.97	112.61	89.02	98.23	94.85	107.74	101.25	115.71	96.26	97.36	cTCI/TCI
NS (NET)	-13.03	12.61	-10.98	-1.77	-5.15	7.74	1.25	15.71	-3.74	-2.64	52.20/46.98





Figure D.6: Dynamic Net Directional Connectedness (Jan 2013 – Jan 2025)

(a) Dynamic return net directional connectedness



(b) Dynamic volatility net directional connectedness

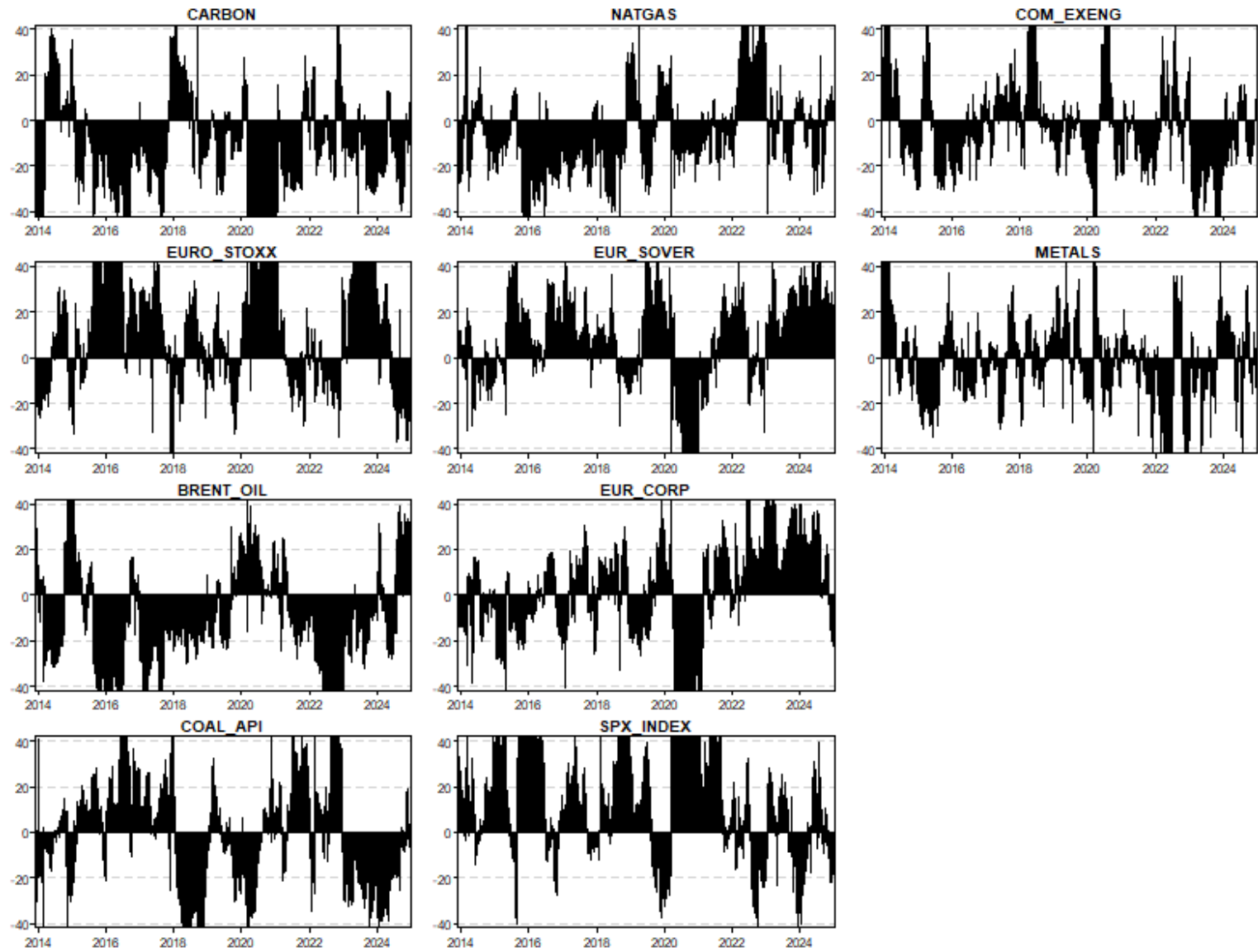
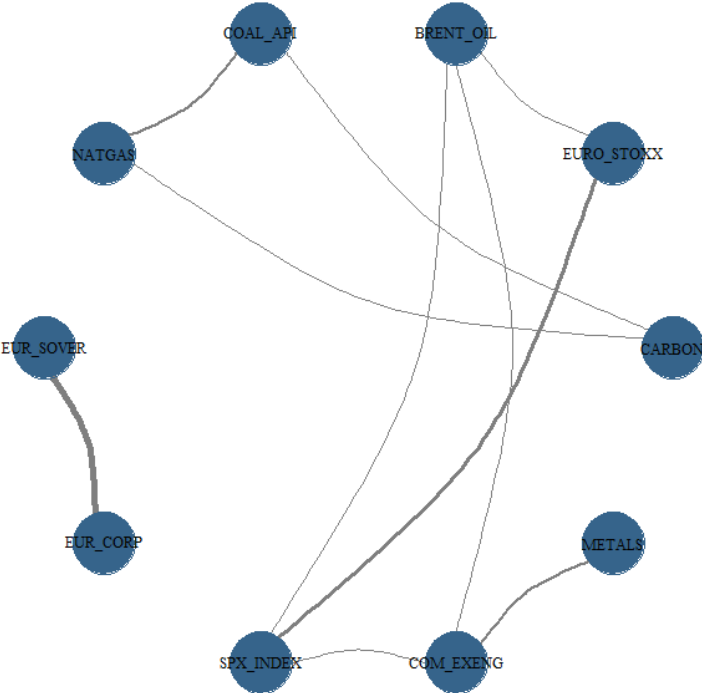
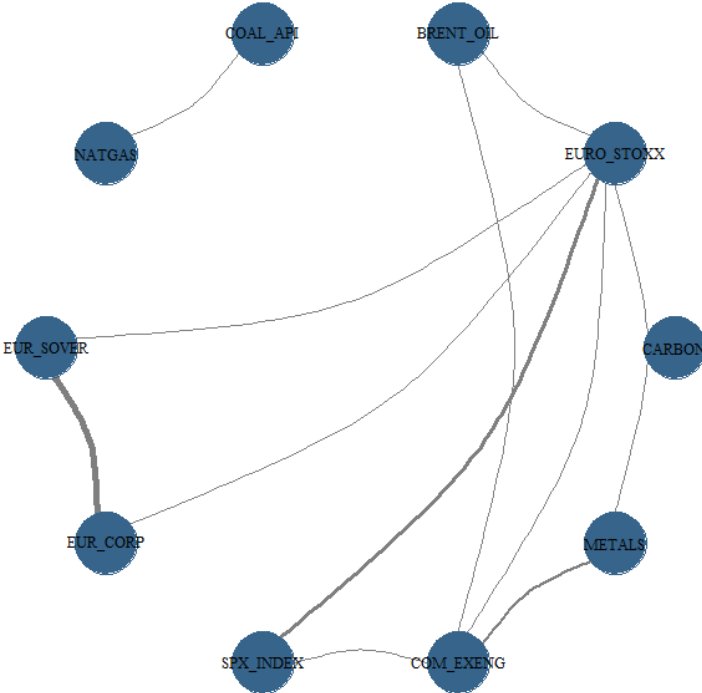


Figure D.7: Network Representation of Pairwise Connectedness Index (Jan 2013 – Jan 2025)

(a) Static Return PCI network



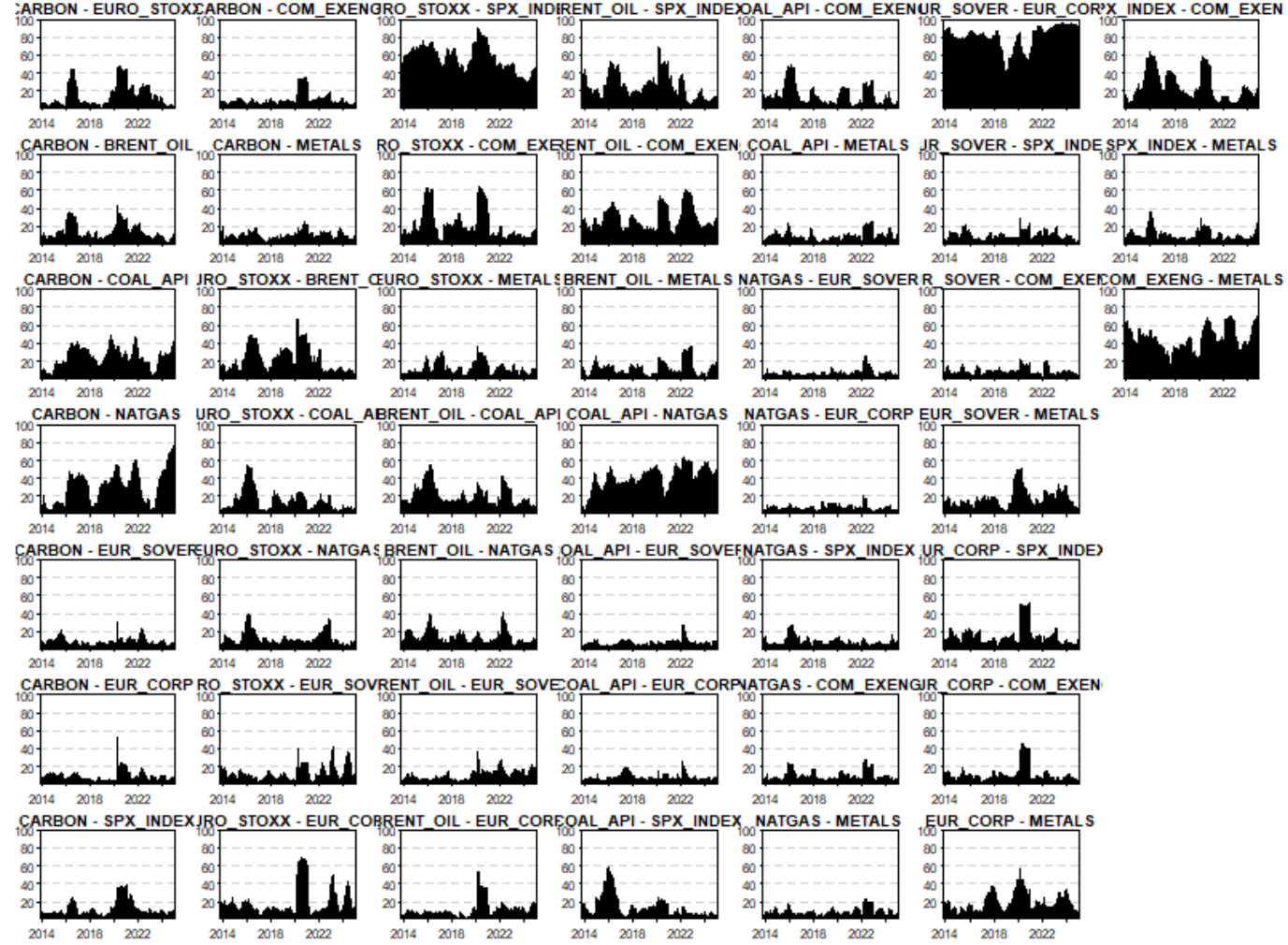
(b) Static Volatility PCI network



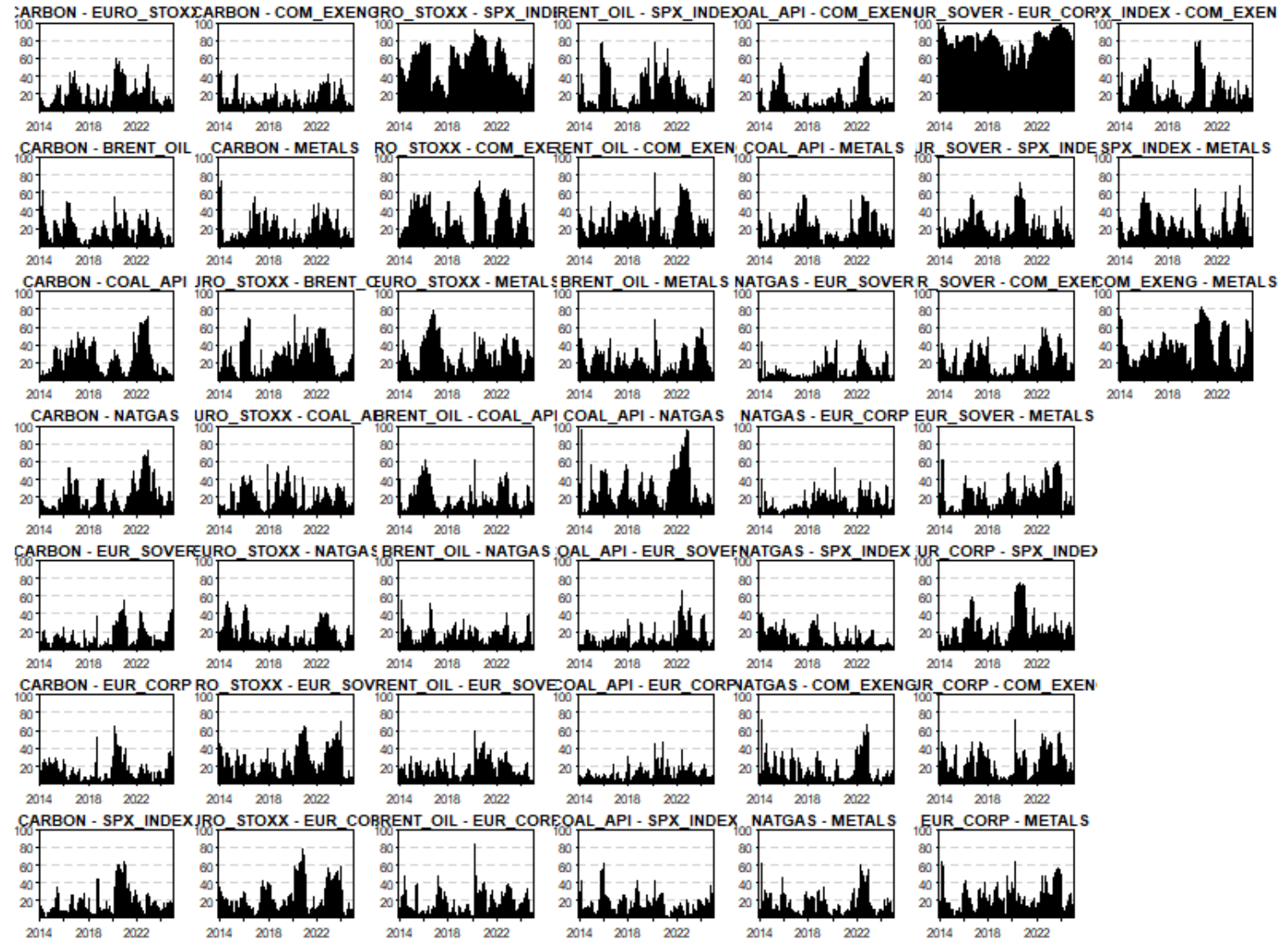
Appendix D.2.4. Dynamic Return and Volatility Pairwise Directional Connectedness

Figure D.8: Dynamic Return and Volatility Pairwise Connectedness Index (Jan 2013 – Jan 2025)

(a) Dynamic return PCI



(b) Dynamic volatility PCI



Appendix D.3. 8-period forecast horizon and a rolling window of 180 observations

Appendix D.3.1. Static Return and Volatility Connectedness Matrix

Table D.4: Static Return and Volatility Connectedness Matrix (Jan 2013 - Jan 2025)

(a) Carbon returns connectedness matrix

	CARBON	EUROSTOXX	BRENTOIL	COALAPI	NATGAS	EUROOVER	EURCORP	SPXINDEX	COMEXENG	METALS	FROM
CARBON	58.73	4.12	3.91	7.88	10.34	2.69	2.43	3.68	2.92	3.3	41.27
EUROSTOXX	3.39	48.68	5.76	3.42	3.3	3.36	3.91	19.61	5.29	3.28	51.32
BRENTOIL	3.7	6.12	56.35	5.5	3.71	2.85	2.46	7.32	8.25	3.74	43.65
COALAPI	6.46	3.9	5.87	54.95	13.64	2.04	2.22	3.99	4.08	2.87	45.05
NATGAS	10.06	3.2	4.03	13.38	57.41	2.03	1.95	2.71	2.77	2.45	42.59
EUROOVER	2.21	3.22	2.9	1.85	1.87	47.39	31.45	2.41	2.25	4.43	52.61
EURCORP	2.16	5.13	2.86	1.94	1.99	30.01	44.76	4.01	2.69	4.47	55.24
SPXINDEX	2.58	17.81	6.93	3.46	2.26	2.47	2.89	52.51	6.38	2.71	47.49
COMEXENG	2.66	5.13	7.45	3.6	2.65	2.37	2.51	6.56	52.2	14.86	47.8
METALS	2.55	3.37	3.34	2.48	2.67	4.89	5.64	3.13	15.99	55.95	44.05
DST(TO)	35.76	51.99	43.06	43.51	42.42	52.71	55.46	53.43	50.61	42.12	471.08
Inc. Own	94.5	100.68	99.41	98.45	99.83	100.1	100.22	105.94	102.81	98.07	cTCI/TCI
NS (NET)	-5.5	0.68	-0.59	-1.55	-0.17	0.1	0.22	5.94	2.81	-1.93	52.34/47.11

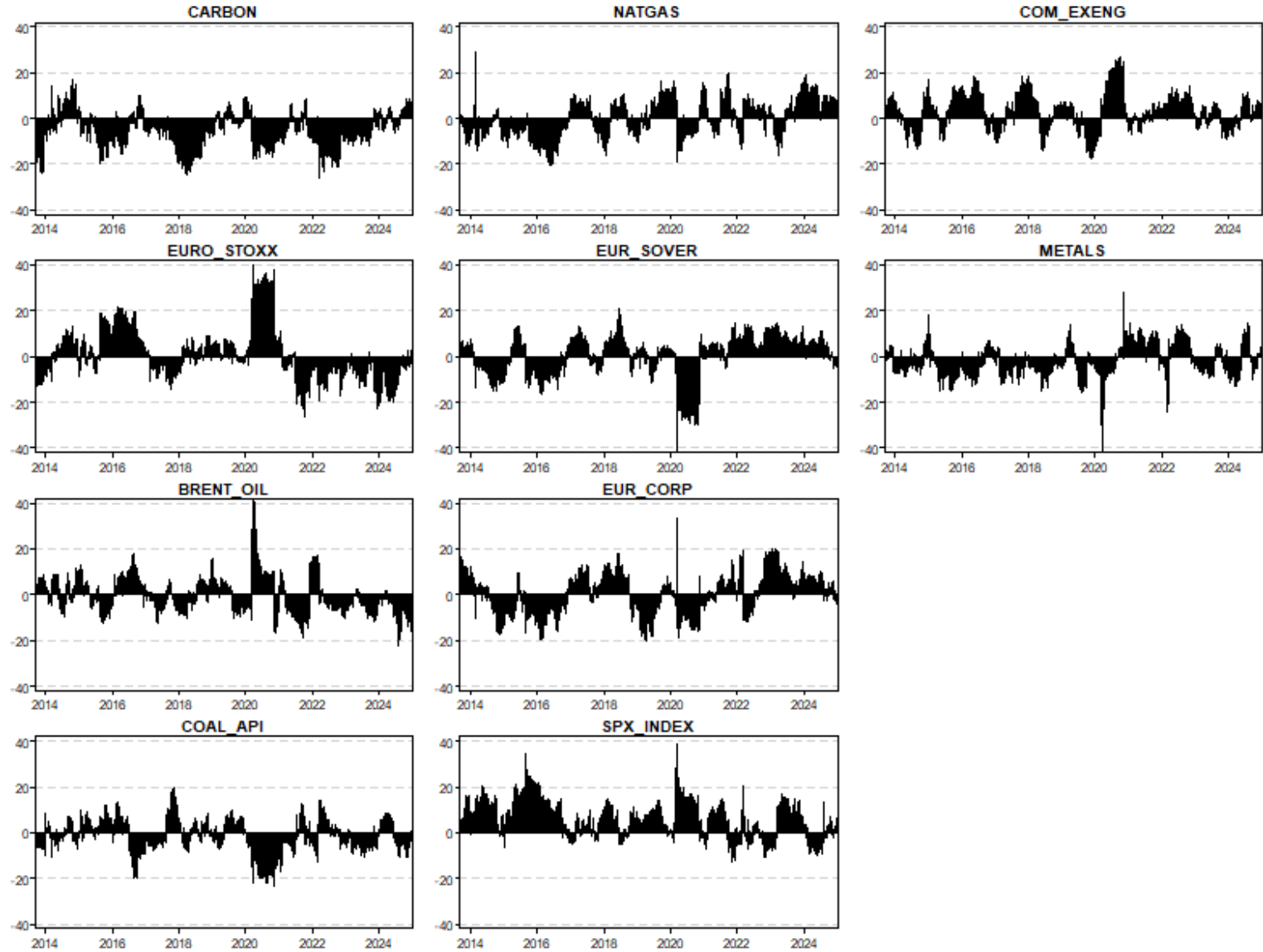
(b) Carbon volatility connectedness matrix

	CARBON	EUROSTOXX	BRENTOIL	COALAPI	NATGAS	EUROOVER	EURCORP	SPXINDEX	COMEXENG	METALS	FROM
CARBON	57.54	4.29	4.24	6.61	7.04	3.68	3.29	4.63	3.58	5.1	42.46
EUROSTOXX	3.64	47.92	5.2	3.73	3.31	5.24	4.1	16.18	4.86	5.81	52.08
BRENTOIL	4.54	6.27	54.13	4.66	3.32	3.65	4.43	6.37	6.68	5.96	45.87
COALAPI	4.31	5.16	4.37	59.14	7.71	3.82	2.8	4.58	3.16	4.95	40.86
NATGAS	4.37	4.61	3.24	7.83	61.1	3.29	3.43	4.7	3.63	3.81	38.9
EUROOVER	2.2	5.98	3.36	2.47	2.19	44.51	25.76	5.33	3.96	4.24	55.49
EURCORP	2.95	5.35	2.3	2.49	2.54	28.14	42.31	5.81	4.68	3.43	57.69
SPXINDEX	3.08	15.12	5.25	2.88	1.77	4.81	4.19	53.9	4.15	4.85	46.1
COMEXENG	2.82	7.63	4.56	4.09	4.03	5.57	5.32	6.51	49.19	10.29	50.81
METALS	3.96	7.74	4.37	3.92	3.82	5.1	6.4	6.17	9.52	49.01	50.99
DST(TO)	31.86	62.14	36.9	38.68	35.72	63.29	59.73	60.27	44.22	48.44	481.25
Inc. Own	89.41	110.06	91.03	97.82	96.83	107.8	102.03	114.17	93.41	97.45	cTCI/TCI
NS (NET)	-10.59	10.06	-8.97	-2.18	-3.17	7.8	2.03	14.17	-6.59	-2.55	53.47/48.12



Figure D.9: Dynamic Net Directional Connectedness (Jan 2013 – Jan 2025)

(a) Dynamic return net directional connectedness





(b) Dynamic volatility net directional connectedness

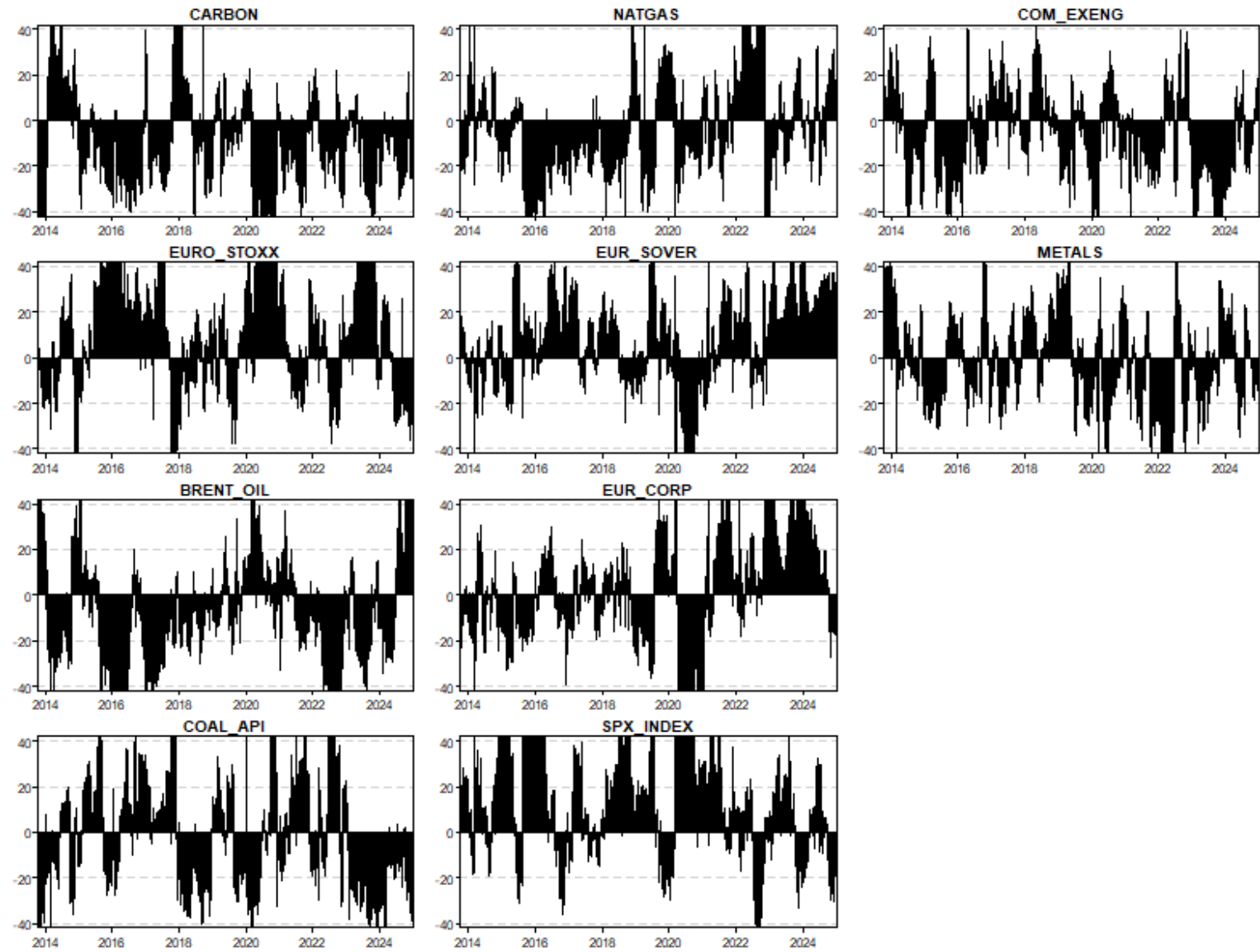
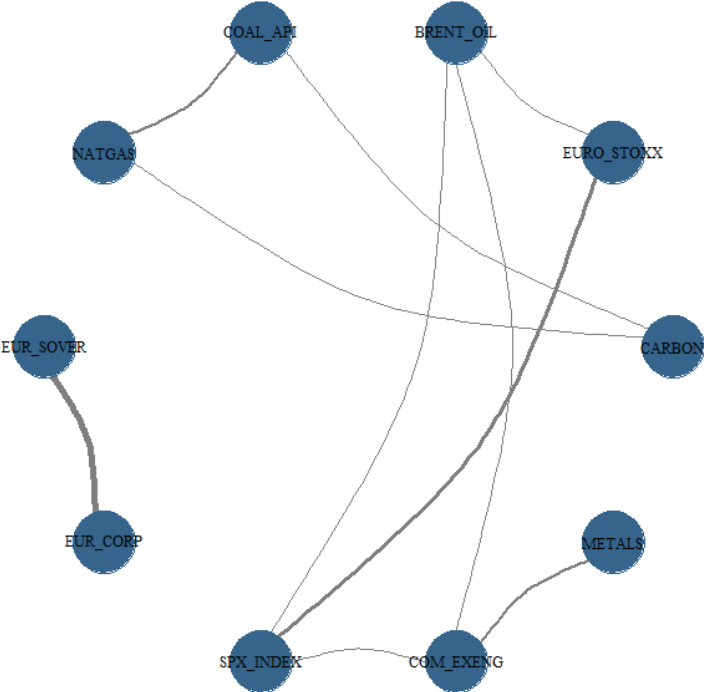
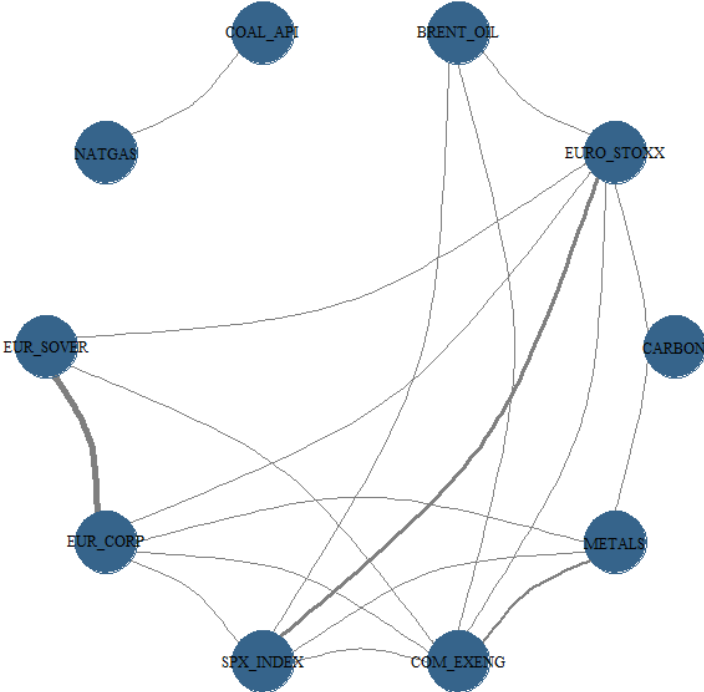


Figure D.10: Network Representation of Pairwise Connectedness Index (Jan 2013 – Jan 2025)

(a) Static Return PCI network



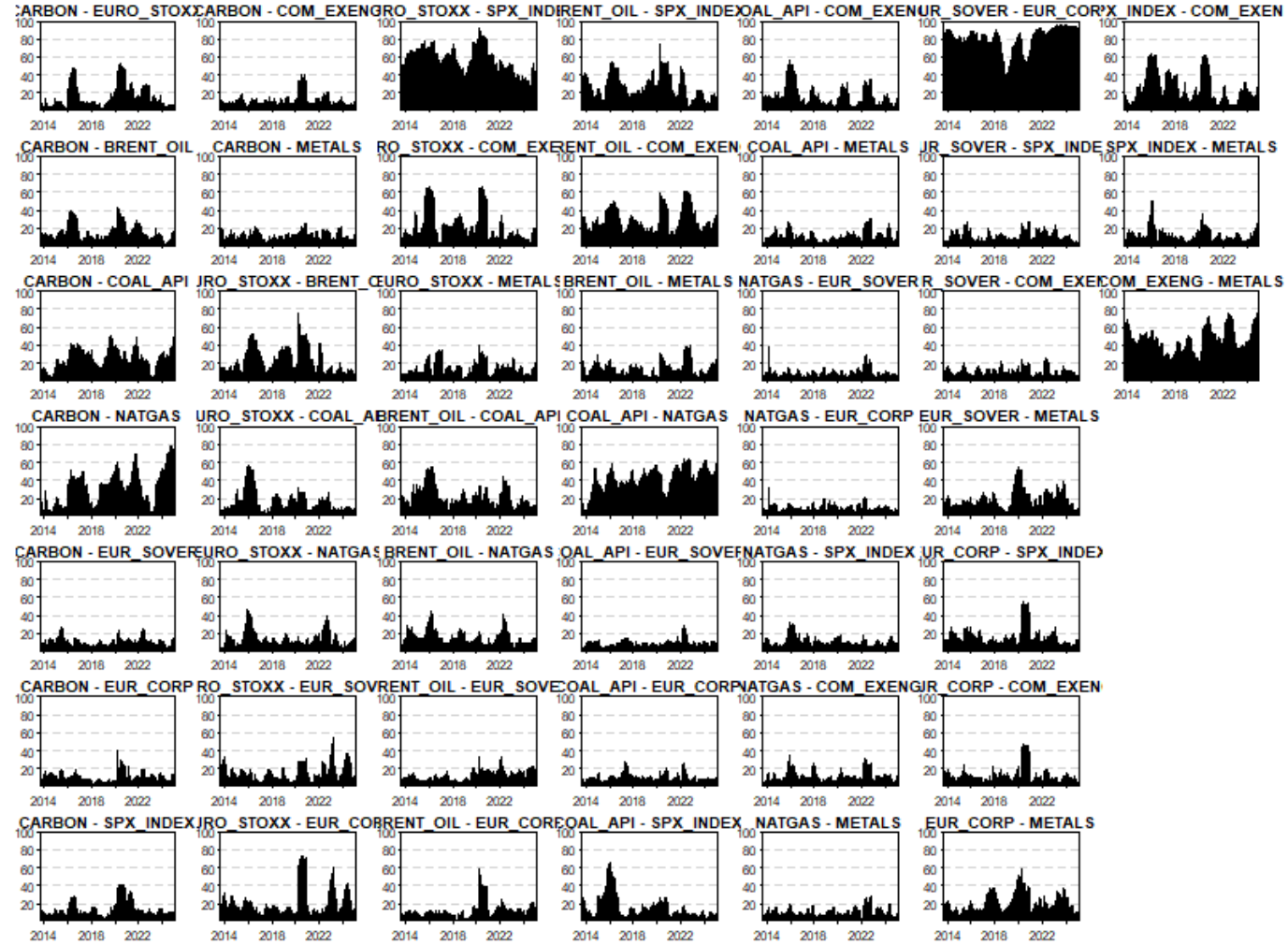
(b) Static Volatility PCI network



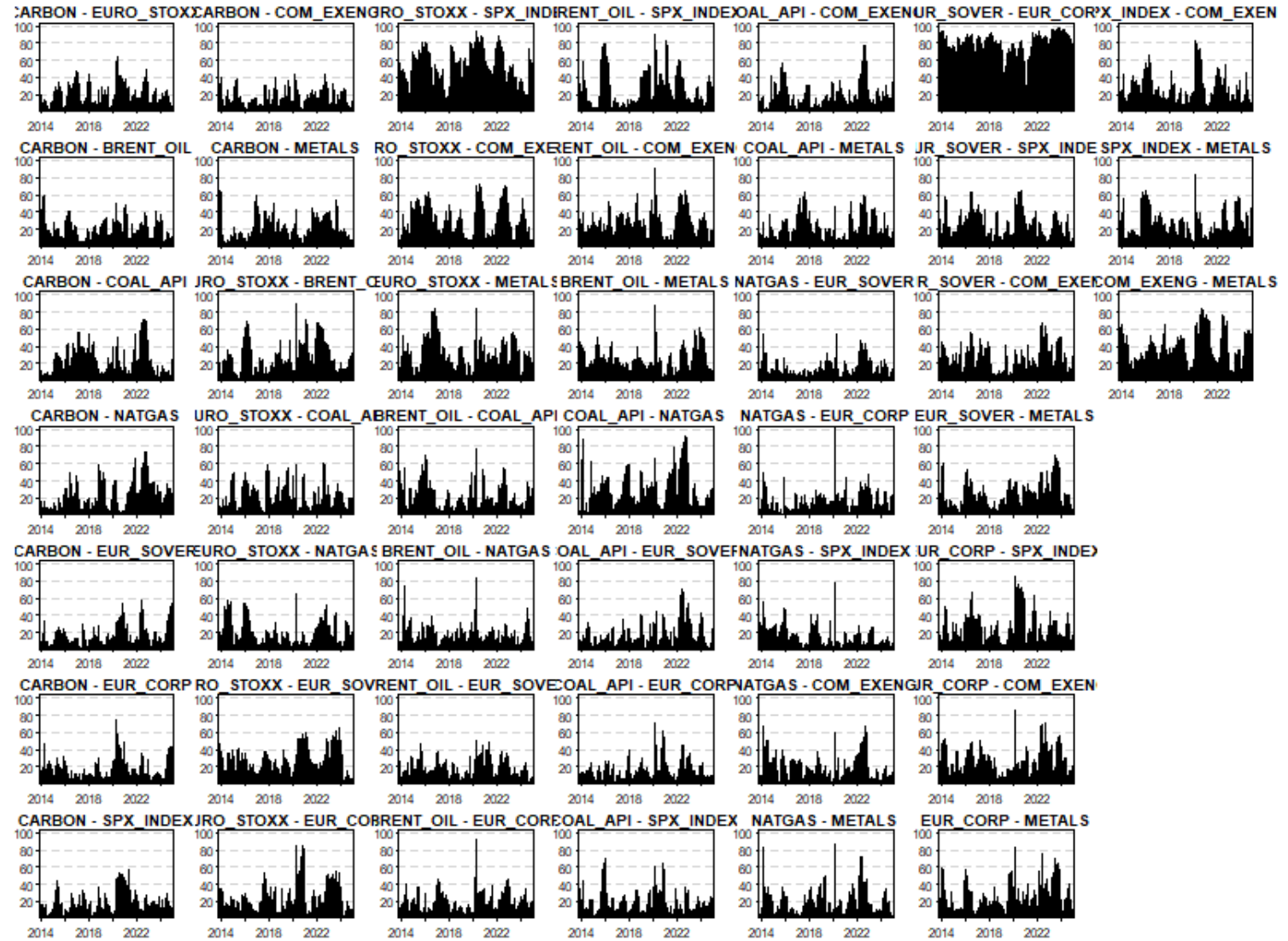
Appendix D.3.4. Dynamic Return and Volatility Pairwise Directional Connectedness

Figure D.11: Dynamic Return and Volatility Pairwise Connectedness Index (Jan 2013 – Jan 2025)

(a) Dynamic return PCI



(b) Dynamic volatility PCI



Appendix D.4. 8-period forecast horizon and a rolling window of 200 observations

Appendix D.4.1. Static Return and Volatility Connectedness Matrix

Table D.5: Static Return and Volatility Connectedness Matrix (Jan 2013 - Jan 2025)

(a) Carbon returns connectedness matrix

	CARBON	EUROSTOXX	BRENT OIL	COAL API	NAT GAS	EURO OVER	EURO CORP	SPX INDEX	COMEX ENG	METALS	FROM
CARBON	60.33	3.99	3.77	7.83	10.23	2.42	2.21	3.44	2.72	3.05	39.67
EUROSTOXX	3.26	49.92	5.7	3.3	3.08	3.01	3.64	19.93	5.19	2.98	50.08
BRENT OIL	3.47	5.98	57.62	5.41	3.57	2.65	2.3	7.25	8.28	3.46	42.38
COAL API	6.33	3.75	5.78	56.18	13.78	1.83	2.01	3.82	3.94	2.59	43.82
NAT GAS	9.94	3	3.86	13.6	58.93	1.78	1.72	2.44	2.52	2.21	41.07
EURO OVER	1.99	2.97	2.64	1.64	1.63	48.54	32.01	2.25	2	4.33	51.46
EURO CORP	1.94	5.03	2.68	1.71	1.75	30.44	45.63	3.94	2.53	4.33	54.37
SPX INDEX	2.38	17.98	6.82	3.32	2	2.25	2.7	53.68	6.39	2.47	46.32
COMEX ENG	2.47	5.04	7.42	3.46	2.38	2.12	2.33	6.56	53.26	14.96	46.74
METALS	2.34	3.1	3.07	2.25	2.42	4.81	5.56	2.9	16.18	57.37	42.63
DST(TO)	34.12	50.84	41.75	42.53	40.82	51.31	54.49	52.53	49.76	40.39	458.54
Inc. Own	94.45	100.75	99.37	98.71	99.76	99.85	100.12	106.21	103.02	97.76	cTCI/TCI
NS (NET)	-5.55	0.75	-0.63	-1.29	-0.24	-0.15	0.12	6.21	3.02	-2.24	50.95/45.85

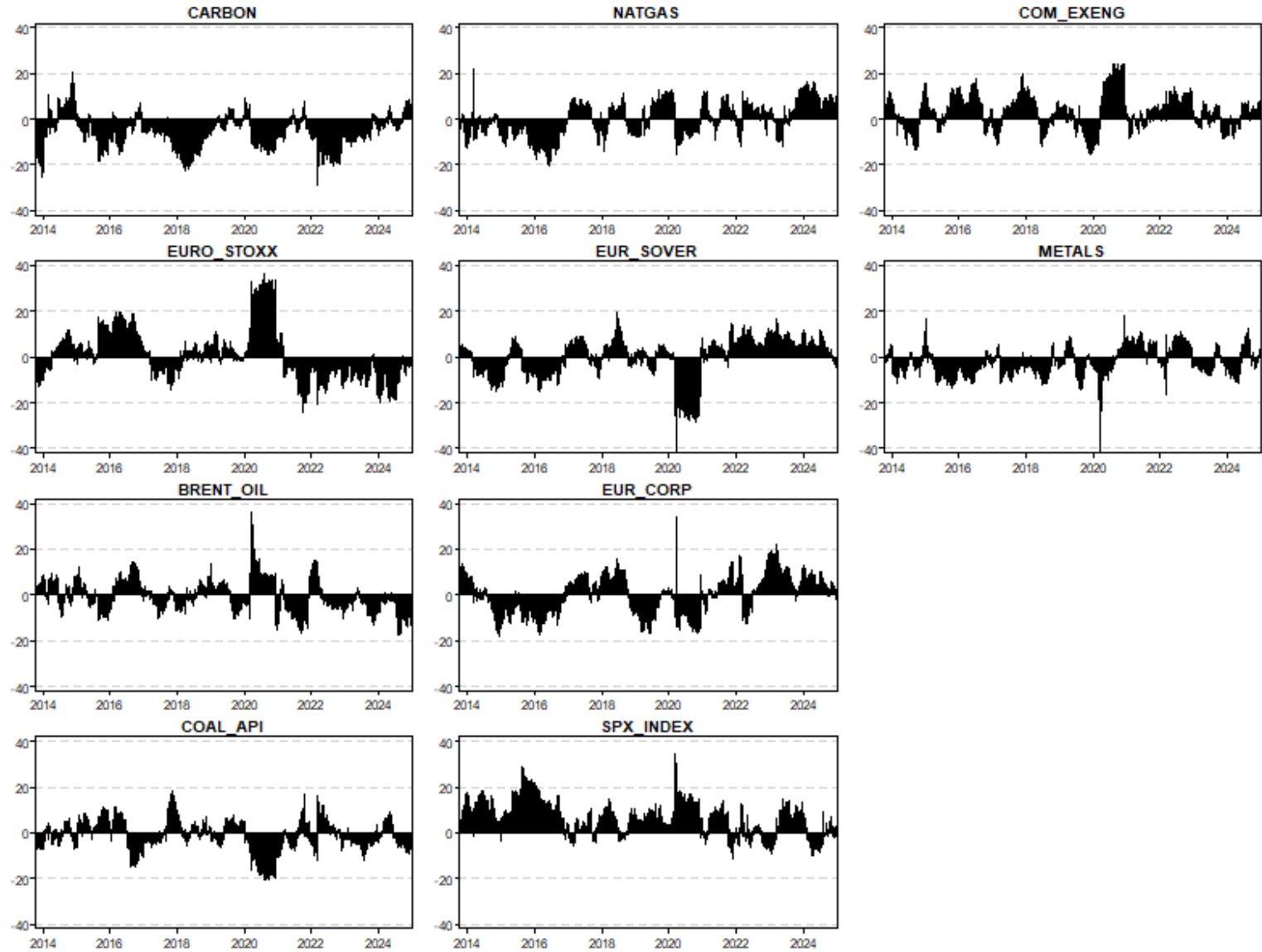
(b) Carbon volatility connectedness matrix

	CARBON	EUROSTOXX	BRENT OIL	COAL API	NAT GAS	EURO OVER	EURO CORP	SPX INDEX	COMEX ENG	METALS	FROM
CARBON	60.17	4.17	3.78	6.68	6.57	3.32	3.11	4.33	3.26	4.61	39.83
EUROSTOXX	3.29	49.69	5.1	3.09	2.94	4.86	3.93	16.76	4.8	5.55	50.31
BRENT OIL	4.03	6.12	56.72	4.48	3.04	3.25	4.01	6.11	6.72	5.54	43.28
COAL API	4.14	4.95	3.92	62.24	7.35	3.39	2.39	4.07	2.83	4.7	37.76
NAT GAS	4.18	4.25	2.96	7.77	63.79	2.87	3.22	4.26	3.21	3.49	36.21
EURO OVER	1.94	5.82	3.08	2.1	1.74	46.3	26.28	5.1	3.44	4.21	53.7
EURO CORP	2.58	5.27	2.19	2.05	2.04	28.8	44.04	5.7	4.16	3.17	55.96
SPX INDEX	2.84	15.41	4.97	2.56	1.49	4.35	3.82	56.19	3.92	4.45	43.81
COMEX ENG	2.32	7.68	4.52	3.73	3.57	4.87	4.97	6.12	51.84	10.37	48.16
METALS	3.62	7.62	4.07	3.51	3.33	4.94	5.95	5.62	9.94	51.42	48.58
DST(TO)	28.93	61.29	34.59	35.97	32.07	60.65	57.69	58.07	42.27	46.09	457.61
Inc. Own	89.1	110.98	91.3	98.21	95.85	106.95	101.73	114.26	94.11	97.51	cTCI/TCI
NS (NET)	-10.9	10.98	-8.7	-1.79	-4.15	6.95	1.73	14.26	-5.89	-2.49	50.85/45.76



Figure D.12: Dynamic Net Directional Connectedness (Jan 2013 – Jan 2025)

(a) Dynamic return net directional connectedness



(b) Dynamic volatility net directional connectedness

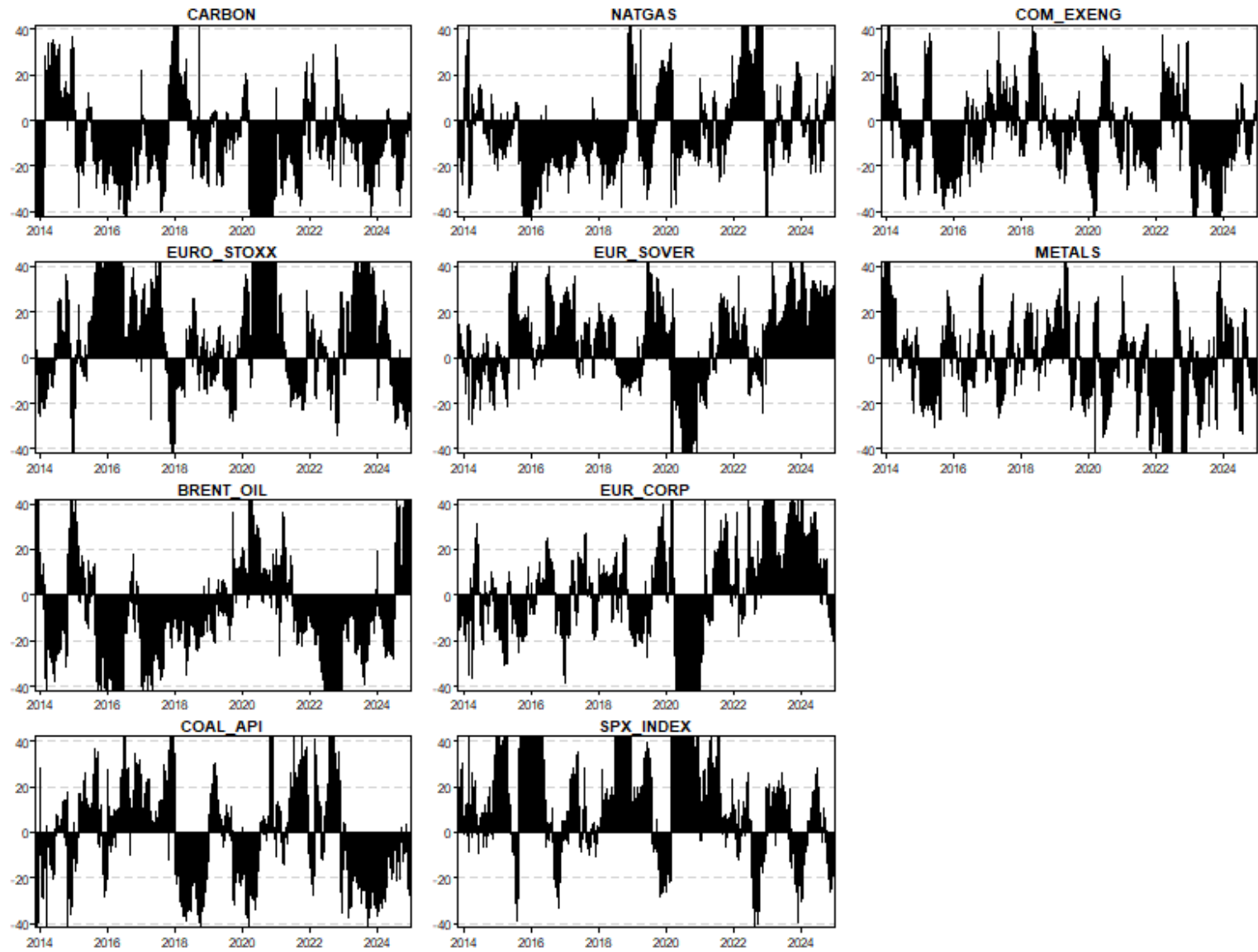
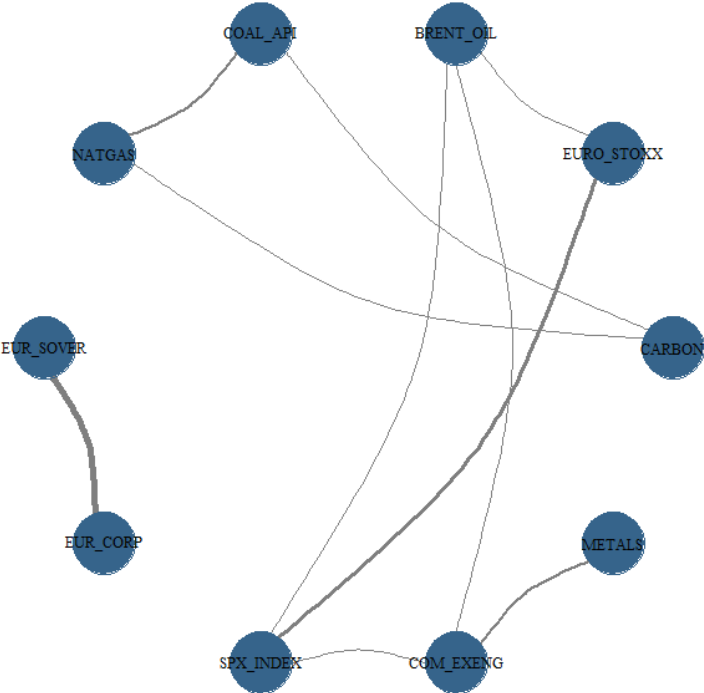


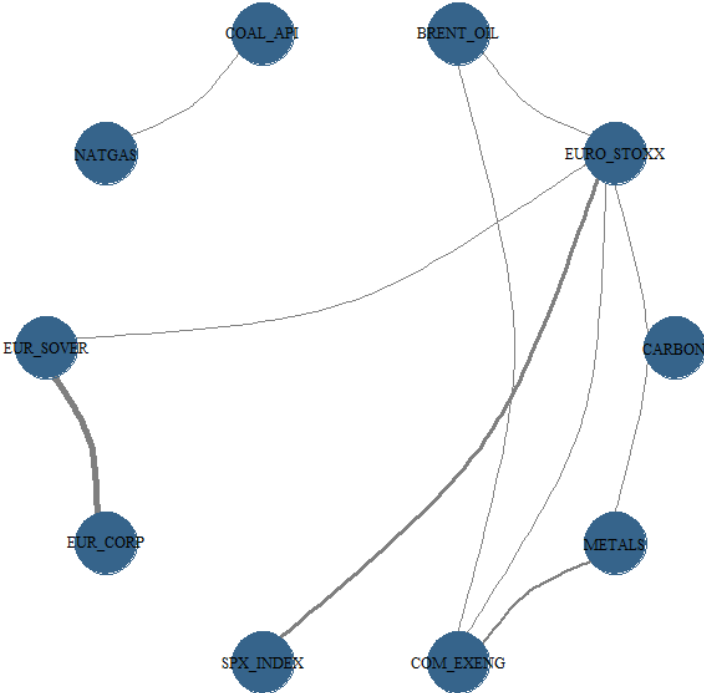


Figure D.13: Network Representation of Pairwise Connectedness Index (Jan 2013 – Jan 2025)

(a) Static Return PCI network



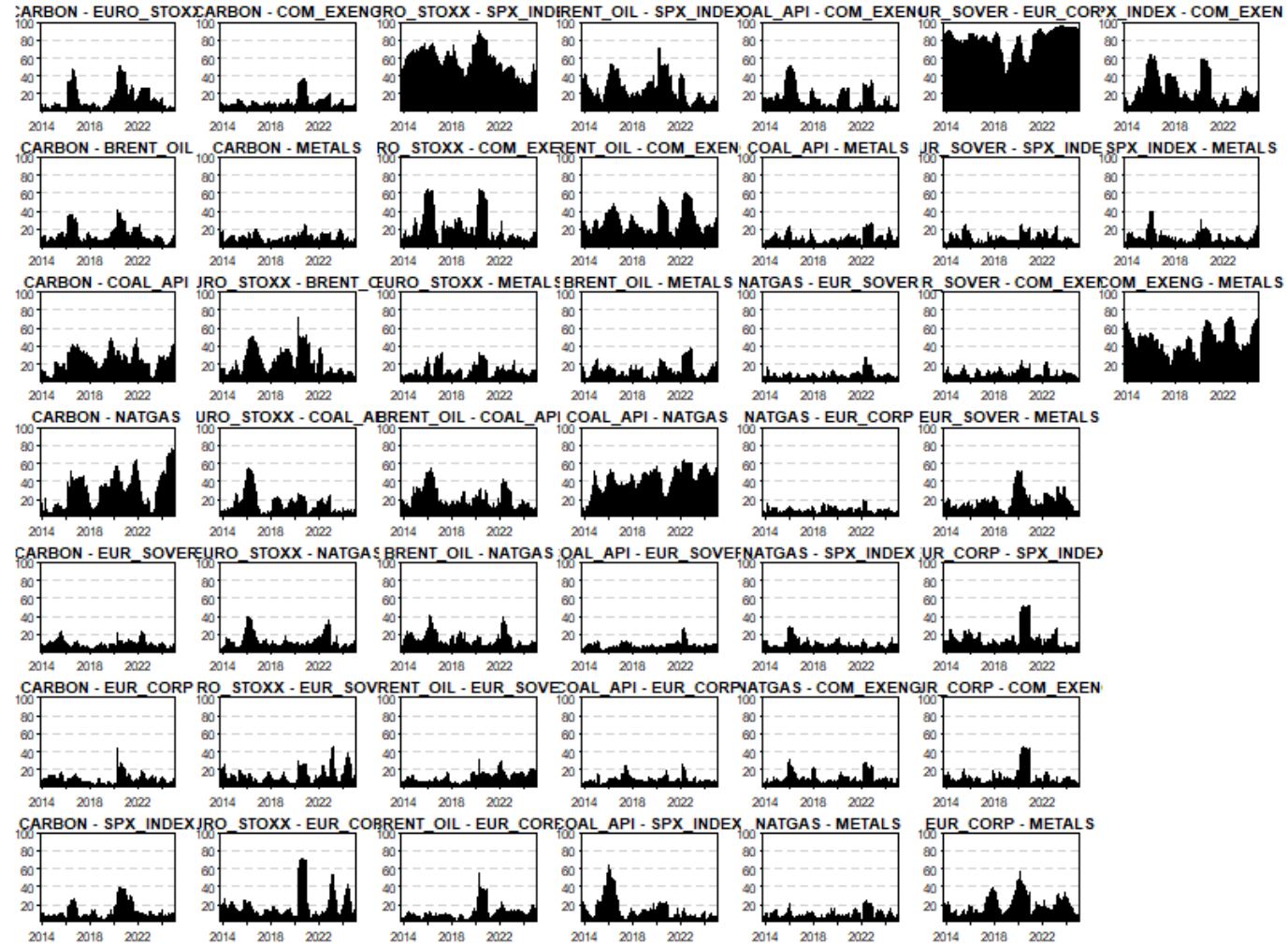
(b) Static Volatility PCI network



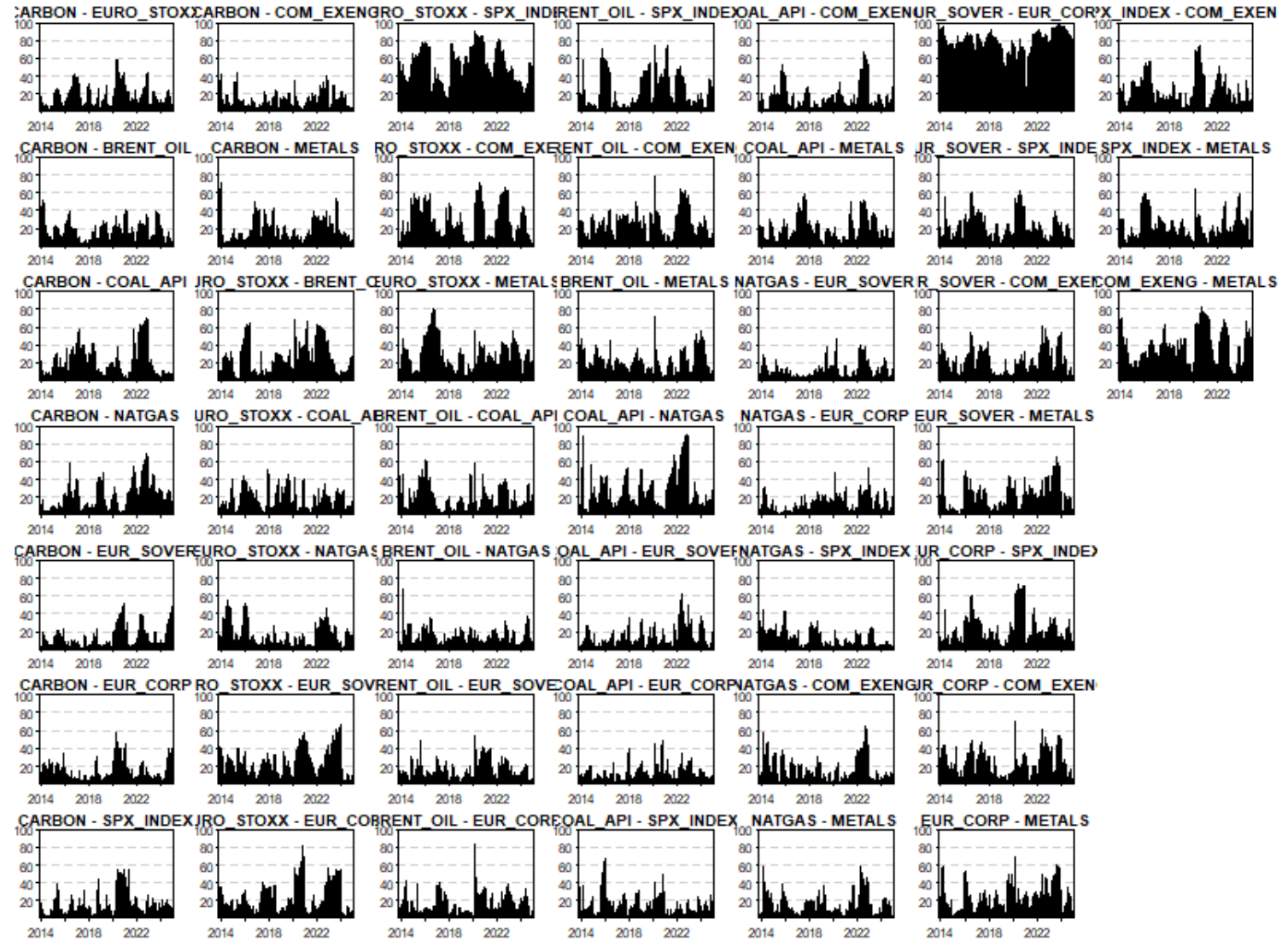
Appendix D.4.4. Dynamic Return and Volatility Pairwise Directional Connectedness

Figure D.14: Dynamic Return and Volatility Pairwise Connectedness Index (Jan 2013 – Jan 2025)

(a) Dynamic return PCI



(b) Dynamic volatility PCI



Appendix D.5. 8-period forecast horizon and a rolling window of 220 observations

Appendix D.5.1. Static Return and Volatility Connectedness Matrix

Table D.6: Static Return and Volatility Connectedness Matrix (Jan 2013 - Jan 2025)

(a) Carbon returns connectedness matrix

	CARBON	EUROSTOXX	BRENTOIL	COALAPI	NATGAS	EUROOVER	EURCORP	SPXINDEX	COMEXENG	METALS	FROM
CARBON	61.59	3.93	3.64	7.76	10.08	2.24	2.07	3.26	2.57	2.86	38.41
EUROSTOXX	3.15	50.93	5.67	3.2	2.9	2.71	3.41	20.17	5.13	2.73	49.07
BRENTOIL	3.3	5.9	58.62	5.37	3.45	2.48	2.19	7.17	8.31	3.22	41.38
COALAPI	6.2	3.63	5.73	57.17	13.87	1.69	1.86	3.68	3.8	2.36	42.83
NATGAS	9.8	2.83	3.73	13.77	60.14	1.6	1.57	2.19	2.34	2.03	39.86
EUROOVER	1.83	2.76	2.44	1.47	1.43	49.48	32.44	2.12	1.8	4.23	50.52
EURCORP	1.81	4.98	2.57	1.53	1.55	30.74	46.27	3.9	2.43	4.21	53.73
SPXINDEX	2.22	18.15	6.71	3.18	1.78	2.07	2.56	54.62	6.44	2.26	45.38
COMEXENG	2.31	4.99	7.41	3.32	2.15	1.93	2.17	6.6	54.09	15.02	45.91
METALS	2.19	2.85	2.84	2.05	2.2	4.76	5.48	2.69	16.34	58.6	41.4
DST(TO)	32.81	50.03	40.74	41.65	39.42	50.23	53.75	51.77	49.15	38.94	448.48
Inc. Own	94.4	100.96	99.36	98.83	99.56	99.71	100.02	106.39	103.24	97.54	cTCI/TCI
NS (NET)	-5.6	0.96	-0.64	-1.17	-0.44	-0.29	0.02	6.39	3.24	-2.46	49.83/44.85

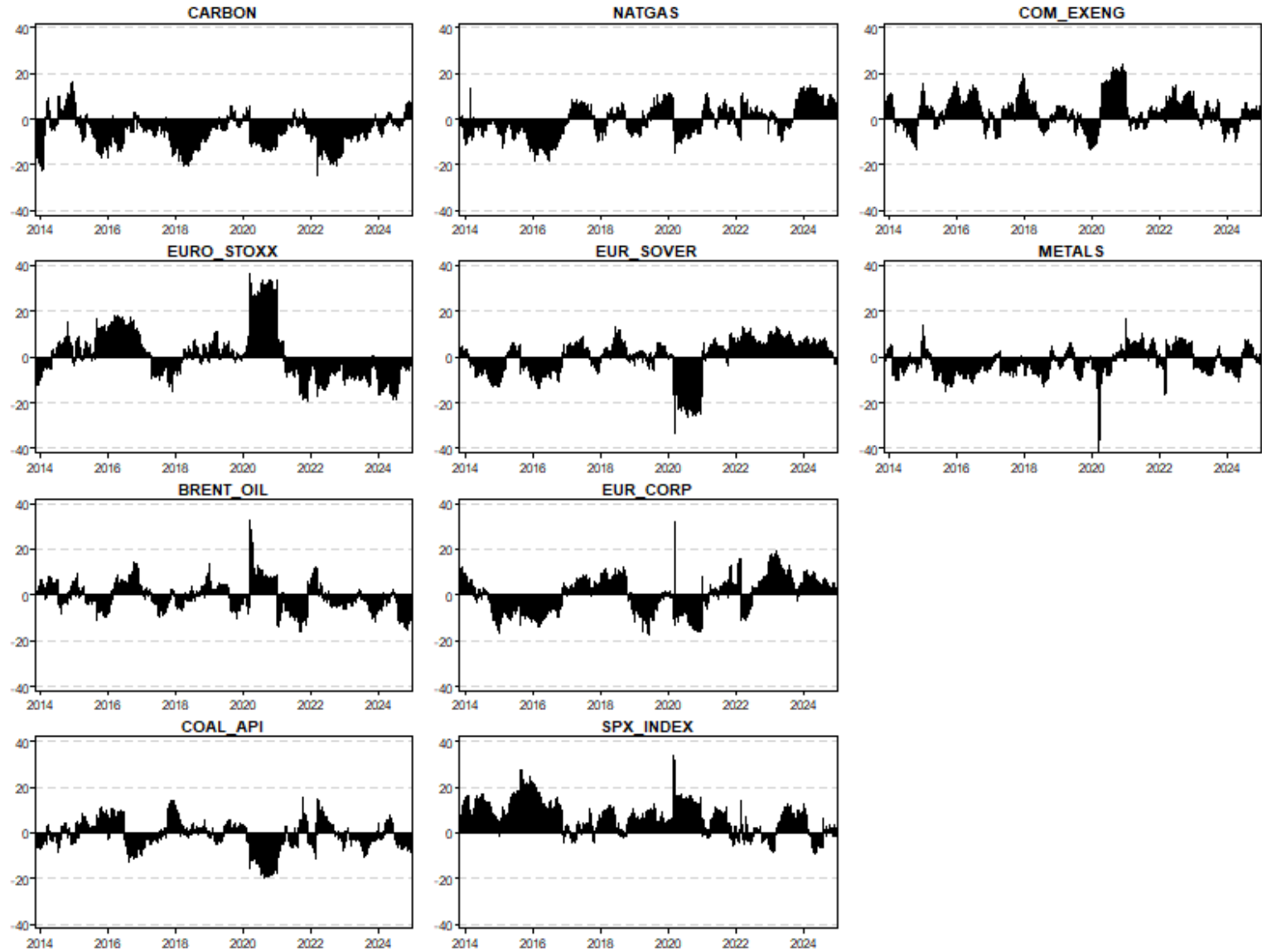
(b) Carbon volatility connectedness matrix

	CARBON	EUROSTOXX	BRENTOIL	COALAPI	NATGAS	EUROOVER	EURCORP	SPXINDEX	COMEXENG	METALS	FROM
CARBON	62.2	4.14	3.49	6.68	6.23	3.06	2.83	4.04	3.14	4.2	37.8
EUROSTOXX	2.95	50.86	4.93	2.73	2.66	4.69	3.87	17.15	4.84	5.33	49.14
BRENTOIL	3.56	6.04	58.65	4.31	2.84	2.92	3.59	5.91	6.93	5.24	41.35
COALAPI	4.12	4.62	3.28	64.8	7	3.13	2.22	3.66	2.66	4.52	35.2
NATGAS	4.07	3.96	2.61	7.59	66.13	2.57	3.05	3.93	2.92	3.16	33.87
EUROOVER	1.71	5.66	2.88	1.82	1.5	47.64	26.63	4.99	3.08	4.09	52.36
EURCORP	2.3	5.25	2.14	1.71	1.66	29.27	45.3	5.68	3.66	3.02	54.7
SPXINDEX	2.61	15.47	4.61	2.36	1.32	4.01	3.62	58.11	3.72	4.17	41.89
COMEXENG	1.91	7.65	4.54	3.52	3.19	4.42	4.56	5.92	53.86	10.43	46.14
METALS	3.41	7.37	3.76	3.24	2.95	4.79	5.5	5.17	10.24	53.57	46.43
DST(TO)	26.64	60.17	32.23	33.96	29.35	58.88	55.87	56.45	41.18	44.17	438.89
Inc. Own	88.84	111.02	90.88	98.75	95.49	106.52	101.17	114.56	95.04	97.73	cTCI/TCI
NS (NET)	-11.16	11.02	-9.12	-1.25	-4.51	6.52	1.17	14.56	-4.96	-2.27	48.77/43.89



Figure D.15: Dynamic Net Directional Connectedness (Jan 2013 – Jan 2025)

(a) Dynamic return net directional connectedness



(b) Dynamic volatility net directional connectedness

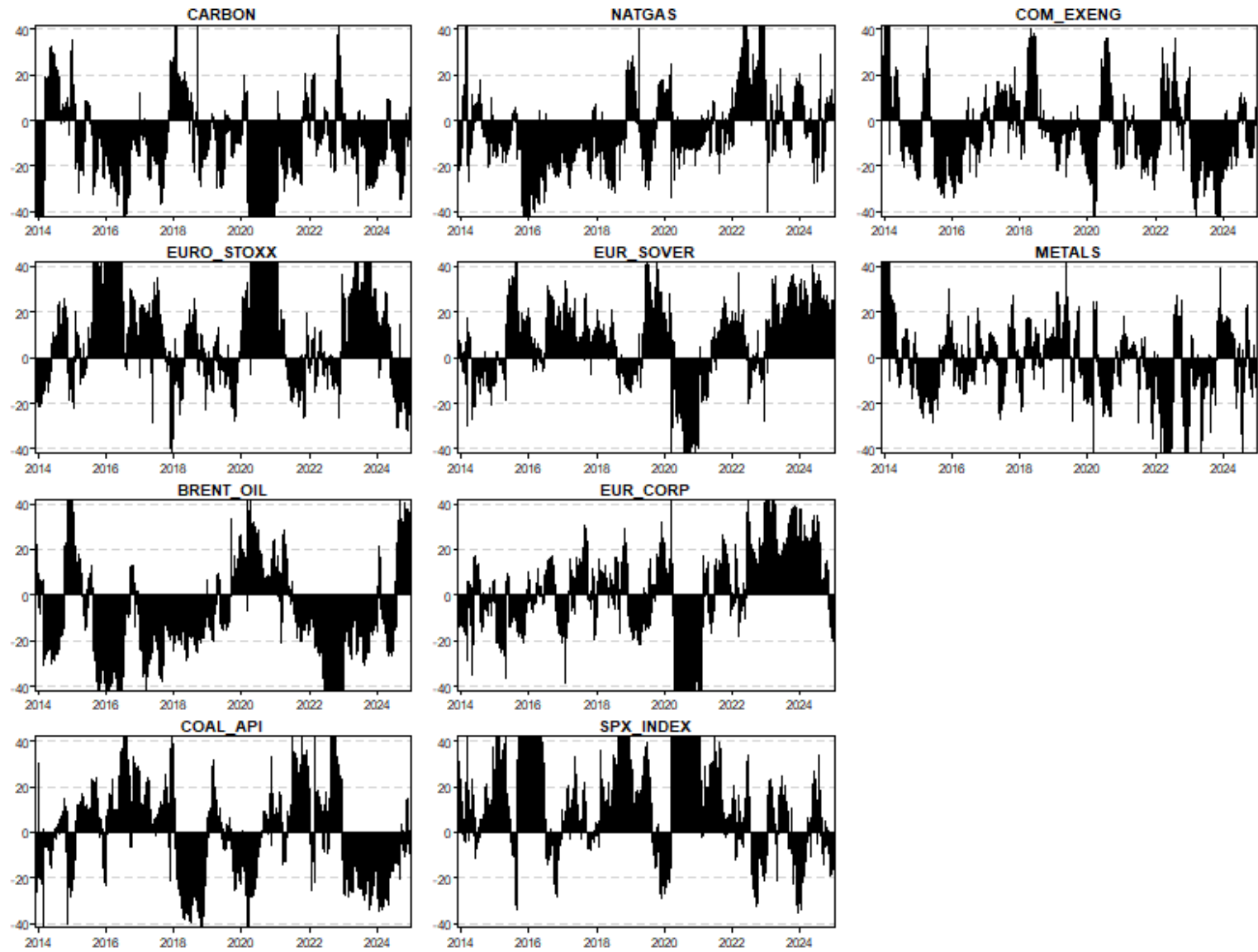
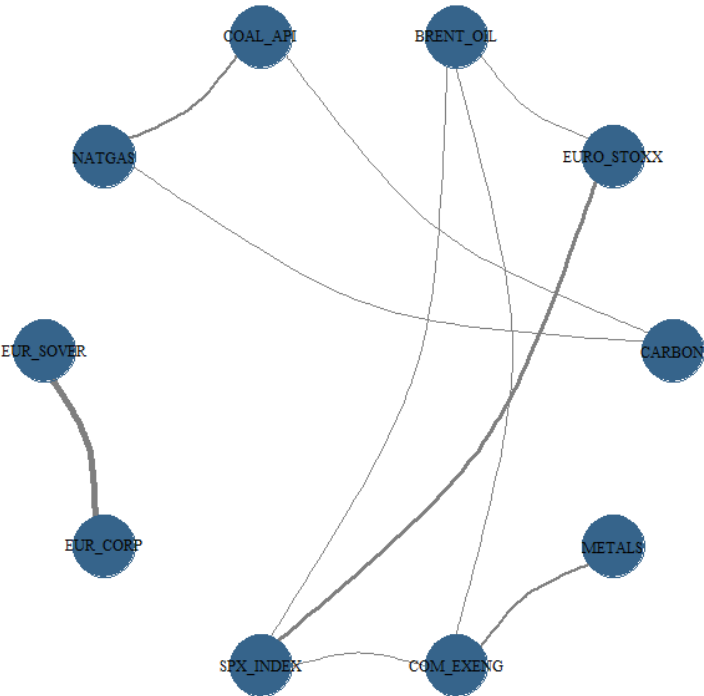
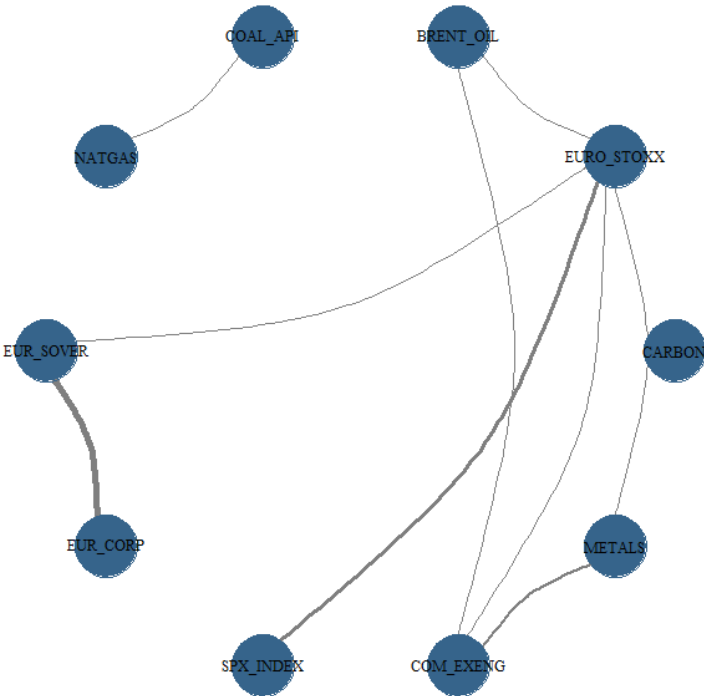


Figure D.16: Network Representation of Pairwise Connectedness Index (Jan 2013 – Jan 2025)

(a) Static Return PCI network



(b) Static Volatility PCI network

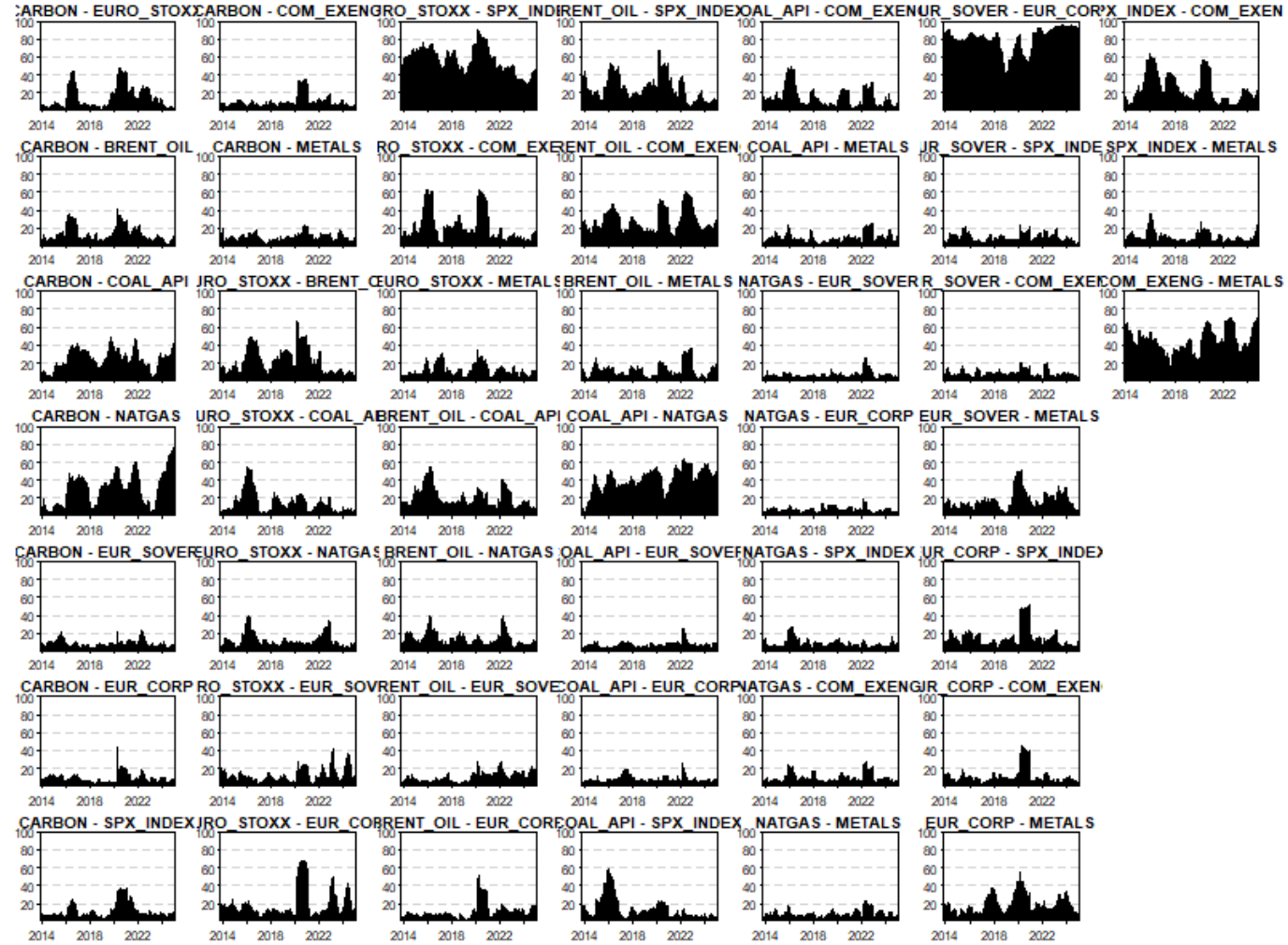




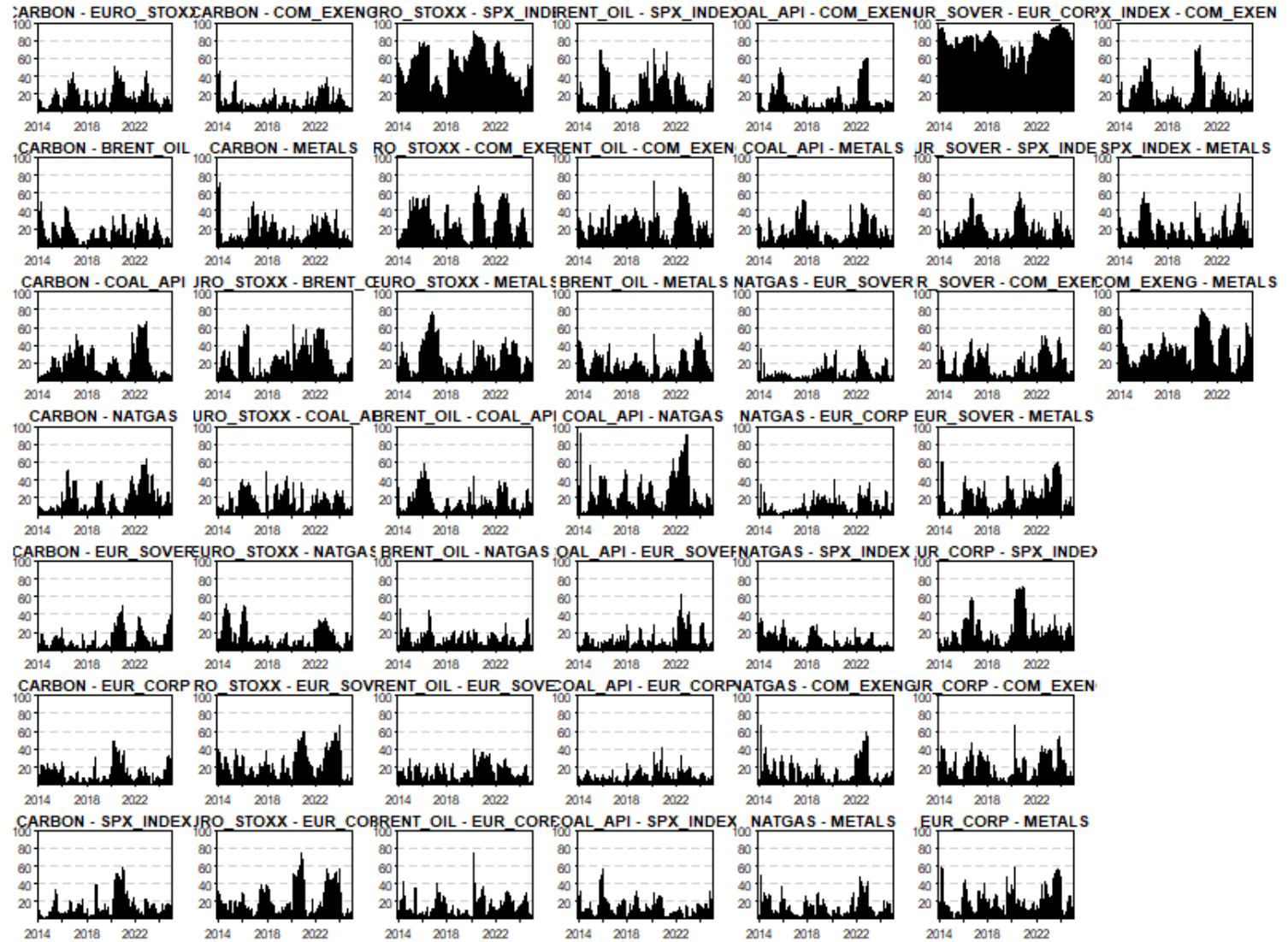
Appendix D.5.4. Dynamic Return and Volatility Pairwise Directional Connectedness

Figure D.17: Dynamic Return and Volatility Pairwise Connectedness Index (Jan 2013 – Jan 2025)

(a) Dynamic return PCI



(b) Dynamic volatility PCI



Appendix D.6. 12-period forecast horizon and a rolling window of 180 observations

Appendix D.6.1. Static Return and Volatility Connectedness Matrix

Table D.7: Static Return and Volatility Connectedness Matrix (Jan 2013 - Jan 2025)

(a) Carbon returns connectedness matrix

	CARBON	EUROSTOXX	BRENTOIL	COALAPI	NATGAS	EUROVER	EURCORP	SPXINDEX	COMEXENG	METALS	FROM
CARBON	58.33	4.13	3.97	7.9	10.32	2.77	2.5	3.72	2.98	3.39	41.67
EUROSTOXX	3.43	48.44	5.78	3.45	3.36	3.41	3.95	19.53	5.31	3.33	51.56
BRENTOIL	3.74	6.15	55.99	5.54	3.77	2.9	2.52	7.35	8.26	3.79	44.01
COALAPI	6.48	3.93	5.89	54.66	13.62	2.09	2.26	4.03	4.12	2.93	45.34
NATGAS	10.05	3.25	4.07	13.36	57.07	2.08	2.01	2.78	2.84	2.5	42.93
EUROVER	2.27	3.27	2.96	1.9	1.95	47.08	31.3	2.47	2.32	4.48	52.92
EURCORP	2.19	5.15	2.91	1.99	2.07	29.9	44.54	4.04	2.71	4.5	55.46
SPXINDEX	2.63	17.76	6.94	3.51	2.3	2.54	2.93	52.24	6.4	2.76	47.76
COMEXENG	2.69	5.18	7.48	3.64	2.69	2.43	2.57	6.6	51.91	14.81	48.09
METALS	2.58	3.45	3.41	2.53	2.74	4.92	5.68	3.22	15.92	55.54	44.46
DST(TO)	36.06	52.28	43.39	43.82	42.82	53.03	55.73	53.74	50.85	42.49	474.2
Inc. Own	94.39	100.72	99.38	98.47	99.89	100.11	100.27	105.98	102.76	98.03	cTCI/TCI
NS (NET)	-5.61	0.72	-0.62	-1.53	-0.11	0.11	0.27	5.98	2.76	-1.97	52.69/47.42

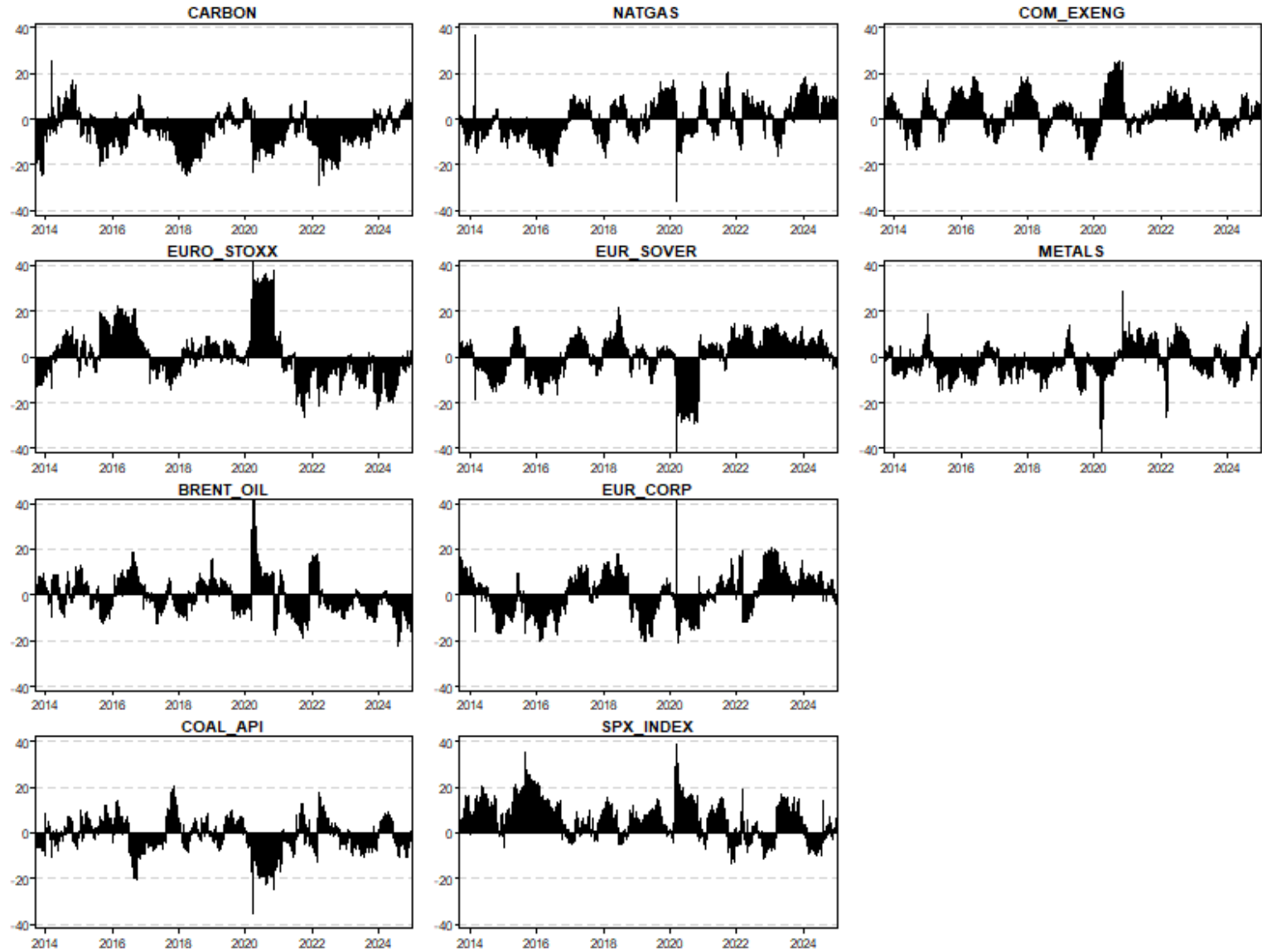
(b) Carbon volatility connectedness matrix

	CARBON	EUROSTOXX	BRENTOIL	COALAPI	NATGAS	EUROVER	EURCORP	SPXINDEX	COMEXENG	METALS	FROM
CARBON	49.07	5.05	5.04	7.53	8.1	4.71	4.25	6.24	4.55	5.47	50.93
EUROSTOXX	4.34	42.48	5.5	4.66	4.47	5.91	4.68	15.49	5.76	6.72	57.52
BRENTOIL	4.91	7.05	46.16	5.52	4.3	4.89	5.5	7.04	7.5	7.13	53.84
COALAPI	5.42	6.83	4.96	50.79	8.67	4.61	3.48	5.51	3.82	5.91	49.21
NATGAS	5.12	5.38	4.23	8.78	52.69	4.47	4.44	5.78	4.38	4.72	47.31
EUROVER	2.74	6.84	3.83	3.16	2.59	41.18	23.89	6.2	4.83	4.75	58.82
EURCORP	3.51	6.06	2.89	3.07	3.37	26.97	38.08	6.43	5.71	3.9	61.92
SPXINDEX	4	14.79	5.55	3.89	2.41	5.65	4.67	47.45	5.22	6.37	52.55
COMEXENG	3.54	8.03	4.9	4.53	4.92	6.48	6.13	7.47	44.23	9.77	55.77
METALS	4.45	8.84	5.11	4.64	4.75	5.52	7.13	7.41	9.82	42.32	57.68
DST(TO)	38.03	68.87	42.02	45.78	43.58	69.22	64.17	67.57	51.57	54.74	545.55
Inc. Own	87.1	111.35	88.18	96.57	96.27	110.4	102.26	115.01	95.8	97.06	cTCI/TCI
NS (NET)	-12.9	11.35	-11.82	-3.43	-3.73	10.4	2.26	15.01	-4.2	-2.94	60.62/54.55



Figure D.18: Dynamic Net Directional Connectedness (Jan 2013 – Jan 2025)

(a) Dynamic return net directional connectedness



(b) Dynamic volatility net directional connectedness

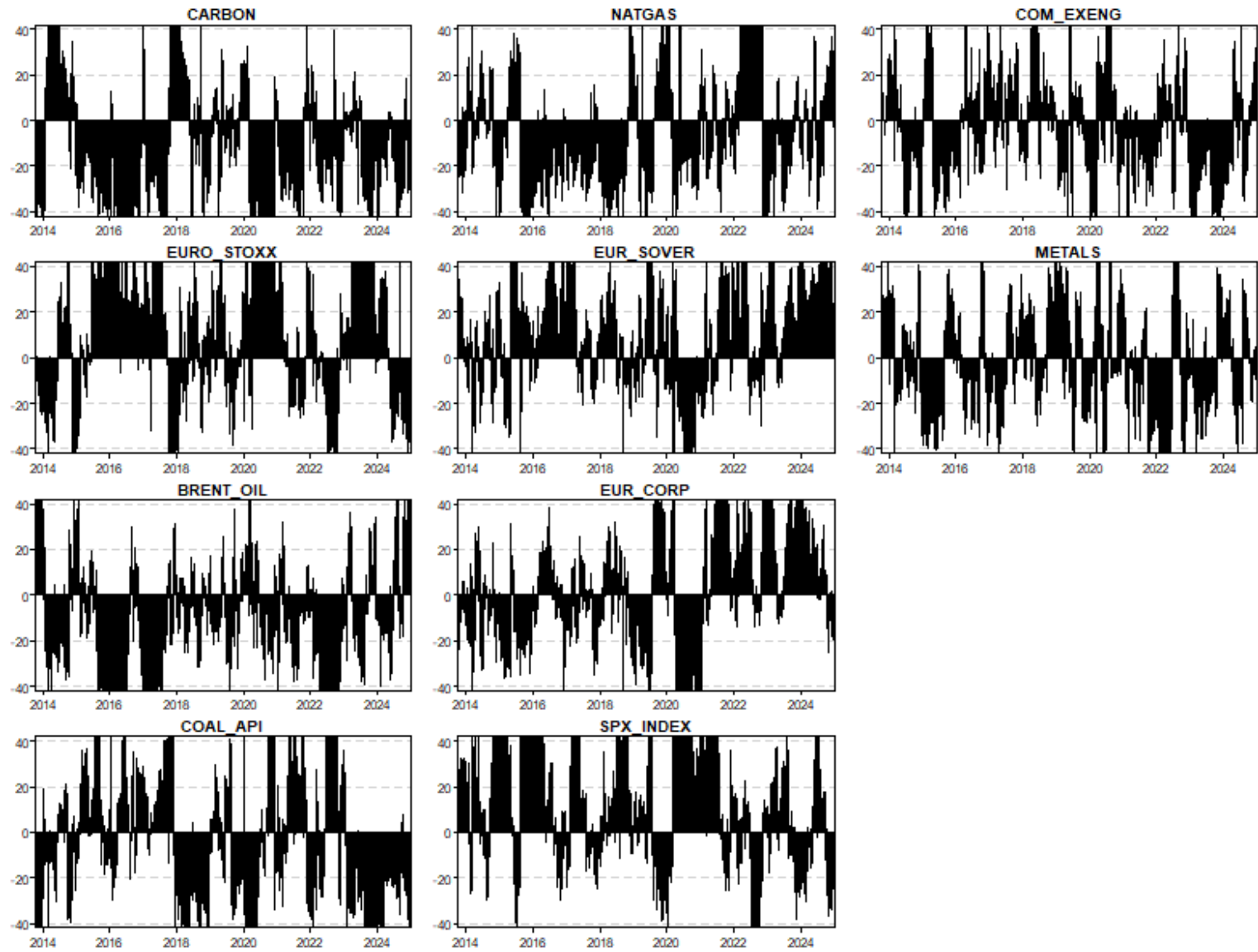
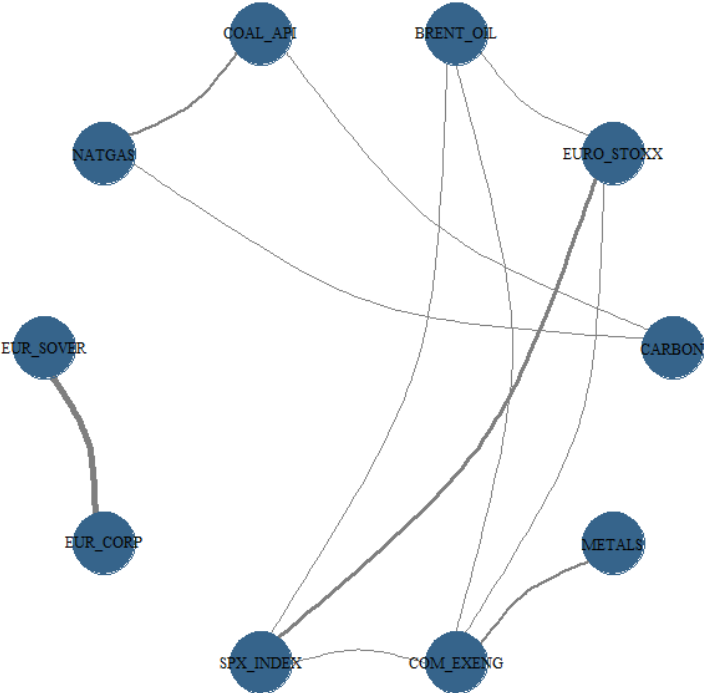
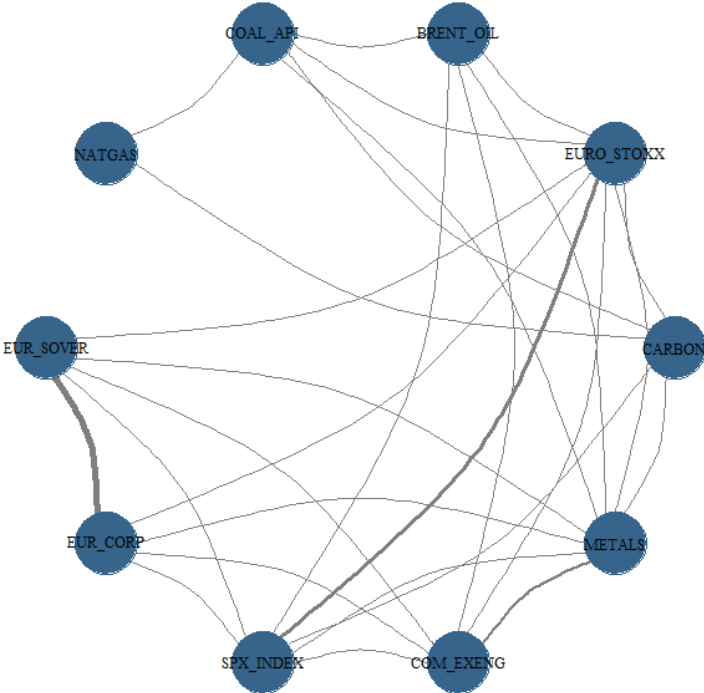


Figure D.19: Network Representation of Pairwise Connectedness Index (Jan 2013 – Jan 2025)

(a) Static Return PCI network



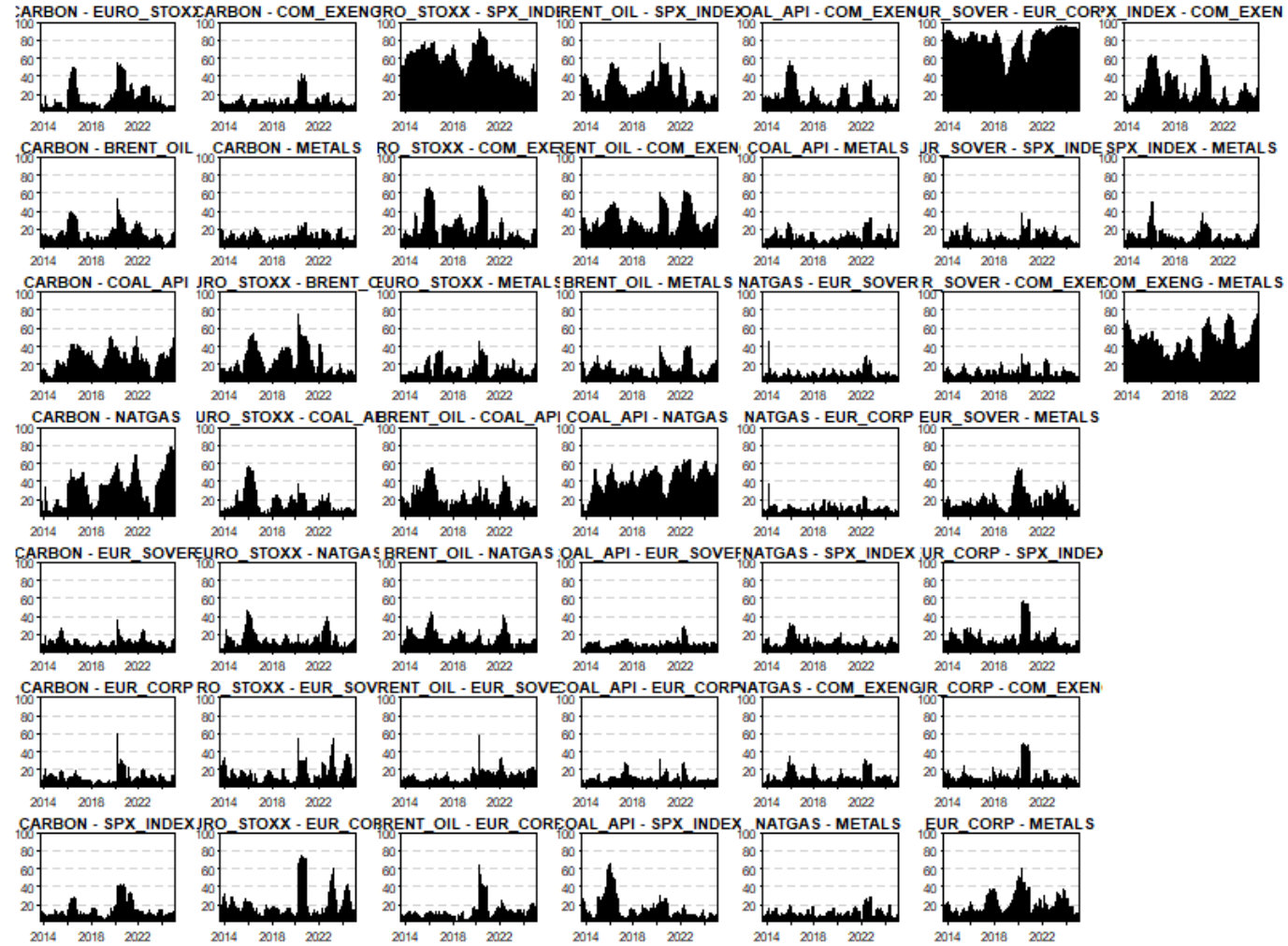
(b) Static Volatility PCI network



Appendix D.6.4. Dynamic Return and Volatility Pairwise Directional Connectedness

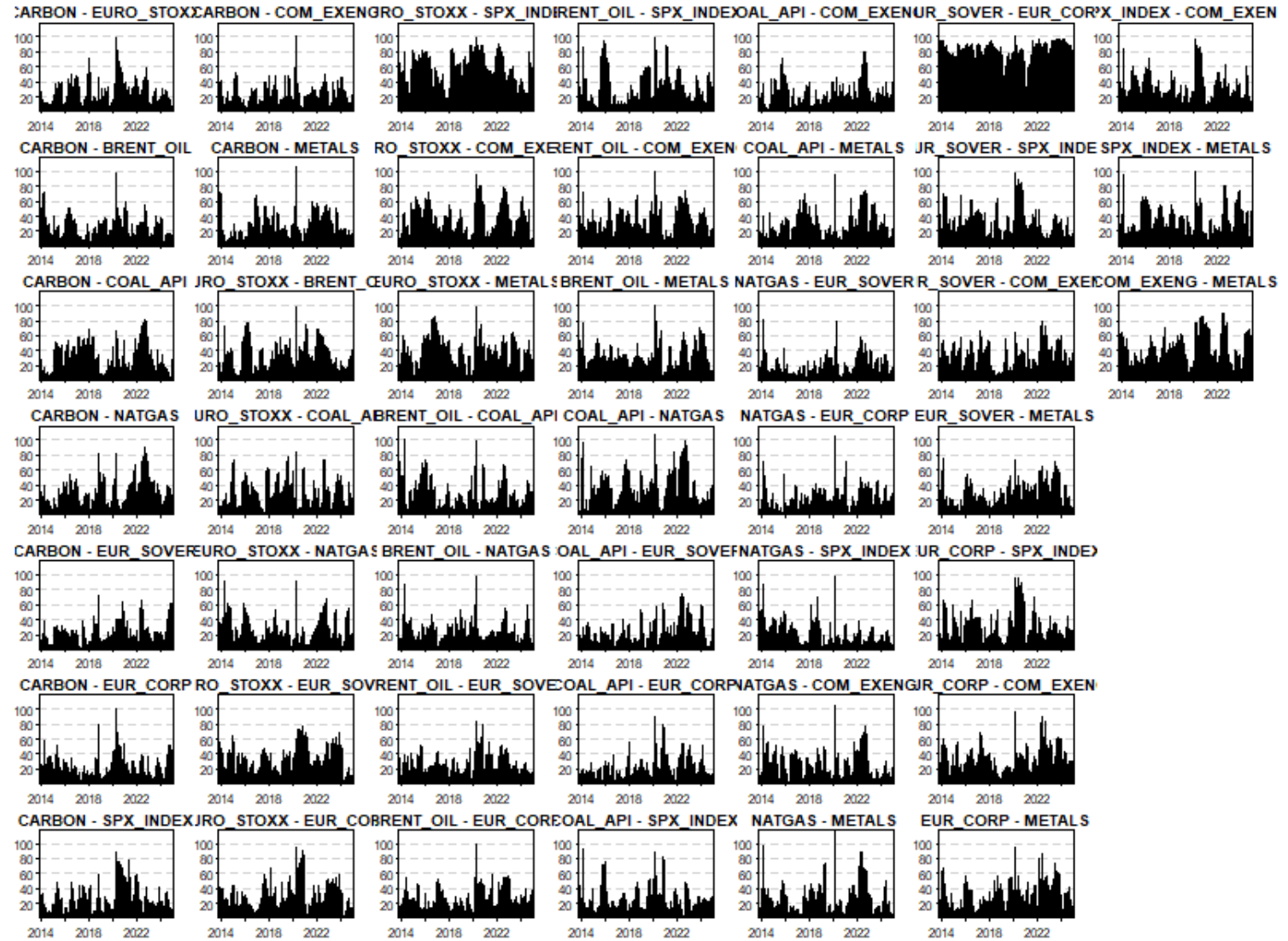
Figure D.20: Dynamic Return and Volatility Pairwise Connectedness Index (Jan 2013 – Jan 2025)

(a) Dynamic return PCI





(b) Dynamic volatility PCI



Appendix D.7. 12-period forecast horizon and a rolling window of 200 observations

Appendix D.7.1. Static Return and Volatility Connectedness Matrix

Table D.8: Static Return and Volatility Connectedness Matrix (Jan 2013 - Jan 2025)

(a) Carbon returns connectedness matrix

	CARBON	EUROSTOXX	BRENTOIL	COALAPI	NATGAS	EUROVER	EURCORP	SPXINDEX	COMEXENG	METALS	FROM
CARBON	59.98	4	3.81	7.85	10.21	2.49	2.28	3.48	2.77	3.13	40.02
EUROSTOXX	3.28	49.71	5.71	3.34	3.13	3.05	3.68	19.85	5.21	3.03	50.29
BRENTOIL	3.5	6.01	57.33	5.44	3.62	2.69	2.35	7.28	8.29	3.5	42.67
COALAPI	6.34	3.78	5.8	55.96	13.77	1.86	2.05	3.84	3.96	2.64	44.04
NATGAS	9.93	3.04	3.89	13.57	58.66	1.81	1.77	2.5	2.57	2.25	41.34
EUROVER	2.04	3.01	2.69	1.68	1.69	48.28	31.89	2.3	2.06	4.36	51.72
EURCORP	1.98	5.05	2.72	1.75	1.82	30.35	45.45	3.97	2.55	4.36	54.55
SPXINDEX	2.43	17.94	6.82	3.36	2.04	2.32	2.74	53.46	6.4	2.51	46.54
COMEXENG	2.49	5.09	7.45	3.49	2.41	2.17	2.38	6.6	53.02	14.9	46.98
METALS	2.38	3.18	3.13	2.29	2.47	4.84	5.59	2.98	16.13	57.02	42.98
DST(TO)	34.37	51.09	42.02	42.78	41.16	51.58	54.72	52.79	49.94	40.68	461.13
Inc. Own	94.35	100.8	99.35	98.74	99.82	99.86	100.17	106.25	102.96	97.69	cTCI/TCI
NS (NET)	-5.65	0.8	-0.65	-1.26	-0.18	-0.14	0.17	6.25	2.96	-2.31	51.24/46.11

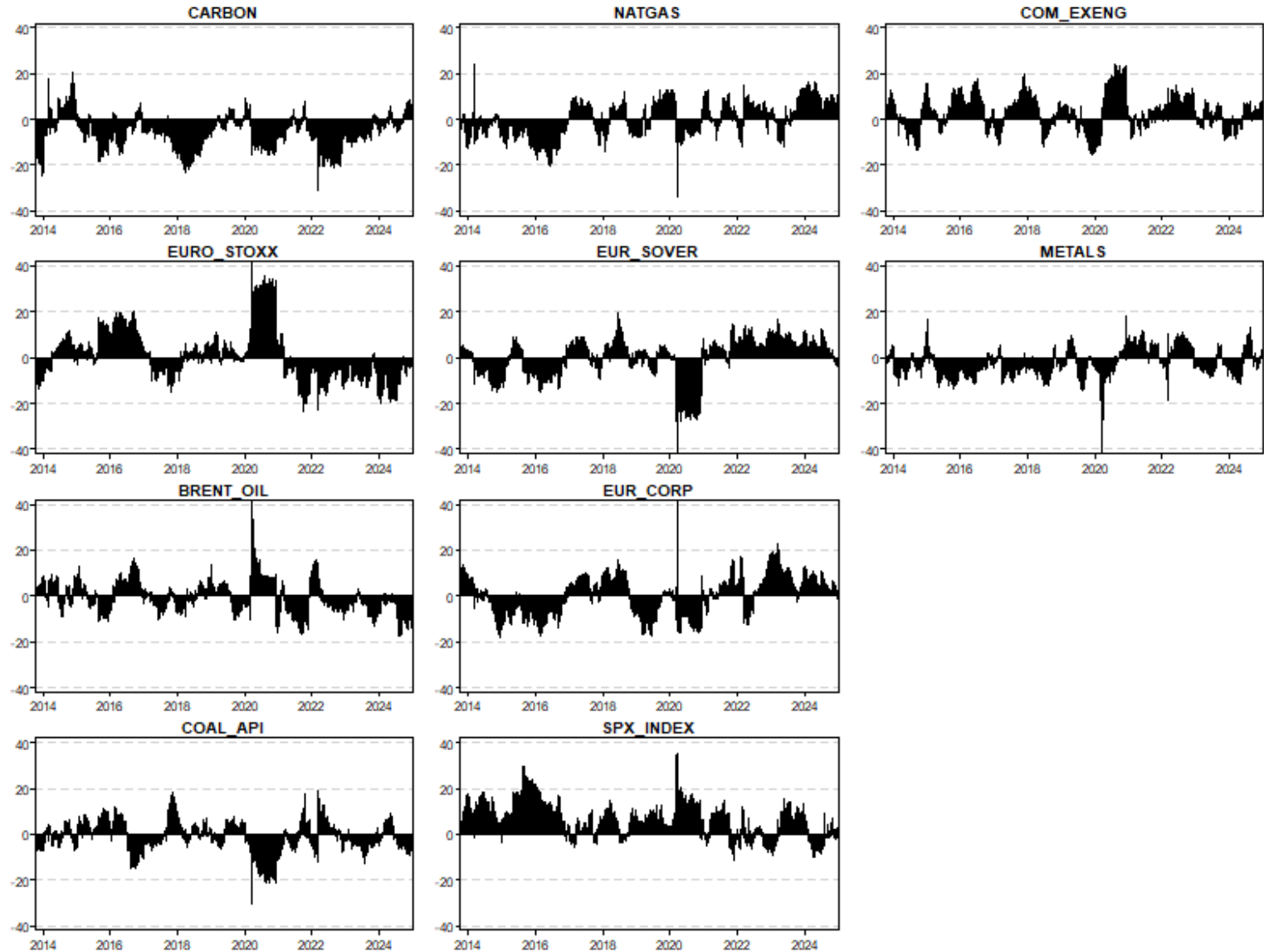
(b) Carbon volatility connectedness matrix

	CARBON	EUROSTOXX	BRENTOIL	COALAPI	NATGAS	EUROVER	EURCORP	SPXINDEX	COMEXENG	METALS	FROM
CARBON	51.77	4.95	4.62	7.64	7.57	4.25	4.08	5.87	4.28	4.97	48.23
EUROSTOXX	3.95	44.7	5.26	4	4.01	5.47	4.39	16.25	5.63	6.33	55.3
BRENTOIL	4.33	6.94	48.98	5.34	4.07	4.39	5.01	6.77	7.45	6.73	51.02
COALAPI	5.18	6.48	4.42	54.18	8.27	4.19	3.09	5.01	3.51	5.67	45.82
NATGAS	4.87	5.04	3.94	8.7	55.58	4.08	4.28	5.31	3.85	4.35	44.42
EUROVER	2.39	6.61	3.52	2.68	2.03	43.31	24.59	5.95	4.24	4.68	56.69
EURCORP	3.04	6.01	2.75	2.55	2.71	27.87	40.08	6.26	5.14	3.58	59.92
SPXINDEX	3.75	15.2	5.1	3.55	2.01	5.11	4.18	50.28	4.96	5.87	49.72
COMEXENG	2.95	8.09	4.83	4.12	4.36	5.67	5.7	7.07	47.39	9.81	52.61
METALS	4.08	8.78	4.77	4.27	4.3	5.29	6.67	6.72	10.22	44.9	55.1
DST(TO)	34.53	68.1	39.22	42.85	39.32	66.32	61.99	65.21	49.29	51.99	518.82
Inc. Own	86.3	112.8	88.19	97.03	94.9	109.63	102.07	115.49	96.68	96.89	cTCI/TCI
NS (NET)	-13.7	12.8	-11.81	-2.97	-5.1	9.63	2.07	15.49	-3.32	-3.11	57.65/51.88



Figure D.21: Dynamic Net Directional Connectedness (Jan 2013 – Jan 2025)

(a) Dynamic return net directional connectedness



(b) Dynamic volatility net directional connectedness

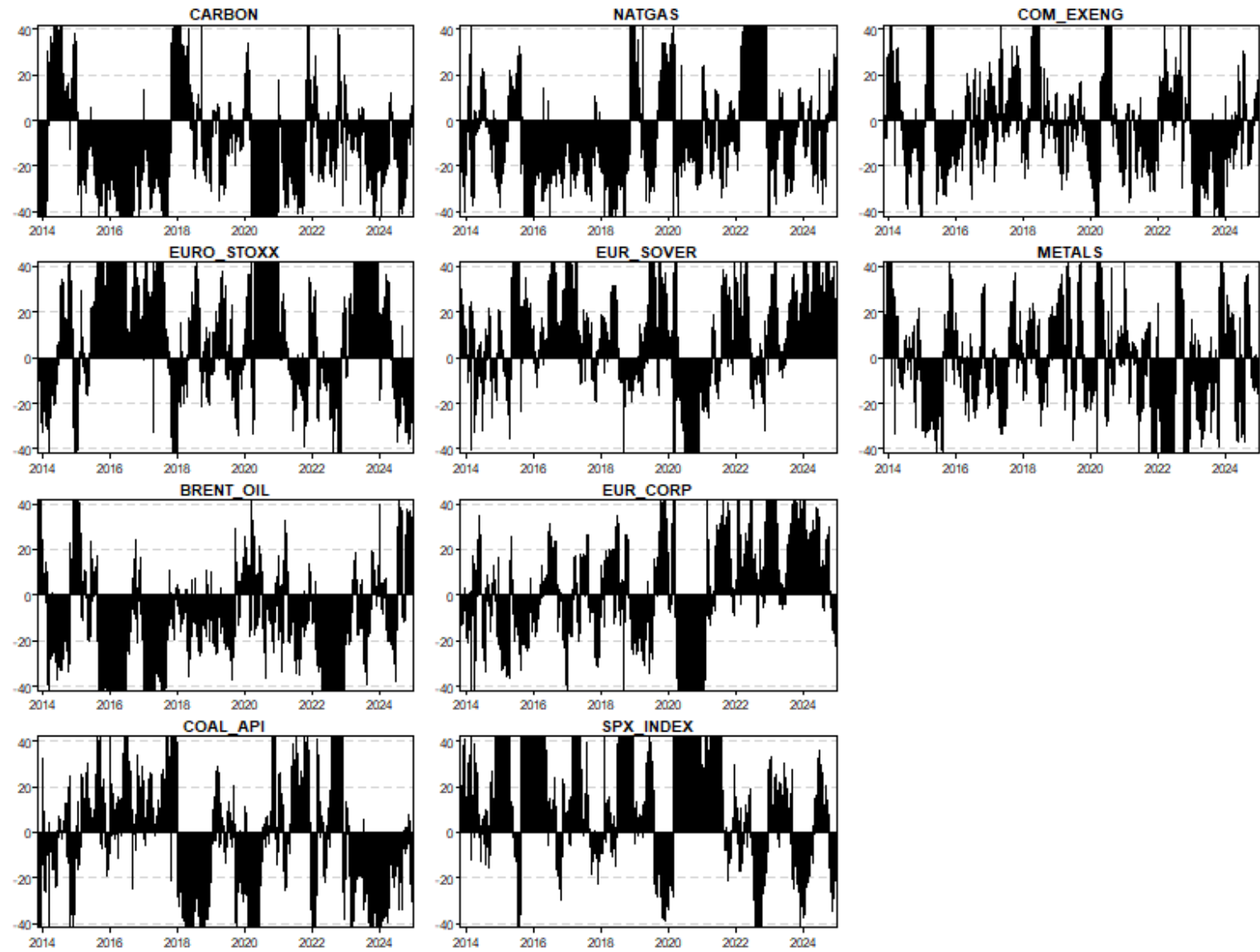
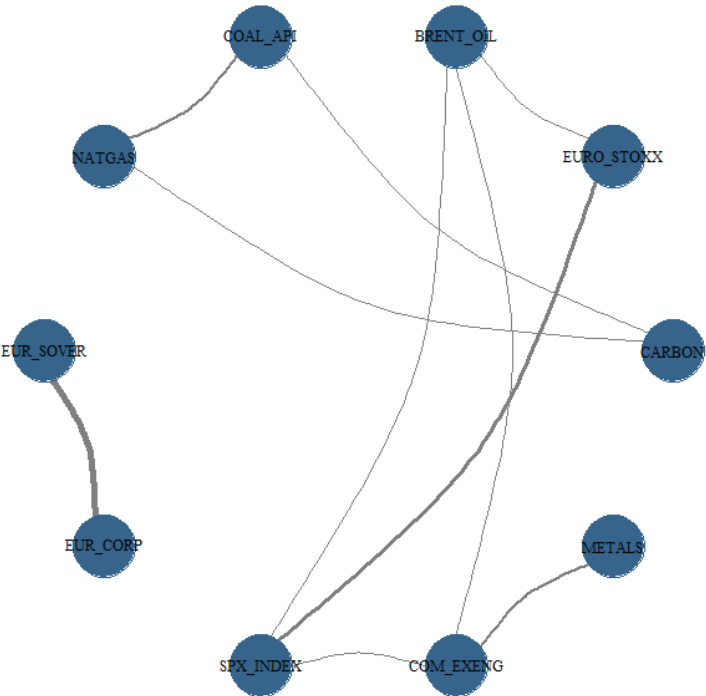
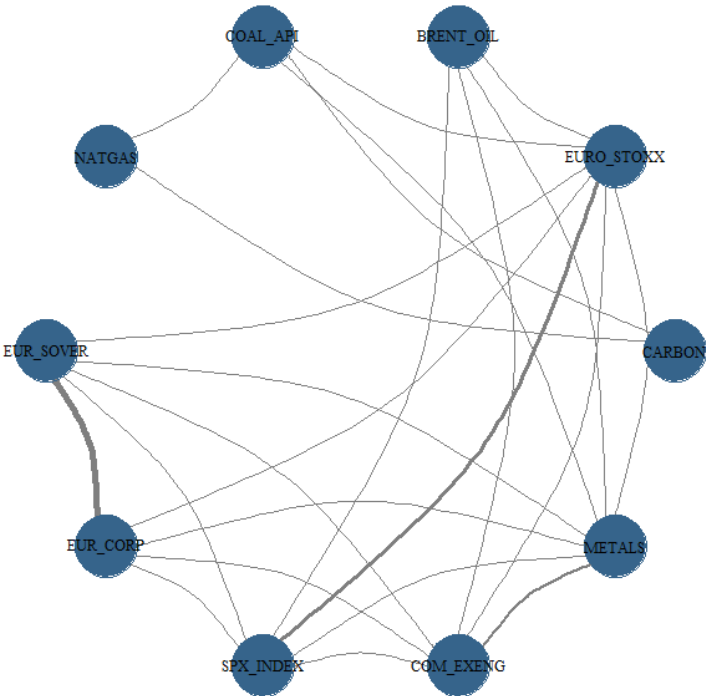


Figure D.22: Network Representation of Pairwise Connectedness Index (Jan 2013 – Jan 2025)

(a) Static Return PCI network



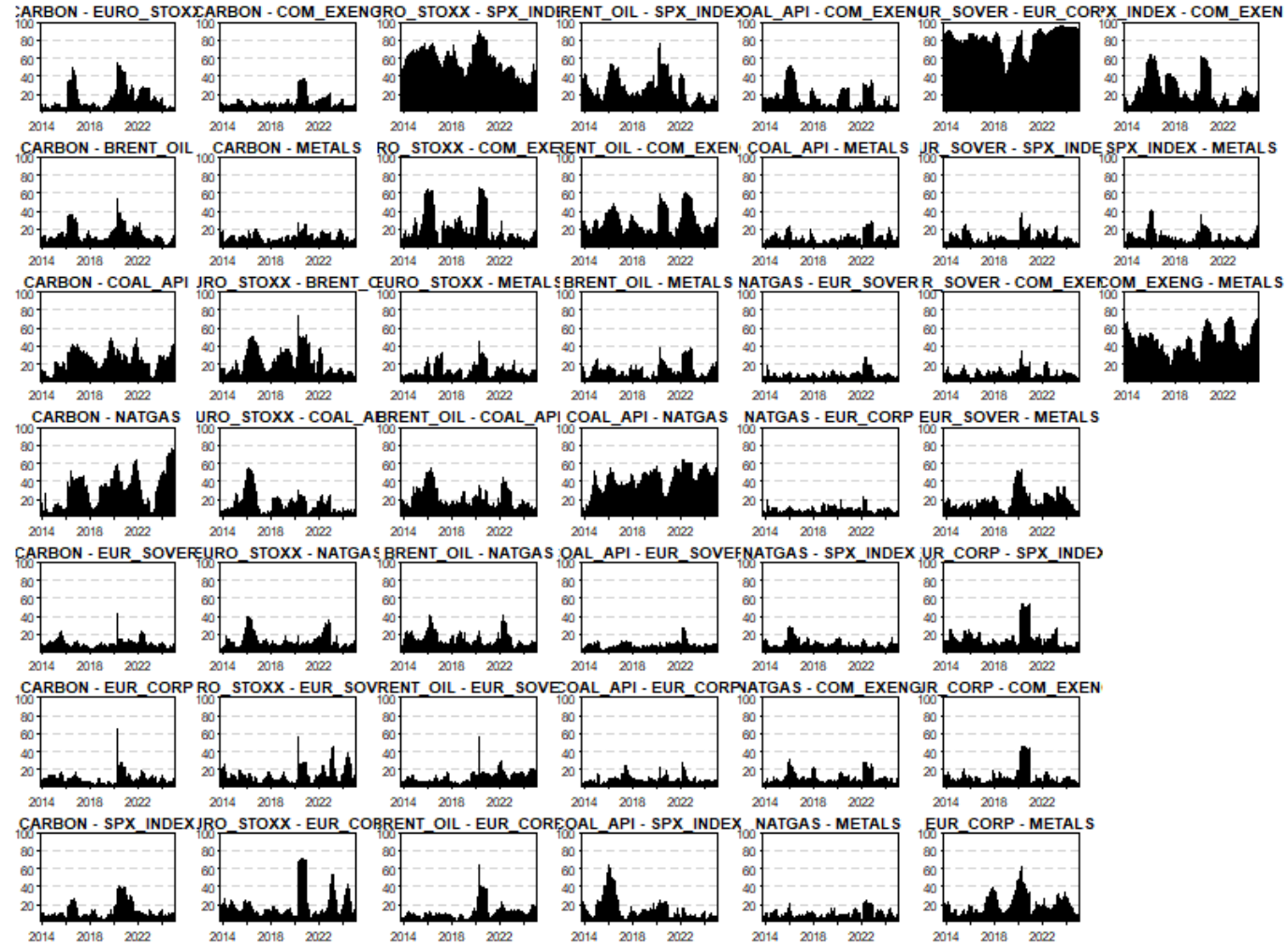
(b) Static Volatility PCI network



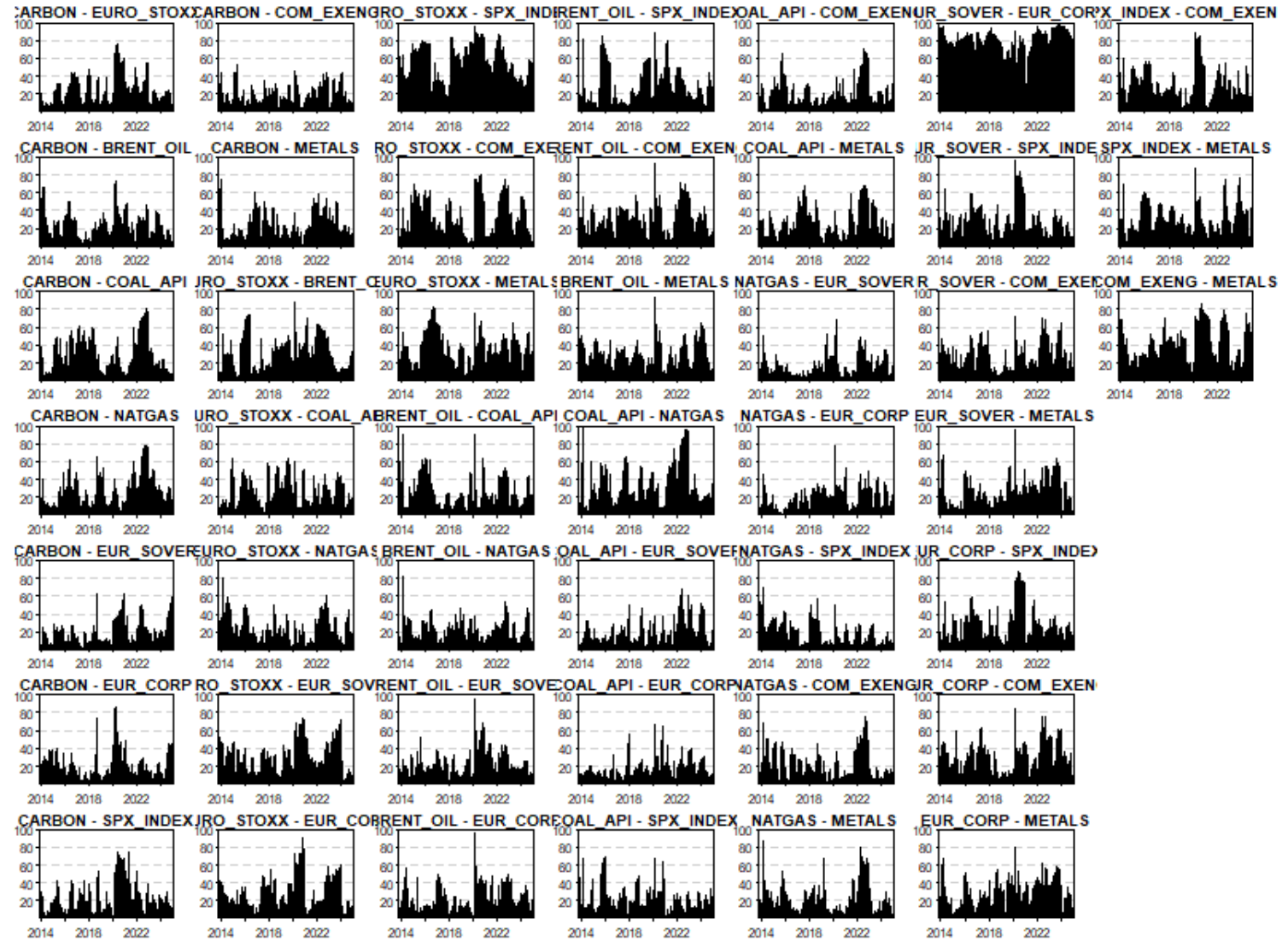
Appendix D.7.4. Dynamic Return and Volatility Pairwise Directional Connectedness

Figure D.23: Dynamic Return and Volatility Pairwise Connectedness Index (Jan 2013 – Jan 2025)

(a) Dynamic return PCI



(b) Dynamic volatility PCI





Appendix D.8. 12-period forecast horizon and a rolling window of 220 observations

Appendix D.8.1. Static Return and Volatility Connectedness Matrix

Table D.9: Static Return and Volatility Connectedness Matrix (Jan 2013 - Jan 2025)

(a) Carbon returns connectedness matrix

	CARBON	EUROSTOXX	BRENTOIL	COALAPI	NATGAS	EUROVER	EURCORP	SPXINDEX	COMEXENG	METALS	FROM
CARBON	61.29	3.94	3.67	7.78	10.07	2.3	2.13	3.29	2.61	2.93	38.71
EUROSTOXX	3.18	50.75	5.67	3.23	2.95	2.75	3.44	20.11	5.14	2.78	49.25
BRENTOIL	3.31	5.92	58.37	5.39	3.49	2.52	2.23	7.2	8.31	3.26	41.63
COALAPI	6.22	3.66	5.74	56.99	13.87	1.72	1.89	3.7	3.83	2.39	43.01
NATGAS	9.79	2.87	3.75	13.75	59.92	1.63	1.61	2.24	2.38	2.06	40.08
EUROVER	1.87	2.8	2.48	1.5	1.48	49.27	32.33	2.16	1.85	4.26	50.73
EURCORP	1.84	5	2.61	1.57	1.62	30.67	46.12	3.92	2.43	4.23	53.88
SPXINDEX	2.26	18.11	6.71	3.22	1.81	2.14	2.59	54.44	6.44	2.29	45.56
COMEXENG	2.33	5.03	7.43	3.35	2.18	1.97	2.22	6.63	53.89	14.98	46.11
METALS	2.22	2.93	2.91	2.08	2.25	4.77	5.51	2.77	16.29	58.28	41.72
DST(TO)	33.01	50.26	40.96	41.87	39.71	50.46	53.95	52	49.28	39.18	450.7
Inc. Own	94.3	101.01	99.33	98.86	99.62	99.73	100.06	106.44	103.17	97.47	cTCI/TCI
NS (NET)	-5.7	1.01	-0.67	-1.14	-0.38	-0.27	0.06	6.44	3.17	-2.53	50.08/45.07

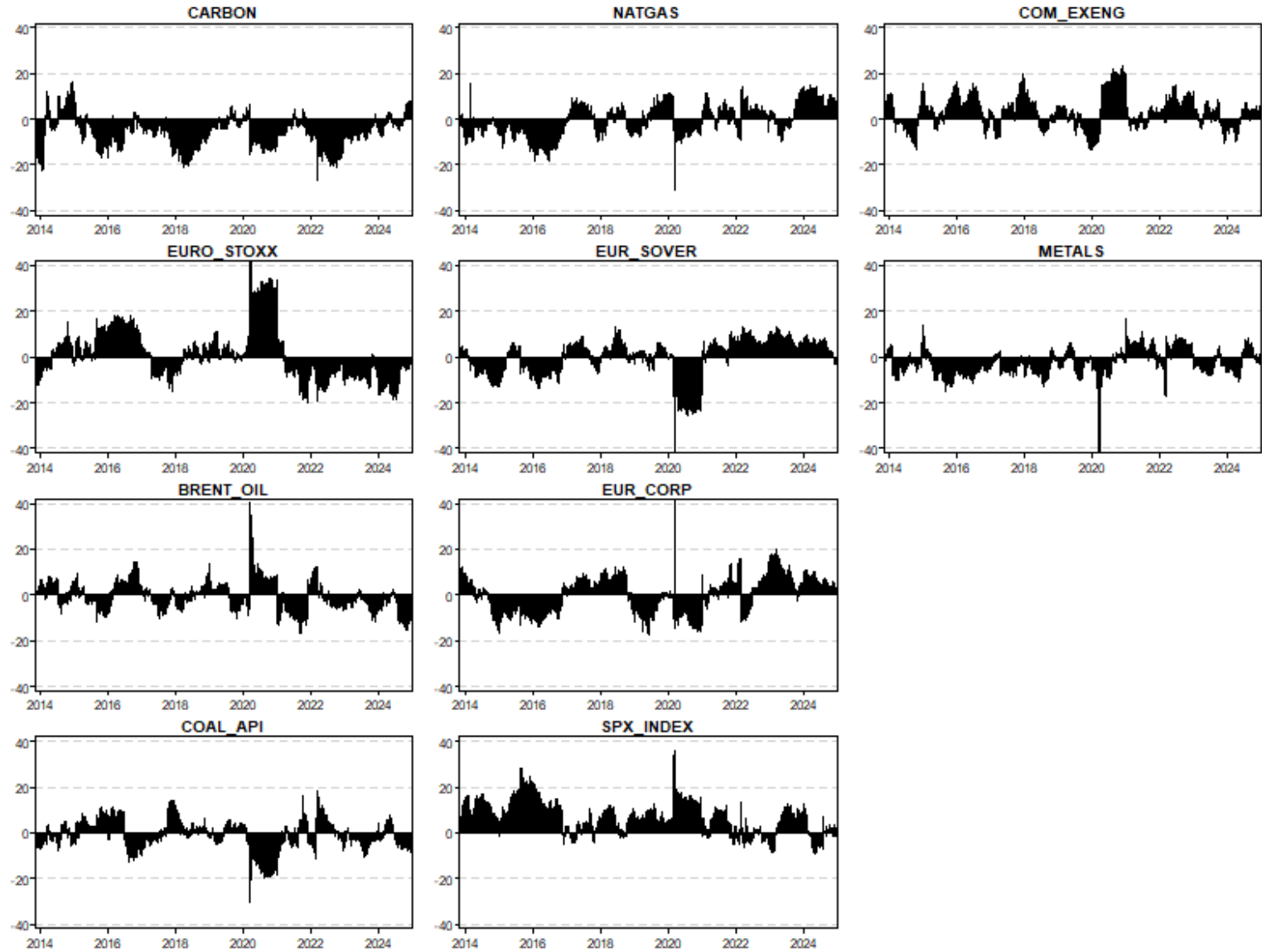
(b) Carbon volatility connectedness matrix

	CARBON	EUROSTOXX	BRENTOIL	COALAPI	NATGAS	EUROVER	EURCORP	SPXINDEX	COMEXENG	METALS	FROM
CARBON	53.98	4.97	4.32	7.64	7.18	3.84	3.72	5.49	4.29	4.56	46.02
EUROSTOXX	3.55	46.21	4.99	3.61	3.61	5.32	4.27	16.81	5.63	6.01	53.79
BRENTOIL	3.82	6.9	51.01	5.18	3.86	3.98	4.53	6.63	7.62	6.47	48.99
COALAPI	5.06	5.98	3.68	57.01	7.87	3.96	2.92	4.6	3.39	5.53	42.99
NATGAS	4.63	4.71	3.52	8.47	58.3	3.77	4.15	4.94	3.53	3.99	41.7
EUROVER	2.06	6.39	3.31	2.32	1.72	44.95	25.12	5.85	3.77	4.53	55.05
EURCORP	2.67	6.01	2.68	2.1	2.2	28.56	41.62	6.19	4.53	3.42	58.38
SPXINDEX	3.46	15.35	4.67	3.27	1.77	4.68	3.85	52.71	4.66	5.58	47.29
COMEXENG	2.45	8.05	4.81	3.83	3.94	5.14	5.21	6.79	49.88	9.9	50.12
METALS	3.87	8.67	4.35	4	3.91	5.1	6.19	6.11	10.51	47.28	52.72
DST(TO)	31.56	67.03	36.35	40.42	36.07	64.35	59.96	63.39	47.93	49.97	497.04
Inc. Own	85.54	113.25	87.36	97.43	94.38	109.3	101.59	116.09	97.81	97.25	cTCI/TCI
NS (NET)	-14.46	13.25	-12.64	-2.57	-5.62	9.3	1.59	16.09	-2.19	-2.75	55.23/49.70



Figure D.24: Dynamic Net Directional Connectedness (Jan 2013 – Jan 2025)

(a) Dynamic return net directional connectedness



(b) Dynamic volatility net directional connectedness

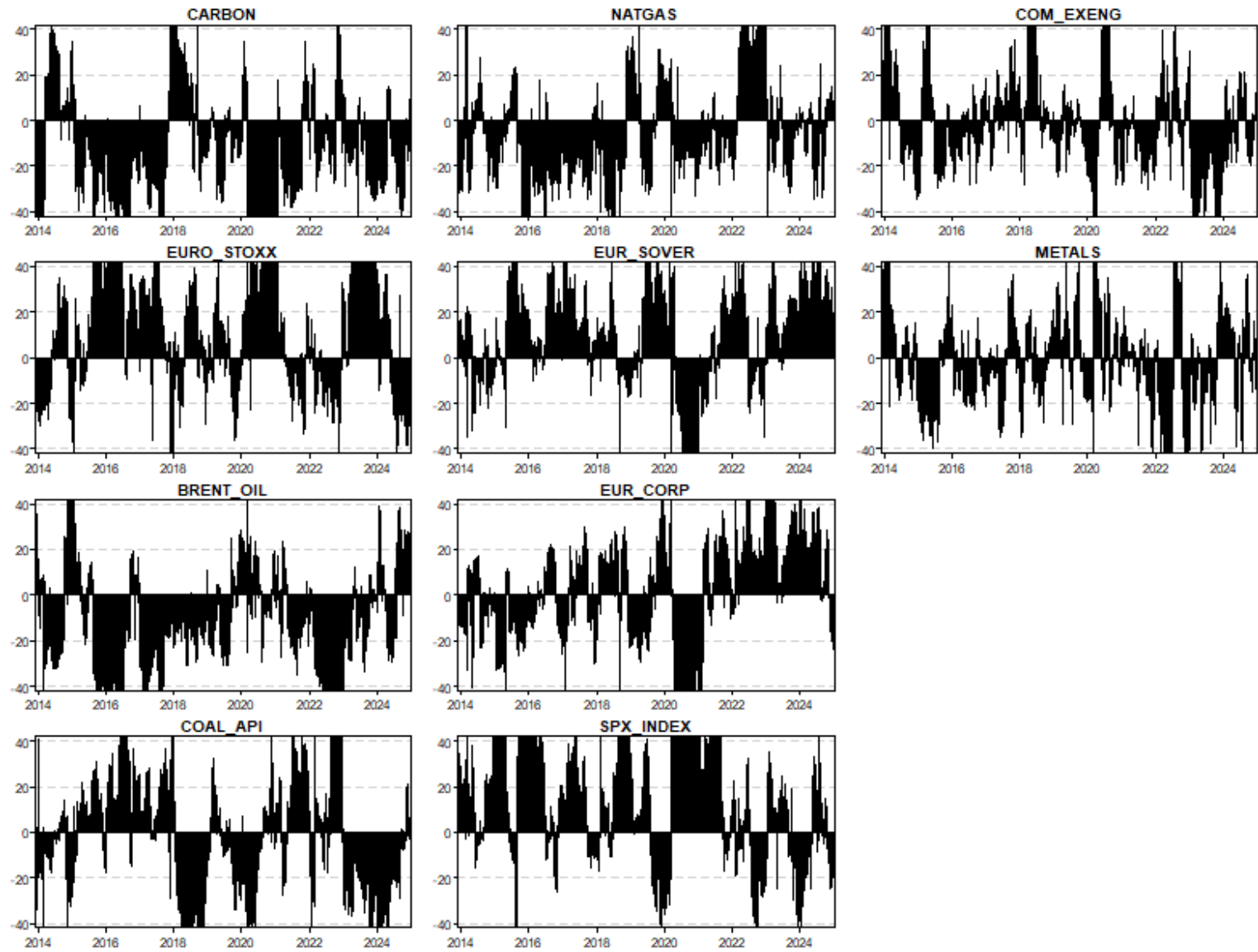
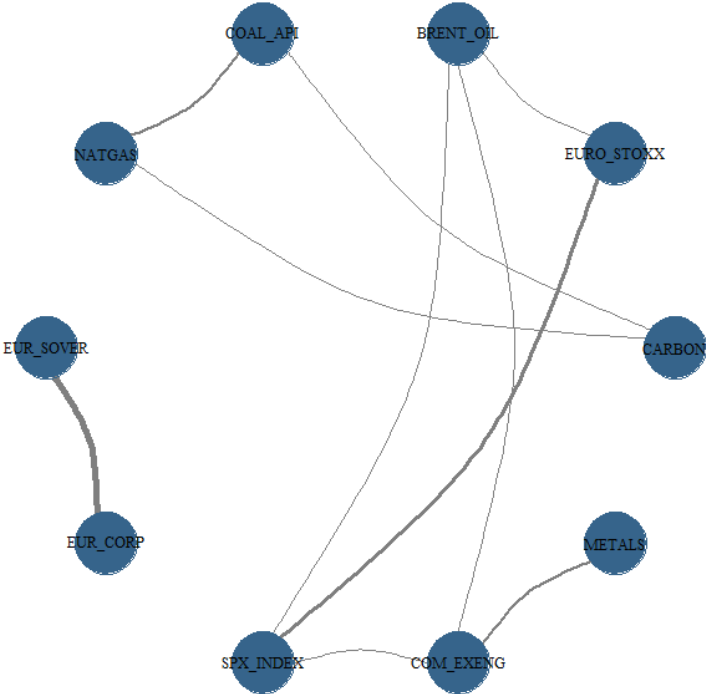
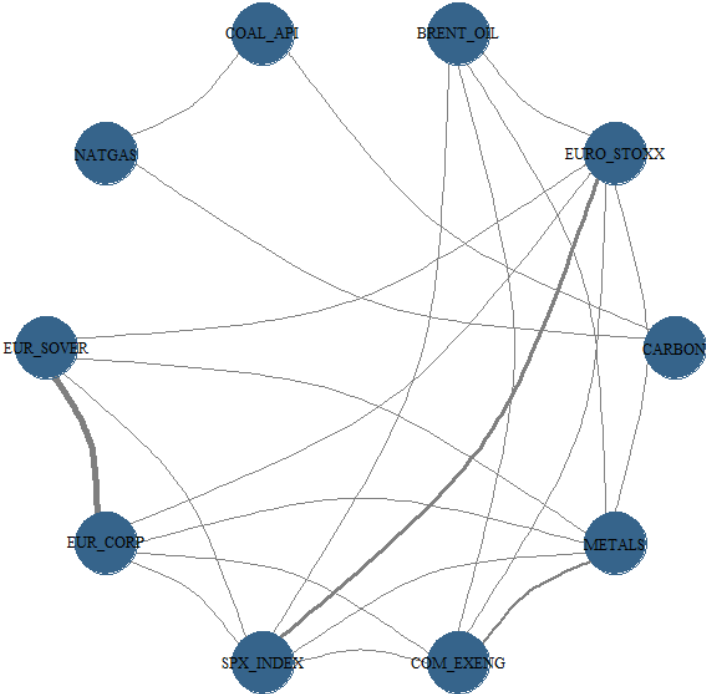


Figure D.25: Network Representation of Pairwise Connectedness Index (Jan 2013 – Jan 2025)

(a) Static Return PCI network



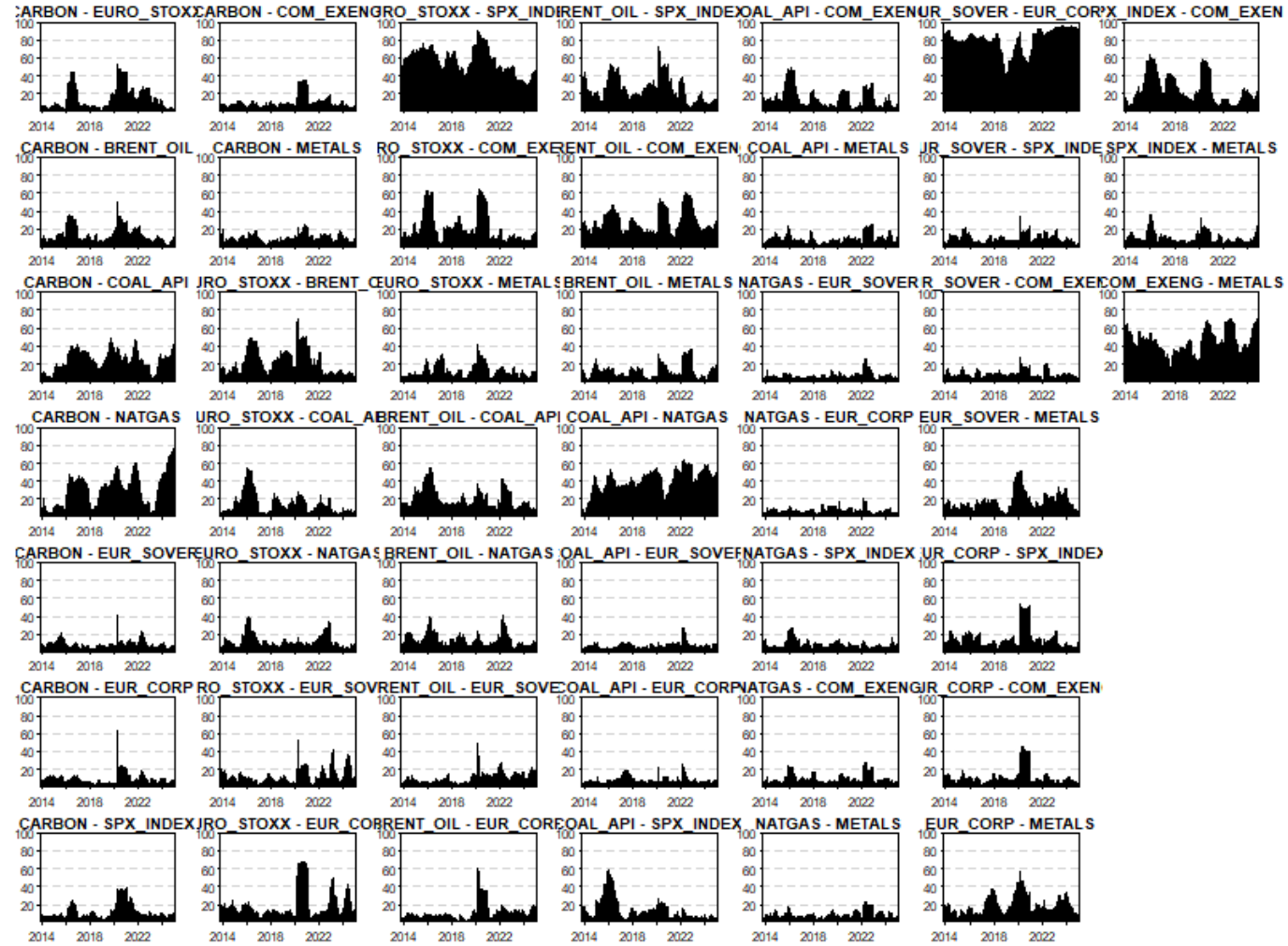
(b) Static Volatility PCI network



Appendix D.8.4. Dynamic Return and Volatility Pairwise Directional Connectedness

Figure D.26: Dynamic Return and Volatility Pairwise Connectedness Index (Jan 2013 – Jan 2025)

(a) Dynamic return PCI



(b) Dynamic volatility PCI

