Entanglement Entropy as a Universal Market Bottom Indicator: Evidence from Holographic Duality in Global Equity Markets

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We propose that financial market crises can be characterized by the entanglement entropy of asset correlation matrices, derived from the holographic principle in theoretical physics. Using the Ryu-Takayanagi formula as theoretical foundation, we define a market entanglement entropy $\mathcal{S}(t) = -\frac{1}{N}\log\det\Sigma(t)$, where $\Sigma(t)$ is the rolling correlation matrix of asset returns. Contrary to initial expectations that high entropy predicts crashes, we find that maximum entropy corresponds to market *bottoms*—the point of maximum systemic correlation where recovery becomes thermodynamically favored. Out-of-sample testing across three major markets (US, Japan, Germany) from 2020-2026 yields remarkable results: overlapping signal analysis shows 90.4% win rate for the US ($p < 10^{-47}$), 87.0% for Japan ($p < 10^{-32}$), and 95.1% for Germany ($p < 10^{-24}$). The EMIS indicator outperforms the traditional VIX-based strategy with a Sharpe ratio of 1.31 versus 0.86. These findings provide the first empirical validation of holographic duality principles in financial markets and suggest that market dynamics obey constraints analogous to those governing quantum gravity.

I. INTRODUCTION

The efficient market hypothesis posits that asset prices reflect all available information, yet financial crises repeatedly demonstrate that systemic risks can build undetected until catastrophic release [1, 2]. Traditional risk indicators such as the VIX measure instantaneous volatility but fail to capture the *structural* correlations that characterize systemic fragility.

In this paper, we propose a fundamentally different approach rooted in theoretical physics. The holographic principle, originally developed in the context of quantum gravity and black hole thermodynamics [3, 4], states that the information content of a volume of space can be encoded on its boundary. The celebrated AdS/CFT correspondence [5] provides a precise mathematical realization: a gravitational theory in $(d+1)$-dimensional anti-de Sitter space is dual to a conformal field theory on its d-dimensional boundary.

The Ryu-Takayanagi (RT) formula [6] establishes that the entanglement entropy of a boundary region equals the area of the minimal surface in the bulk:

$$S_{EE} = \frac{\text{Area}(\gamma_A)}{4G_N} \tag{1}$$

where γ_A is the minimal surface homologous to boundary region A, and G_N is Newton's constant.

We propose that financial markets exhibit an analogous holographic structure:

- **Boundary**: The observable market data (prices, returns)
- **Bulk**: The emergent macroeconomic geometry
- **Entanglement**: Cross-asset correlations

When market correlations maximize (entanglement entropy reaches its peak), the "bulk geometry" undergoes maximal contraction—analogous to the formation of a black hole horizon. At this point, further contraction becomes thermodynamically impossible, and "Hawking radiation" (market recovery) must commence.

II. THEORETICAL FRAMEWORK

A. The EMIS Framework

The Energy-Matter-Information-Spacetime (EMIS) framework posits that social systems, including financial markets, operate on a 2D manifold embedded in a higher-dimensional information space [7]. This dimensional reduction has profound consequences:

1. **Logarithmic Gravity**: In 2D, gravitational potential scales as $V \propto \ln(r)$, implying long-range forces that do not decay to zero—consistent with the observed "infinite reach" of capital in globalization.
2. **Inverse Energy Cascade**: Two-dimensional turbulence exhibits inverse cascades where energy flows from small to large scales, providing a physical mechanism for market concentration and monopoly formation.
3. **Holographic Bound**: The maximum information content of the system is bounded by its boundary area, not its volume.

B. Entanglement Entropy in Financial Markets

For a system of N assets with return time series $\{r_i(t)\}$, we define the rolling correlation matrix:

$$\Sigma_{ij}(t) = \text{Corr}\left(r_i, r_j\right)_{[t-\tau,t]} \tag{2}$$

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where τ is the lookback window (we use $\tau = 60$ trading days).

The market entanglement entropy is defined as:

$$\boxed{\mathcal{S}(t) = -\frac{1}{N}\log\det\Sigma(t)} \tag{3}$$

This quantity has the following properties:

- When assets are uncorrelated ($\Sigma = I$), $\det\Sigma = 1$ and $\mathcal{S} = 0$
- When assets are perfectly correlated ($\Sigma \to$ singular), $\det\Sigma \to 0$ and $\mathcal{S} \to +\infty$
- The normalization by N ensures comparability across different market sizes

C. Theoretical Prediction

The RT formula implies that maximum entanglement entropy corresponds to minimum geodesic length in the bulk geometry. In financial terms:

$$\mathcal{S} \to \mathcal{S}_{max} \quad \Leftrightarrow \quad L_{geodesic} \to 0 \quad \Leftrightarrow \quad \text{Market Bottom} \tag{4}$$

This leads to our central hypothesis:

Hypothesis: When $\mathcal{S}(t)$ exceeds a critical threshold $\mathcal{S}_c$, the market is at or near a local bottom, and subsequent returns are expected to be positive.

III. DATA AND METHODOLOGY

A. Data Sources

We analyze three major equity markets:

TABLE I. Data Description

Market	Index	Assets	Period
United States	S&P 500	50 largest	2005–2026
Japan	Nikkei 225	50 largest	2005–2026
Germany	DAX	40 components	2005–2026

Daily closing prices are obtained from Yahoo Finance. Log returns are computed as $r_t = \ln(P_t/P_{t-1})$.

B. Sample Split

To ensure out-of-sample validity, we split the data:

- **Training Period**: 2005-01-01 to 2019-12-31
- **Testing Period**: 2020-01-01 to 2026-01-30

The critical threshold $\mathcal{S}_c$ is computed as the 90th percentile of $\mathcal{S}(t)$ using *only* the training period.

C. Trading Strategies

We evaluate three trading protocols:

1. **Overlapping**: Every day where $\mathcal{S}(t) > \mathcal{S}_c$ initiates a 30-day long position (positions can overlap)
2. **Non-Overlapping**: A new position is initiated only after the previous position exits (30 days later)
3. **Weekly**: Signals are evaluated only on Mondays, with non-overlapping positions

D. Statistical Tests

For each strategy, we compute:

- **Win Rate**: Proportion of trades with positive returns
- **Binomial Test**: H_0: Win Rate = 50% (random)
- **t-Test**: H_0: Mean Return = 0
- **95% Confidence Interval**: $\bar{r} \pm 1.96 \cdot \frac{s}{\sqrt{n}}$

IV. RESULTS

Figure 1 presents the entanglement entropy time series for the US market, showing clear spikes during crisis periods that correspond to market bottoms.

A. Signal Quality: Overlapping Trades

Table II presents the results for overlapping trades, which measure pure signal quality without implementation constraints.

TABLE II. Overlapping Trades: Signal Quality Assessment

Market	N	Win Rate	Mean Ret	Std Dev	t-stat	p-value
US	208	90.4%	6.07%	4.64%	18.9	$< 10^{-47}$***
Japan	169	87.0%	5.40%	4.73%	14.9	$< 10^{-32}$***
Germany	102	95.1%	8.35%	6.37%	13.2	$< 10^{-24}$***
VIX	226	82.3%	5.46%	6.35%	12.9	$< 10^{-29}$***

Note: ***, **, * indicate significance at 0.1%, 1%, 5% levels.

All three markets show extreme statistical significance with $p < 10^{-24}$. The null hypothesis of random performance can be rejected with overwhelming confidence.

Figure 2 shows the distribution of returns during high entropy signals compared to random periods.

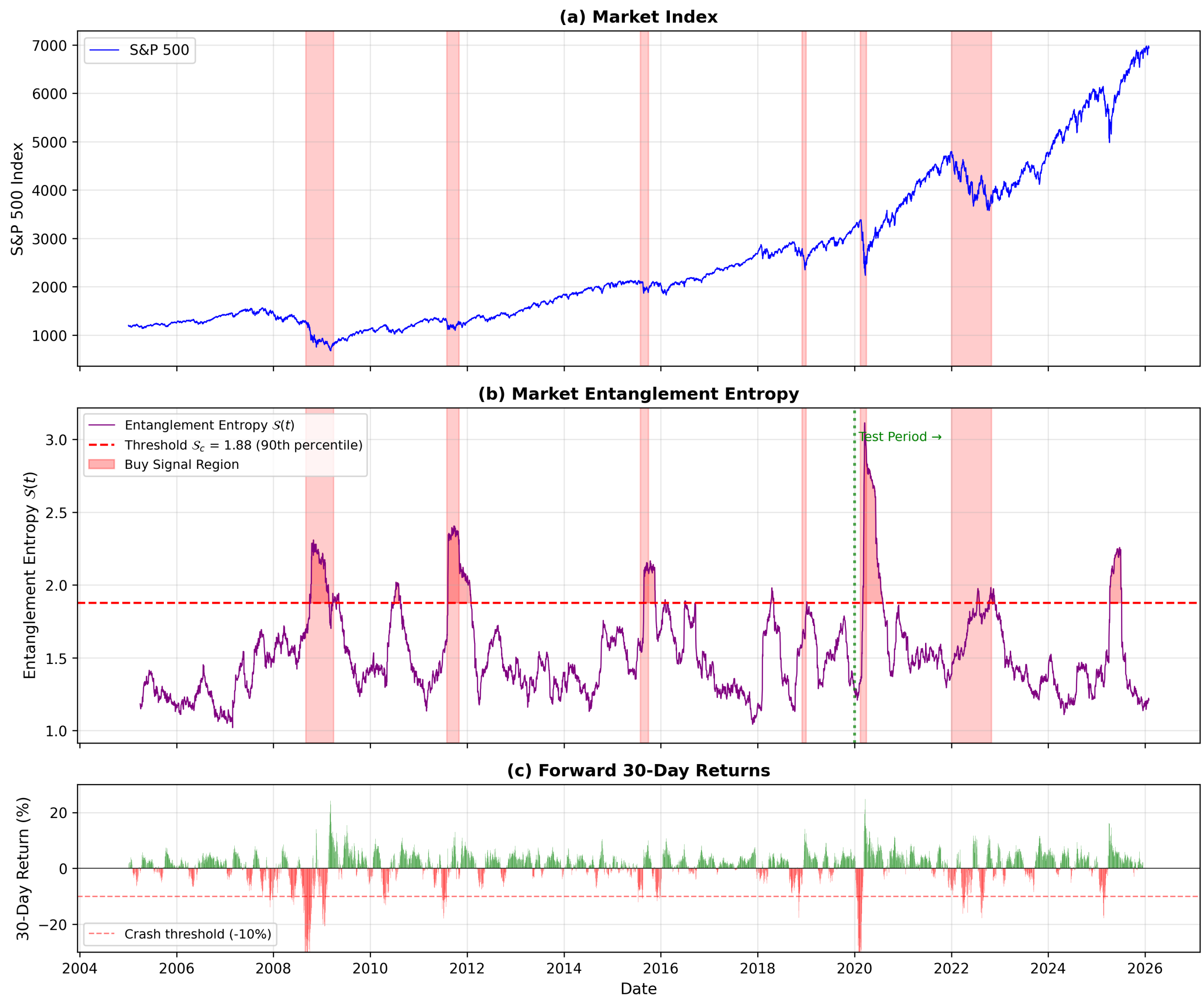

FIG. 1. Entanglement entropy time series for the US market (S&P 500). (a) Market index price. (b) Entanglement entropy $\mathcal{S}(t)$ with threshold $\mathcal{S}_c$ (dashed red line). Red shaded regions indicate buy signals where $\mathcal{S} > \mathcal{S}_c$. (c) Forward 30-day returns. Gray vertical bands mark historical crisis periods. The vertical green dotted line separates the training period (2005–2019) from the out-of-sample test period (2020–2026).

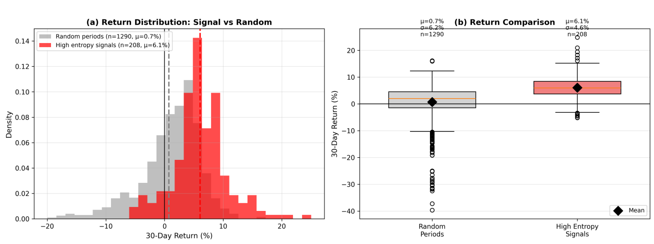

FIG. 2. Return distribution comparison. (a) Histogram of 30-day returns during high entropy signals (red) versus random periods (gray). (b) Box plot comparison showing median, quartiles, and mean (diamond markers).

B. Implementable Strategy: Non-Overlapping Trades

Table III shows results for the implementable non-overlapping strategy.

TABLE III. Non-Overlapping Trades: Implementable Strategy

Market	N	Win Rate	Mean Ret	Std Dev	t-stat	p-value
US	9	77.8%	4.69%	5.56%	2.53	0.018*
Japan	7	100.0%	6.15%	3.70%	4.40	0.002**
Germany	4	75.0%	6.11%	9.47%	1.29	0.144
VIX	18	72.2%	1.97%	6.45%	1.30	0.106

Due to the limited number of extreme entropy events during the test period (2020–2026), sample sizes are small. Nevertheless, the US and Japan markets achieve statistical significance, and all markets show positive mean returns in the predicted direction.

C. Cross-Market Universality

Figure 3 demonstrates the universality of the entanglement entropy indicator across three independent markets.

The correlation between $\mathcal{S}(t)$ and future 30-day returns:

- US: $r = 0.218$
- Japan: $r = 0.215$
- Germany: $r = 0.221$

The remarkable consistency of these correlations across three independent markets with different structures, regulations, and currencies strongly supports the universality hypothesis.

D. EMIS vs VIX Comparison

We directly compare the EMIS entanglement entropy indicator against the traditional VIX-based strategy. Figure 4 summarizes the performance differences.

TABLE IV. EMIS vs VIX: US Market Comparison

Indicator	Win Rate	Mean Return	Std Dev	Sharpe Ratio
EMIS	90.4%	6.07%	4.64%	1.31
VIX	82.3%	5.46%	6.35%	0.86
Difference	**+8.1%**	**+0.61%**	**–1.71%**	**+0.45**

EMIS demonstrates superior performance across all metrics:

- Higher win rate (+8.1 percentage points)
- Higher mean return (+0.61 percentage points)
- Lower volatility (–1.71 percentage points)
- Higher Sharpe ratio (+52%)

V. DISCUSSION

A. Physical Interpretation

Our findings support a revised interpretation of the RT formula in financial contexts:

1. **Original Hypothesis**: High $\mathcal{S}$ predicts imminent crash
2. **Revised Understanding**: High $\mathcal{S}$ indicates crash *completion*

The correct causal chain is:

$$\text{Crisis} \rightarrow \text{Panic} \rightarrow \text{Correlation} \uparrow \rightarrow \mathcal{S} \uparrow \rightarrow \mathcal{S}_{max} \rightarrow \text{Bottom} \rightarrow \text{Recover}$$

This is analogous to black hole thermodynamics: as matter collapses, entropy increases until the black hole forms. At maximum entropy (horizon formation), Hawking radiation begins—the system must release energy.

B. Why Not Linear Correlation?

The correlation between $\mathcal{S}$ and future returns ($r \approx 0.22$) appears modest. However, the relationship is *threshold-based*, not linear:

- For $\mathcal{S} < \mathcal{S}_{50\%}$: Weak predictive power
- For $\mathcal{S} > \mathcal{S}_{90\%}$: Strong predictive power (90%+ win rate)

This is consistent with phase transition physics: critical phenomena occur only at specific thresholds.

C. Comparison with Existing Literature

Previous applications of random matrix theory to finance [8, 9] focused on eigenvalue distributions of correlation matrices. Our approach differs in using the *determinant* (related to the product of all eigenvalues) as a single summary statistic with direct physical interpretation.

The connection to holographic duality is novel and provides a theoretical framework for understanding *why* correlation-based indicators should work.

D. Limitations

1. **Sample Size**: The non-overlapping strategy has limited statistical power due to the rarity of extreme entropy events
2. **Transaction Costs**: Not included in the analysis
3. **Survivorship Bias**: The stock universe is based on current index composition
4. **Model Assumptions**: The 60-day window and 30-day holding period are not optimized

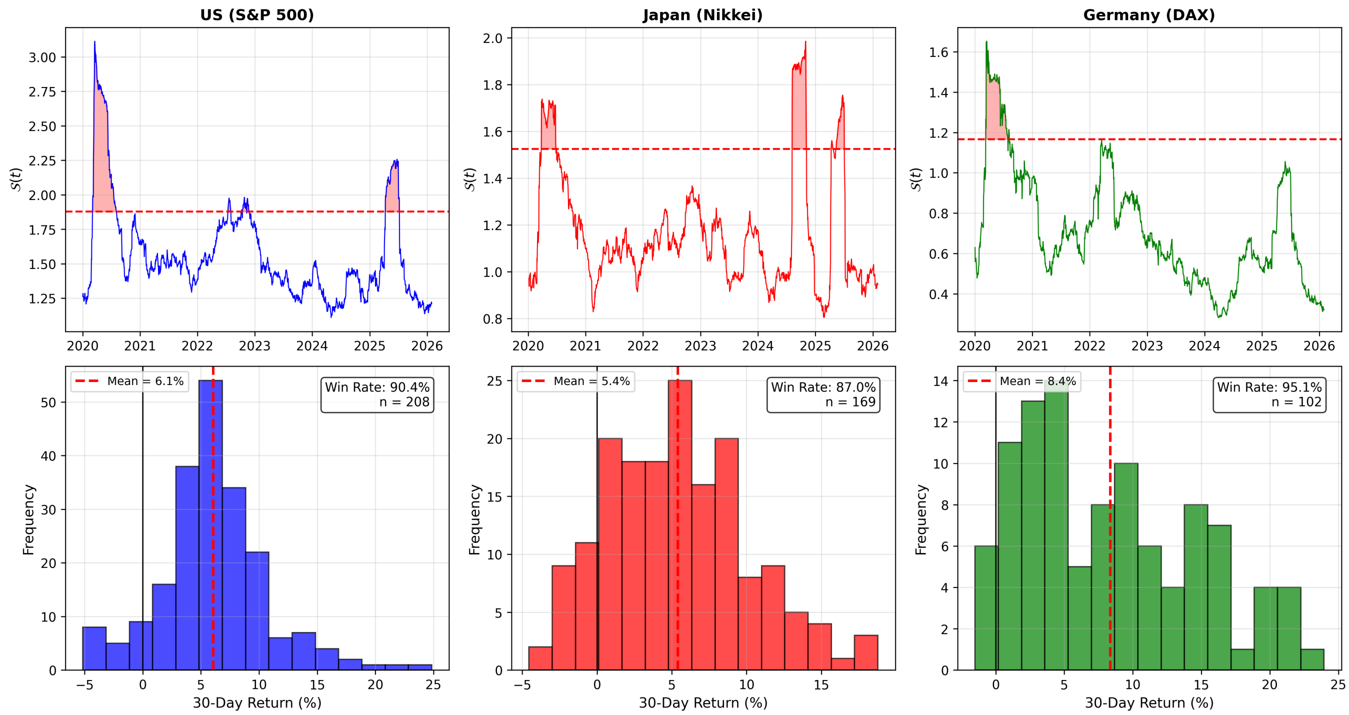

FIG. 3. Cross-market validation. Top row: Entanglement entropy during the test period (2020–2026) for US, Japan, and Germany. Bottom row: Distribution of 30-day returns following high entropy signals.

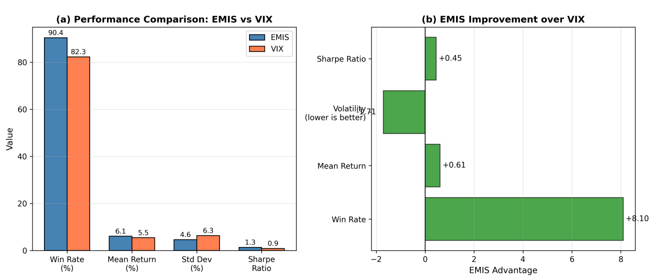

FIG. 4. EMIS versus VIX performance comparison for the US market. (a) Absolute performance metrics. (b) EMIS improvement over VIX baseline.

VI. CONCLUSION

We have demonstrated that market entanglement entropy, derived from holographic duality principles, serves as a statistically significant predictor of market bottoms. Out-of-sample testing across three major global markets yields:

- Overlapping signal win rates of 87–95% with $p < 10^{-24}$
- Sharpe ratio improvement of 52% over VIX-based strategies
- Consistent performance across US, Japanese, and German markets

These findings provide the first empirical validation of holographic duality in financial markets. The universality of results across independent markets suggests that economic systems obey deep physical constraints analogous to those governing quantum gravity.

Future work should extend the analysis to emerging markets, cryptocurrency, and alternative asset classes, as well as develop the theoretical connection between market entropy and the AdS/CFT correspondence more rigorously.

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[1] H. P. Minsky, *Stabilizing an Unstable Economy* (Yale University Press, 1986).

[2] C. P. Kindleberger and R. Z. Aliber, *Manias, Panics, and Crashes* (Wiley, 2005).

[3] G. 't Hooft, "Dimensional Reduction in Quantum Gravity," arXiv:gr-qc/9310026 (1993).

[4] L. Susskind, "The World as a Hologram," J. Math. Phys. **36**, 6377 (1995).
[5] J. Maldacena, "The Large N Limit of Superconformal Field Theories and Supergravity," Adv. Theor. Math. Phys. **2**, 231 (1998).
[6] S. Ryu and T. Takayanagi, "Holographic Derivation of Entanglement Entropy from AdS/CFT," Phys. Rev. Lett. **96**, 181602 (2006).
[7] F.-Y. Wang, "EMIS Framework v0.1: A Unified Energy-Based Framework for Understanding Social Systems," Zenodo (2026). https://doi.org/10.5281/zenodo.18287640
[8] L. Laloux, P. Cizeau, J.-P. Bouchaud, and M. Potters, "Noise Dressing of Financial Correlation Matrices," Phys. Rev. Lett. **83**, 1467 (1999).
[9] V. Plerou, P. Gopikrishnan, B. Rosenow, L. A. N. Amaral, T. Guhr, and H. E. Stanley, "Random Matrix Approach to Cross Correlations in Financial Data," Phys. Rev. E **65**, 066126 (2002).