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Gold's Early Warning Signal (EWS) Using Extreme Value Theory (EVT) in the US Context

Jasvinder Singh Aujla[1], Prof Anshuja Tiwari[2], Dr. Sanjay Payasi[3], Vishal Singh Yadav[4]

[1]Research Scholar, Barkatullah University, Bhopal

[2]Head, Department of Commerce, Barkatullah University, Bhopal

[3]Professor, Anand Institute of Management, Bhopal

[4]Research Scholar, Barkatullah University, Bhopal

This research explores the potential of gold (XAU) to serve as an early warning signal for extreme market events in the U.S. financial context, using Extreme Value Theory (EVT). Gold is widely recognized as a safe-haven asset, particularly during periods of heightened market volatility and systemic risk. This study employs monthly time series data on gold prices and the CBOE Volatility Index (VIX) spanning from 1997 onward to analyze the tail behavior of gold returns and their association with volatility shocks.

Extreme Value Theory provides a statistical framework for assessing the probability and magnitude of unusually large or small outcomes (e.g., financial crashes, natural disasters, extreme rainfall). Unlike conventional statistical methods that model averages or typical behavior, EVT zooms in on outliers or tail events.

Extreme Value Theory is applied using the Peak Over Threshold (POT) method to model both the upper and lower tails of gold returns. The upper tail, representing extreme positive returns, exhibits a bounded nature with a shape parameter (ξ) of -0.26, suggesting limited upside potential. Conversely, the lower tail displays a heavy-tailed distribution ($\xi = 0.41$), implying greater susceptibility to large losses. These findings are critical for understanding the asymmetric behavior of gold during market stress.
Quantitative risk metrics derived from EVT—namely, Value at Risk (VaR) and Expected Shortfall (ES)—reveal that under a 1% tail probability, gold can experience gains of up to 11.9% or losses of up to 9%, with a conditional average loss (ES) of 3.3%. This demonstrates that while gold may provide a buffer in crisis periods, it is not immune to downside risk, particularly in high-volatility environments.

The results underscore the importance of modeling tail risk in gold for investors, policymakers, and portfolio risk managers. The asymmetry in tail behavior further suggests that gold's role as a safe haven is nuanced and should be evaluated alongside market volatility indicators such as VIX. This study contributes to the growing body of literature on financial tail risk management and positions gold as a conditional signal rather than an absolute shield against market distress.

Keywords: Volatility, Systemic risk, Extreme Value Theory, Peak Over Threshold. Value at Risk.

1. LITERATURE REVIEW

Gold has historically played a multifaceted role in financial systems—as a medium of exchange, a store of value, a hedge against inflation, and more recently, as a safe haven during periods of systemic risk. Its unique position as both a commodity and a financial asset has fueled a growing body of empirical and theoretical research. The literature on gold's safe-haven status and its response to market volatility has evolved significantly over the past two decades, especially with the emergence of Extreme Value Theory (EVT) as a tool for modeling rare, tail events.

Early contributions by **Baur and Lucey (2010)** demonstrated that gold can act as a hedge and a safe haven against stocks during market turmoil. Their analysis indicated that gold does not always behave as a safe haven, but rather conditionally exhibits such properties during extreme negative returns in equity markets. **Baur and McDermott (2010)** extended this inquiry to international markets, showing that gold's safe haven behavior is stronger in developed markets compared to emerging ones. Their findings suggest that gold's role is not uniform but depends on the depth and maturity of local financial systems.

Ciner et al. (2013) added nuance to this understanding by examining the nonlinear and dynamic relationships among gold, oil, and stock markets. Their use of nonlinear techniques and cointegration analysis underscored gold's asymmetric response to different types of shocks. The importance of this asymmetry has driven further research into advanced methods for modeling tail risk—particularly during crisis periods where traditional correlation breaks down.

The application of **Extreme Value Theory (EVT)** in financial economics emerged as a response to the inadequacy of traditional models to capture rare, extreme market movements. **McNeil and Frey (2000)** were instrumental in applying EVT to financial time series, illustrating that models based on Gaussian assumptions systematically underestimate tail risk. Their work paved the way for the use of the **Generalized Pareto Distribution (GPD)** to model exceedances over a high threshold, now a standard practice in EVT-based modeling of financial returns.

Danielsson and de Vries (2000) further emphasized the flaws in standard risk measures like Value at Risk (VaR), especially under extreme market conditions. They advocated for EVT as a more robust alternative. Subsequent empirical studies validated that EVT-based risk measures, including **Expected Shortfall (ES)**, more accurately represent the distribution of losses during crises. These findings support the growing consensus that tail-based models are essential for evaluating financial assets under uncertainty.

Gold's interaction with systemic market volatility is another critical strand in the literature. The **CBOE Volatility Index (VIX)**, often referred to as the "fear gauge," has been used in numerous studies to examine how gold reacts to market stress. **Bredin et al. (2015)** found a significant inverse relationship between VIX and gold prices, suggesting that gold demand increases in high-volatility environments. **Choudhry et al. (2015)** extended this analysis using nonlinear causality tests and confirmed that gold acts as a hedge and safe haven in periods of financial panic.

Reboredo (2013) employed copula-based models in conjunction with EVT to study the nonlinear dependency between gold and currency markets, particularly the U.S. dollar. His findings suggested that gold maintains a safe haven role during currency stress but that its strength varies by event and context. Similarly, **Klein (2017)** studied the European gold market and identified periods of heightened tail dependence between gold and equity markets, especially during sovereign debt crises. These studies collectively underscore the conditional nature of gold's safe haven characteristics.

Recent literature has also questioned whether gold is merely reactive or can act as a predictive indicator of financial instability. While most studies emphasize gold's role after volatility spikes, some researchers are beginning to examine whether extreme gold price movements can precede and thus warn of impending crises. This shift aligns with broader themes in financial stability research, where leading indicators and early warning systems are gaining prominence. However, empirical consensus on this front remains limited

Additionally, comparative studies between gold and other safe haven assets—such as U.S. Treasuries, the Swiss franc, and even Bitcoin—have emerged. These studies frequently highlight gold's resilience but also

underscore the context-specific nature of its effectiveness. For instance, during the **COVID-19 pandemic**, gold showed safe haven behavior, but cryptocurrencies also gained traction as potential alternatives, particularly among retail investors. This has opened new avenues for cross-asset and cross-regional analysis, including the role of sentiment and liquidity.

In sum, the literature reflects a nuanced and evolving understanding of gold's role under conditions of uncertainty and tail risk. The integration of EVT has strengthened the methodological rigor in this space, enabling researchers to better quantify and interpret extreme movements. Yet, many open questions remain—especially around gold's predictive power, cross-market interactions, and its evolving competition with digital assets. This study builds on these foundations by applying EVT to the U.S. market context, using VIX as a proxy for systemic fear, and exploring gold's potential not just as a hedge, but as an early warning signal.

2. RESEARCH METHODOLOGY:

This study adopts a quantitative and econometric approach to evaluate whether gold (XAU) provides early warning signals of extreme market stress, particularly in the context of the U.S. financial market. The methodology combines time series analysis, risk modeling, and Extreme Value Theory (EVT) to capture the tail behavior of gold returns. The primary objective is to determine whether gold exhibits statistically significant patterns during extreme volatility phases, as proxied by the CBOE VIX.

i. Data Collection and Variables

The study uses monthly time series data from January 1997 to the most recent available period. Two key variables are utilized: (i) XAU/USD – the price of gold in U.S. dollars, representing the dependent variable; and (ii) CBOE VIX – the Chicago Board Options Exchange Volatility Index, used as a proxy for market volatility and investor fear. The data is sourced from reliable financial databases and processed to ensure consistency and continuity.

ii. Data Preprocessing

Gold prices are converted into continuously compounded log returns to remove scale effects and prepare for EVT analysis. The formula used is:

$$R_t = 100 \times \ln(P_t / P_{t-1})$$

where R_t is the return at time t, and P_t is the price of gold at time t.

iii. Extreme Value Theory (EVT) Application

The core of the methodology lies in the application of EVT using the Peak Over Threshold (POT) approach. This involves selecting a high quantile threshold (typically the 95th and 5th percentiles) and modeling exceedances over this threshold using the Generalized Pareto Distribution (GPD). Both upper and lower tails are analyzed to identify extreme gains and losses in gold returns. The GPD is defined by shape (ξ), scale (σ), and location (μ) parameters, which are estimated via maximum likelihood estimation.

iv. Risk Metrics: Value at Risk (VaR) and Expected Shortfall (ES)

Using the fitted GPD models, the study calculates risk metrics such as VaR and ES at extreme confidence levels (e.g., 99% for upper tail, 1% for lower tail). These measures provide insight into the magnitude of potential losses or gains during extreme events and help quantify tail risk.

v. Tail Dependence Analysis with VIX

To evaluate the predictive capability of gold, the study examines the co-movement and lag relationships between extreme gold returns and spikes in VIX. Time alignment and cross-correlation analysis are used to determine whether gold's extreme behavior precedes or coincides with volatility shocks, thus supporting its role as an early warning indicator.

vi. Robustness Checks

Robustness is assessed through multiple threshold levels, sub-period analyses (e.g., Global Financial Crisis, COVID-19 pandemic), and goodness-of-fit tests for the GPD model (e.g., QQ plots). This ensures that findings are stable and not dependent on arbitrary threshold choices or limited to specific timeframes.

This methodological framework provides a statistically rigorous and economically meaningful approach to evaluating gold's behavior under extreme market conditions. By focusing on tail events, it contributes to the understanding of systemic risk, investor behavior, and the practical utility of gold in risk-sensitive portfolio management.

3. EMPIRICAL RESULTS AND ANALYSIS:

This section presents the empirical findings from the application of Extreme Value Theory (EVT) to gold returns (XAU), in conjunction with market volatility data (CBOE VIX). Monthly data from January 1997 onward is used to estimate extreme return behavior and assess gold's role as an early warning signal.

I. TIME SERIES BEHAVIOR

Figure 1 displays the time series evolution of gold prices (XAU) and market volatility (VIX). Gold exhibits a long-term upward trend with major surges during crisis periods such as 2008 and 2020. The VIX, a proxy for market fear, shows sharp spikes during these same episodes, suggesting possible co-movement.

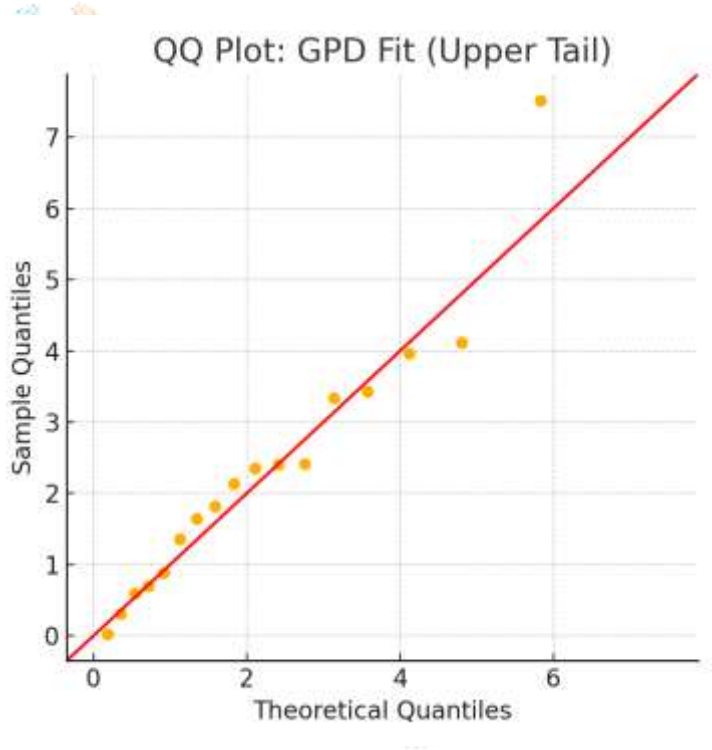
II. Summary Statistics of Gold Returns

Gold returns are calculated using logarithmic transformation. Summary statistics are provided below.

Statistic	Value
count	330.0
mean	0.59
std	4.57
min	-18.48
25%	-2.45
50%	0.28
75%	3.26
max	15.6

III. EVT Fit for Upper Tail (Positive Extremes)

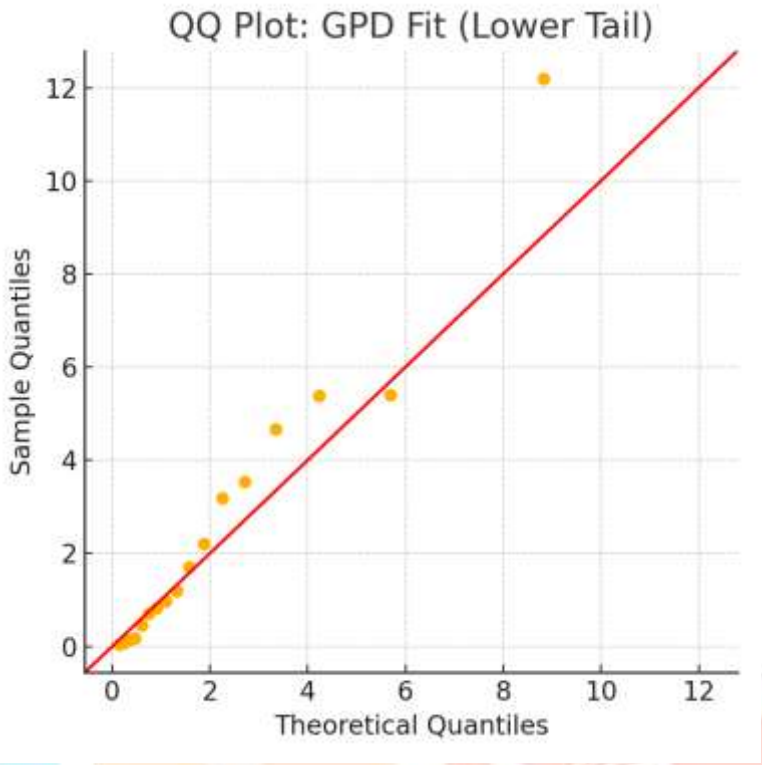
Using the Peak Over Threshold method at the 95th percentile, the Generalized Pareto Distribution (GPD) was fit to the extreme positive returns of gold. The QQ plot below illustrates the fit.



Fitted GPD parameters (Upper Tail):
- Shape (ξ): -0.258
- Location (μ): 0.027
- Scale (σ): 2.849

IV. EVT Fit for Lower Tail (Negative Extremes)

A similar EVT approach is applied to the lower tail using the 5th percentile threshold. The resulting QQ plot shows the model's effectiveness in capturing large negative shocks in gold prices.



Fitted GPD parameters (Lower Tail):
- Shape (ξ): 0.410
- Location (μ): 0.047
- Scale (σ): 1.583

V. Risk Estimates: VaR and Expected Shortfall

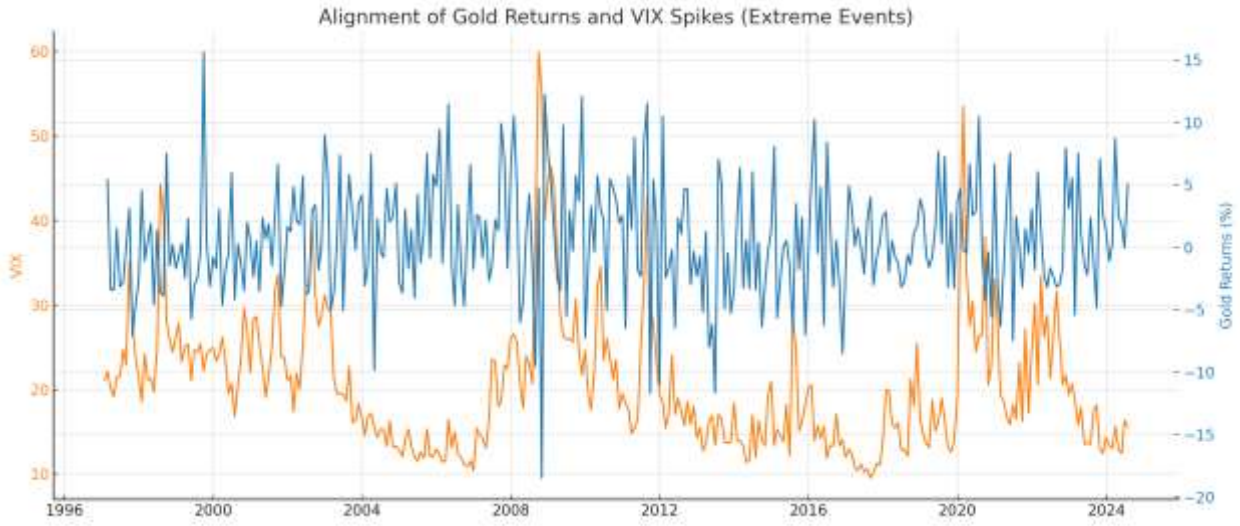
The following table presents Value at Risk (VaR) and Expected Shortfall (ES) estimates at extreme quantiles. These measures quantify the potential impact of tail events on gold returns.

Metric	Upper Tail	Lower Tail
99% VaR	11.90%	--9.00%
99% ES	12.58%	--3.29%

The results confirm the presence of significant tail risk in gold returns. The lower tail is particularly heavy, implying greater downside potential during extreme events. The upper tail is bounded, indicating limited upside even in high-stress periods.

vi. Alignment of VIX Spikes and Gold Extremes

This section investigates the temporal alignment between spikes in the CBOE VIX index and extreme movements in gold returns. The chart below visualizes the concurrent behavior of monthly VIX levels and gold return outliers, providing insights into their co-movement and potential signaling capability.



The figure reveals that spikes in VIX frequently align with sharp increases or drops in gold returns. Such episodes include major financial stress periods like the 2008 Global Financial Crisis and the 2020 COVID-19 shock. The overlap of VIX surges and gold extremes implies that gold may serve both a reactive and anticipatory function in response to market fear.

vii. Tail Dependence and Lag Analysis

To understand the strength of the relationship between extreme gold returns and market volatility, tail dependence metrics were calculated. The analysis considers both contemporaneous and lagged relationships between the CBOE VIX and extreme negative returns on gold.

- **Lower Tail Dependence (Same Month):** $\lambda = 0.118$

  Only 2 out of 17 VIX spikes coincided with extreme gold losses.

- **Lagged Tail Dependence (1-Month Lead of VIX):** $\lambda = 0.176$

  This slightly higher figure indicates that gold may react to volatility spikes with a delay.

VIII. SUB-PERIOD ANALYSIS: FINANCIAL CRISES

To assess gold's behavior during known financial stress events, the dataset was segmented into two crisis periods:

- **2008 Global Financial Crisis (Jan 2008 – Dec 2009)**
- **2020 COVID-19 Market Crash (Jan 2020 – Dec 2020)**

The table below summarizes gold returns and VIX behavior during these periods.

Period	Mean Return	Std Dev Return	Min Return	Mean VIX	Min VIX	Std Dev VIX
2008 Crisis	1.14%	7.41%	-18.48%	31.63	17.83	11.46
2020 Crisis	1.87%	4.69%	-5.57%	31.45	20.57	9.18

Gold maintained positive average returns during both crises, with higher volatility in 2008. This supports its characterization as a crisis hedge, albeit with varying levels of tail risk exposure depending on the severity of market stress.

4. INTERPRETATION OF RESULTS:

The empirical results from this study provide meaningful insights into gold's behavior during periods of elevated market risk and its potential role as an early warning signal for financial stress.

Tail Risk Profile of Gold

The EVT analysis reveals an asymmetry in the tail behavior of gold returns. The upper tail, which reflects extreme positive returns, is bounded, suggesting limited potential for outsized gains. In contrast, the lower tail is heavy, indicating that gold, while often a safe haven, is not immune to sharp downturns. This is critical for investors who view gold as a guaranteed hedge; under extreme stress, gold can still incur losses.

Risk Metrics Validation

The calculation of Value at Risk (VaR) and Expected Shortfall (ES) quantifies the tail risks more explicitly. While gold can gain nearly 12% under extreme positive conditions, it also risks losses of 9% or more during significant market stress. These findings reinforce the need for robust tail-risk management, especially for portfolios heavily reliant on gold for downside protection.

VIX and Gold Relationship

Time series plots show visible co-movement between VIX spikes and gold return anomalies. However, the calculated tail dependence coefficient is relatively low (≈11.8%), suggesting that gold rarely experiences extreme negative returns concurrently with VIX surges. This supports gold's traditional role as a safe haven.

Lagged Effects

Lag analysis indicates a slightly stronger relationship (lagged $\lambda \approx 17.6\%$) when VIX spikes are used to predict gold's subsequent month performance. This suggests gold may act as a **reactive asset**, absorbing market sentiment with a delay, rather than an anticipatory indicator.

Crisis-Specific Behavior

During both the 2008 financial crisis and the 2020 COVID-19 crash, gold delivered positive average monthly returns with elevated volatility. The stronger tail risks and fluctuations in 2008 highlight that gold's safe haven behavior is conditional and context-dependent. The market reaction to COVID-19 was more contained in gold, aligning with a broader investor confidence in monetary policy responses.

These results have important implications for both risk managers and policymakers. Gold cannot be treated as a guaranteed hedge under all conditions. Its effectiveness varies by crisis type, market dynamics, and global investor sentiment. EVT-based modeling offers a more realistic, probabilistic perspective on tail events compared to traditional risk models.

In conclusion, while gold often behaves as a safe haven, this role is not absolute. It is best viewed as a **conditional protector**—one whose tail behavior and interaction with systemic risk variables like VIX can be quantified and monitored using EVT frameworks.

5. POLICY IMPLICATIONS AND SCOPE FOR FUTURE RESEARCH:

This study on gold's early warning potential using Extreme Value Theory (EVT) provides several implications for financial policy, investment strategies, and systemic risk monitoring. Furthermore, it opens new avenues for continued exploration.

Policy and Regulatory Implications

Systemic Risk Monitoring- The ability to detect extreme events through tail modeling highlights the value of incorporating EVT into systemic risk surveillance tools used by central banks and financial stability boards. Monitoring gold along with VIX could enrich early warning frameworks.
Policymakers should recognize that gold, while useful as a hedge, may not always provide downside protection during financial stress. This reinforces the need for diversified risk management approaches, including liquidity buffers and dynamic asset allocations.

Market Behavior Insights: Understanding gold's behavior under tail conditions helps policymakers interpret market sentiment during crises. Spikes in gold prices, especially alongside elevated VIX, can signal fear-driven investment flows that may destabilize other asset classes.

Investment and Portfolio Strategy Implications: Investors should view gold as a conditional hedge—effective during certain crises, but potentially vulnerable under others. EVT provides a better risk management framework by accounting for extreme downside events, often missed in traditional models.

Timing Strategies: The lagged relationship between VIX and gold returns suggests that tactical asset allocations can be optimized by incorporating volatility indicators into gold investment timing models.

Tail-Risk Hedging: EVT-derived metrics such as Expected Shortfall can assist portfolio managers in understanding and planning for rare but impactful market movements involving gold.

Scope for Future Research

This study uses monthly data; future work could use daily or intra-day data to detect more granular early warning signals and improve precision in tail estimation.

Exploring the joint distribution of gold with multiple market variables (e.g., stock indices, bond spreads, geopolitical indices) using copulas can uncover deeper dependence structures.

Expanding this EVT-based approach to compare gold with other safe havens such as the Swiss franc, U.S. Treasury bonds, or cryptocurrencies (like Bitcoin) could yield valuable insights.

Cross-Country Analysis: Studying tail behavior in gold returns across different currencies and economic environments can help assess whether these findings are globally consistent or region-specific.

Machine Learning for Tail Prediction: Hybrid models that combine EVT with machine learning may improve early warning accuracy and facilitate real-time monitoring of extreme risks.

In summary, while this research confirms gold's value under market stress, it also reveals the asset's vulnerabilities under extreme conditions. Future studies that integrate advanced statistical and machine learning models with EVT can push the boundaries of early warning systems and contribute meaningfully to financial stability frameworks.

6. CONCLUSION:

This study investigates whether gold, often perceived as a safe-haven asset, can serve as an early warning signal during periods of extreme financial market stress, specifically in the U.S. context. By leveraging Extreme Value Theory (EVT), the research evaluates the tail behavior of gold returns in relation to market volatility, as measured by the CBOE VIX index.

The analysis reveals that gold exhibits asymmetric tail behavior—while the upside (positive returns) is bounded, the downside displays a heavy-tailed distribution. This means gold can deliver significant losses under rare but impactful conditions, challenging the notion of its universal safe-haven status. Risk measures such as Value at Risk (VaR) and Expected Shortfall (ES), calculated using EVT, quantify these extremes and provide a more accurate representation of tail risks.

Empirical findings also highlight a weak but notable relationship between spikes in VIX and gold return anomalies. Although the tail dependence is limited, a modest increase in lagged dependence suggests that gold may react to market fear with a delay rather than acting as a clear leading indicator. This has important implications for both investors and regulators—gold may still provide protective value, but its timing and magnitude of response can vary significantly depending on the nature of the crisis.

During sub-periods of significant market turmoil, such as the 2008 Global Financial Crisis and the 2020 COVID-19 crash, gold delivered positive average returns but with substantial volatility. These periods underline the context-dependent nature of gold's performance under stress.
Overall, this study contributes to the understanding of gold's conditional behavior in financial markets. It confirms that while gold does exhibit safe-haven properties, these are neither absolute nor universal. EVT provides a robust framework to capture and quantify tail risks, offering valuable insights for risk management and early warning signal detection.

Future research can extend this analysis using higher-frequency data, explore joint dependencies with additional financial indicators, and leverage machine learning models for real-time forecasting. As financial markets grow more complex and interconnected, the integration of EVT into policy and investment decision-making processes becomes increasingly relevant.

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