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Dynamic interaction between the market for upstream co-product raw materials and the downstream new energy vehicle market

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Outline

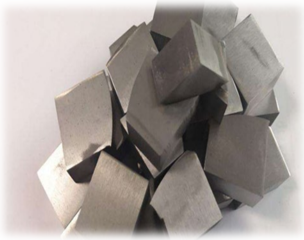
Outline

Carbon Neutrality

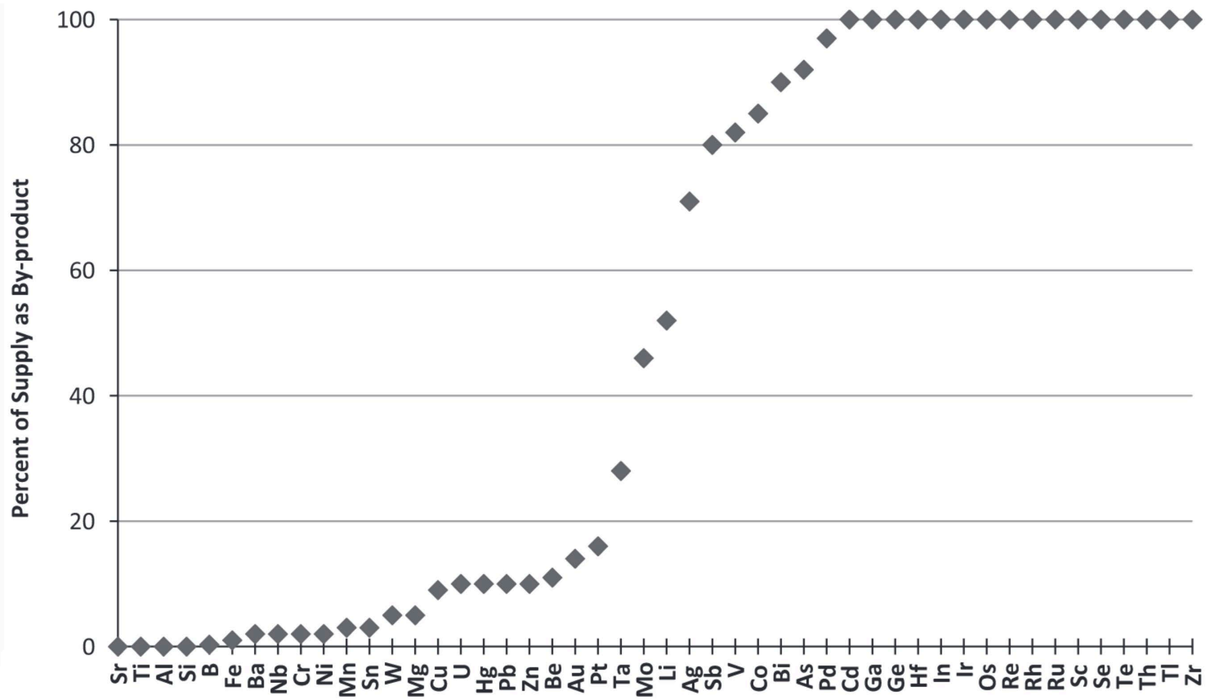
New Energy Industry Development

Critical Minerals

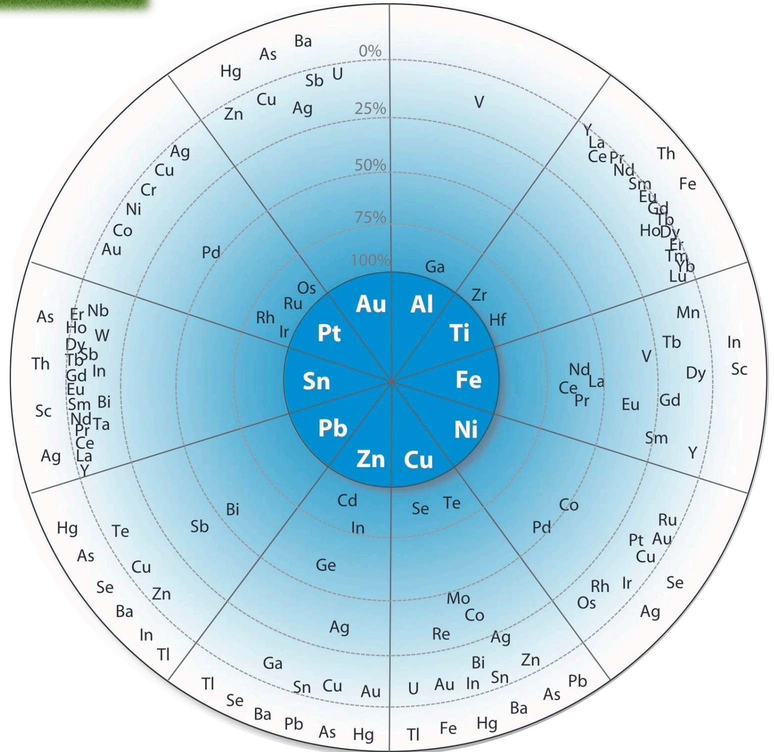
primary metals



by (co)-product metals



Share of element supplied as by-product.
(Nassar et al. , 2015; Redlinger et al., 2016)



The wheel of metal companionality
(Nassar, Graedel, Harper, 2015)

capacity constraint

price relationship between primary and by(co)-product metals

加一张铜钴镍的关系。娜姐那篇文章的图。和新能源汽车需要铜钴镍的关系图

Price relationship between primary and by(co)-product metals	**one-way causal link** (Campbell,1985), **one-way causation** (Kim and Heo, 2012), **Granger cause** (Shammugam et al.,2019), **nonlinear correlations** (Fizaine, 2013; Shammugam et al., 2019b), **linear relationships** (Afflerbach et al., 2014), **time-varing** (Fizaine, 2013; Kim et al., 2012; Shammugam et al., 2019b))
Price spillover between metal markets	**ARDL model** (Martino and Parson, 2013), **HAR model** (Todorova et al., 2014), **GARCH model** (Lien and Yang, 2009; Yue et al., 2015; Wen et al., 2015; Wu and Hu, 2016), **Diebold and Yilmaz** (Al-Yahyaee (2020), **wavelet approach** (Tweneboah (2019), **other approaches** (Ciner et al., 2020; Balcilar and Ozdemir, 2019; Bhatia et al., 2020; Demiralay and Ulusoy, 2014; He et al., 2016; Reboredo and Ugolini, 2015)
The impact of downstream market development on upsteam raw material market	**solar energy could affect silver prices significantly in the short term** (Apergis et al.,2020), **time-varying dependence** (Yahya et al., 2020), **alter demand and price** (Watari et al., 2020; He et al.,2021; Ali et al., 2017; Greim et al., 2020), **technology development** (He et al.,2021), **price changes of metals influence the market prices** (Tiwari et al., 2020; Shao et al., 2020; Song et al., 2022)

- **The relationship between the price of primary metal and by(co)-product metal in different time scale**
- **The impact of downstream market development on the price spillover effect upstream co-product raw materials**

Outline

Methodology

The volatility spillover analysis

- Diebold and Yilmaz (2012, 2014）
- The maximum overlap discrete wavelet transform
- Wavelet multiple correlation and wavelet multiple intercorrelation
- Wavelet coherence

➢ Analyzing the volatility spillovers

➢ Analyzing the market spillover effects under different time scales

The impact of new energy vehicles market on the spillover effect of the raw material markets

- Linear causality test
- The nonparametric quantile causality approach

➢ Analyzing the impact of new energy vehicles market on the spillover effect of the raw material markets

Volatility spillover analysis

$$y_t = \sum_{i=1}^{p} C_p y_{t-i} + u_t \quad (1)$$

$$y_t = \sum_{i=0}^{\infty} A_i \varepsilon_{t-i} \quad (2)$$

$$\theta_{ij}^{g}(H) = \frac{\sigma_{ii}^{-1} \Sigma_{h=0}^{H-1} \left(e_i' A_h \Sigma e_j\right)}{\Sigma_{h=0}^{H-1} \left(e_i' A_h \Sigma A_h' e_i\right)} \quad (3)$$

$$\tilde{\theta}_{ij}^{g}(H) = \frac{\theta_{ij}^{g}(H)}{\sum_{j=1}^{k} \theta_{ij}^{g}(H)} \quad (4)$$

$$S^{g}(H) = \frac{1}{N} \sum_{\substack{i,j=1 \\ i \neq j}}^{k} \tilde{\theta}_{ij}^{g}(H) \times 100 \quad (5)$$

Maximal overlap discrete wavelet transformation

$$\rho_{xy}(\lambda_j) = Corr(w_{ij,t}, \tilde{w}_{ij,t}) = \frac{Cov(w_{ij,t}, \tilde{w}_{ij,t})}{\sqrt{var(w_{ij,t}) var(\tilde{w}_{ij,t})}} \quad (6)$$

Wavelet multiple correlation and wavelet multiple intercorrelation

$$\phi_X(\lambda_j) = \sqrt{1 - \frac{1}{max \operatorname{diag} P_j^{-1}}} \quad (7)$$

$$\phi_X(\lambda_j) = \operatorname{Corr}(w_{ij,t} \tilde{w}_{ij,t}) = \frac{\operatorname{Cov}(w_{ij,t}, \tilde{w}_{ij,t})}{\sqrt{\operatorname{var}(w_{ij,t}) \operatorname{var}(\tilde{w}_{ij,t})}} \quad (8)$$

$$\phi_X, \tau(\lambda_j) = \operatorname{Corr}(w_{ij,t} \hat{w}_{ij,t}) = \frac{\operatorname{Cov}(w_{ij,t}, \tilde{w}_{ij,t+\tau})}{\sqrt{\operatorname{var}(w_{ij,t}) \operatorname{var}(\tilde{w}_{ij,t+\tau})}} \quad (9)$$

Wavelet coherence

$$R^2(u,s) = \frac{\left|S\left(s^{-1}W_{xy}(u,s)\right)\right|^2}{S(s^{-1}|W_x(u,s)|^2)S\left(s^{-1}\left|W_y(u,s)\right|^2\right)} \quad (10)$$

Causality tests

$$y_t = \alpha + \sum_{p=1}^{\kappa} \beta_p x_{t-p} + \sum_{q=1}^{l} \theta_q y_{t-q} + \mu_t \quad (11)$$

$$x_t = \theta + \sum_{p=1}^{k} \tau_p x_{t-p} + \sum_{q=1}^{l} \pi_q y_{t-q} + \varepsilon_t \quad (12)$$

$$H_0: P\{F_{y_t|Z_{t-1}}\{Q_\theta(Y_{t-1}) \mid Z_{t-1}\} = \theta = 1$$
$$H_1: P\{F_{y_t|Z_{t-1}}\{Q_\theta(Y_{t-1}) \mid Z_{t-1}\} = \theta < 1 \quad (13)$$

$$J = \{\varepsilon_t E(\varepsilon_t \mid Z_{t-1}) F_Z(Z_{t-1})\} \quad (14)$$

$$\hat{\varepsilon}_t = 1\{y_t \le \hat{Q}_\theta(Y_{t-1})\} - \theta \quad (15)$$

$$\hat{Q}_\theta(Y_{t-1}) = \hat{F}^{-1}_{y_t|Y_{t-1}}(\theta \mid Y_{t-1}) \quad (16)$$

$$\hat{F}^{-1}_{y_t|Y_{t-1}}(y_t \mid Y_{t-1}) = \frac{\sum_{s=p+1, s\neq t}^{T} L\left(\frac{Y_{t-1} - Y_{s-1}}{h}\right) 1(y_s \le y_t)}{\sum_{s=p+1, s\neq t}^{T} L\left(\frac{Y_{t-1} - Y_{s-1}}{h}\right)} \quad (17)$$

$$H_0: P\left\{F_{y_t^k} \mid z_{t-1}\{Q_\theta(Y_{t-1}) \mid Z_{t-1}\} = \theta\right\} = 1 \text{ for } k = 1,2,\cdots,K$$
$$H_1: P\left\{F_{y_t^k|} \mid z_{t-1}\{Q_\theta(Y_{t-1}) \mid Z_{t-1}\} = \theta\right\} < 1 \text{ for } k = 1,2,\cdots,K \quad (18)$$

■ Data

Variable	Data sources	Time
Daily closing spot prices for copper, cobalt, and nickel	London Metal Exchang（LME)	From January 4 in 2006 to May 16 in 2022
The new energy vehicle market index (NEA)	Consists of 50 of the largest and most liquid A-share stocks in the new energy vehicle sector listed on the Shenzhen Stock Exchange and the Shanghai Stock Exchange	From December 30 in 2014 to May 24 in 2021.
The new energy market index (ZNE)	Consists of 80 stocks that provide renewable energy production, energy application, storage and interaction equipment or other new energy services as constituents.	From December 30 in 2014 to May 24 in 2021.

- The data of NEA and ZNE from：Dai Z, Zhu H, Zhang X. Dynamic spillover effects and portfolio strategies between crude oil, gold and Chinese stock markets related to new energy vehicle[J]. Energy Economics, 2022, 109: 105959.

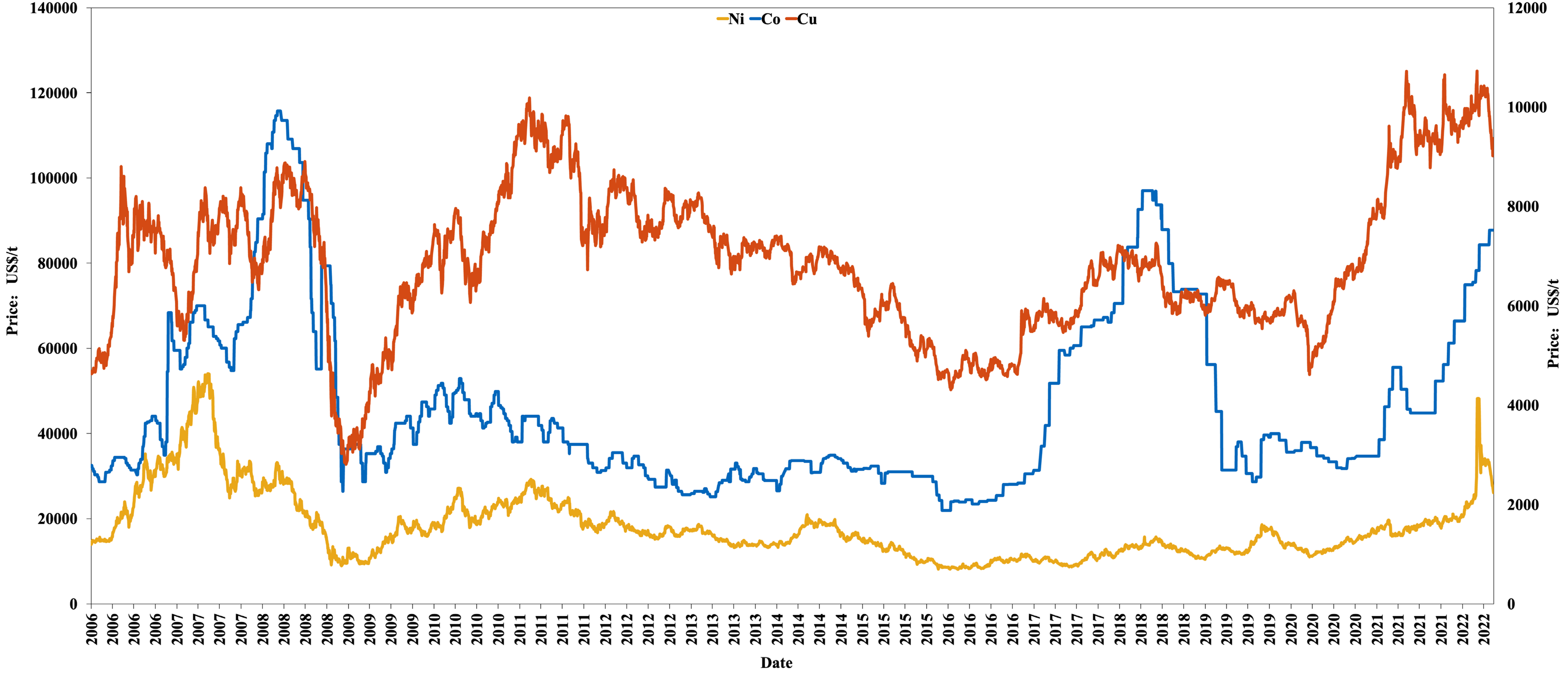


Figure 1. Time trend of price of copper, nickel, and cobalt

Note: Nickel and cobalt prices are on the left-hand axis; copper prices are on the right-hand axis

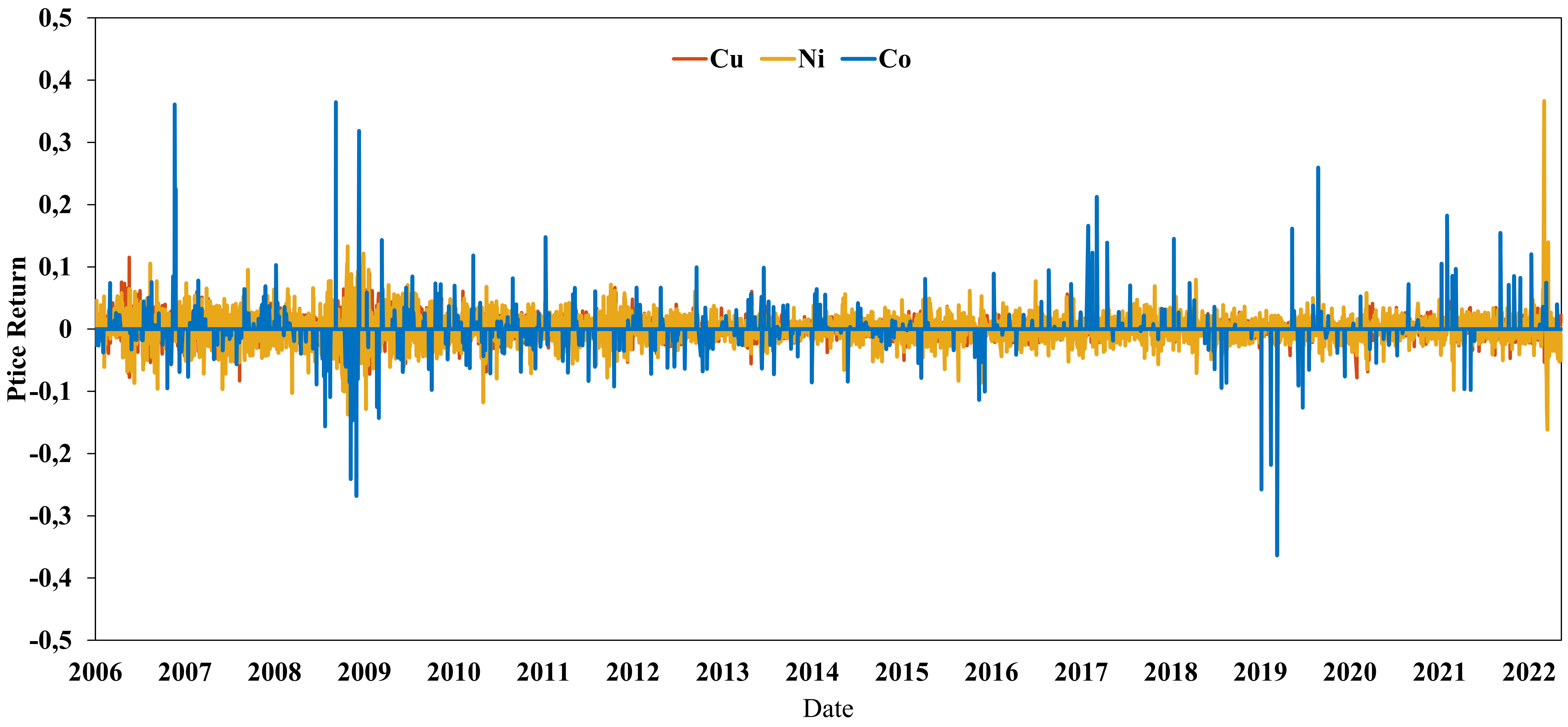


Figure 2. Price return dynamics of copper, nickel, and cobalt

Table 1 Descriptive statistics.

	Copper	Nickel	Copper	NEV	NE
Mean	0.0001	0.0001	0.0002	0.0006	0.0004
Max	0.1172	0.3665	0.3646	0.07403	0.0684
Min	-0.1032	-0.1615	-0.3636	-0.0973	-0.0972
Stand.Dev	0.0173	0.0238	0.0222	0.0219	0.0204
Skewness	-0.0910	0.8138	1.6647	-0.6442	-0.9263
Kurtosis	4.0518	17.0613	98.2767	2.4978	3.5576
JB Stats	2740.36*	48904.02*	1609602.31*	500.48*	1018.61*
SW Stats	0.952*	0.929*	0.264*	0.955*	0.932*
PP	-67.431*	-59.124*	-63.327*	-36.585*	-37.02*
ADF	-46.325*	-43.726*	-42.233*	-26.695*	-26.813*
KPSS	0.078	0.109	0.119	0.131	0.111
LB	37.12*	31.874*	44.985*	21.855*	21.792*
ARCH	756.84*	267.42*	53.958*	231.84*	228.24*

- All the data deviate from the normal distribution.
- All return series do not have unit root and are smooth series.
- The residual series of all return series are correlated.

Table 2 Unconditional correlation between Copper-Nickel-Cobalt market

Variables	Copper	Nickel	Cobalt
Copper	1.0000	0.5806	0.0433
Nickel		1.0000	0.0175
Cobalt			1.0000

- **The linear correlation between copper-nickel-cobalt market**
- **All three-return series have positive correlation**
- **The strongest correlation is between copper and nickel**

Table 3 BDS test statistics for nonlinearity between Copper-Nickel-Cobalt market

Variables	M				
	2	3	4	5	6
Copper	10.2598***	14.2596***	17.1021***	19.5653***	22.5715***
Nickel	9.1424***	12.4101***	13.9159***	14.9475***	16.4213***
Cobalt	-2.1350**	-2.8455***	-3.5499***	-3.4004***	-2.2298**

Notes: M denotes parameter in the embedding dimension. *** represents significance level at 1%.

- **A non-linear relationship between the three markets under different embedding dimensions.**

Outline

■ Volatility spillover analysis

Table 4 Results of volatility spillover among between Copper-Nickel-Cobalt market

Variables	Copper	Nickel	Cobalt	From
Copper	74.23	25.48	0.28	25.77
Nickel	25.51	74.41	0.08	25.59
Cobalt	0.43	0.41	99.16	0.84
To others	25.94	25.89	0.37	52.20
All	100.17	100.30	99.53	
Net	0.17	0.30	-0.47	17.40

- ✓ **Copper contributes the most to other market risk, while nickel is slightly smaller than copper and cobalt contributes the least to other market risk.**
- ✓ **Copper and nickel are exposed to shocks in other markets at a much higher rate than cobalt**
- ✓ **Cobalt is a net recipient of other market shocks, while copper and nickel are net contributors.**

✓ **The maximum value of the total volatility overflow exceeds 25%, and the minimum value is less than 12%**

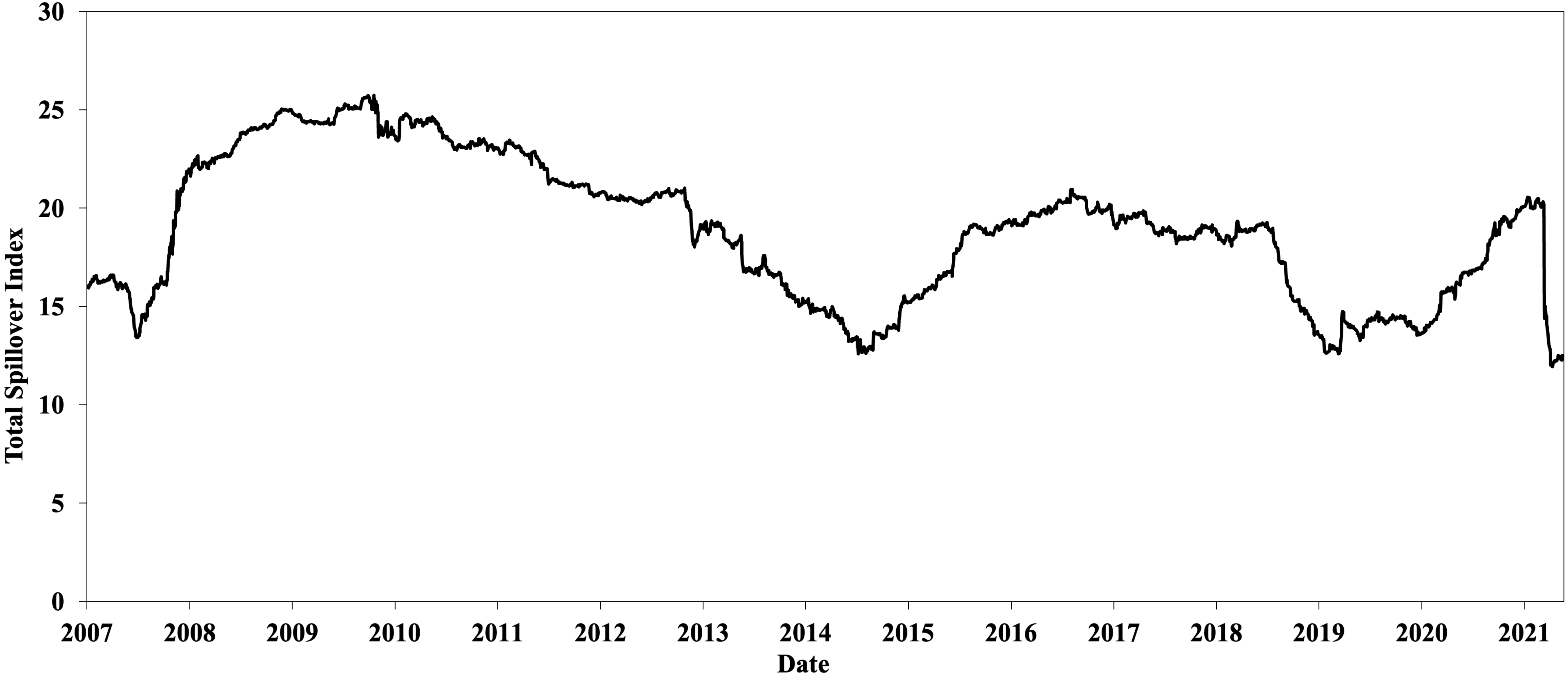


Figure 3. Time variations of total spillover index

✓ **Copper, cobalt, and nickel volatilities have large peaks in 2008 during the financia crisis and in 2020 covid-19**

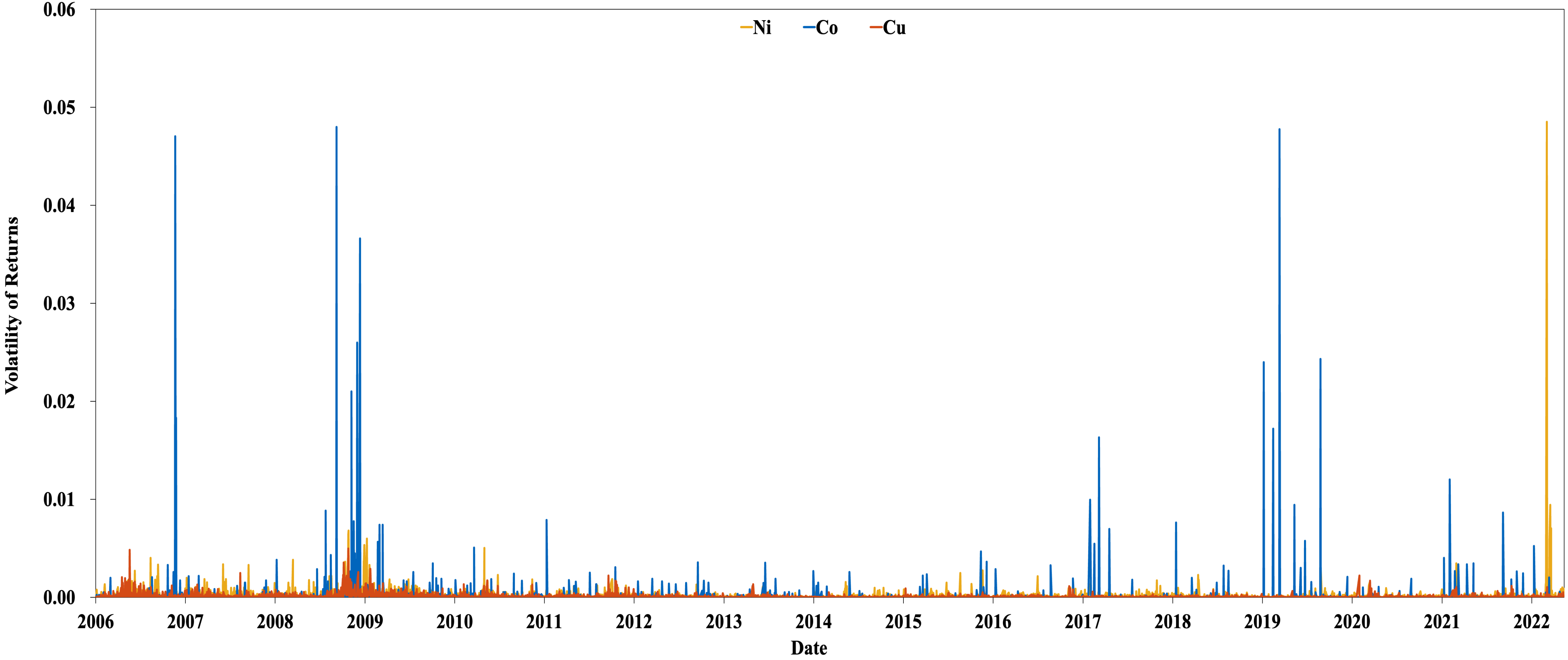


Figure 4. Time variations of volatility of returns

■ Market integration and contagion via wavelet analysis

Table 5 Wavelet scale and frequencies wavelet scales

Decomposed Components	Wavelet Scales	Frequency Bands (Days)
D_1	1	2-4 Days
D_2	2	4-8 Days
D_3	4	8-16 Days
D_4	8	16-32 Days
D_5	16	32-64 Days
D_6	32	64-128 Days
D_7	64	128-256 Days
D_8	128	256-512 Days
D_9	256	512-1024 Days

- D1 and D2 scales : short-term investment traders; D3-D4 scales : medium-term investors; D5-D7 scales institutional investors with a long-term focus

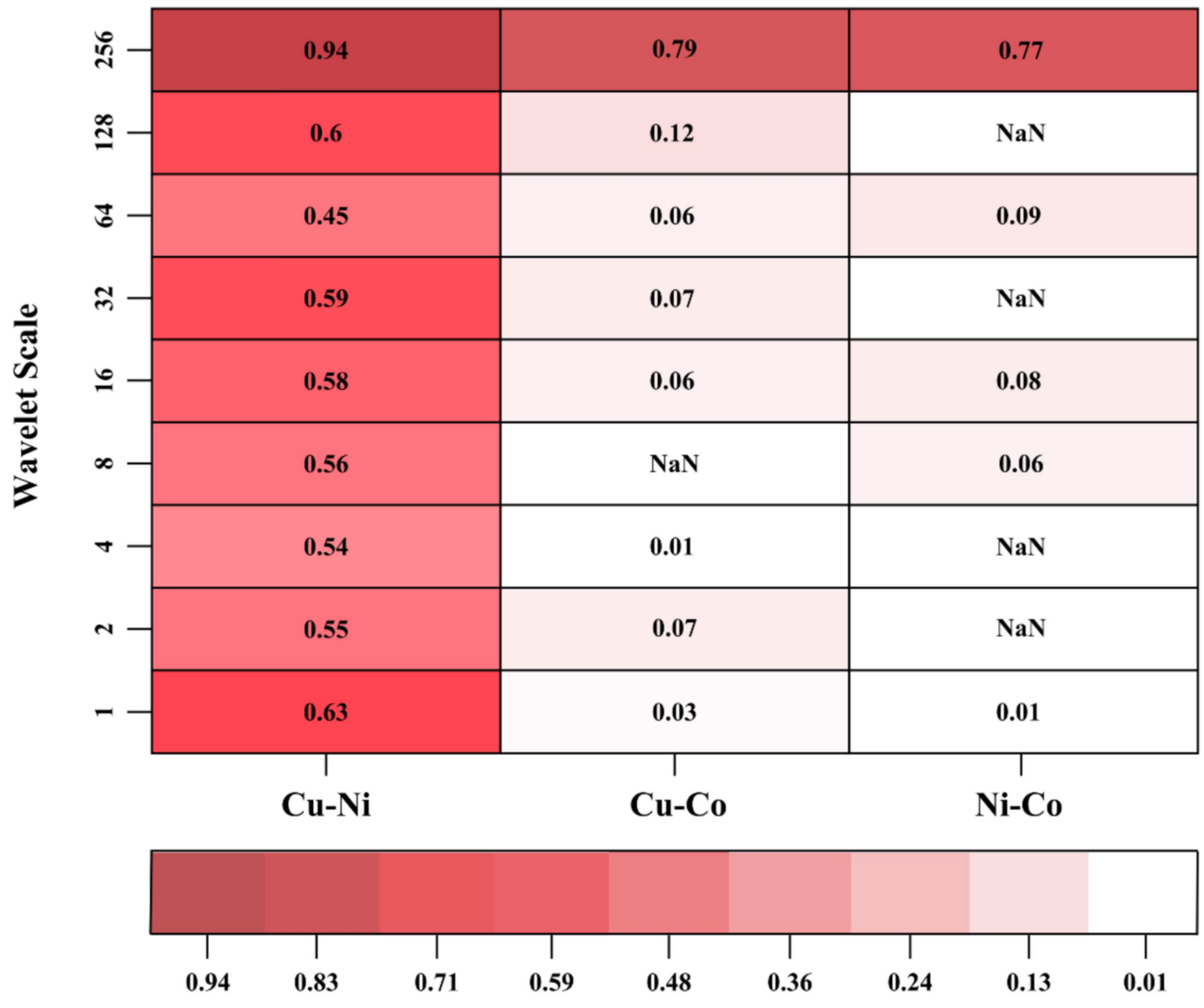


Figure 5. Wavelet Correlation Matrix

- ✓ **Copper and nickel is the most correlated market**
- ✓ **Cu-Co and Ni-Co do not show correlation at high frequencies**
- ✓ **Markets are correlated differently on different time scales**

✓ **The possibility of integration of the copper-cobalt-nickel market.**

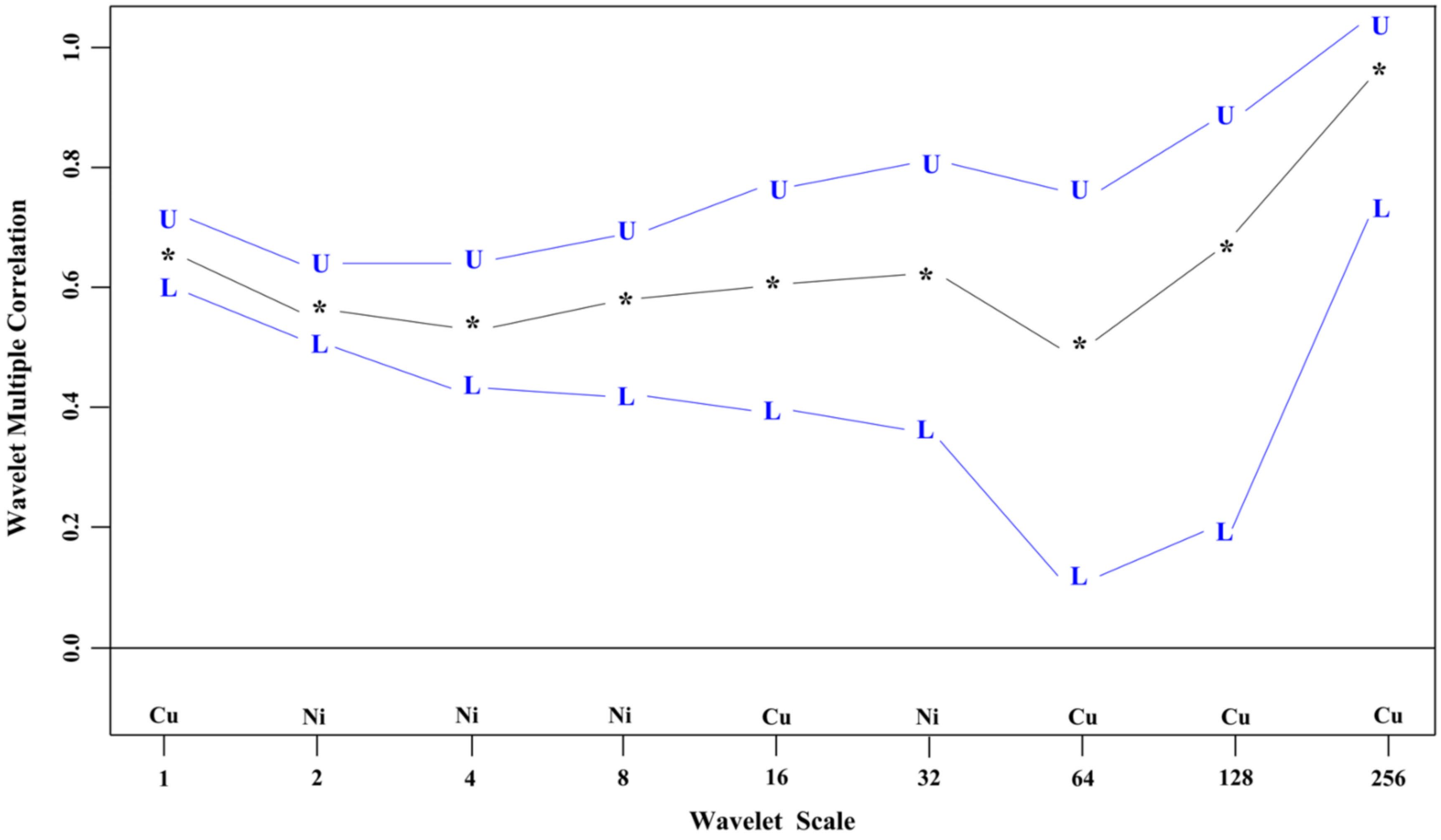
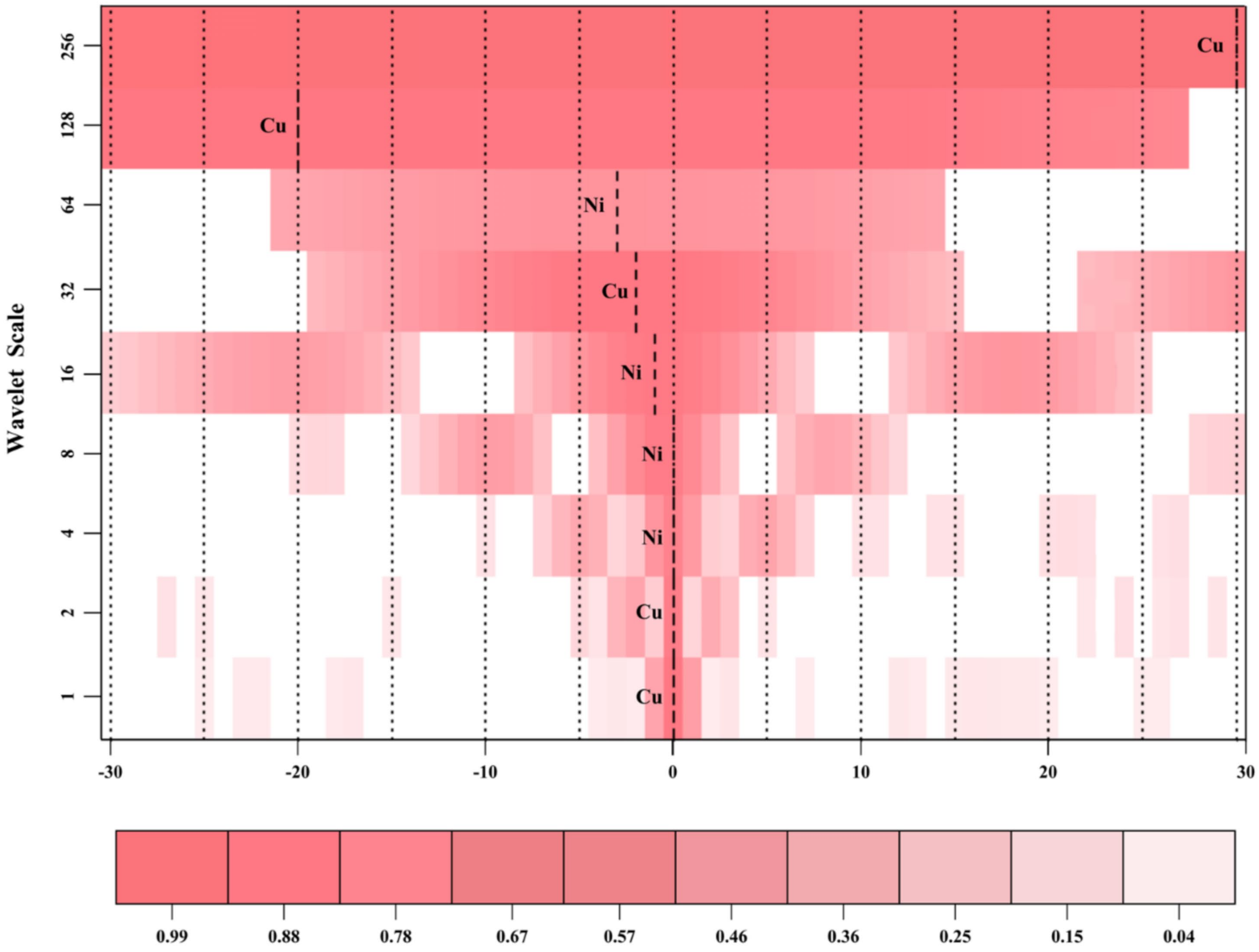


Figure 6. Wavelet Multiple Correlation.

Note: Blue lines highlight lower and upper bound at 95% confidence interval



✓ **Copper and nickel are in the leading position in all frequencies in each of the three markets.**

Figure 7. Wavelet Multiple Cross-Correlation.

Note: For each wavelet correlation value in the above figure, the significance is at 95% confidence interval.

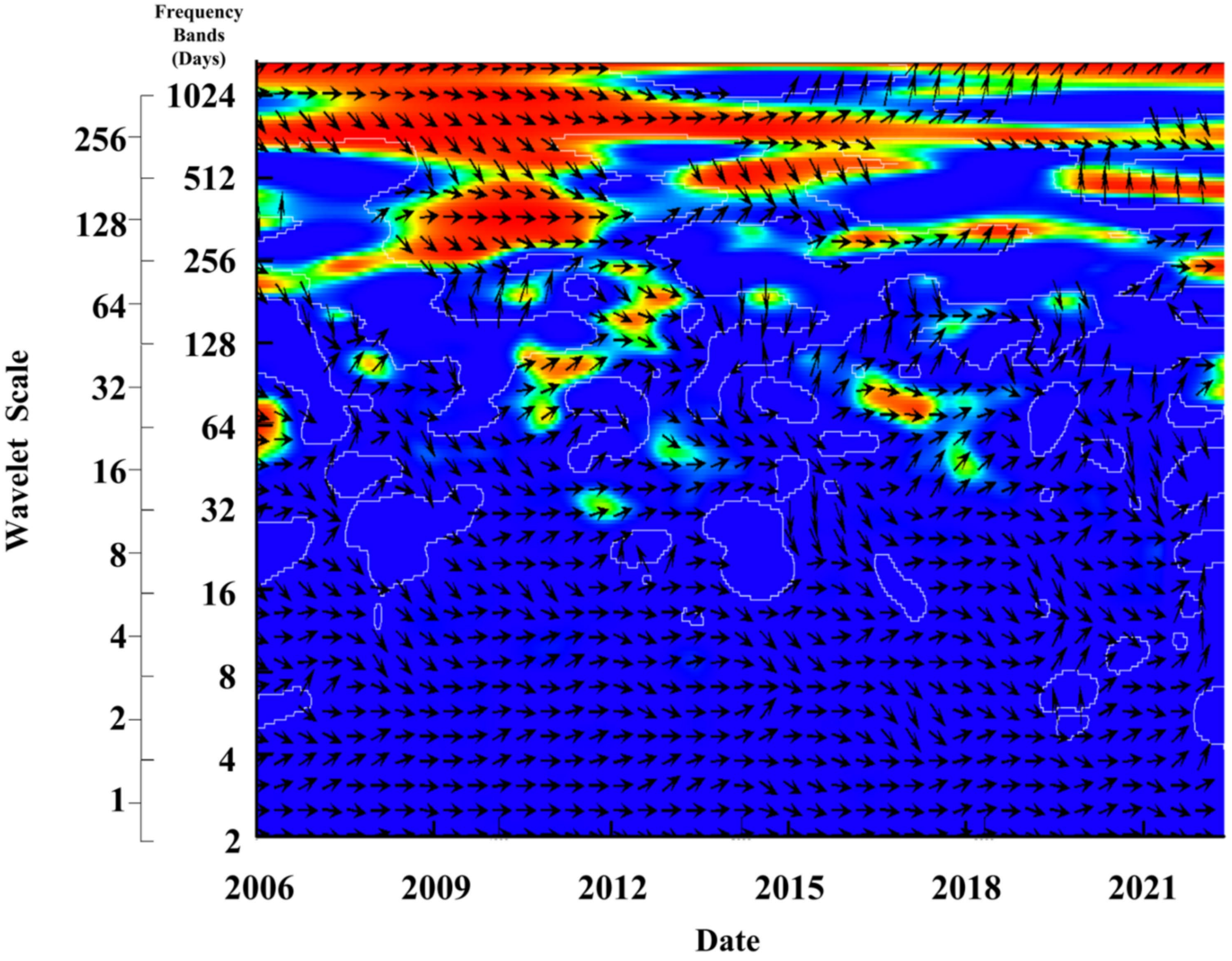


Figure 8. Wavelet Coherence between copper and nickel markets

- ✓ **Not strongly coherent at high frequencies**
- ✓ **The frequency of 64 days, the shorter time periods around 2006, around 2011, and 2016-2018 show significant co-movement.**

Note: Figure The direction of black arrows highlights phase difference between two markets. The direction of arrow towards right highlight that the variables are in-phase (both markets move in the same direction) whereas their direction towards left indicate that the variables are out-of-phase (both markets move in inverse direction). The directions of arrows highlighting leading and lagging relationships are as follows. (→) = variables are in-phase (i.e., cyclical effect on each other); (←) = variables are out-of-phase (anti-cyclical effect). () or ()= first market is leading; () or ()= first market is lagging. The horizontal axis presents timeline whereas vertical axis highlights frequency in terms of days. Red color indicates the presence of strong coherence between primary and by(co)-product metal markets.

- ✓ The copper and cobalt do not show significant co-movement at high-frequency time scale
- ✓ Only at low-frequency time scale show significant co-movement

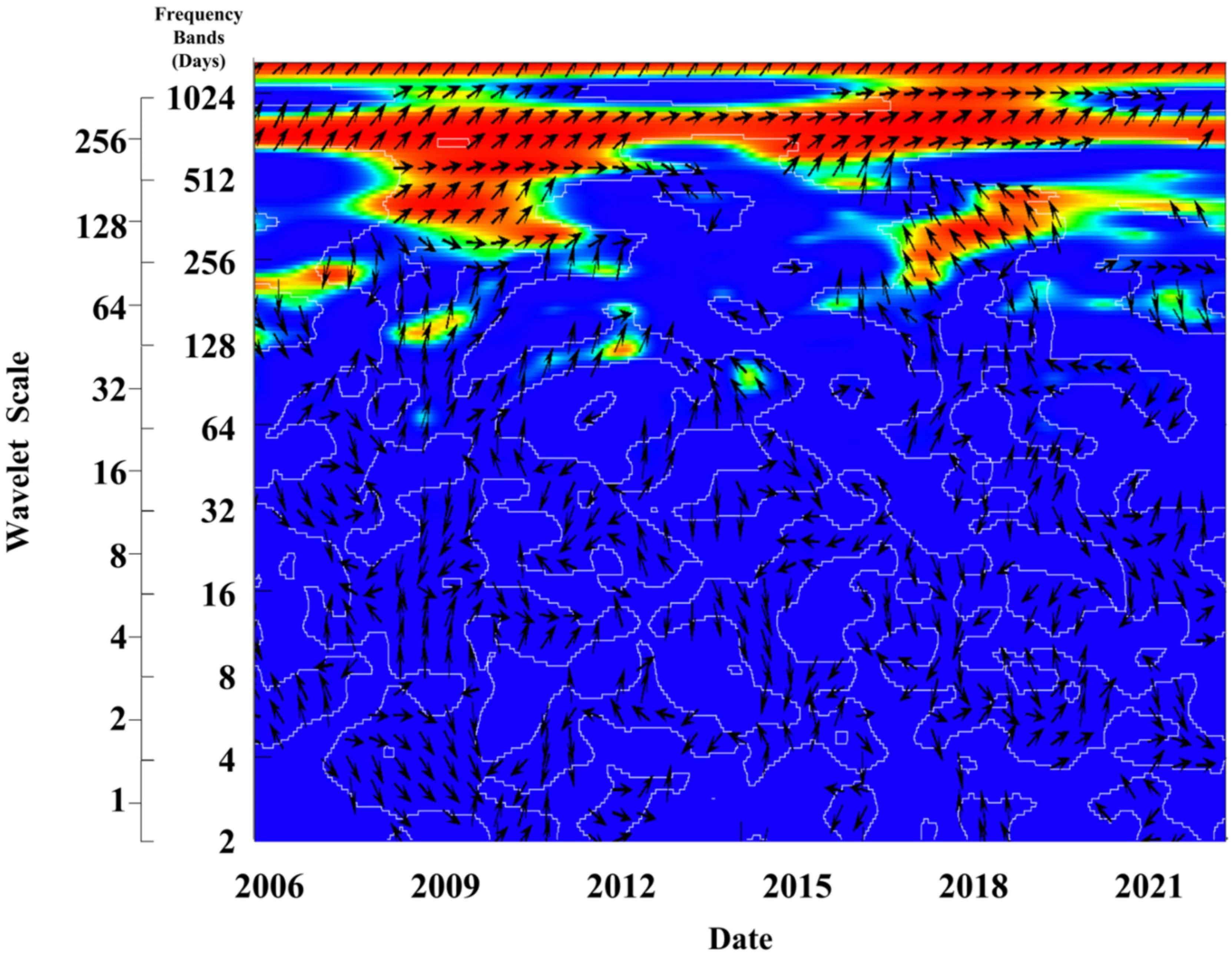


Figure 9. Wavelet Coherence between copper and cobalt markets

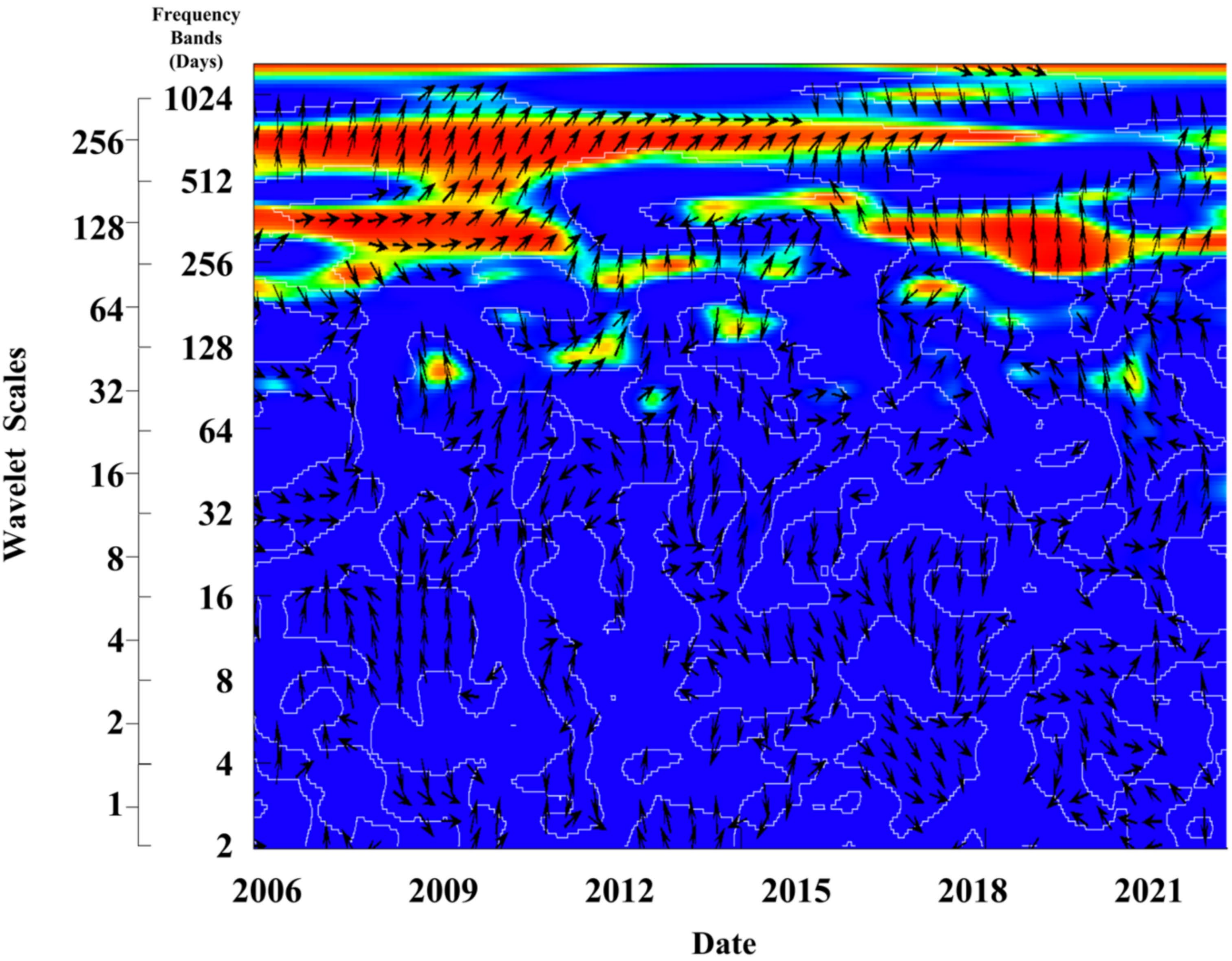


Figure 10. Wavelet Coherence between nickel and cobalt markets

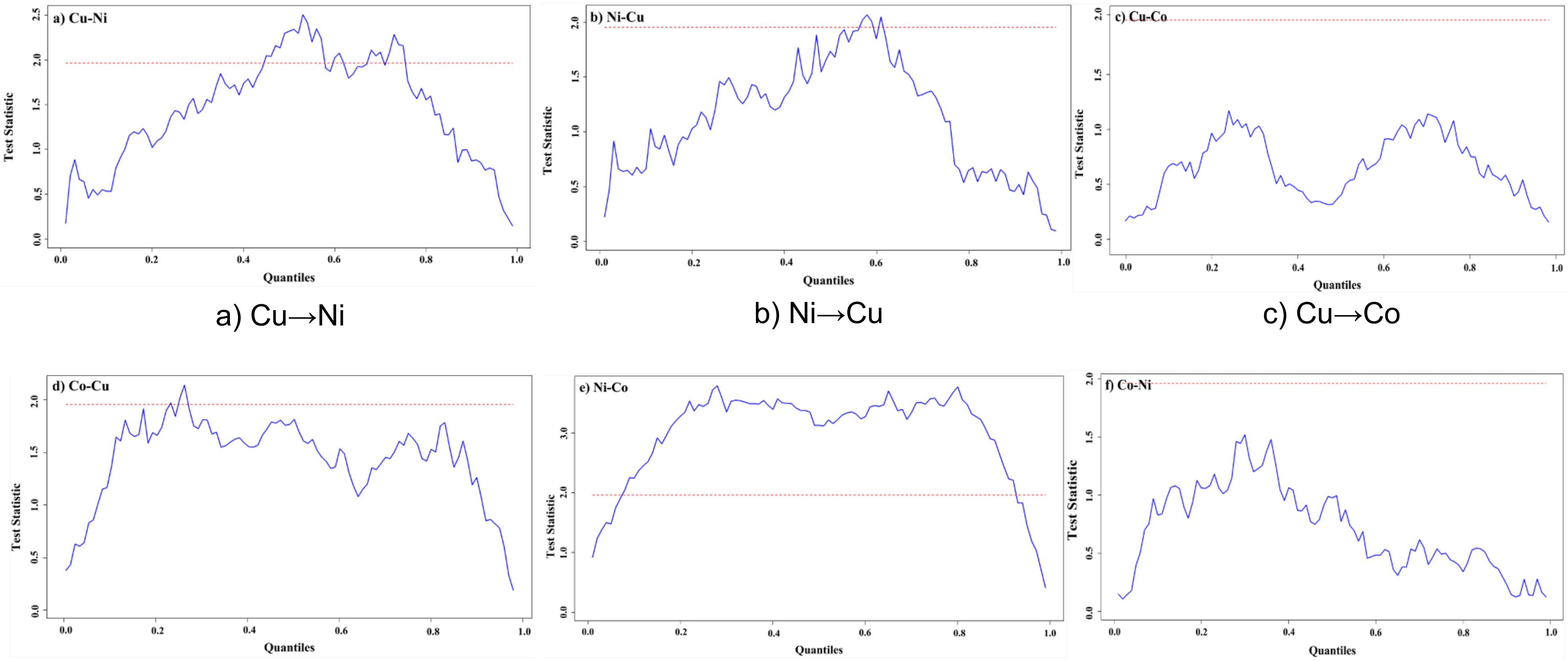
- ✓ Nickel and cobalt markets do not show significant co-movement at high-frequency time scale
- ✓ Significant co-movement mainly at low-frequency time scale

The influence of new energy market on the spillover effect of copper, cobalt and nickel market

Table 6 The linear Granger causality test results for the new energy vehicle index on the connectedness between copper, cobalt, and nickel metal markets.

H_0	lag									
	1	2	3	4	5	6	7	8	9	10
Cu-Ni										
Total spillover	6.474*	11.211***								
Spillover from Cu to Ni	5.520*	10.674***								
Spillover from Ni to Cu	7.142**	11.259***								
Cu -Co										
Total spillover	0.282	0.163	2.342							
Spillover from Cu to Co	0.070	0.250	1.071	0.845	0.948	1.155	0.981	1.038	1.36	2.252*
Spillover from Co to Cu	0.298									
Ni - Co										
Total spillover	4.203*	3.952*								
Spillover from Ni to Co	5.914*	7.067***								
Spillover from Co to Ni	1.451	0.835								

*Note: * stands for significance at 10% level, ** stands for significance at 5% level, *** stands for significance at 1% level.*



a) Cu→Ni   b) Ni→Cu   c) Cu→Co

d)Co→Cu   e)Ni→Co   f)Co→Ni

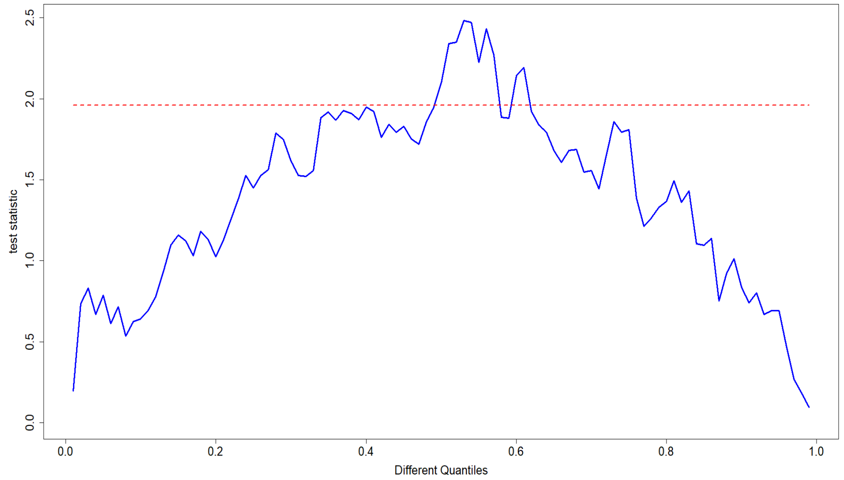
Figure11. Causality-in-quantiles test for the new energy vehicle market on the spillover.

- Robust test

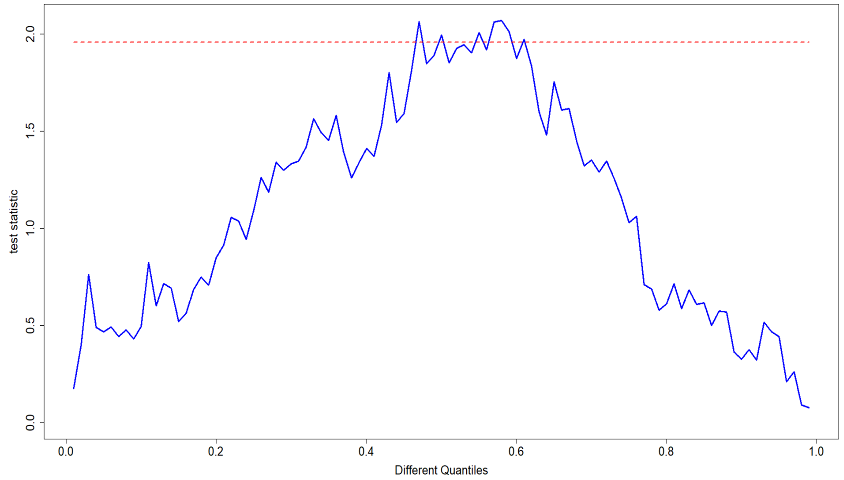
Table 7 The linear Granger causality test results for the new energy index on the connectedness between copper, cobalt, and nickel metal markets.

H_0	lag									
	1	2	3	4	5	6	7	8	9	10
Cu-Ni										
Total	2.542	9.536***								
Cu→Ni	1.772	9.467***								
Ni→Cu	3.266	9.225***								
Cu-Co										
Total	0.045	0.228	2.789*	2.112	2.088	2.270*	1.950	2.001*	2.136*	
Cu→Co	0.282	1.235	1.723	1.524	1.398	1.561	1.337	1.341	1.578	2.283*
Co→Cu	0.000									
Ni-Co										
Total	2.682	3.306*								
Ni→Co	4.663*	6.686**								
Co→Ni	1.99	0.998								

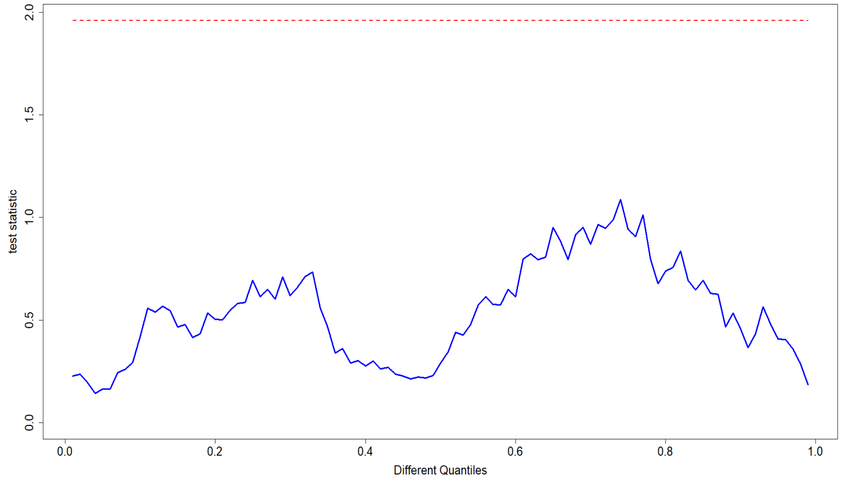
*Note: * stands for significance at 10% level, ** stands for significance at 5% level, *** stands for significance at 1% level.*



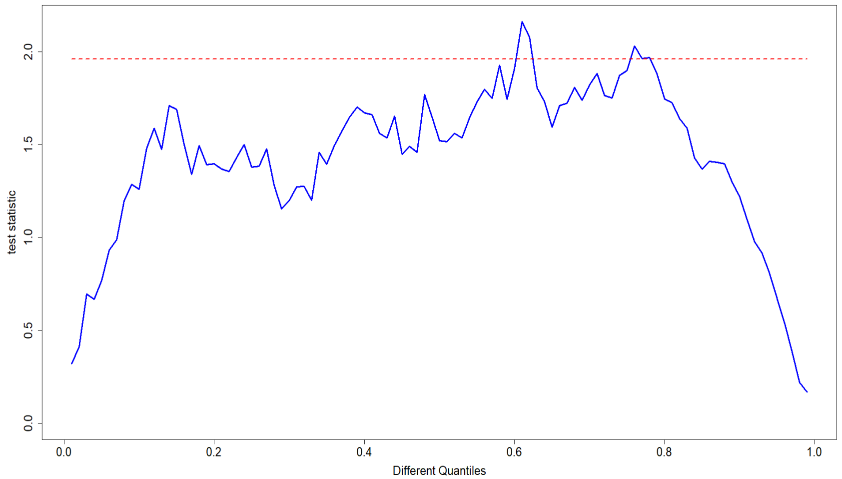
a) Cu→Ni



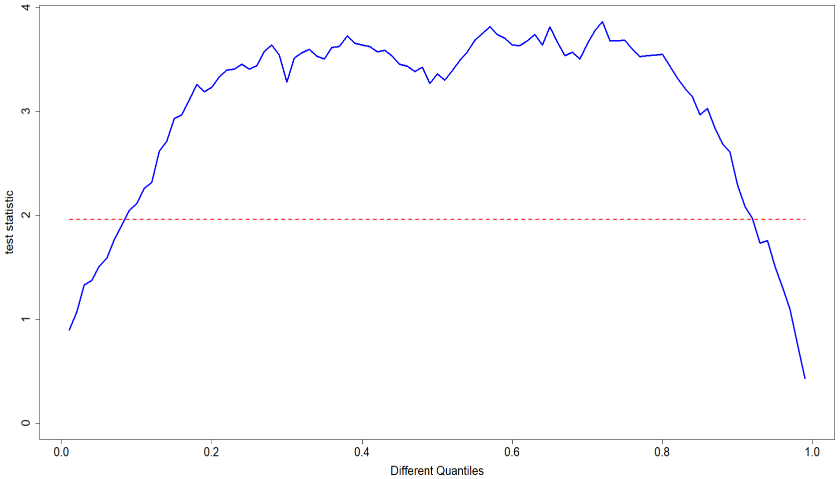
b) Ni→Cu



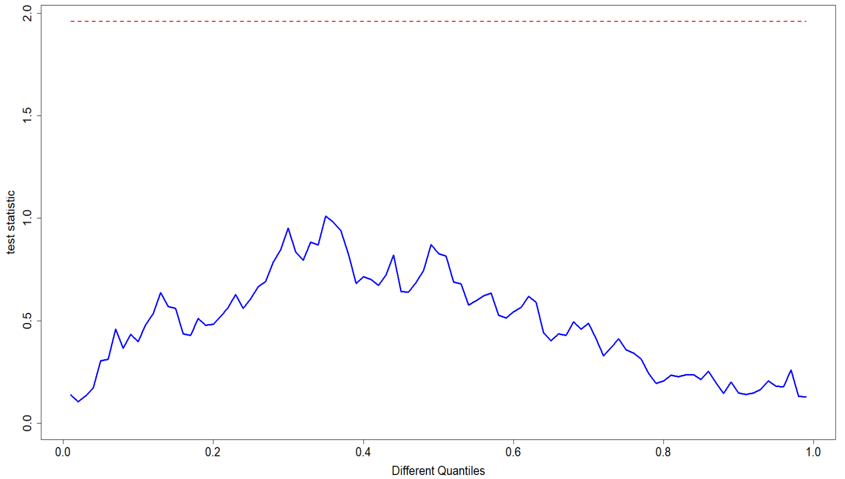
c) Cu→Co



d)Co→Cu



e)Ni→Co



f)Co→Ni

Figure 12. Causality-in-quantiles test for the new energy market on the spillover

Outline

① The results from the DY spillover index found that copper makes the largest contribution to risk in the other two markets and cobalt makes the smallest contribution to risk in the other markets, in addition to cobalt being a net recipient of shocks in the other markets, while copper and nickel are net contributors.

② Wavelet correlation analysis found that copper and nickel were highly correlated at all time scales, while cobalt was only correlated with copper and nickel at long-term time scales.

③ Wavelet coherence analysis reveals that significant wavelet coherence and co-movement exist between the three markets only at low-frequency time scale over the most of the time period.

④ The NEVs market will have an impact on the copper-cobalt-nickel price spillover effect.

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THANKS