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INDIA GOLD POLICY CENTRE

9th IGPC-IIMA ANNUAL GOLD & GOLD MARKETS CONFERENCE 2026

Optimizing Gold ETFs as Safe Havens in Crisis-Responsive Portfolios

Integrating Wavelet Quantile Correlation Insights With Ant Colony Optimization

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Why Gold Safe-Haven Protection may Fail Investors?

Why Gold Matters During Market Stress

Indian retail investors increasingly hold gold ETFs alongside equities (SEBI, 2025).

Gold moves inversely to equities during crises, reducing portfolio losses.

Static portfolio allocations assume consistent protective behaviour.

Gold ETF leading the price discovery process of GOLD (Ivanov 2013; Dhingra et. al 2025)

Portfolio protection mechanism under stress

The Unresolved Economic Question

Literature documents short-term safe-haven effects (Baur & McDermott, 2010).

Whether protection persists across medium and long-term horizons remains unclear.

Gold ETF behaviour under prolonged stress is empirically unexamined.

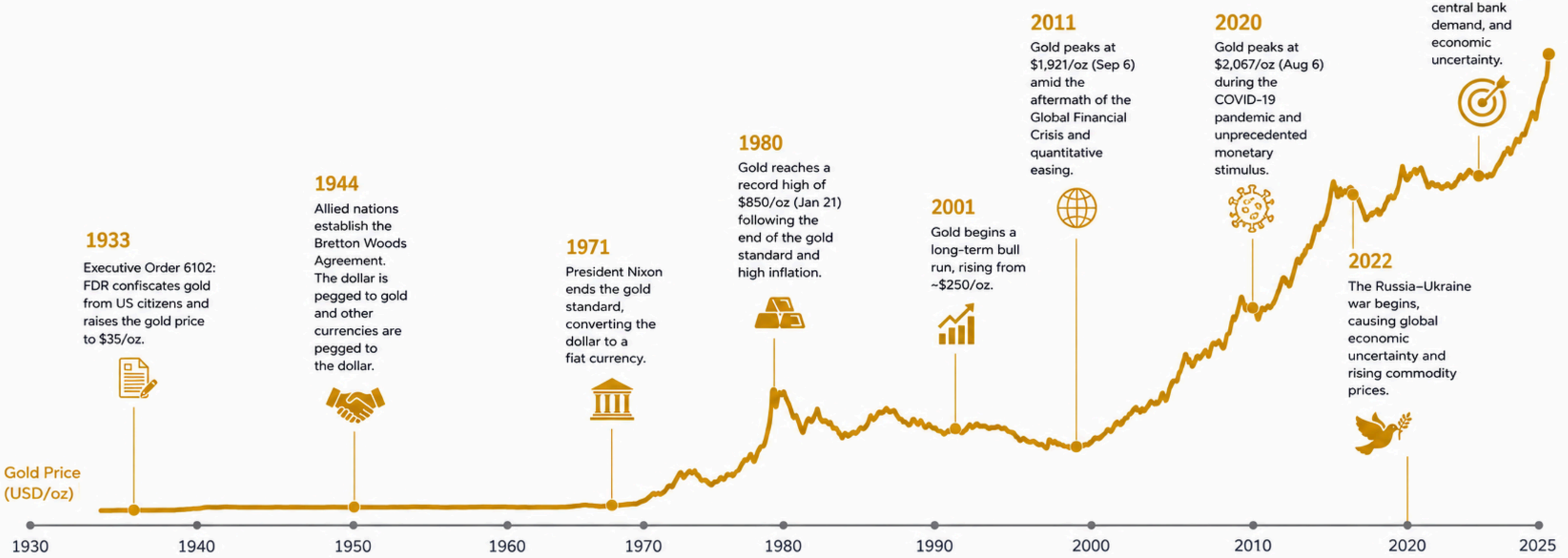
Static allocations may fail when protection deteriorates during extended downturns.

Research Questions

- **RQ1: Do gold ETFs exhibit safe haven properties across different investment horizons?**
- **RQ3: Does stress-triggered rebalancing outperform static portfolio strategies?**

A Century of Gold

Key historical events and gold price milestones over the past century.



Over the past century, gold has proven its enduring value as a store of wealth and a hedge against economic uncertainty, inflation, and geopolitical crises.

1930 Price	1980 Price	2000 Price	2010 Price	2025 Price (Apr 22)
~$20.67/oz	~$615/oz	~$279/oz	~$1,225/oz	$2,431/oz

Source: World Gold Council, MacroTrends, Federal Reserve, Historical Gold Prices | Note: Prices are in nominal USD. | Data as of April 22, 2025

Gold in Portfolio Management:

Review of Literature and Gap

Gold as Diversifier

Low to moderate correlation (0.004–0.45) with equities and bonds enhances portfolio diversification.

2.5% allocation increases Sharpe ratio ~12%; optimal range 5–20% (World Gold Council, 2024).

Gold ETFs show tracking efficiency but carry currency exposure.

(FTSE Russell, 2025; World Gold Council, 2024; Salisu et al., 2021)

Safe-Haven Dynamics

Gold acts as hedge on average, safe-haven during extreme equity downturns.

Safe-haven properties are frequency-dependent across time scales; not uniform.

Outperforms Bitcoin; protection increases during crises.

(Baur & Lucey, 2010; Kumar & Padakandla, 2022; Harvey, 2025)

Portfolio Allocation Evidence

Optimal gold allocation improves risk-adjusted returns across market regimes.

Benefit increases during stress periods; protection strengthens during market downturns.

Evidence varies by market capitalisation and time horizon.

(Wagner & Poppe, 2024; Ngene et al., 2025; Kumar et al., 2025)

Research Gap

Horizon-dependent safe-haven behaviour remains unresolved.

ETF protection effectiveness during stress underexplored in emerging markets.

Operationalising protection for investor resilience largely unexamined.

Empirical implication

Short-lived protection across horizons – **Static allocation becomes inefficient during stress** – **Dynamic rebalancing may improve resilience**

Objectives

i. To assess safe-haven properties of gold and gold ETFs across short-term, medium-term, and long-term investment horizons

ii. To develop and evaluate a frequency-informed dynamic portfolio optimization strategy

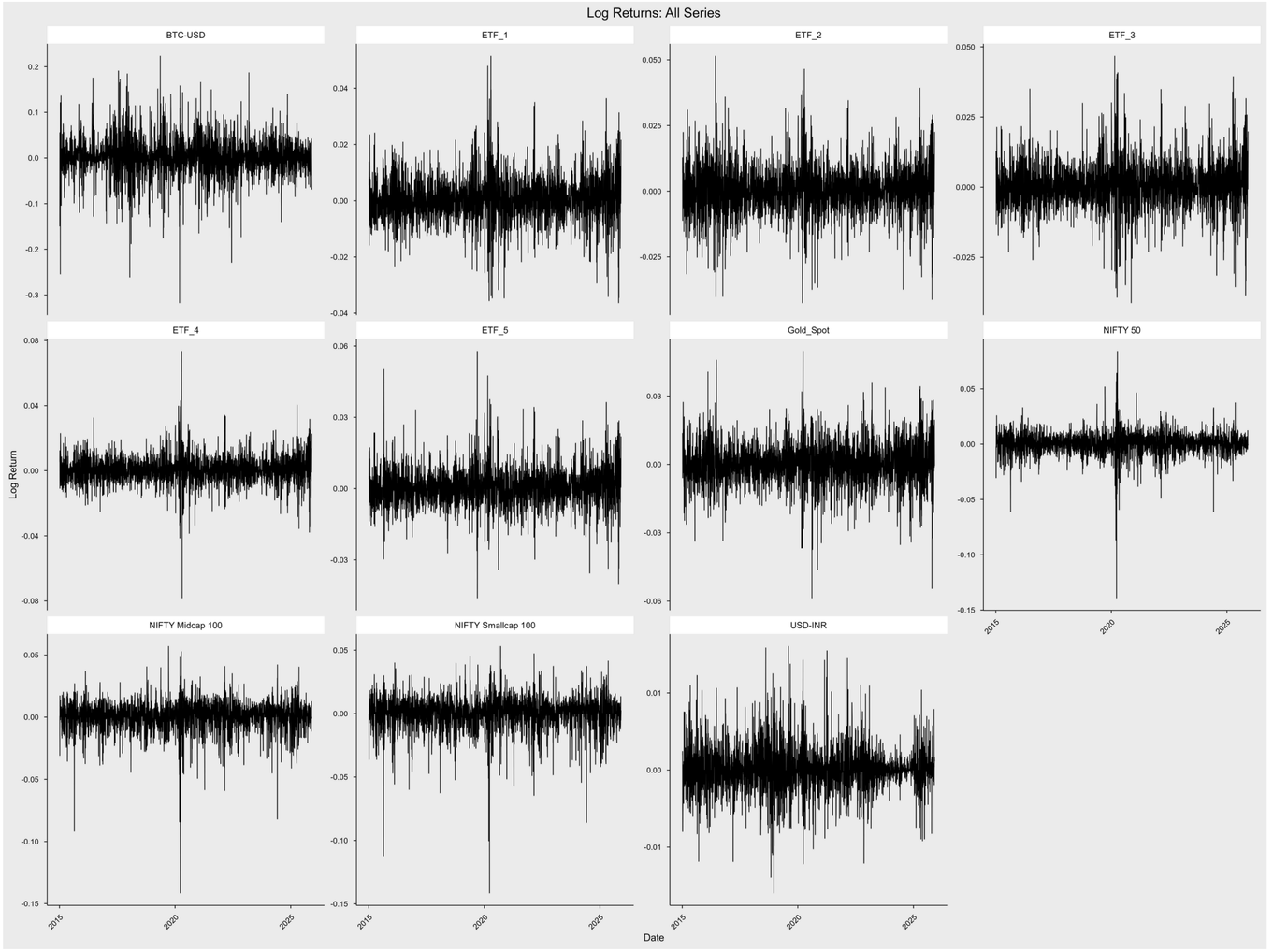
Methodology: Data

Equities: NIFTY 50, NIFTY Midcap 100, NIFTY Smallcap 100.

Gold Assets: International gold spot and five Indian gold ETFs.

Other Risk Factors: Bitcoin and USD–INR exchange rate.

Daily prices from 2015–2025 (Bloomberg) and calculated log returns



Empirical Strategy

Market Stress — Horizon Dependence — Dynamic Allocation — Portfolio Resilience

STEP 1

Tail Dependence Valida

Copula Analysis

Evaluates extreme co-movement and crisis-period tail dependence to validate horizon-dependent findings.

Salisu et al. (2021)

STEP 2

Horizon-Dependent De

Wavelet Quantile Correlati

Identifies safe-haven behaviour across short-, medium-, and long-term horizons under stressed conditions.

Kumar & Padakandla (2022)

STEP 3

Dynamic Allocation Fra

Heuristic Optimisation (AC

Adjusts gold exposure under changing stress conditions using non-linear allocation constraints.

Deng & Lin (2010)

STEP 4

Portfolio Resilience Eva

Rolling-Window Backtestin

Evaluates downside resilience and risk-adjusted returns using Sharpe ratio, Sortino ratio, and maximum drawdown.

Wagner & Poppe (2024)

Portfolio Strategies & Rebalancing

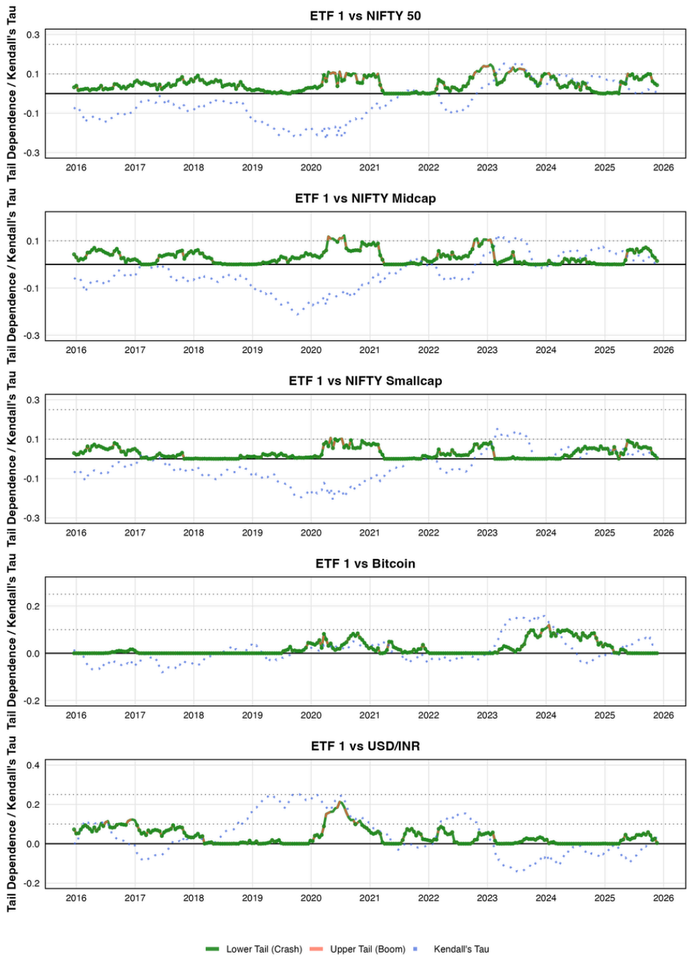
Strategy	Composition	Allocation Approach
Baseline	Equity Only (NIFTY indices)	Static
Crypto-Gold Enhanced	Equity + Gold + Bitcoin	Static
Dynamic Gold	Equity + Gold ETFs	Stress-Adaptive
Dynamic Multi-Asset	Equity + Gold + Bitcoin	Stress-Adaptive
Dynamic All-Asset	Equity + Gold + Bitcoin + USD-INR	Stress-Adaptive

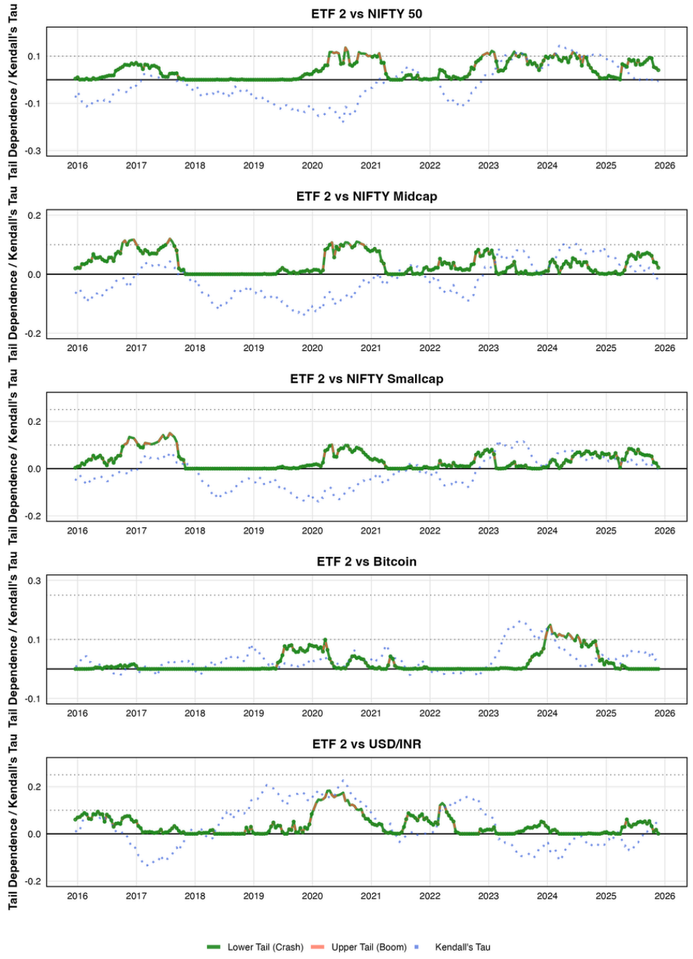
Rebalancing Strategies:

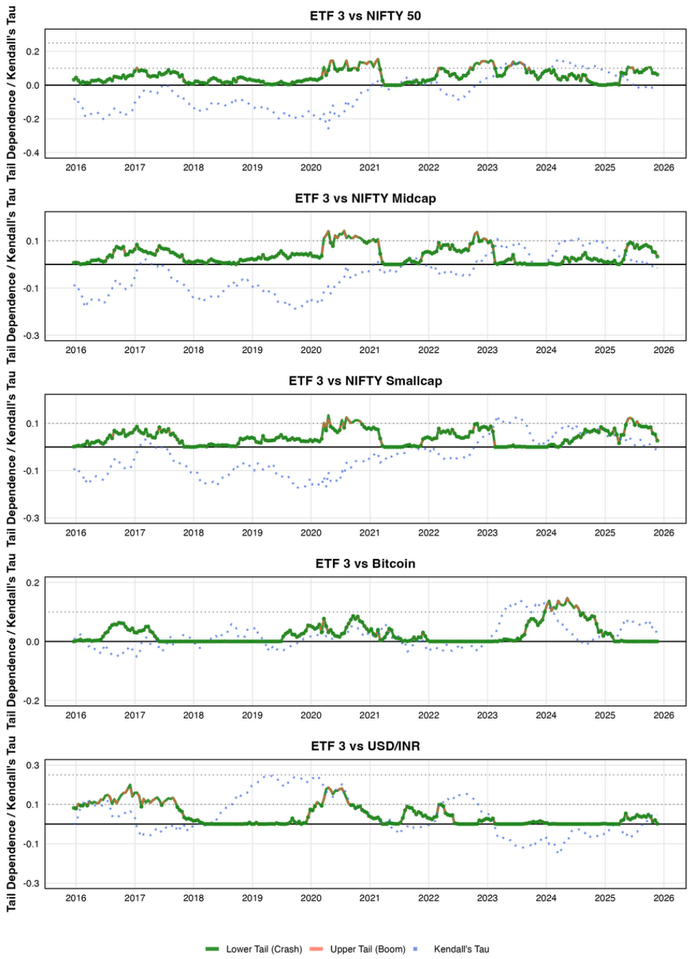
- **Monthly Rebalancing (21-day)** → High responsiveness to market changes
- **Semi-Annual Rebalancing (126-day)** → Lower transaction costs, stable allocations

EMPIRICAL RESULTS

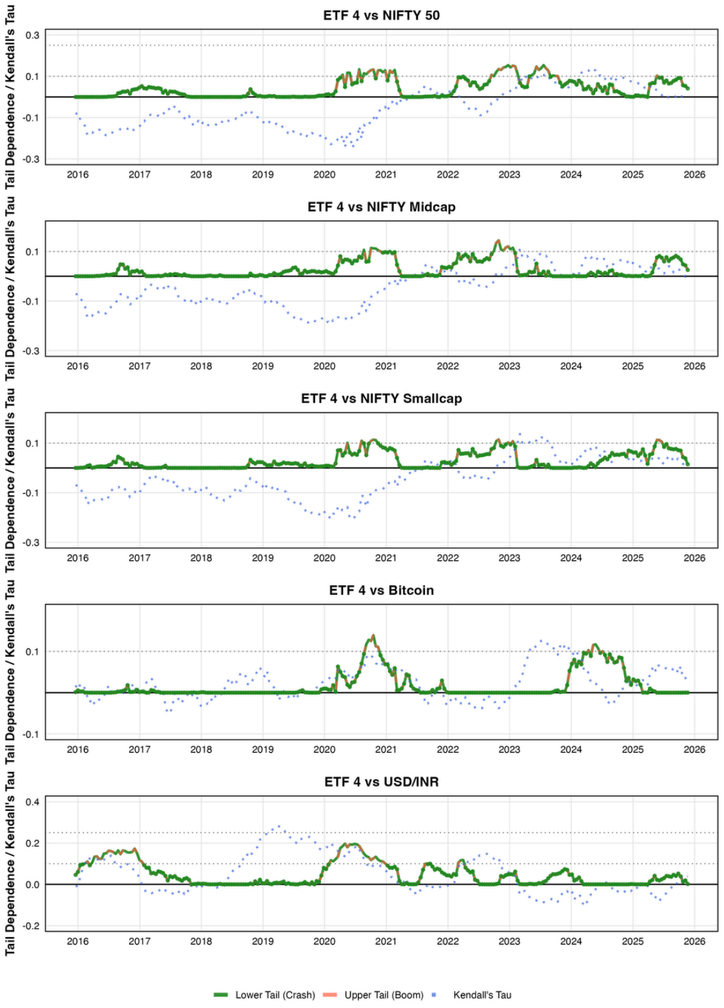
Rolling Tail Dependence- Copula

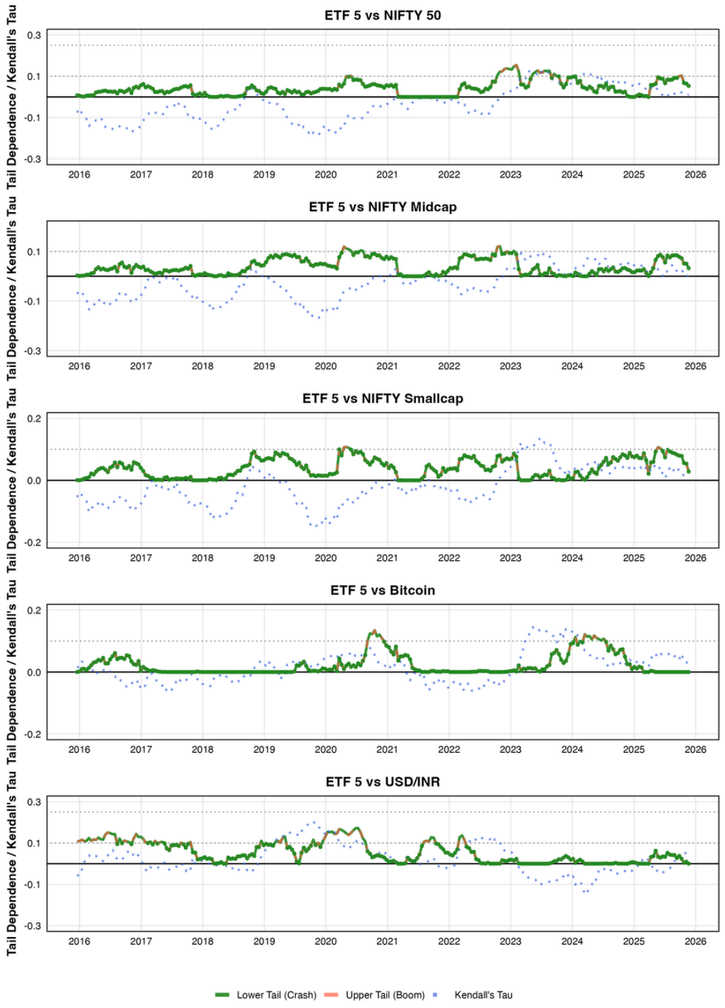


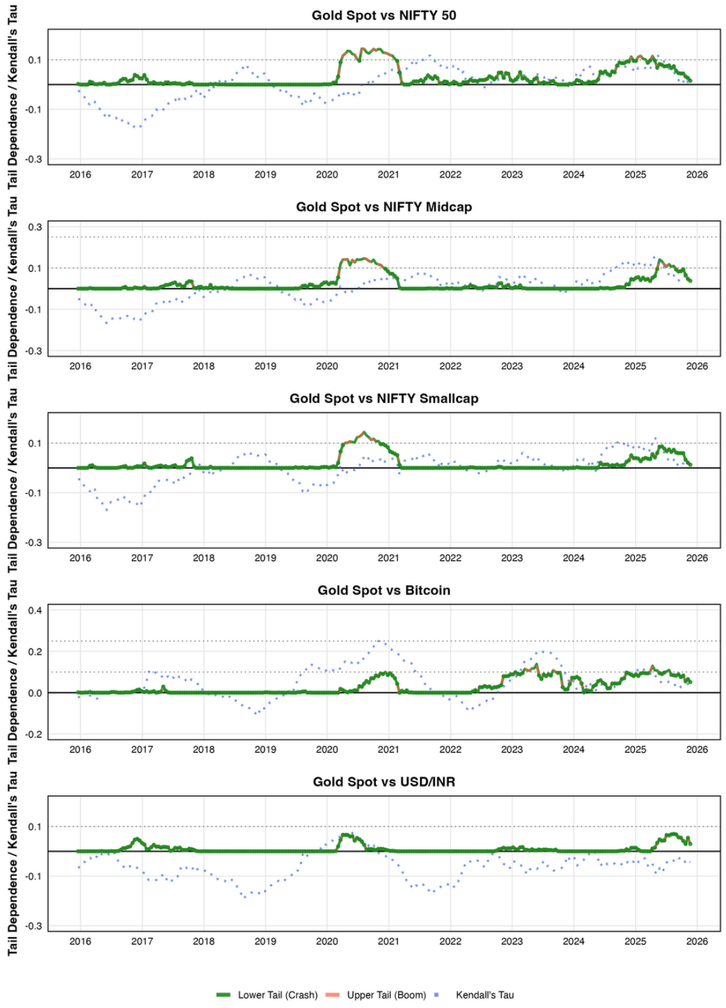




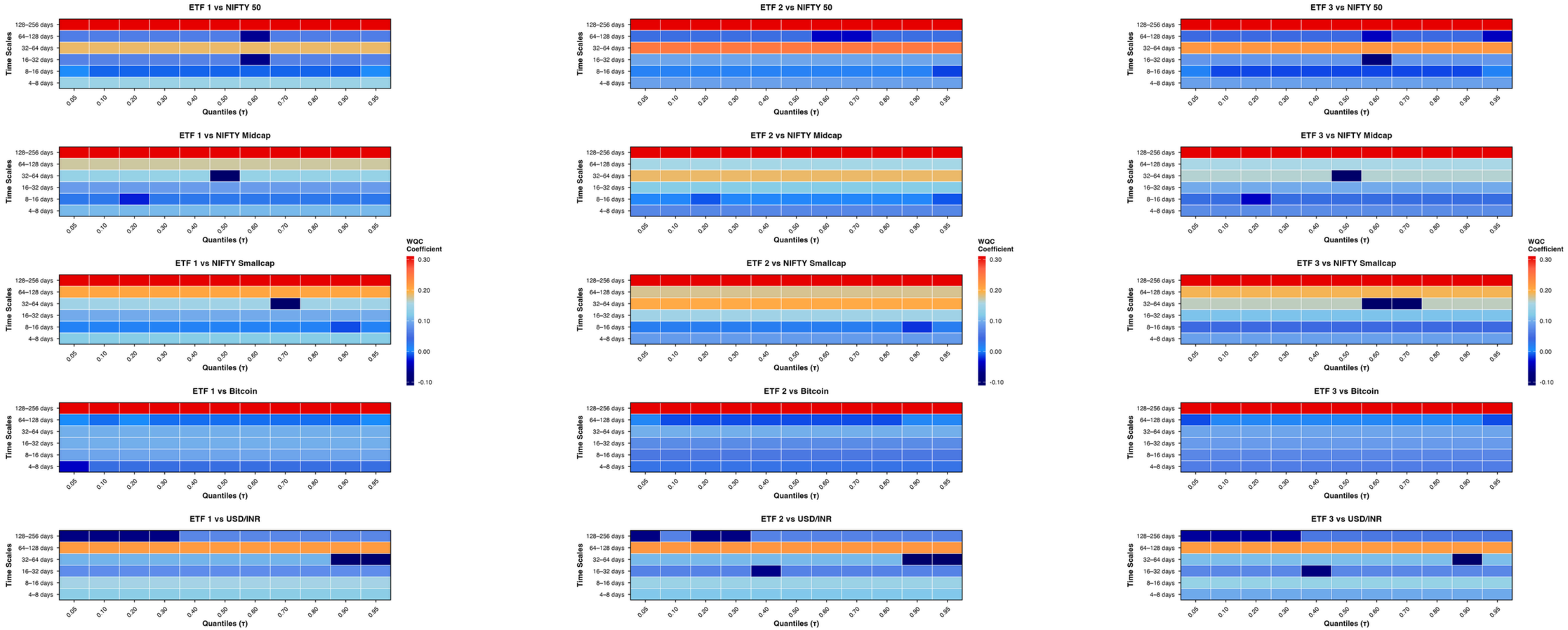
Rolling Tail Dependence- Copula



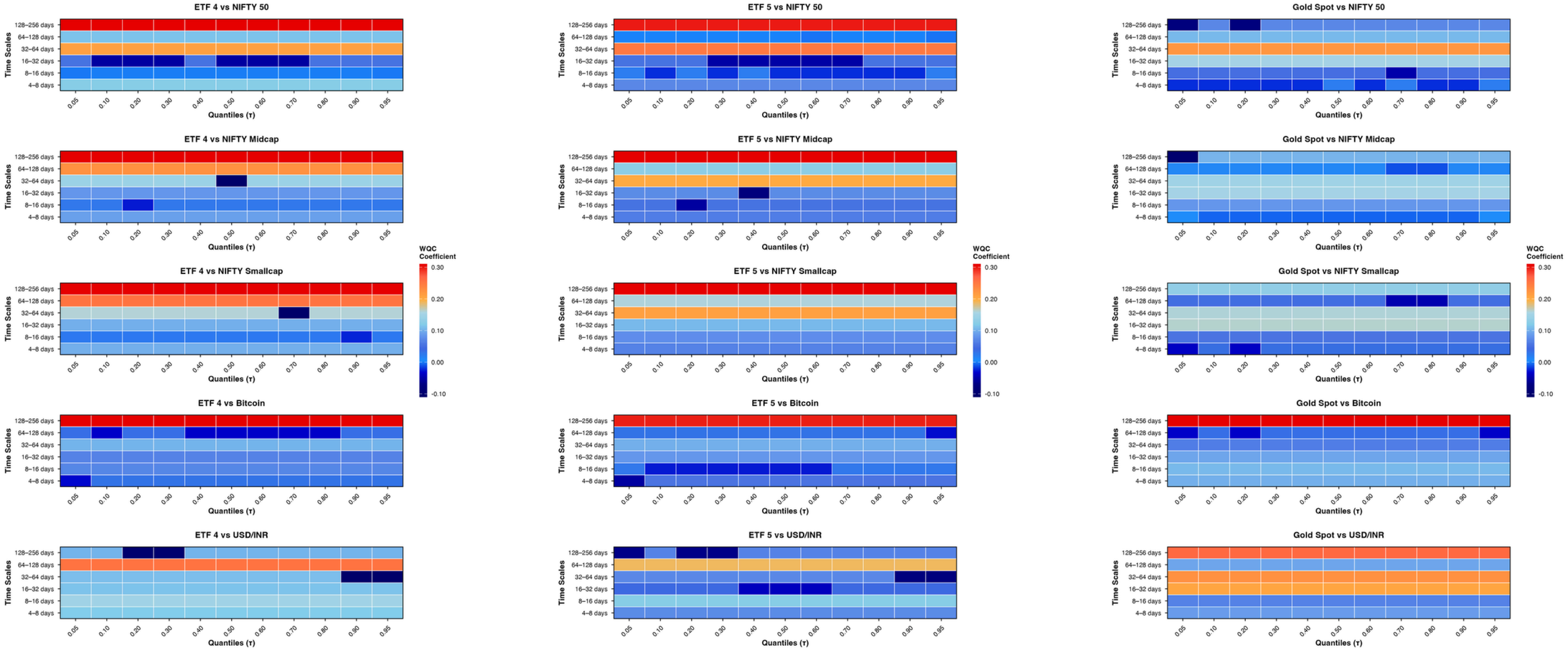




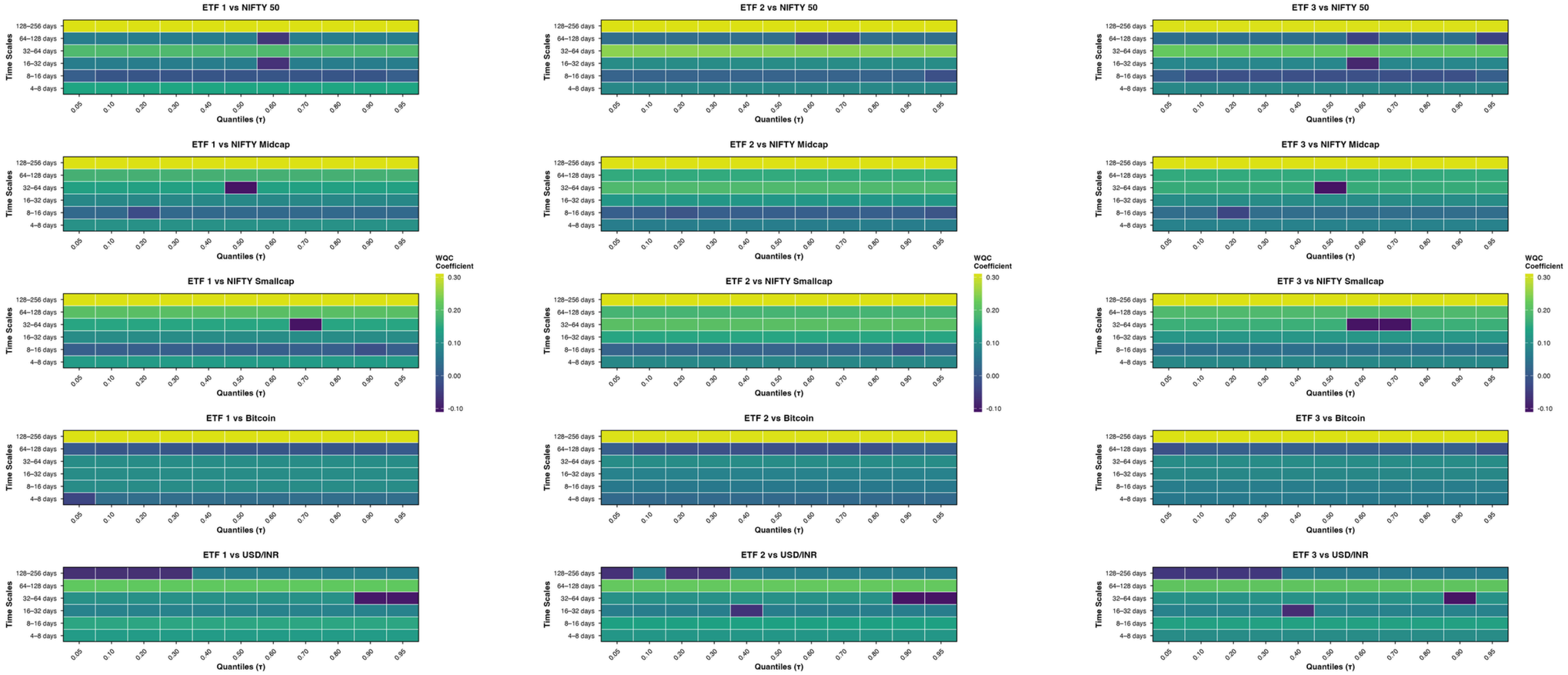
Wavelet Quantile Correlation



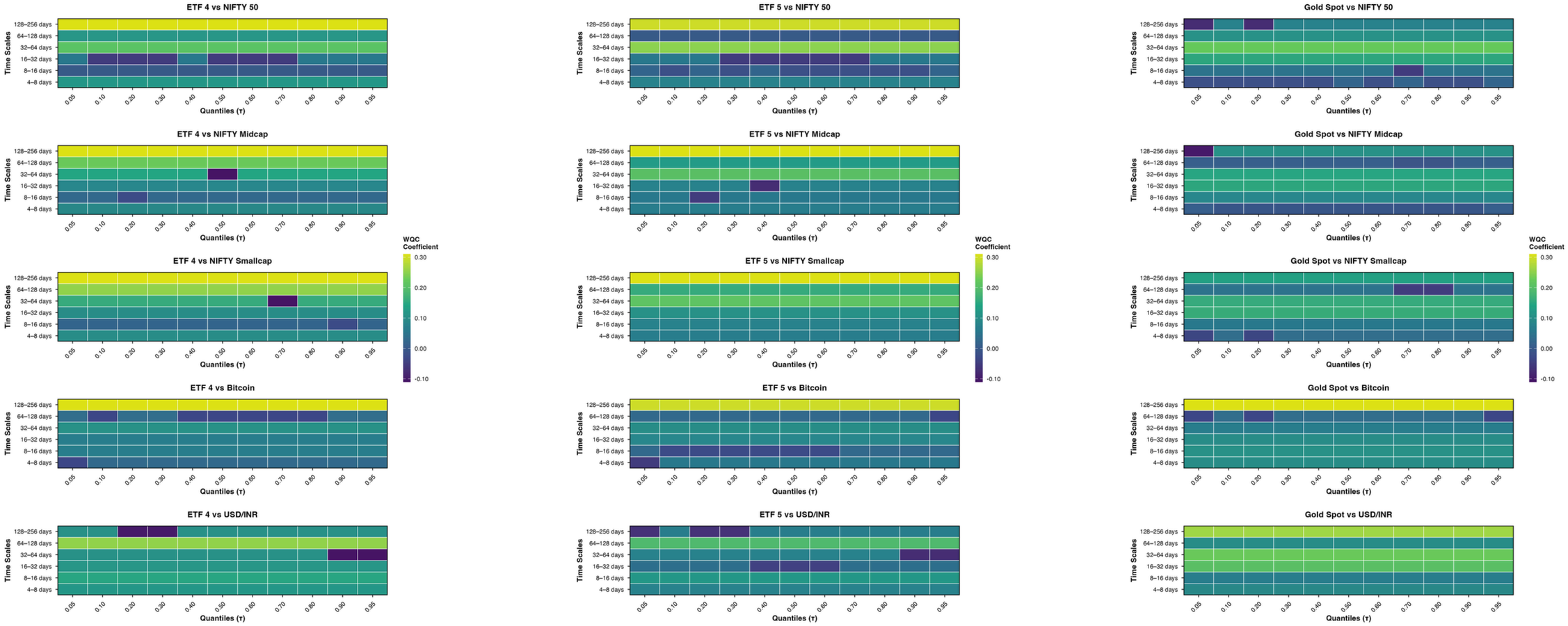
Wavelet Quantile Correlation



Robustness-Bootstrap



Robustness-Bootstrap



Post Covid Performance of all Portfolio Optimization Strategies

No	Strategy	Freq	Return	Vol	Sharpe	Sortino	Calmar	Max DD	Rb
1	Equity Only	Semi Annual	**21.51%**	**17.24%**	0.825	0.941	0.728	**-29.52%**	11
2	Equity Only	Monthly	26.08%	16.64%	1.070	1.279	1.010	-25.82%	69
3	Equity + Gold + BTC	Semi Annual	24.33%	14.62%	1.100	1.473	1.066	-22.83%	11
4	Equity + Gold + BTC	Monthly	28.54%	**15.50%**	1.261	1.799	1.162	-24.55%	69
5	Equity + Gold (Dynamic)	Semi Annual	21.29%	**13.30%**	1.010	1.182	0.957	-22.24%	11
6	Equity + Gold (Dynamic)	Monthly	27.75%	**12.49%**	1.483	1.794	1.685	-16.47%	69
7	Equity + Gold + BTC (Dynamic)	Semi Annual	25.01%	**12.90%**	1.272	1.631	1.102	-22.69%	11
8	Equity + Gold + BTC (Dynamic)	Monthly	30.24%	**12.27%**	1.664	2.201	1.265	-23.91%	69
9	ALL (Dynamic)	Semi Annual	26.05%	**11.79%**	1.450	1.921	1.334	-19.53%	11
10	ALL (Dynamic)	Monthly	28.45%	**11.52%**	1.645	2.274	1.329	-21.41%	69

Findings and Discussion

- **RQ1: Safe Haven Properties Across Horizons**
  - **Gold exhibits frequency-dependent behavior** – Strong safe-haven at Short-term (4-8 days) with negative correlations (128-256 days) Confirms Kumar & Padakandla (2022); Extends with Indian gold ETFs across market cap segments and also contradicts the Long-term safe-haven
- **RQ2: Frequency-Informed Optimization**
  - **WQC-ACO integration successful** – First framework linking wavelet-based frequency insights to nature-inspired optimization; short-horizon correlations trigger dynamic rebalancing
  - Extends Deng & Lin (2010) and Kumar & Padakandla (2022); Novel methodology bridging frequency analysis with metaheuristic optimization
  - **Stress-adaptive allocation rules** – Gold weights shift from 10-30% (normal) to 35-60% (crisis) based on frequency-conditioned triggers
  - Extends Wagner & Poppe (2024) **First stress-triggered allocation framework**
- **RQ3: Performance of Dynamic Strategies**
  - **Dynamic strategies significantly outperform** – Sharpe ratios > 1.2 vs. 0.68 (equity-only); maximum drawdown reduced from 49% to 24% (51% improvement)
  - **First** ACO-based stress-triggered rebalancing with Indian assets
  - **Monthly rebalancing optimal** – 21-day cycles outperform 126-day semi-annual (+0.08 Sharpe); post-COVID validation confirms robustness (2020-2025) Extends dynamic allocation literature with frequency-informed rebalancing cycles

Empirical Strategy for Gold

A Mamba–ACO Framework for Adaptive Gold Allocation

01 Feature Engineering

Market Stress
VIX, Economic Policy Uncertainty, Credit Spreads, Geopolitical Risk

Momentum
Gold returns, Moving averages, RSI, MACD, Trend strength

Safe-Haven Demand
Dollar Index (DXY), Real Yields, Inflation Expectations

Liquidity & Volatility
Gold volatility, Bid–ask spread, Volume, Open interest

Standardization & Normalization

02 Temporal Modeling with Mamba

Linear Projection (Embed features)
↓
Mamba Block (Selective SSM)
↓
Layer Normalization
↓
Output (Latent States)

Captures long-range dependencies and non-stationary dynamics in gold-related features.

03 Dynamic Allocation via ACO

Heuristic Information (Mamba Forecasts)
↓
Ant Colony Optimization (Portfolio Weights)
↓
Constraints (Budget, Risk, Turnover)
↓
Optimal Allocation (w^*)

Heuristic-driven ACO searches for the optimal allocation under changing market conditions.

04 Rebalancing & Backtesting based on WQC

Rebalancing with WQC Insights

Dynamic rebalancing horizon determined by Wavelet Quantile Correlation (WQC).

- High WQC (strong dependence) → shorter horizon
- Low WQC (weak dependence) → longer horizon

Backtesting with WQC Evaluation

Rolling-window backtesting guided by WQC to assess performance across market regimes.

- Captures tail dependence and regime-specific relationships.

Performance & Robustness

Sharpe, Sortino, Max Drawdown, Calmar Ratio
Out-of-sample, Sub-period, Stress scenarios

Mamba: Selective State Space Model (SSM)

Selective SSM Dynamics

$$h_t = \bar{A}_t h_{t-1} + \bar{B}_t x_t$$
$$y_t = C_t h_t + D_t x_t$$

Input-Dependent Parameter Generation

$$\bar{A}_t, \bar{B}_t, C_t, D_t = f_\theta(x_t)$$

Mamba adaptively selects parameters of the state space model based on current input, enabling long-range dependency modeling with linear complexity.

Ant Colony Optimization (ACO)

Pheromone Update

$$\tau_{ij}^{t+1} = (1-\rho)\tau_{ij}^{t} + \Delta\tau_{ij}^{t}$$

Transition Probability

$$P_{ij}^{t} = \frac{(\tau_{ij}^{t})^{\alpha}\,(\eta_{ij}^{t})^{\beta}}{\sum_{k \in allowed}(\tau_{ik}^{t})^{\alpha}\,(\eta_{ik}^{t})^{\beta}}$$

Heuristic Function

$$\eta_{ij}^{t} = \frac{1}{\epsilon + d_{ij}^{t}}$$

Pheromone Deposit

$$\Delta\tau_{ij}^{t} = \sum_{m=1}^{M} \frac{Q \cdot f_m}{L_m}$$

τ : Pheromone η_{ij} : Heuristic desirability α, β : Influence factors
ρ : Evaporation rate Q : Constant f_m : Fitness of solution m
L_m : Length (cost) of solution m

WQC: Wavelet Quantile Correlation

Wavelet Decomposition

Decompose return series into time–frequency components using MODWT.

Quantile Correlation

Compute correlation at quantiles $\tau \in \{0.05, 0.25, 0.5, 0.75, 0.95\}$ across scales.

$$\rho_j^{\tau}(X, Y) = Corr(Q_j^{\tau}(X), Q_j^{\tau}(Y))$$

WQC Measure (Aggregate)

$$WQC = \sum_{j=1}^{J} w_j \cdot \frac{1}{|T|} \sum_{\tau \in T} |\rho_j^{\tau}(X, Y)|$$

Rebalancing Horizon Rule

$$H_t = H_{min} + (H_{max} - H_{min}) \cdot (1 - WQC_t)$$

Strong dependence (high WQC) → **shorter** H_t

Implications

Implications for Individual Investors

- **Horizon-specific allocation** – Use gold ETFs for short-term protection (4-8 days); reduce gold in long-term portfolios as effectiveness diminishes
- **Crisis response** – Increase gold allocation to 35-60% during stress; revert to 10-30% during normal conditions based on stress signals

Implications for Portfolio Managers

- **Dynamic rebalancing** – Implement stress-triggered ACO framework with monthly (21-day) rebalancing for Sharpe >1.2 and 51% drawdown reduction
- **Frequency-informed strategies** – Condition portfolio weights on investment horizon; short-term portfolios require higher gold allocation than long-term

Implications for Policy Makers

- **Retail investor protection** – Promote frequency-based gold ETF allocation guidelines
- **Stress-adaptive product regulation** – Encourage transparent disclosure of dynamic rebalancing mechanisms in advisory services; support development of automated stress-triggered allocation tools

Theoretical Contributions

- **Frequency-domain portfolio framework** – First integration of Wavelet Quantile Correlation with Ant Colony Optimization; establishes horizon-conditional allocation theory
- **Dynamic safe-haven model** – Quantifies frequency-dependent protection patterns; extends Baur & Lucey (2010) with time-scale-specific allocation rules

Limitations and Future Research Directions

- Evidence is limited to Indian equity markets and gold ETFs.
- Safe haven dynamics may vary across different market structures and crisis regimes.
- Extend horizon-dependent analysis across international markets.
- Examine broader defensive assets and alternative stress environments.

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HIGHLIGHTS

- **Short-term safe-haven** – Gold protection strongest at 4-8 day horizons
- **Frequency-informed optimization** – WQC identifies timing; ACO adjusts weights dynamically
- **Superior performance** – Sharpe >1.2; drawdowns cut from 49% to 24%
- **Practical solution** – Dynamic allocation of gold addresses SEBI-reported retail losses

"The four most dangerous words in investing are:
'**This time it's different**.'"
- Sir John Templeton

THANK YOU

Moni. M

PORTFOLIO WEIGHT