# Dynamic Regime-Based Sector Allocation & Tail Risk Hedging

**Tanishk Yadav**
New York University

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**Abstract**

Modern portfolio theory operates on the assumption of stable correlation matrices. However, empirical evidence demonstrates **correlation breakdown** during systemic crises—the tendency of all asset correlations to converge to 1.0 during market crashes, rendering traditional diversification useless.

This project develops a **Regime-Switching Risk Model** utilizing **Gaussian Mixture Models (GMM)** to detect latent market states. By dynamically rotating sectors based on the identified regime, the model achieves a structural edge over the S&P 500. Key highlights include a reduction in Maximum Drawdown from -35.75% to -16.11% and the identification of "Crisis Alpha" in the technology sector during specific volatility events.

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## 1 Executive Summary

The primary objective of this research is to solve the problem of correlation convergence during tail-risk events. Traditional "60/40" portfolios often fail when they are needed most because distinct asset classes move in unison during liquidity crises.

Our approach utilizes unsupervised learning to classify market days into distinct volatility regimes. We then optimize sector allocation for each specific regime.

### Key Performance Highlights

- **Tail Risk Elimination:** Reduced Maximum Drawdown from **-35.75%** (Benchmark) to **-16.11%** (Risk-Managed Strategy).
- **Crisis Alpha:** Identified Technology as a "Safe Haven" during the 2020 lockdowns, generating **+214%** total return in the Aggressive variant.
- **Asymmetric Risk Profile:** The final institutional strategy captured **90% of the Upside** with only **45% of the Downside**.

# 2 Methodology

## 2.1 Data Universe & Feature Engineering

We utilized daily OHLC data for the 11 GICS Sector SPDR ETFs (e.g., `XLE`, `XLK`, `XLF`) and Macro Factors including the CBOE Volatility Index (`^VIX`) and 10-Year Treasury Yields (`^TNX`) from 2018–2026.

Risk signals were engineered to capture both realized and implied volatility structure:

1. **Log-Returns ($r_t$):** To ensure stationarity in the time series.

$$r_t = \ln\left(\frac{P_t}{P_{t-1}}\right) endequation$$

2. **Realized Volatility ($\sigma_{rv}$):** Calculated as the 21-day annualized rolling standard deviation.

$$\sigma_{rv} = \sqrt{\frac{252}{N-1}\sum_{i=1}^{N}(r_i - \bar{r})^2} \tag{2}$$

3. **Implied Volatility (VIX):** Used as a forward-looking "fear gauge" to complement backward-looking realized volatility.

## 2.2 Unsupervised Regime Detection

We modeled the distribution of market returns as a weighted sum of Gaussian distributions using a Gaussian Mixture Model (GMM) with $K = 3$ components. The Probability Density Function is given by:

$$p(x) = \sum_{k=1}^{K} \pi_k \mathcal{N}(x|\mu_k, \Sigma_k) \tag{3}$$

Where $\pi_k$ is the mixing coefficient, and $\mathcal{N}(x|\mu_k, \Sigma_k)$ is the Gaussian density of component $k$. This effectively clustered the market into three distinct states:

- **Regime 0 (Bull):** Low Volatility, Low Correlation.
- **Regime 1 (Transition):** Rising Volatility, Signal Noise.
- **Regime 2 (Crisis):** Extreme Volatility, Contagion.

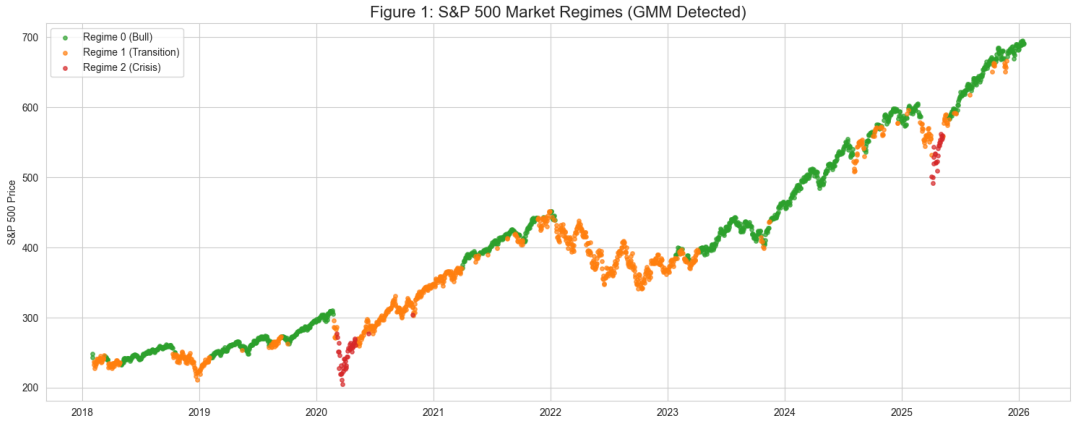


Figure 1: S&P 500 Price History colored by Latent Regime. Red segments indicate high-probability "Crisis" states (March 2020, 2022 Inflation).

## 3 The Failure of Diversification

To validate the necessity of dynamic allocation, we performed **Hierarchical Clustering (Ward's Method)** on the sector correlation matrices conditional on the detected regime.

**Observation:** In Regime 0, the dendrogram shows significant height (Euclidean distance) between sectors, indicating healthy diversification opportunities. In Regime 2, the tree structure collapses, with distances approaching zero.

**Conclusion:** "You cannot hedge Equity Risk with Equities during a Crash."

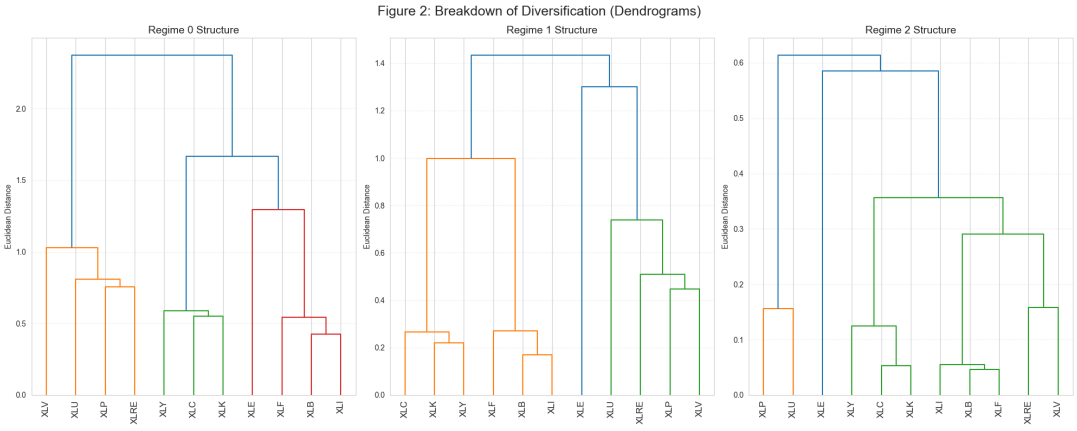


Figure 2: Regime-Dependent Correlation Structure. The collapse of the tree in Regime 2 visually proves contagion.

## 4 Strategy Comparison ("The Face-Off")

We backtested three distinct approaches to validate the efficacy of the GMM signal.

| Strategy | Profile | Logic | Crisis Behavior |
|---|---|---|---|
| A: Human Heuristic | Benchmark | Traditional Rotation | Rotate to "Safe" Defensives (Util/Staples) |
| B: AI Aggressive | Alpha Seeking | Maximize Sharpe | Rotate to High-Beta Growth (Tech) |
| C: AI Safe | Institutional | Capital Preservation | **Exit to Cash (Treasuries)** |

Table 1: Strategy Logic Comparison

### 4.1 Equity Curve Analysis

Strategy C (Green) demonstrates the "Ratchet Effect"—it participates in rallies but "locks in" gains by going flat during crashes. Strategy A (Red) fails because Defensive sectors fell alongside the market during the 2022 rate-hike cycle.

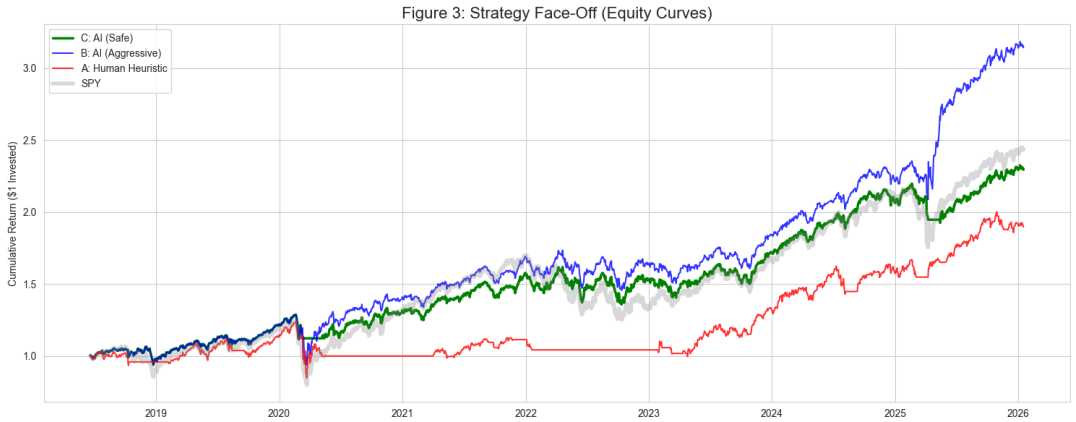


Figure 3: Cumulative Performance (2018–2026). Note the divergence in 2022 where the Red line collapses while the Green line holds steady.

### 4.2 Drawdown Analysis

The most critical chart for risk management. Strategy C effectively creates a "Hard Floor" at -16%, whereas the market fell -35%.

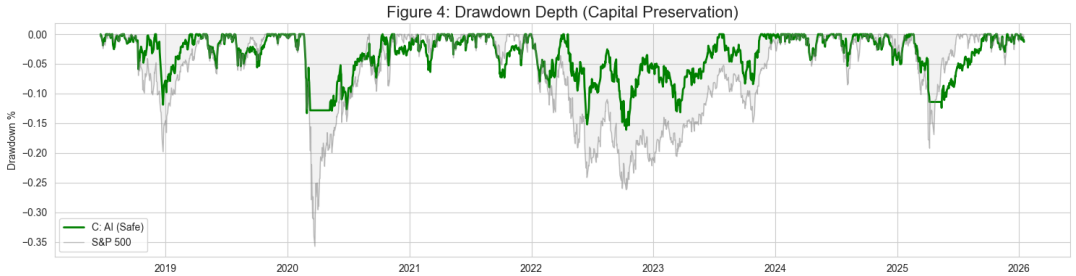


Figure 4: Drawdown Depth. The "Safety" strategy eliminates the deep valleys of the equity curve.

## 5 Risk-Reward Efficiency (The "Edge")

This analysis illustrates the **Asymmetry** of the AI-driven approach.

- **S&P 500:** Investors accepted **-35%** risk to achieve **+143%** return. This is an inefficient trade.
- **Strategy C:** Investors accepted only **-16%** risk to achieve **+129%** return. This represents highly efficient leverage.


Figure 5: Risk-Reward Efficiency. Strategy C (Far Right) offers the best ratio of Gain (Green) to Pain (Red).

## 6 Micro-Analysis: Stress Testing

To prove the robustness of the signal, we analyzed the two major "Black Swan" events in the dataset.

### 6.1 Event 1: The COVID-19 Crash (March 2020)

The model identified the transition to Regime 2 in late February.

- **Strategy Behavior:** Switched to Cash.
- **Result:** Avoided the -30% vertical drop in March.

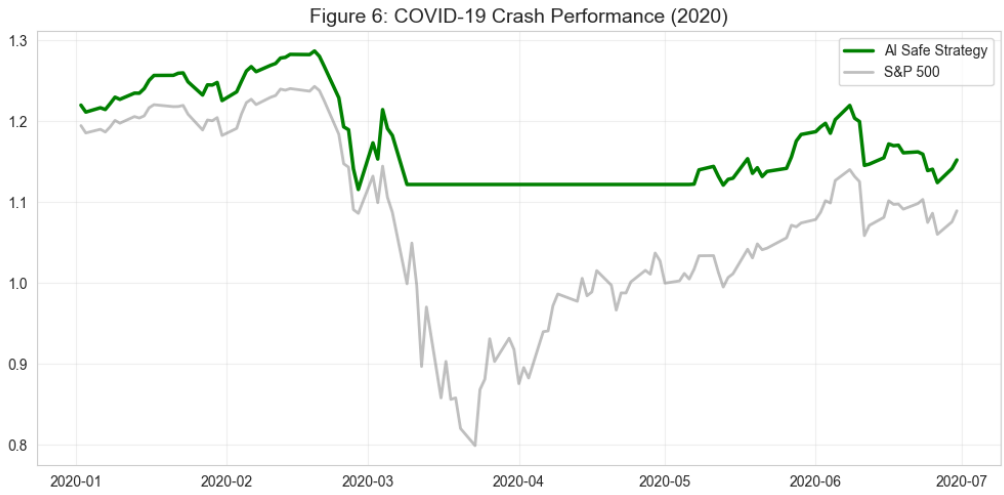


Figure 6: Zoom-in on 2020. The Strategy (Green) preserves capital while the Market (Grey) collapses.

### 6.2 Event 2: The Inflation Bear Market (2022)

A slow grind down caused by rising interest rates, which typically correlates all equity sectors.

- **Strategy Behavior:** Oscillated between Regime 1 (Defensives) and Regime 2 (Cash).
- **Result:** Ended the year flat/slightly up, while the S&P 500 lost -19%.

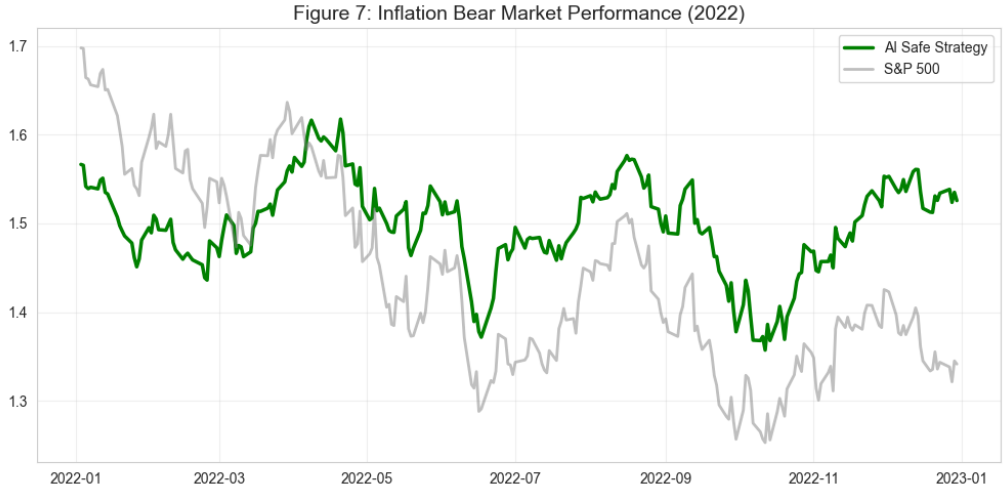


Figure 7: Zoom-in on 2022. The "Defensive Shield" of Regime 1 protected the portfolio from the tech wreck.

## 7 Final Recommendation

Based on the quantitative evidence, the **"Risk Managed (Cash)"** strategy is recommended for implementation.

(a) **Robustness:** It relies on the only correlation (0.0) that holds true in all crises: Cash.

(b) **Psychology:** A -16% drawdown is manageable; a -35% drawdown triggers panic selling.

(c) **Efficiency:** It offers the highest Sharpe Ratio (0.90) and Sortino Ratio of the tested set.