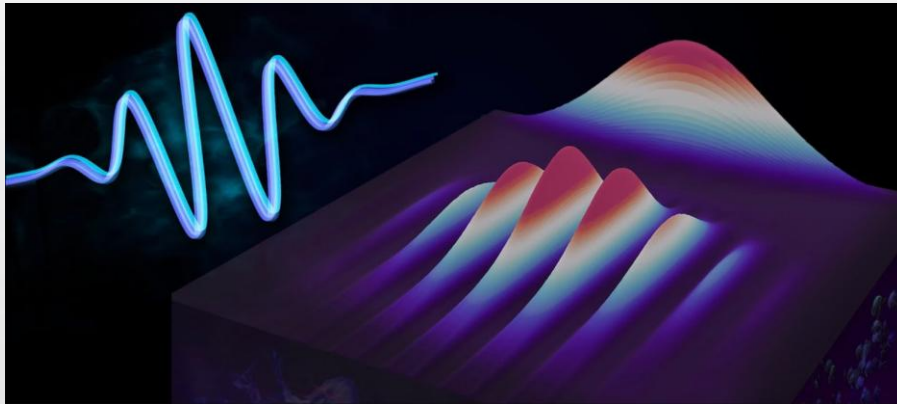# INTERDEPENDENCE BETWEEN INDIAN FINANCIAL STRESS INDEX AND GLOBAL COMMODITY PRICES: A WAVELET BASED APPROACH AND ANOMALY DETECTION

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ABSTRACT

This research examines the relationship between the **Indian Financial Stress Index (IFSI) and key global commodities (gold, silver, copper, crude oil, natural gas)** using a wavelet-based approach. Wavelet analysis effectively captures dynamic, multi-scale interactions in volatile markets. The study uses **Daubechies Discrete Wavelet Transform (DWT)** to convert monthly data into weekly frequency, with interpolation for enhanced insights.

This study uses the **Continuous Wavelet Transform (CWT) with the Morlet wavelet** to analyze the time-frequency characteristics of the Indian Financial Stress Index (IFSI) and global commodity prices. The **Cross Wavelet Transform (XWT)** identifies co-movement and lead-lag relationships, focusing on events like **2008 Global Financial Crisis and the 2020 COVID-19 pandemic**. Wavelet Coherence (WTC) assesses the strength of these relationships, while **Monte Carlo simulations** validate the robustness of the results.

Wavelet-based anomaly detection was used to identify unusual fluctuations in commodity prices relative to changes in the Indian Financial Stress Index (IFSI). Using **Daubechies (DWT),** commodity price series were decomposed into **approximation** (long-term trends) and **detail** (short-term movements) coefficients. Anomalies were flagged by defining a threshold on the detail coefficients and compared with periods of financial stress.

INTRODUCTION

- The **Indian Financial Stress Index (IFSI)** is a key indicator used to track instability in the financial system.

- **Commodity markets**, are often considered **sensitive to financial stress**.

- Traditional time-domain methods often **fail to capture evolving patterns** over time and across different frequencies.

- Therefore, this study adopts a **wavelet-based framework** to explore **time-frequency relationships** between IFSI and major commodity prices.

- This research can be used in the real world for improved **forecasting of commodity prices**, enhanced **investor decision-making,Improved Anomaly Detection** , and providing **sector-specific insights for commodity markets**.

OBJECTIVES

- **Wavelet Upsampling**: Evaluate the use of wavelet decomposition to convert monthly financial data into weekly frequency for **more detailed time-series insights**.

- **Wavelet Coherence Analysis**: Analyze the **co-movements and lead-lag relationships** between global commodity prices (gold, silver, copper, crude oil, natural gas) and the Indian Financial Stress Index (IFSI) using wavelets also validate our results using **Monte Carlo simulations**

- **Anomaly Detection**: Identify abnormal trends, patterns, or shocks in financial time series by analyzing **wavelet detail coefficients** and comparing them with **periods of financial stress.**

LITERATURE REVIEW

Wavelet Applications in Finance and Commodities:
- Armah et al. (2022), Ferrer et al. (2018), Aguiar-Conraria & Soares (2011), and Karamati & Belhassine (2022) explore the use of wavelet analysis in examining financial and commodity market dynamics.

Financial Stress Transmission and Economic Impacts:
- Aboura & Van Roye (2017), Dovern & Van Roye (2014), and Hubrich & Tetlow (2015) investigate the transmission of financial stress and its macroeconomic consequences.

**Financialization, Commodity Markets, and Volatility:**
- Cheng & Xiong (2014), Das et al. (2018), and Umar et al. (2021) focus on the role of financialization in commodity markets, with particular attention to volatility patterns.

Methodological and Technical Contributions:
- Agrapart & Batailly(2020), Gençay et al. (2001), and Roesch et al. (2014) provide key methodological advancements and technical foundations for the use of wavelet analysis in economics and finance.

LITERATURE REVIEW

Figure 2. Wavelet coherence of NFCI and global commodities prices.
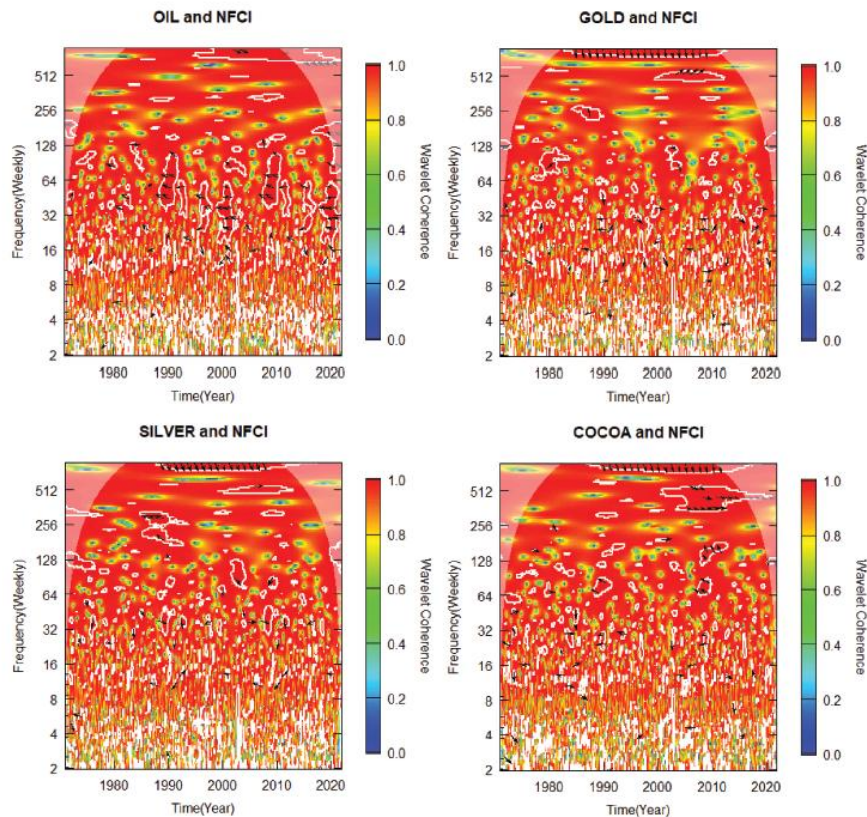
DATA–PREPARATION

- **IFSI Data**: Monthly IFSI data (Jan 2006–Aug 2023) sourced from Asian Regional Integration Center (ARIC)

- **Frequency Conversion Attempt**: Tried converting IFSI to weekly using DWT (Daubechies), but results misaligned,retained monthly frequency to preserve data integrity.

- **Commodity Data**: Daily spot prices for gold, silver, copper, crude oil, and natural gas from Multi Commodity Exchange (MCX) (Jan 2006–Aug 2023), excluding non-trading days.

- **Data Aggregation**: Daily MCX prices converted to monthly values using the **median method** to align with IFSI data.

- **Anomaly Detection**: Used **monthly median-aggregated data** for identifying price anomalies in commodities.
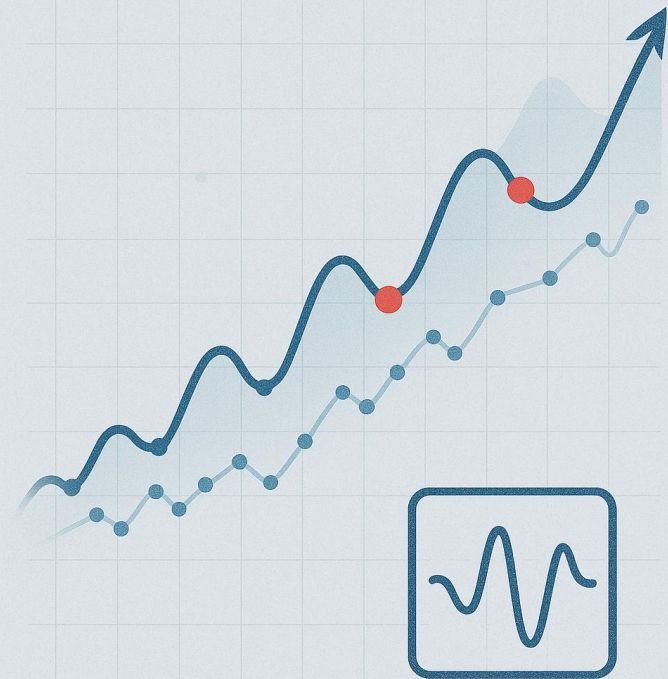
UPSAMPLING

FROM MONTHLY
TO WEEKLY

01

UPSAMPLING

UPSAMPLING ANALYSIS

01   Wavelet based upsampling   Discrete Wavelet Transform (DWT) was used to convert monthly data into higher-frequency components.

02   Cubic Spline Interpolation   Cubic spline interpolation is used to generate smooth, realistic curves from coarse or sparse data ideal for weekly upsampling from monthly time series.

DAUBECHIES WAVELET

Daubechies Wavelet

A family of orthogonal wavelets characterized by maximum vanishing moments for a given support length which is ideal for analyzing non-stationary signals with sharp changes or discontinuities.

Why Daubechies?

- Captures both **long-term trends** (approximation) and **short-term fluctuations** (detail).
- Powerful for **denoising**, **compression**, and **multi-resolution analysis**.
- Suitable for **economic and financial signals** with abrupt shifts (e.g., financial stress indicators).

Use:

- Apply **Discrete Wavelet Transform** on **monthly FSI** to:
    - Decompose signal into **approximation & detail coefficients**
    - **Denoise** and **enhance resolution** for interpolation
- Enable **multi-scale analysis** of financial stress
- Support further **reconstruction** via **inverse DWT (IDWT)** for refined time series

RESULT

Wavelet-Based Upsampling: Monthly to Weekly FSI

Upsampling FSI with wavelets-1
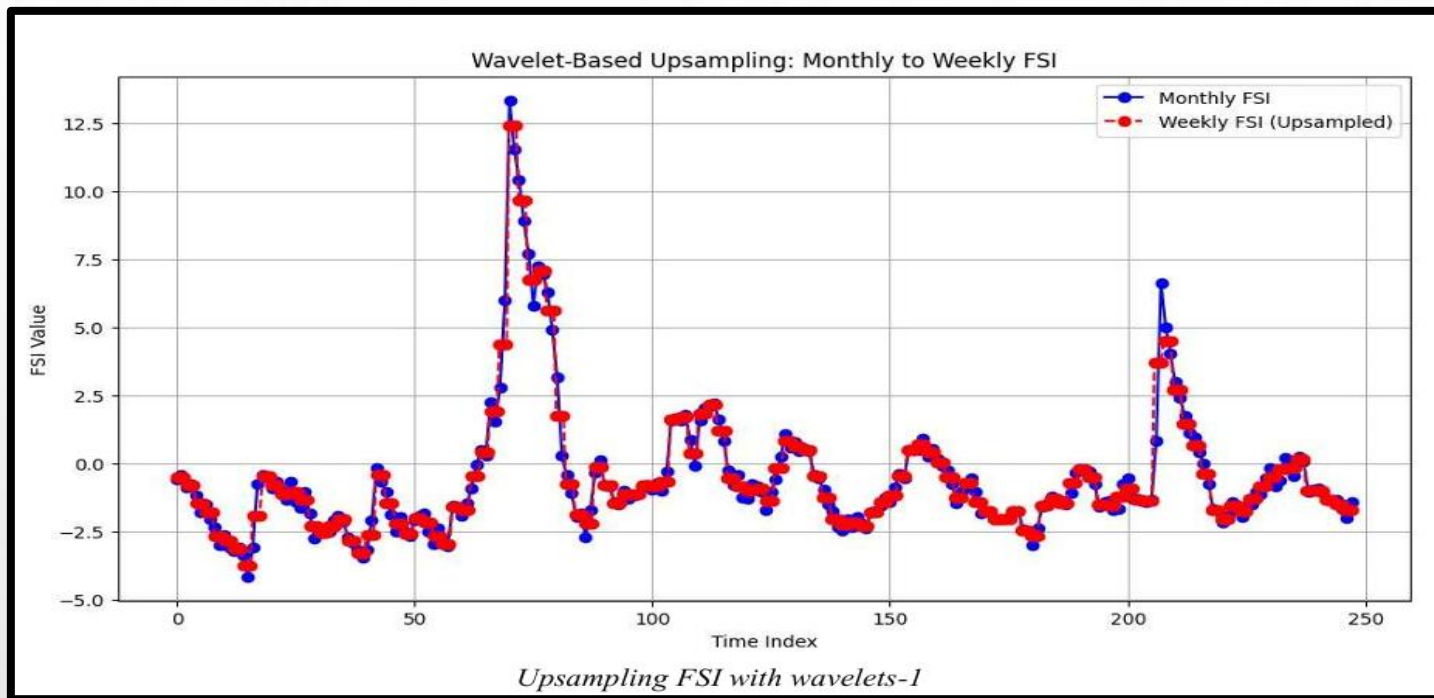
RESULT
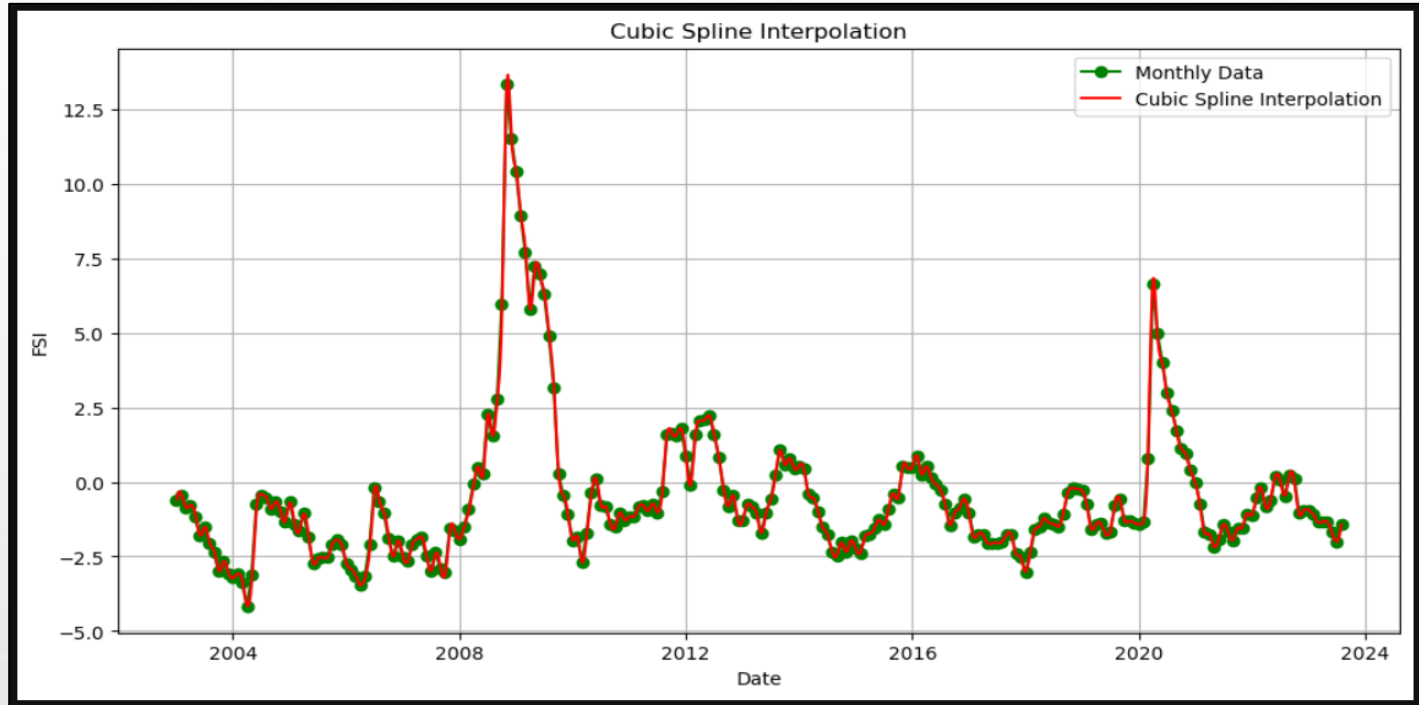
O2

LEAD/LAG RELATIONSHIP

MORLET WAVELET

Morlet Wavelet:

- A complex wavelet combining a sinusoidal wave with a Gaussian envelope

$$\psi(t) = \pi^{-1/4} \cdot e^{i\omega_0 t} \cdot e^{-t^2/2}$$

ω_0: Central frequency

$e^{i\omega_0 t}$: Complex sine wave

$e^{-t^2/2}$: Gaussian window for time localisation

why morlet?

- Balances time and frequency localisation.
- Captures both short-term shocks and long-term trends.
- Perfect for analysing financial stress (FSI) with commodity prices.

Use:

- Transform time series (FSI & Prices) into time-frequency domain.
- Compute wavelet coherence to detect:
    - Strength of relationship (coherence)
    - Direction of relationship (phase angle)

LEAD/LAG RELATIONSHIP ANALYSIS

01 Continuous Wavelet Transform (CWT) using Morlet Wavelet — Used biwavelet package in R to decompose IFSI & Commodity prices

02 Cross-Wavelet Transform (XWT) and Cross-Wavelet Power Spectrum — To understand the periods of co-movements between both the time series

03 Wavelet Coherence (WTC) Analysis — To find the coherence i.e value of R (0 to 1)

04 Phase Difference Calculation and Interpretation of Lead-Lag Dynamics — To interpret directional causality, using phase arrows

05 Monte Carlo Significance Testing and Visualisation — To validate the robustness of detected patterns(Los=5%), and visualized findings using cross-wavelet power spectrum

Wavelet Coherence: FSI vs Gold
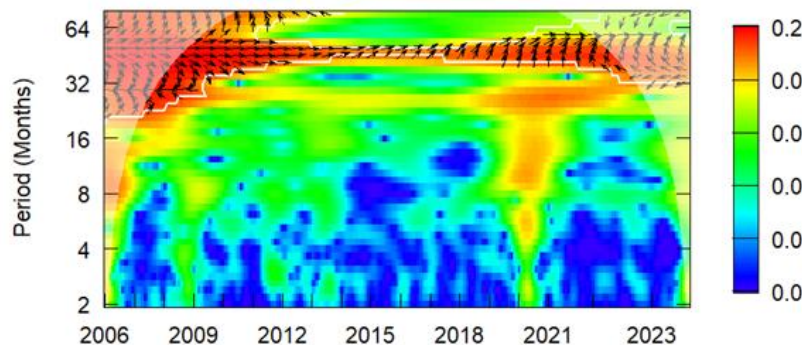
- **X-axis** = Time (years:2006-2023)
- **Y-axis** = Period (in months)

● = Low coherence

● = Moderate coherence

● = High coherence

- ○ → : In phase (move together).
- ○ ← : Anti-phase (move opposite.
- ○ ↗ or ↘ : Lead-lag relationships

2006–2009: Over the multi-year cycle, gold and financial stress rose together—when stress spiked, people bought gold as a safe haven.

2010–2013: On one- to two-year horizons, they were somewhat linked but mixed—sometimes gold jumped first (as fears built), sometimes stress did—thanks to Europe's debt woes and India's import rules.

2014–2017: The connection almost disappeared; domestic reforms like GST and demonetisation meant gold and stress moved largely on their own.

2018–2020: They re-coupled moderately over one- to five-year spans, with gold often leading when U.S.–China trade tensions flared.

2020–2021: During the pandemic shock, they moved almost in lockstep over long cycles—stress and gold rose together as Covid hit.

2022–2023: The link weakened again and became mixed, as interest-rate hikes and inflation pressures drove gold in new directions.

Wavelet Coherence: FSI vs Silver
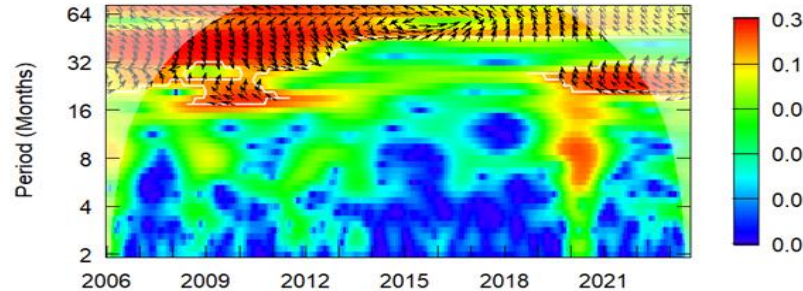
Silver's Dual Role: Period-by-Period

2006–2009 (32–64 m, strong red coherence, →↓ arrows) – Silver moved in-phase with FSI (FSI → silver), behaving as a safe-haven alongside gold during the global financial crisis.

2010–2013 (32–64 m, high red coherence, →↓ arrows) – Continued safe-haven behavior under Euro-area debt stress and India's import curbs, with FSI spikes driving silver up.
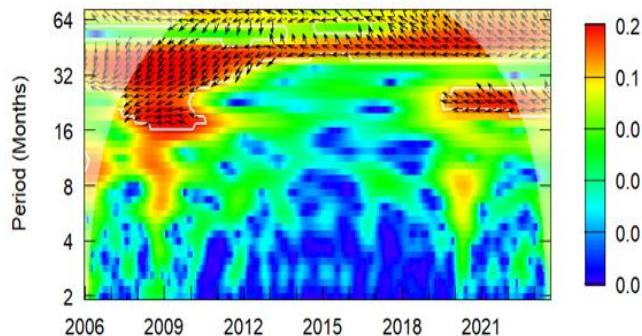
2014–2017 (8–32 m, moderate green-yellow coherence, ↗ arrows mixed with →) – Industrial demand dominated: silver price led FSI (↗) at medium scales, reflecting commodity-cycle anticipation around GST prep and global manufacturing shifts; occasional in-phase at longer scales shows minor hedge buying.

2018–2020 (16–64 m, red patches, ↗→ arrows) – A blend: NBFC liquidity worries triggered safe-haven buying (in-phase segments), but manufacturing slowdowns saw silver leading FSI (↗) on medium scales as an industrial signal.

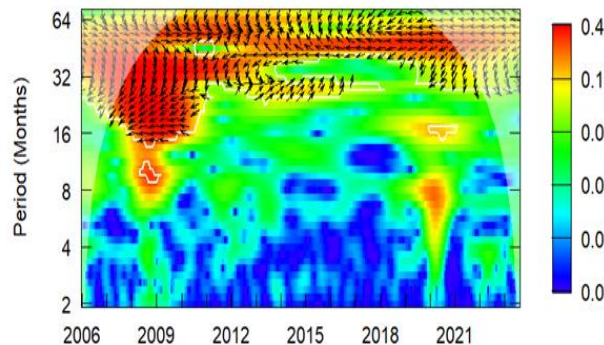**2020–2021 (long scales, strong red-orange, ↗→ arrows)** – Sharp, simultaneous in-phase moves marked pure safe-haven behavior as pandemic shock drove both stress and silver spikes together.

2022–2023 (all scales, weak blue-green coherence, sparse mixed arrows) – Decoupling: industrial normalization after Covid and shifting inflation/FX dynamics meant silver no longer tracked stress closely, acting neither a clear hedge nor pure industrial bellwether.
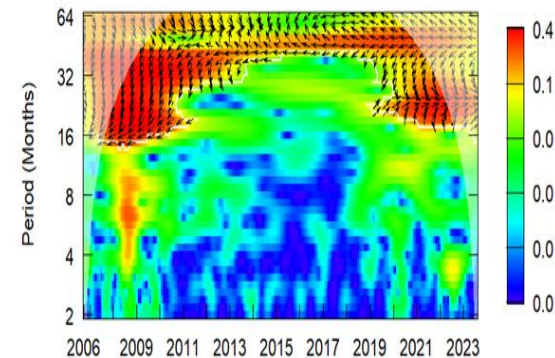
Wavelet Coherence: FSI vs Copper — Wavelet Coherence: FSI vs Crude Oil — Wavelet Coherence: FSI vs Natural Gas

2006–2009 (long term 32–64 m, strong red-orange coherence, ←↓ arrows)** – FSI's global-crisis spikes led sharp downturns in copper, oil and gas as industrial demand collapsed.

2010–2013 (long term 32–64 m, strong red coherence, ← arrows)** – As FSI eased post-crisis, commodities rebounded inversely; FSI dips preceded copper/oil/gas rallies at multi-year scales.

2014–2017: There was too much oil, gas and copper on the market (thanks to U.S. shale and small OPEC cuts), and India's big reforms (GST, demonetisation) slowed industry. So when financial stress rose, commodity prices fell a few months later.

2018–2020: U.S.–China trade tensions and India's NBFC troubles hurt manufacturing. Copper and energy prices dipped before stress spiked, meaning the commodities led the stress.

2020–2021: Massive stimulus after the Covid crash drove copper, oil and gas prices back up first. Financial stress eased afterward, so again commodities moved before the stress indicator.

2022–2023: The Ukraine war sent gas prices and stress up together briefly, but oil and copper mostly fell when stress rose—and rose when stress eased—so the link was mixed and event-driven.

03
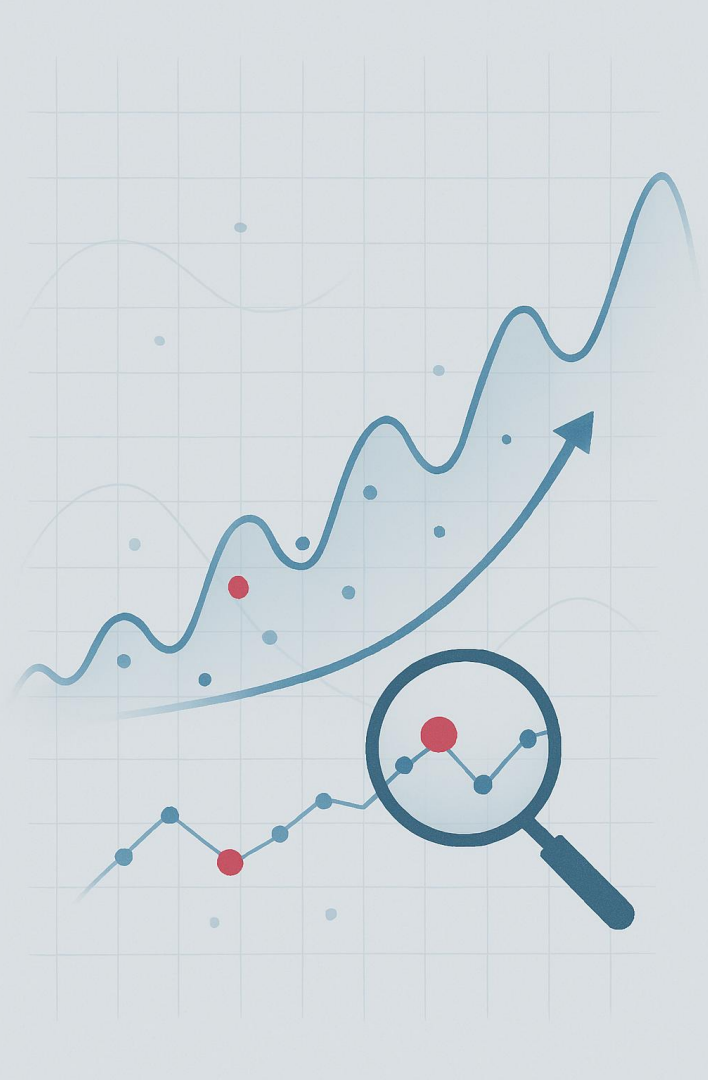
ANOMALY DETECTION

ANOMALY ANALYSIS

01	Anomaly Detection	To identify sudden fluctuations, unusual trading, and disruptions,,
02	Wavelet Transform	To isolate irregular movements from the overall trend.
03	Daubechies 4 (db4)	To highlight **high-frequency variations** (sudden price jumps/drops).
04	Rolling Mean Deviation	To calculate a **52-week rolling average** and **absolute deviation** between actual prices and the rolling mean.
05	Threshold	Flagged anomalies where |**z-score**| **> 2** Flagged anomalies where deviation exceeded **2 times the mean deviation**,

6.3.1 Gold
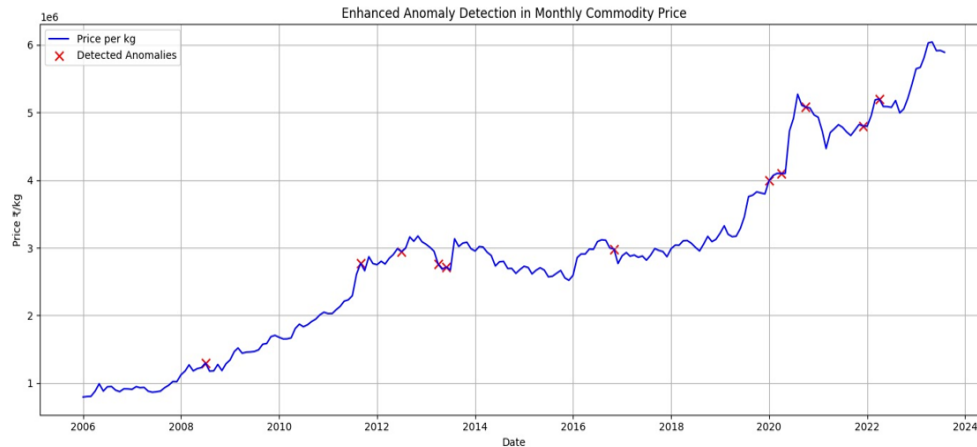
Fig.8-Anomaly detection in Gold Price

- **2006–2009: You see one big jump around 2008–09 when the global crash hit—people rushed into gold as a safe bet.**

- **2010–2013: A few bumps in 2011–12 during Europe's debt troubles and India's import-duty changes—gold popped above its normal trend.**

- **2014–2017: A small spike in late 2016 around demonetisation—cash-ban worries drove a short gold rush.**

- **2018–2020: Almost flat until early 2020, when the first Covid fears nudged gold higher before the full lockdown surge.**

- **2020–2021: Several big waves as pandemic panic and supply delays sent gold prices up in bursts.**

- **2022–2023: A few sharp moves when the Russia–Ukraine war heated up, but otherwise gold stuck closer to its usual path.**
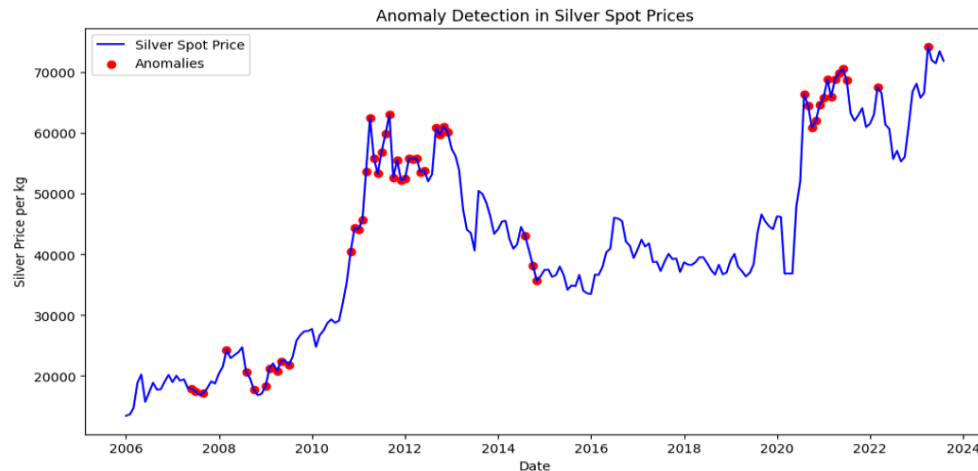
6.3.2 Silver

Fig.10-Anomaly detection in Silver_Price

- **2006–2009: Silver jumped a couple of times in 2008 along with gold as investors sought safety.**

- **2010–2013: More sharp spikes in 2011–12 from the same debt-crisis fear and import-duty shifts.**

- **2014–2017: Minor blips in late 2016 (demonetisation) and early 2014 (post-taper tantrum)—sometimes driven by industry, sometimes by investors.**

- **2018–2020: Quiet until early 2020, when Covid worries gave silver a small boost.**

- **2020–2021: Lots of sudden jumps as silver bounced between panic buying and hopes for industrial recovery.**

- **2022–2023: Just a handful of outlier moves during energy-inflation scares, otherwise silver was pretty steady.**
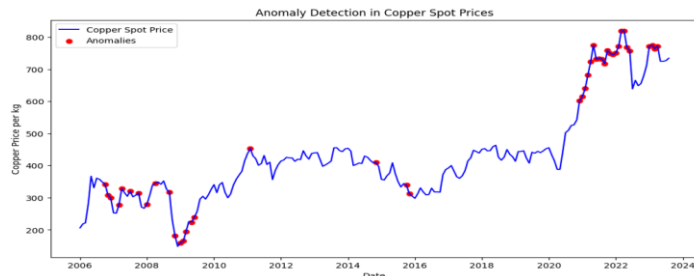
6.3.3 Copper

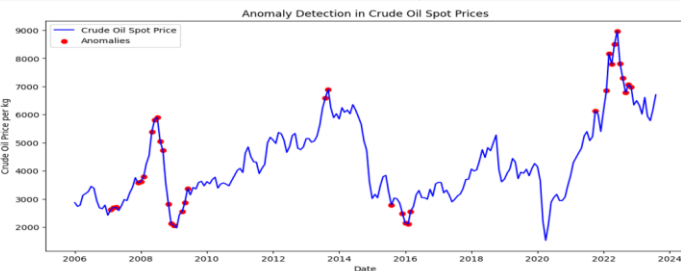Fig.12-Anomaly detection in Copper Price

6.3.4 Crude Oil

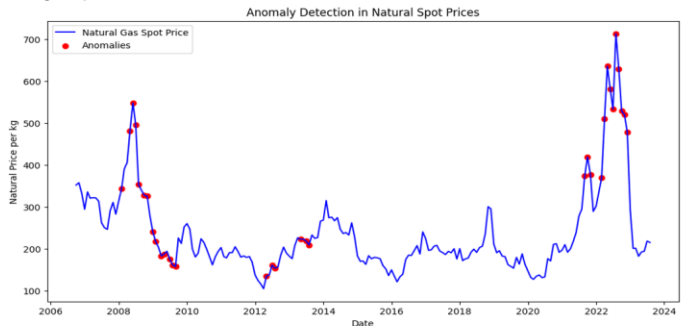Fig.14-Anomaly detection in Crude Oil_Price

6.3.5 Natural Gas

Fig.16-Anomaly detection in Natural Gas_Price

- **2006–2009: All three crashed hard in 2008 when industry froze up—clear anomalies at the financial crisis low.**

- **2010–2013: Strong rebounds in 2009–11 showed up as spikes, then quick dips when Europe's troubles resurfaced.**

- **2014–2017: A few big corrections in 2013–14 (oil glut) and 2015–16 (shale-oil slide), but mostly these kept to normal cycles.**

- **2018–2020: Quiet until early 2020, then all three dropped sharply as Covid lockdowns hit demand.**

- **2020–2021: Big synchronized surges as stimulus money and reopening boosted prices before stress eased.**

- **2022–2023: Several wild swings in 2022 from the Ukraine war and its fallout, especially in oil and gas, with copper also jumping around as markets adjusted.**

CONCLUSIONS

01

Spline Interpolation vs. Wavelet Upsampling for FSI Expansion

Spline interpolation outperformed wavelet decomposition for upsampling monthly FSI to weekly, offering smoother trends aligned with market events.
Wavelet-based upsampling remains valuable for larger or more volatile datasets due to its ability to capture multi-scale signal variations.

02

Wavelet Coherence Analysis

During financial stress, clear patterns emerge: **crude oil and Natural Gas show Strong Negative correlations with Financial Stress**, especially during the 2008 crisis and 2020 pandemic, with oil being the most reactive. Copper also shows Negative correlations, influenced by global demand. **Gold acts as a Safe-haven**, rising with stress, while **Silver shows Mixed behavior** due to its dual industrial and monetary roles

03

Anomaly Detection

Wavelet methods detected anomalies during key events (2008 GFC, 2016 Demonetization, COVID-19).**Gold and Silver rise during Financial Crises** as safe-haven assets, **Copper is driven by Manufacturing and Trade**, while **Crude Oil and Natural Gas prices are influenced by Demand-Supply dynamics and Geopolitical factors.**

LIMITATIONS

- Monthly Data Resolution: Using monthly data smooths short-term volatility but might miss quick shocks or flash crashes that occur within a month.

- Limited Commodity Scope: Only major commodities (gold, silver, copper, crude oil, natural gas) were analyzed. Other factors (like food prices, broader indexes) might also play roles during stress periods.

FUTURE SCOPE

- Extend the analysis using high-frequency (daily/intraday) data for finer insights.

- Apply alternative wavelet families or advanced time-frequency tools like Empirical Mode Decomposition (EMD).

- Develop real-time financial stress monitoring systems using wavelet-based analytics.

- Analyse policy impacts by examining shifts in wavelet coherence pre/post interventions.

- Integrate macroeconomic indicators to capture broader economic dynamics.