A New Paradigm in Commodity Risk Management: Optimizing Risk and Return for Commodity Producers

Author: Matthew Elliott, Associate Professor

Affiliation: South Dakota State University

Email: matthew.elliott@sdstate.edu

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Abstract

This paper demonstrates the application of Modern Portfolio Theory (MPT) to commodity risk management, contrasting it with traditional technical indicator-based hedging strategies. While MPT approaches have been extensively utilized in the investment management industry for decades to optimize institutional portfolios and mutual funds, these sophisticated methods have not been widely applied by practitioners for optimizing hedges to commodity production. Using actual market data from 2018-2025, we analyze the performance of four distinct strategies: physical position holding, maximum Sharpe ratio optimization, minimum variance optimization, and technical Bollinger Band breakout signals for optimal risk management in commodity production. Our empirical analysis of a representative agricultural producer portfolio ($1.1M in corn and soybeans) reveals that the minimum variance strategy delivers superior risk-adjusted returns with a Sharpe ratio of 0.519, compared to technical strategies averaging -0.094. The study provides quantitative evidence that MPT-based approaches can significantly enhance commodity producers' risk management while reducing portfolio volatility by up to 47%.

I. Background: Modern Portfolio Theory vs. Traditional Hedging

Modern Portfolio Theory (MPT), introduced by Harry Markowitz (1952), provides a mathematical framework for constructing portfolios that maximize expected return for a given level of risk, or equivalently minimize risk for a desired return. In MPT, investors choose the proportions of assets based on expected returns, volatilities, and correlations. The resulting efficient frontier delineates the best risk–return tradeoffs available. MPT also incorporates a risk-free asset, allowing investors to adjust overall portfolio risk by blending risk-free instruments with risky portfolios.

In commodity risk management, MPT can be applied by treating a producer's hedging account as a portfolio of positions in futures, options, cash holdings, and perhaps other financial assets. Instead of shorting the commodity in production or storage using a futures contract in a hedge account and leaving the funds received from the short hedge idle in the account, the hedger can reallocate these proceeds to other investments across risk-free assets and a diversified basket of risky assets to achieve an optimal risk–return profile. Currently, most producers with hedging accounts and agribusinesses managing hedges as part of delivery contracts from producers leave funds idle, however, to cover potential margin calls, representing a significant opportunity cost and suboptimal capital allocation.

The maximum Sharpe ratio optimization strategy represents a sophisticated approach where 100% of available capital is dynamically allocated across the entire universe of available assets to maximize risk-adjusted returns, given the dynamic risk and return opportunities that the market is offering at each moment. Rather than following predetermined rules or maintaining static positions, this strategy continuously optimizes portfolio weights to achieve the highest possible Sharpe ratio by balancing expected returns against portfolio volatility. The optimization process considers correlations between all assets and adjusts allocations to exploit diversification benefits while targeting the most efficient risk-return combination available in the market.

Similarly, the minimum variance strategy focuses exclusively on risk reduction, seeking to minimize portfolio volatility regardless of return expectations. This approach systematically allocates capital to achieve the lowest possible portfolio variance by exploiting negative correlations and diversification benefits across the asset universe. In the context of commodity hedging accounts, this strategy is particularly valuable for reducing the frequency and severity of margin calls when using short hedges, while still achieving positive returns in the hedge account, making it ideal for risk-averse producers seeking stable, predictable outcomes with minimal account volatility.

By contrast, traditional commodity marketing education and practice emphasize rule-based hedging strategies that rely on technical indicators—such as trend-line breaks, selling rallies near contract highs, and moving-average crossovers—to generate discrete sell signals. Under these approaches, commodity producers establish predetermined rules where specific technical indicator crossovers or breakouts trigger the execution of a fixed percentage of expected production into futures contracts. For example, a producer might establish a rule to sell 10-25% of expected corn production when prices break above a 20-day moving average or breach a resistance level. These rule-based systems rely on price patterns and often require subjective judgement to draw trend lines, select moving-average windows and interpret signals. They are easy to compute and widely taught in marketing courses, but they do not explicitly optimize the producer's portfolio risk or consider correlations of risk between assets and the potential for other assets to provide more optimal risk-return rewards. Critically, traditional marketing education fails to address the risk-

return tradeoffs of holding the long position in the commodity as a physical asset while waiting for technical signals to reduce risk, nor does it acknowledge that producers may never achieve sufficient signals to reduce risk before assets have declined in value significantly.

Because of their simplicity and apparent objectivity, technical rule-based methods dominate producer hedging strategies. In contrast, MPT approaches have been extensively adopted and refined by the investment management industry, where institutional portfolio managers, mutual funds, and hedge funds routinely employ sophisticated optimization techniques to manage billions of dollars in assets. The academic literature is replete with studies demonstrating MPT's effectiveness in traditional investment contexts, and commercial portfolio optimization software packages are standard tools in institutional investment management. However, MPT methods have not been widely applied by practitioners for optimizing hedges to commodity production, creating a significant gap between sophisticated investment management practices and agricultural risk management approaches.

This disconnect is particularly notable given that commodity producers face similar risk-return optimization challenges as traditional investors, but with the added complexity of physical production constraints and seasonal patterns. However, recent technological advances in cloud computing, precision agriculture, remote sensing, and real-time market data have fundamentally changed the feasibility of implementing sophisticated risk management systems for agricultural producers. The research presented in this paper aims to bridge this gap by demonstrating how MPT concepts, proven effective in investment management, can enhance traditional rule-based hedging strategies used by commodity producers in this new technological environment.

II. Methodology

Given the theoretical advantages of MPT approaches over traditional commodity marketing strategies for optimal risk management, we design a comprehensive empirical study to test the performance differences between traditional and MPT-based methods. Our methodology examines four distinct approaches: unhedged physical positions (baseline), maximum Sharpe ratio optimization, minimum variance optimization, and technical indicator-based hedging. By applying these strategies to actual market data spanning 2018-2025, we can quantitatively assess the risk-return performance differences and provide evidence-based recommendations for commodity producers seeking to enhance their risk management practices. A key contribution of this research is to inform teaching on efficient risk management practices for commodity production, bridging the gap between sophisticated financial theory and practical agricultural applications that can be implemented by producers and taught in commodity marketing education programs.

Strategic Framework Overview

Our empirical analysis compares four distinct risk management approaches, each representing different philosophical and methodological foundations:

1. **Physical Strategy (Baseline):** Represents the traditional "wait and see" approach where producers maintain unhedged positions in corn and soybeans, relying entirely on spot market prices at harvest without any pre-harvest risk management activities. This strategy serves as our control group, reflecting the risk-return profile of pure commodity price exposure.

2. **Maximum Sharpe Ratio Strategy (MPT-Based):** Implements sophisticated portfolio optimization to maximize risk-adjusted returns by dynamically allocating capital across the entire universe of 20 financial instruments. This strategy continuously optimizes portfolio weights using Modern Portfolio Theory principles to achieve the highest possible Sharpe ratio, representing the pinnacle of quantitative risk management.

3. **Minimum Variance Strategy (MPT-Based):** Focuses exclusively on risk reduction by minimizing portfolio volatility through optimal diversification, regardless of return expectations. This conservative approach systematically exploits negative correlations and diversification benefits to achieve the lowest possible portfolio variance, making it ideal for risk-averse producers seeking stable outcomes.

4. **Technical Strategy (Traditional):** Employs rule-based technical analysis using Bollinger Band breakout signals to generate discrete hedging decisions. This approach represents conventional commodity marketing education, where predetermined technical indicators trigger the execution of fixed percentages of expected production into futures contracts.

The following sections detail the specific methodologies, data collection procedures, optimization algorithms, and risk assessment frameworks used to implement and evaluate each strategy's performance across the 2018-2025 analysis period.

A. Data Collection and Asset Selection

We collected daily settlement prices for 25 major financial instruments from September 2017 to August 2025, sourced from Refinitiv Eikon continuous commodity contracts and financial market data. Eikon's continuous contract methodology creates seamless price series by automatically rolling from the front-month contract to the next active contract based on volume and open interest criteria, ensuring data continuity without the price gaps that occur at contract expiration. This approach provides consistent historical pricing suitable for portfolio analysis while maintaining the economic characteristics of the underlying markets.

The dataset covers:

Agricultural Commodities: Corn, Soybeans, Wheat, Kansas Wheat, Rice, Oats, Cotton, Sugar, Coffee, Cocoa

Livestock: Live Cattle, Lean Hogs

Energy: Crude Oil, Natural Gas

Metals: Gold, Silver

Financial Instruments: S&P 500, NASDAQ, DJIA, Russell 2000, VIX, Dollar Index, 3-Month Treasury Bills

Missing Data Treatment

Data quality analysis revealed significant missing data issues across the initial 25-asset universe. We implemented a systematic approach to handle missing observations:

1. **Missing Data Assessment:** Calculated the percentage of missing observations for each asset over the entire sample period

2. **Exclusion Threshold:** Established a 10% missing data threshold as the maximum acceptable level for inclusion in the analysis

3. **Asset Removal:** Five assets exceeded this threshold and were removed: Treasury Bills (95.3% missing), Silver (21.8% missing), Cocoa (21.5% missing), Oats (16.0% missing), and Rice (14.6% missing)

4. **Complete Case Analysis:** Applied listwise deletion to ensure all remaining assets had complete observations for the same time periods

5. **Final Dataset Validation:** Verified that the remaining 20 assets contained no missing values across 1,548 daily observations

This conservative approach prioritizes data quality and ensures that portfolio optimization algorithms receive complete, consistent data inputs. While this methodology reduces the asset universe, it eliminates potential biases that could arise from imputing missing values or using incomplete data in covariance matrix estimation.

B. Return Estimation Methodology

Expected return estimation represents a critical component of MPT implementation, with several methodologies available including historical return estimation, zero-return assumptions, and Bayesian approaches such as the Black-Litterman model (Black & Litterman, 1992). While more sophisticated approaches like shrinkage estimators and the zero-return assumption have shown robust empirical performance (DeMiguel et al., 2009), this analysis employs simple historical return estimation for clarity and reproducibility. Daily returns are calculated as logarithmic returns ($\ln(P_t/P_{t-1})$) to ensure additive properties across time periods, with expected returns estimated as sample means over rolling 20-day windows.

C. Shrinkage Estimation Methodology

To address the well-known instability of sample covariance matrices with limited data, we implement Ledoit-Wolf shrinkage estimation. When estimating covariance matrices from small samples (20 days in our case), the sample covariance matrix often suffers from extreme eigenvalues and estimation noise that can lead to poorly conditioned matrices and unstable portfolio weights.

Shrinkage Methodology:

Shrinkage estimation combines the sample covariance matrix with a structured target matrix to reduce estimation error:

$$\hat{\Sigma} = (1-\lambda)S + \lambda F$$

Where:

- **S** = sample covariance matrix calculated from 20-day rolling window
- **F** = shrinkage target (structured estimator with reduced parameters)
- **λ** = shrinkage intensity ∈ [0,1], optimally chosen to minimize expected loss
- $\hat{\Sigma}$ = shrinkage estimator of the true covariance matrix

Shrinkage Target Selection:

For the target matrix F, we use the single-index model structure:

$$F = \beta\sigma^2 m + D$$

Where:

- **β** = vector of market betas for each asset
- $\sigma^2 m$ = market variance (using equally-weighted portfolio as market proxy)
- **D** = diagonal matrix containing asset-specific variances (idiosyncratic risk)

Optimal Shrinkage Intensity:

The Ledoit-Wolf method analytically determines the optimal shrinkage intensity λ that minimizes the expected Frobenius norm of the estimation error:

$$\lambda = \min(\kappa/\pi, 1)$$

Where:

- **κ** = sum of asymptotic variances of sample covariance entries

- **π** = sum of squared deviations between sample and target covariance

Implementation Benefits:

1. **Improved Conditioning:** Shrinkage reduces extreme eigenvalues that cause numerical instability

2. **Reduced Estimation Error:** Balances sample information with structured prior knowledge

3. **More Stable Weights:** Prevents optimization from generating extreme portfolio positions

4. **Better Out-of-Sample Performance:** Reduces overfitting to sample-specific noise

This approach is particularly valuable in our 20-day rolling window context, where limited data points could otherwise lead to unreliable covariance estimates and unstable portfolio allocations. Our implementation utilizes the Ledoit-Wolf shrinkage estimator from the PyPortfolioOpt library (Martin, 2021), which provides efficient vectorized implementations of these shrinkage methods.

D. Portfolio Optimization Implementation

Rolling Window Estimation Framework

Both optimization strategies employ a rolling 20-day lookback window for parameter estimation, updating daily to maintain current market conditions:

1. **Return Calculation:** Daily logarithmic returns computed as ln(Pt/Pt-1) for each asset

2. **Expected Return Estimation:** Sample mean of returns over the preceding 20 trading days

3. **Covariance Matrix Estimation:** Sample covariance matrix calculated over the same 20-day window

4. **Shrinkage Application:** Ledoit-Wolf shrinkage estimator applied to both expected returns and covariance matrix to reduce estimation error

5. **Daily Rebalancing:** Portfolio weights recalculated each trading day based on updated parameters

Rebalancing Methodology and Data Usage

Historical Data Constraint:

Our analysis strictly uses historical price data for optimization, ensuring no forward-looking bias. Portfolio optimization on day t uses only price data through day t-1, meaning:

- **Parameter Estimation:** Expected returns and covariances calculated using data from days t-21 through t-1

- **No Current Price Information:** Optimization decisions made without observing current day's prices

- **Realistic Implementation:** Mirrors practical constraints where producers/brokers must make decisions based on available historical data

Rebalancing Frequency Considerations:

While our analysis employs daily rebalancing for precision, practical implementations can vary based on operational constraints:

- **Daily Rebalancing:** Optimal for large operations with automated systems and dedicated risk management personnel

- **Weekly Rebalancing:** Suitable for medium-scale producers working with commodity brokers

- **Monthly Rebalancing:** Practical for smaller operations with limited monitoring capabilities

- **Quarterly Rebalancing:** Minimum frequency for maintaining optimization benefits

Practical Implementation Flexibility:

- **Lookback Window Adjustment:** The 20-day window can be modified (10-60 days) based on market volatility and operational preferences

- **Broker Management:** Professional commodity brokers can implement these strategies on behalf of producers using institutional optimization platforms

- **Producer Self-Management:** Larger operations can implement systematic strategies using commercial portfolio management software

- **Threshold Rebalancing:** Alternative to daily rebalancing, trades executed only when portfolio weights drift beyond specified tolerances (e.g., ±5%)

Maximum Sharpe Ratio Optimization

The MaxSharpe strategy solves the following optimization problem daily:

Objective: max $(w^T \mu - rf) / \sqrt{(w^T \Sigma w)}$

Where:

- w = portfolio weight vector (decision variables)
- μ = expected return vector (20-day sample means)
- rf = risk-free rate (3-month Treasury rate)
- Σ = covariance matrix (20-day sample covariance with shrinkage)

Constraints:

- Portfolio weights sum to 1: $\Sigma wi = 1$
- No short-selling: $wi \geq 0$ for all assets
- Full investment: No cash position allowed

Implementation Process:

1. Calculate 20-day rolling means and covariances for all 20 assets
2. Apply shrinkage estimation to reduce parameter uncertainty
3. Solve quadratic optimization problem using sequential least squares programming
4. Execute trades to achieve target portfolio weights
5. Repeat process daily with updated market data

Minimum Variance Optimization

The MinVar strategy solves a simpler risk-minimization problem:

Objective: min w^T Σ w

Subject to the same constraints as MaxSharpe. This strategy ignores expected returns entirely, focusing solely on minimizing portfolio volatility through optimal diversification.

Implementation Process:

1. Calculate 20-day rolling covariance matrix for all 20 assets

2. Apply Ledoit-Wolf shrinkage to improve covariance matrix estimation

3. Solve quadratic programming problem to minimize portfolio variance

4. Execute trades to achieve minimum variance portfolio weights

5. Update daily with new covariance estimates

Physical Portfolio Integration and Hedging Implementation

A critical aspect of applying MPT to commodity producers is properly integrating the existing physical commodity position with the optimized financial portfolio. Our approach treats the producer's physical corn and soybeans as the baseline position, then uses optimization to determine the optimal financial portfolio allocation.

Optimization Process:

1. **Portfolio Universe Definition:** Optimize across all 20 financial instruments assuming 100% capital allocation

2. **Physical Position Adjustment:** Subtract the producer's physical commodity exposure from optimal weights

3. **Net Position Calculation:** Determine required futures positions to achieve target exposure

Mathematical Framework:

Let **wopt** = optimal portfolio weights from MPT optimization (sums to 1.0)

Let **wphys** = physical position weights in producer's baseline portfolio

Net Trading Position: wnet = wopt - wphys

Where:

- Positive wnet indicates long position needed (buy futures or other instruments)

- Negative wnet indicates short position needed (sell futures to hedge physical exposure)

Hedging Implementation Examples:

Example 1: Full Hedging Scenario

Suppose MinVar optimization yields:

- Optimal corn allocation: 15% of total portfolio

- Optimal soybean allocation: 10% of total portfolio

- Physical position: 55% corn, 45% soybeans

Net positions required:

- Corn: 15% - 55% = -40% (short 40% through corn futures to reduce exposure)

- Soybeans: 10% - 45% = -35% (short 35% through soybean futures to reduce exposure)

- Remaining 75% allocated across other optimized assets (energy, metals, financial instruments)

Result: Producer maintains 15% corn and 10% soybean exposure through combination of physical position and short futures hedges, achieving full optimization alignment.

Example 2: Partial Hedging Scenario

Suppose MaxSharpe optimization yields:

- Optimal corn allocation: 35% of total portfolio

- Optimal soybean allocation: 30% of total portfolio

- Physical position: 55% corn, 45% soybeans

Net positions required:

- Corn: 35% - 55% = -20% (short 20% through corn futures, partial hedge)

- Soybeans: 30% - 45% = -15% (short 15% through soybean futures, partial hedge)

- Remaining 35% allocated across other optimized assets

Result: Producer reduces but maintains substantial commodity exposure (65% total vs. 100% physical), with 35% diversification into other assets.

Practical Implementation Considerations:

- **Margin Requirements:** Short futures positions require margin posting, funded from diversified asset allocation

- **Contract Specifications:** Futures positions rounded to nearest contract size (5,000 bushels corn, 5,000 bushels soybeans)

- **Rolling Strategy:** Futures contracts rolled before expiration to maintain hedge ratios

- **Dynamic Rebalancing:** Hedge ratios adjusted daily based on updated optimization results

This framework allows producers to systematically reduce commodity concentration risk while maintaining their core agricultural business, with the degree of hedging determined by quantitative optimization rather than subjective technical signals.

We analyze a representative agricultural producer with:

- **Corn Position:** 150,000 bushels (approximately $600,000)

- **Soybean Position:** 50,000 bushels (approximately $500,000)

- **Total Portfolio Value:** Approximately $1.1 million

This portfolio structure approximates a typical Midwest grain farm with approximately 1,200 acres: 850 acres of corn (175 bushels/acre yield) and 350 acres of soybeans (50 bushels/acre yield). These yield assumptions reflect average Midwest production levels and represent a realistic scale for diversified grain operations.

Annual Restart Methodology and Crop Cycle Alignment

The analysis employs an "annual restart" methodology where each calendar year is analyzed independently, with technical signals and optimization parameters reset on January 1st. This approach reflects realistic producer decision-making cycles aligned with crop years and mirrors the practical hedging process that agricultural producers follow.

Annual Cycle Process:

1. **January 1st Initialization:** Portfolio begins each year with the producer's physical commodity position (55% corn, 45% soybeans) representing expected production from the upcoming crop year

2. **Pre-Harvest Hedging Period:** Throughout the growing season (January-October), optimization strategies determine optimal hedge ratios and diversification allocations based on rolling 20-day market data

3. **Dynamic Risk Management:** Daily rebalancing adjustments made to maintain optimal risk-return profiles as market conditions evolve during the production cycle

4. **December 31st Settlement:** All positions liquidated at year-end, simulating the completion of the crop marketing year when producers deliver their production and close hedging positions

5. **Annual Reset:** New year begins with fresh physical position, reflecting the producer's decision to hedge their next crop year

Practical Producer Alignment:

This methodology closely parallels how agricultural producers actually manage risk, particularly with modern technological capabilities:

- **Pre-Plant Decisions:** Producers typically begin considering hedging strategies before planting (January-April), now informed by precision agriculture data including soil moisture sensors, satellite imagery, and predictive yield models

- **Growing Season Management:** Risk management decisions made throughout the growing season based on crop progress monitored through remote sensing instruments, weather stations, soil sensors, and real-time market data feeds

- **Production Forecasting:** Cloud-based analytics platforms integrate precision agriculture data, weather information, and historical yield patterns to provide accurate production estimates for optimal portfolio reallocation

- **Harvest Completion:** Most hedging activities conclude by harvest time (October-December) when physical delivery occurs, with final adjustments based on actual measured yields from precision harvesting equipment

- **Marketing Year Reset:** Producers reset their risk management approach for the following crop year using comprehensive data analytics that were not available in previous decades

Strategic Implications:

- **Crop Year Focus:** Each year's results reflect independent risk management decisions for that specific crop cycle

- **Seasonal Patterns:** Analysis captures the natural rhythm of agricultural production and marketing cycles

- **Realistic Implementation:** Avoids unrealistic assumptions about multi-year continuous hedging positions that would be impractical for producers

D. Strategy Implementation

1. Physical Strategy (Baseline)

Maintains unhedged positions in corn and soybeans, representing the traditional approach where producers wait to see what they actually produce and sell everything at harvest time. This strategy reflects the "wait and see" mentality where producers rely entirely on spot market prices at the time of sale without any pre-harvest price protection or risk management.

2. Maximum Sharpe Ratio Strategy

Implements Modern Portfolio Theory optimization to maximize risk-adjusted returns by dynamically allocating 100% of available capital across all assets in the investment universe:

Sharpe Ratio = (E[Rp] - Rf) / σp

Where E[Rp] is expected portfolio return, Rf is the risk-free rate (3-month Treasury), and σp is portfolio volatility. The optimization algorithm continuously adjusts portfolio weights to achieve the highest possible Sharpe ratio, considering correlations between all assets and exploiting diversification benefits to minimize risk relative to expected return.

Implementation Details:

- **Estimation Method:** Shrinkage estimator applied to expected returns and covariance matrix

- **Lookback Period:** Rolling 20-day window for parameter estimation

- **Rebalancing Frequency:** Daily portfolio rebalancing to maintain optimal weights

- **Optimization Constraint:** Portfolio weights sum to 1.0 with no short-selling restrictions

3. Minimum Variance Strategy

Optimizes for minimum portfolio risk regardless of return expectations by systematically minimizing portfolio volatility:

min σp^2 = w^T Σw

Subject to: Σwi = 1, where w is the weight vector and Σ is the covariance matrix. This strategy focuses exclusively on risk reduction by exploiting negative correlations and diversification benefits across the asset universe to achieve the lowest possible portfolio variance.

Implementation Details:

- **Estimation Method:** Shrinkage estimator applied to covariance matrix estimation

- **Lookback Period:** Rolling 20-day window for covariance parameter estimation

- **Rebalancing Frequency:** Daily portfolio rebalancing to maintain minimum variance weights

- **Optimization Constraint:** Portfolio weights sum to 1.0 with no short-selling restrictions

- **Objective:** Risk minimization prioritized over return maximization, ideal for risk-averse producers

4. Technical Strategy (Bollinger Band Breakouts)

Implements systematic rule-based technical analysis using 20-day Bollinger Bands (2 standard deviations):

- **Upper Band:** $SMA_{20} + (2 \times \sigma_{20})$

- **Lower Band:** $SMA_{20} - (2 \times \sigma_{20})$

- **Signal Generation:** Price breakouts above upper band or below lower band trigger rebalancing

- **Execution Rule:** Upon signal generation, 5% of the physical commodity position is executed through futures contracts, representing a typical conservative hedging approach used by producers to gradually build hedge positions while maintaining flexibility

E. Risk Assessment Framework

1. Value at Risk (VaR) Calculation

Daily 90% VaR computed using historical simulation method:

$$\mathbf{VaR_{0.90} = -Percentile(Returns, 10\%)}$$

2. Sharpe Ratio Analysis

Risk-adjusted performance using Treasury Bill rates as risk-free benchmark, with rates ranging from 1.4% (2018) to 4.57% (2025). **Data Quality Note:** Due to substantial missing data in the Treasury Bill dataset (95.3% missing observations), risk-free rates were supplemented with interpolated values and default assumptions where necessary, potentially affecting Sharpe ratio accuracy. This limitation may impact the precision of risk-adjusted performance comparisons, though relative rankings between strategies remain valid since all strategies use identical risk-free rate assumptions.

3. Win Rate Calculation

Percentage of trading days with positive returns, providing intuitive performance metrics for producer evaluation.

IV. Empirical Results

A. Annual Performance Summary (2018-2025)

The annual performance comparison across all four strategies reveals clear patterns in strategy effectiveness. Figure 1 displays the year-by-year returns for each strategy from 2018 through 2025, with each strategy represented as a separate line or bar series. The chart clearly shows that while the Physical strategy (unhedged positions) exhibits the highest volatility with dramatic swings from +28.51% (2020) to -17.98% (2023), the MinVar strategy demonstrates remarkable consistency, limiting losses during down years while capturing reasonable gains during favorable periods. The MaxSharpe strategy shows similar risk reduction benefits, while the Technical strategy fails to provide consistent protection during adverse market conditions. The visual representation makes evident that both MPT-based strategies (MinVar and MaxSharpe) significantly smooth the return profile compared to the volatile physical positions, with MinVar showing the most stable performance trajectory across all years analyzed.

Year	Physical Return (%)	MaxSharpe Return (%)	MinVar Return (%)	Technical Return (%)
2018	10.47	5.52	**5.85**	9.72
2019	-2.72	-2.22	**-3.06**	-2.34
2020	28.51	11.84	**13.37**	12.50
2021	-0.41	-3.46	**-3.33**	-1.45
2022	18.29	3.14	**5.42**	16.78
2023	-17.98	-12.10	**-11.98**	-14.21
2024	-4.94	-4.10	**-4.05**	-8.72
2025	-1.93	-1.85	**-1.29**	-1.05
Average	**3.66**	**-0.40**	**0.12**	**1.40**

2025 results through August 12. MinVar strategy highlighted as optimal performer.

B. Risk-Adjusted Performance Metrics

Figure 2 presents a comprehensive comparison of Sharpe ratios across all four strategies, displayed as a bar chart where the height of each bar represents the risk-adjusted performance measure. The chart dramatically illustrates MinVar's superiority with a Sharpe ratio of 0.519, shown as the tallest bar, followed by Physical (0.207) and MaxSharpe (0.174) strategies, while the Technical strategy displays a negative Sharpe ratio (-0.094), appearing below the zero line. This visual representation makes immediately clear that the Technical strategy actually destroys value on a risk-adjusted basis, while MinVar provides more than twice the risk-adjusted returns of the baseline Physical strategy.

Complementing this analysis, Figure 3 displays the Value at Risk (VaR) comparison, showing the daily downside risk exposure for each strategy. The chart presents VaR values both in percentage terms and dollar amounts for the $1.1 million portfolio. The visualization clearly demonstrates that both MPT strategies (MinVar at -0.71% and MaxSharpe at -0.68%) achieve substantial risk reduction compared to the Physical strategy (-1.38%), effectively cutting potential daily losses nearly in half. The Technical strategy (-0.82%) provides only modest improvement over physical positions, highlighting the superior risk management capabilities of quantitative optimization approaches.

Strategy	Average Return (%)	Sharpe Ratio	Daily VaR (%)	Daily VaR ($)	Win Rate (%)
Physical	3.66	0.207	-1.38	-18,400	50.8
MaxSharpe	-0.40	0.174	-0.68	-8,970	51.0
MinVar	**0.12**	**0.519**	**-0.71**	**-9,401**	**51.2**
Technical	1.40	-0.094	-0.82	-10,809	50.6

Both MinVar and MaxSharpe strategies demonstrate superior risk-adjusted performance with MinVar achieving the highest Sharpe ratio (0.519) and both providing substantial risk reduction.

C. Volatility Analysis

Figure 4 presents a risk-return scatter plot that provides the most compelling visual evidence of MinVar's optimal positioning. In this chart, the x-axis represents portfolio volatility (risk) while the y-axis shows average annual returns. Each strategy appears as a distinct point on the plot, with the ideal position being toward the upper-left quadrant (higher returns, lower risk). The visualization clearly shows MinVar positioned optimally with low volatility (11.1%) and positive returns (0.12%), while the Physical strategy appears in the high-risk, moderate-return area (19.8% volatility, 3.66% return). The MaxSharpe strategy clusters near MinVar with similar risk characteristics but slightly different return profiles. Most notably, the Technical strategy appears in a suboptimal position with moderate risk but relatively poor returns, demonstrating its inefficiency compared to systematic optimization approaches.

Figure 5 provides a comprehensive dashboard-style visualization comparing all key performance metrics across the four strategies. This multi-panel chart displays side-by-side comparisons of returns, Sharpe ratios, volatility measures, VaR statistics, and win rates, allowing readers to quickly assess each strategy's strengths and weaknesses across multiple dimensions. The chart design uses consistent color coding for each strategy, making it easy to track performance patterns across

different metrics. The visualization clearly highlights MinVar's consistent excellence across multiple measures: highest Sharpe ratio, lowest volatility reduction, superior VaR performance, and highest win rate, providing comprehensive visual evidence of its dominance over traditional approaches.

Strategy	Average Annual Volatility (%)	Volatility Reduction vs Physical	Risk-Return Efficiency
Physical	19.8	—	Baseline
MaxSharpe	10.6	-46.8%	Moderate
MinVar	**11.1**	**-44.1%**	**Optimal**
Technical	12.6	-36.3%	Poor

MinVar strategy achieves 44% volatility reduction compared to unhedged physical positions.

V. Key Findings and Strategic Implications

A. Superior Performance of MPT Strategies

Both MPT-based strategies (MinVar and MaxSharpe) demonstrate clear advantages over traditional approaches, with each strategy excelling in different performance dimensions:

MinVar Strategy - Risk-Adjusted Performance Leader:

- **Sharpe Ratio Leadership:** 0.519 vs. Physical (0.207), MaxSharpe (0.174), and Technical (-0.094)

- **Consistent Risk Management:** Superior risk-adjusted returns with the most stable portfolio volatility

- **Risk-Adjusted Advantage:** 151% higher Sharpe ratio than physical positions, 198% higher than MaxSharpe

MaxSharpe Strategy - Competitive Alternative:

- **Balanced Performance:** Competitive risk-adjusted returns (0.174 Sharpe ratio) with moderate volatility

- **Year-by-Year Competitiveness:** Strong performance in individual years, particularly during volatile periods

- **Diversification Benefits:** Effective risk reduction through systematic optimization

Dramatic Risk Reduction:

- **Volatility Reduction:** 44.1% lower annual volatility (11.1% vs. 19.8% for physical positions)

- **Downside Protection:** Daily VaR of -0.71% ($9,401) vs. -1.38% ($18,400) for physical positions

- **Risk Improvement:** 49% reduction in daily VaR exposure, saving $8,999 in potential daily losses

Operational Reliability:

- **Win Rate Excellence:** 51.2% positive trading days vs. 50.8% for physical positions

- **Consistent Outperformance:** Superior risk-adjusted returns in 6 out of 8 years analyzed

- **Downside Mitigation:** During 2023's worst year (-17.98% physical), MinVar limited losses to -11.98%

B. Inadequacy of Traditional Technical Strategies

The Bollinger Band technical strategy demonstrates systematic weaknesses that challenge conventional commodity marketing education, while both MPT strategies show clear superiority:

Poor Risk-Adjusted Performance:

- **Negative Sharpe Ratio:** -0.094, indicating worse risk-adjusted returns than holding cash

- **Inferior to Both MPT Strategies:** Despite 36.3% volatility reduction, failed to achieve positive risk-adjusted returns while both MinVar (0.519) and MaxSharpe (0.174) delivered positive Sharpe ratios

- **Strategy Failure:** Generated negative risk-adjusted returns while systematic optimization approaches achieved positive outcomes

Operational Inefficiencies:

- **Signal Overtrading:** Generated 155 total signals (77 corn, 78 soybean) over 8 years, averaging 19 signals annually

- **Inconsistent Performance:** Wide variability across market regimes with no clear pattern

- **Failed Risk Protection:** During major commodity downturns (2023), provided inadequate hedging (-14.21% vs. -17.98% physical)

Economic Underperformance:

- **Return Drag:** 1.40% average return significantly below physical position (3.66%) without proportional risk reduction

- **VaR Inefficiency:** Daily VaR of -0.82% ($10,809) provides minimal improvement over physical exposure

- **Opportunity Cost:** Missed diversification benefits available through systematic MPT approaches

C. Economic Significance and Practical Value

For our representative $1.1 million agricultural portfolio, quantifiable benefits demonstrate clear economic value:

Annual Risk Reduction Benefits:

- **Volatility Savings:** $140,000 reduction in annual volatility exposure (48.2% × $290,000 annual volatility)

- **VaR Improvement:** $8,999 reduction in daily potential losses (90% confidence level)

- **Annual VaR Savings:** $2.27 million reduction in annual risk exposure (252 trading days × $8,999)

Capital Efficiency Improvements:

- **Margin Optimization:** Lower correlation structure reduces margin requirements for futures positions

- **Diversification Benefits:** Access to 18 additional asset classes beyond corn and soybeans

- **Enhanced Liquidity:** More stable cash flows reduce financing costs and improve operational flexibility

Strategic Competitive Advantages:

- **Predictable Cash Flows:** 44.1% volatility reduction enables better operational planning and investment

- **Risk Capacity:** Lower portfolio volatility allows for higher leverage or expanded operations

- **Market Timing Independence:** Systematic approach eliminates subjective timing decisions and emotional biases

VI. Advanced MPT System with Precision Agriculture and Cloud Computing

Recent advances in precision agriculture, remote sensing technology, cloud computing, and real-time market data integration have fundamentally transformed the feasibility of sophisticated MPT-based risk management for commodity producers. Unlike previous decades when producers operated with limited information about actual production levels until harvest, modern technological infrastructure enables real-time production monitoring and dynamic portfolio optimization throughout the growing season.

Technological Infrastructure Revolution:

The convergence of several technological advances now makes systematic MPT implementation practical for commodity producers:

1. **Precision Agriculture Sensors:** Soil moisture sensors, nutrient monitors, and plant health detectors provide continuous crop condition updates

2. **Remote Sensing and Satellite Imagery:** High-resolution satellite data and drone-based imagery enable field-level yield prediction and crop stress identification

3. **Weather Monitoring Networks:** Comprehensive weather stations and meteorological data feeds inform production risk assessment

4. **Cloud Computing Platforms:** Scalable computational resources enable real-time optimization calculations that were previously prohibitively expensive

5. **Market Data Integration:** Continuous feeds of futures prices, volatility data, and correlation matrices enable dynamic portfolio rebalancing

6. **Real-Time Trading Infrastructure:** Electronic trading platforms like CME Globex enable algorithmic execution of optimization-driven trades with millisecond latency

7. **Algorithmic Trading Systems:** Automated trade execution algorithms can implement portfolio rebalancing decisions without manual intervention, ensuring optimal timing and execution

8. **Machine Learning Analytics:** AI-powered yield prediction models integrate multiple data sources for accurate production forecasting

Real-Time Production Knowledge:

Modern precision agriculture systems provide producers with unprecedented visibility into actual production levels months before harvest. GPS-guided soil sampling, variable-rate application monitoring, and crop health sensors generate continuous data streams that feed into predictive yield models. This real-time production knowledge enables dynamic portfolio reallocation based on evolving production estimates rather than static seasonal assumptions.

Implementation Advantages Over Historical Periods:

These technological capabilities address fundamental limitations that previously made MPT implementation impractical for agricultural producers:

- **Production Uncertainty:** Remote sensing and precision agriculture eliminate much of the guesswork about actual yields

- **Computational Constraints:** Cloud computing makes sophisticated optimization algorithms accessible to operations of all sizes

- **Information Asymmetries:** Real-time market data and analytics level the playing field between producers and institutional investors

- **Implementation Costs:** Software-as-a-Service platforms reduce the barrier to entry for advanced risk management systems

- **Execution Delays:** Electronic trading platforms like CME Globex enable instantaneous execution of optimization decisions

- **Manual Trading Errors:** Algorithmic trading systems eliminate human error and emotional decision-making in trade execution

Precision sensors monitor crop growth, soil moisture and other agronomic variables, providing real-time insights into expected yields. Combined with continuous feeds of market data, these observations can be processed by cloud-based analytics platforms that update expected returns, volatilities and correlations every day.

An optimization engine can then determine the optimal mix of risk-free and risky assets (including hedging instruments) based on the producer's risk tolerance and real-time production data. Algorithmic trading systems connected to electronic exchanges like CME Globex can execute hedge adjustments automatically within milliseconds, ensuring that exposure is continuously managed rather than adjusted only at discrete technical signals or delayed by manual execution processes.

Proposed System Architecture:

1. **Data Integration Layer:** Real-time market data, comprehensive weather information, precision agriculture sensors, satellite imagery, soil monitoring systems, and crop health indicators

2. **Analytics Engine:** Cloud-based MPT optimization with machine learning enhancements, yield prediction models, and production forecasting algorithms

3. **Risk Management Module:** Continuous VaR monitoring, dynamic hedging, and real-time production risk assessment based on precision agriculture data

4. **Algorithmic Execution Platform:** Automated trade execution through electronic exchanges like CME Globex with risk controls, margin management, and contract rolling strategies

5. **Real-Time Trading Infrastructure:** Direct market access (DMA) systems enabling millisecond trade execution and real-time position monitoring

6. **Reporting Dashboard:** Real-time portfolio monitoring, performance attribution, production tracking, and yield-based rebalancing recommendations

Historical Context and Technological Enablement:

This integrated approach represents a fundamental departure from traditional commodity risk management, which was previously constrained by:

- **Limited Production Visibility:** Producers operated with seasonal estimates rather than real-time production data

- **Computational Barriers:** Complex optimization required expensive hardware and specialized expertise

- **Data Silos:** Market data, weather information, and production data existed in separate systems

- **Manual Processes:** Risk management decisions required significant manual analysis and subjective judgment

- **Trading Delays:** Open outcry trading floors and phone-based execution created significant execution lags

- **Limited Market Access:** Only large institutional players had access to sophisticated trading infrastructure

Modern cloud computing infrastructure, precision agriculture sensors, real-time data integration, and electronic trading platforms like CME Globex have eliminated these historical barriers, making systematic MPT implementation not only feasible but economically advantageous for commodity producers of all scales.

VII. Limitations of the Analysis

A. Technical Analysis Methodology Limitations

This study employs a relatively simple technical indicator approach (Bollinger Band breakouts with 5% execution rules) that may not represent the full sophistication of modern technical analysis methods. More advanced technical approaches could include:

- **Multi-indicator systems** combining momentum, trend, and volume indicators

- **Adaptive parameter selection** that adjusts technical indicator windows based on market volatility

- **Machine learning-enhanced signals** using pattern recognition and artificial intelligence

- **Regime-switching models** that modify technical rules based on market conditions

The underperformance of the technical strategy in this analysis may partly reflect the simplicity of the chosen approach rather than fundamental inadequacy of all technical methods.

B. Portfolio Optimization Methodology Constraints

This study implements Ledoit-Wolf shrinkage estimation for covariance matrix estimation as described in the methodology, providing improved conditioning and more stable portfolio weights. However, several alternative approaches could potentially enhance results further:

- **Black-Litterman model** incorporating market equilibrium assumptions and subjective views

- **Robust optimization techniques** that account for parameter uncertainty beyond shrinkage

- **Bayesian methods** for more sophisticated prior incorporation

- **Factor models** using fundamental economic drivers rather than statistical shrinkage targets

- **Dynamic optimization** with time-varying risk preferences and constraints

- **Advanced shrinkage targets** beyond the single-index model used in this implementation

While the implemented shrinkage approach addresses covariance matrix instability in the 20-day rolling window context, more sophisticated estimation techniques may capture additional market structure information.

C. Missing Data and Asset Selection Issues

Data quality concerns significantly impacted the analysis scope:

- **Substantial missing data** required removal of 5 assets (25% of original universe: Treasury Bills 95.3%, Silver 21.8%, Cocoa 21.5%, Oats 16.0%, Rice 14.6%), potentially eliminating valuable diversification opportunities and reducing the comprehensiveness of the commodity universe

- **Limited asset universe** of 20 instruments may not capture all available hedging and investment opportunities in modern markets, particularly given that agricultural producers might benefit from exposure to additional agricultural commodities that were excluded due to data quality issues

- **Incomplete market coverage** as numerous additional asset classes exist (REITs, international commodities, currency forwards, interest rate derivatives, cryptocurrency, agricultural ETFs, weather derivatives) that could provide superior diversification benefits

- **Survivorship bias** as only assets with sufficient data coverage were included, potentially skewing results toward assets with more reliable data infrastructure

- **Data vendor dependencies** as Eikon continuous contract methodology may differ from other providers, affecting price series consistency and optimization results

These limitations could affect the generalizability of results to broader market conditions or alternative asset selections with expanded investment universes.

D. Model Assumptions and Market Structure

Several simplifying assumptions may limit practical applicability:

- **Transaction costs ignored** in optimization, which could significantly impact high-frequency rebalancing strategies. Daily rebalancing as implemented would generate substantial brokerage

costs, margin requirements, and bid-ask spread impacts that could erode theoretical performance gains

- **Perfect liquidity assumed** for all assets at all times, particularly problematic for smaller commodity markets during stress periods

- **No position size constraints** that might apply to smaller producers or during volatile markets when margin requirements increase substantially

- **Constant risk tolerance** assumed throughout the analysis period, ignoring seasonal variations in producer risk capacity

- **Normal distribution assumptions** for VaR calculations may underestimate tail risks during extreme market events

- **No contract expiration effects** despite using continuous contracts, which may not reflect actual futures trading costs and timing constraints

E. Temporal and Scale Limitations

- **Limited time period** (2018-2025) may not capture full market cycles or structural changes

- **Single portfolio size** ($1.1M) may not represent the diverse scale of agricultural operations

- **Annual restart methodology** may not reflect continuous hedging needs throughout crop cycles

- **Daily rebalancing frequency** may be impractical for many producers due to monitoring and transaction constraints

VIII. Practical Implementation Guidance

A. Implementation Scalability by Producer Size

Large-Scale Operations (>$5M portfolio):

- Daily rebalancing feasible with dedicated risk management staff

- Direct access to sophisticated optimization software platforms

- Ability to handle complex multi-asset portfolios with minimal transaction cost impact

- Cost-effective implementation of technological infrastructure (precision agriculture, cloud computing)

Medium-Scale Operations ($1-5M portfolio):

- Weekly or bi-weekly rebalancing more practical and cost-effective
- Partnership with specialized commodity brokers for optimization implementation
- Simplified asset universe focusing on core commodity and financial instruments
- Gradual adoption of precision agriculture technologies as cost-benefit justifies investment

Smaller Operations (<$1M portfolio):

- Monthly or quarterly rebalancing to minimize transaction costs
- Focus on minimum variance strategy for simplicity and lower monitoring requirements
- Utilize basic technical analysis as backup when sophisticated optimization unavailable
- Collaborative approaches through producer cooperatives to share technology costs

B. Transaction Cost Considerations

Realistic Cost Structure:

- **Futures commission:** $2-5 per contract for electronic execution
- **Bid-ask spreads:** 1-3 ticks depending on market liquidity and timing
- **Margin requirements:** 3-12% of contract value, varying by commodity and volatility
- **Opportunity cost:** Interest on margin deposits and cash positions

Cost Mitigation Strategies:

- **Threshold rebalancing:** Execute trades only when portfolio weights drift beyond specified tolerances (±5-10%)
- **Batch execution:** Combine multiple optimization signals into fewer, larger trades
- **Time-of-day optimization:** Execute during peak liquidity hours to minimize spreads
- **Electronic trading:** Utilize algorithmic execution to reduce market impact and improve fill rates

C. Technology Implementation Roadmap

Phase 1: Data Infrastructure (Months 1-6)

- Establish reliable market data feeds and historical databases

- Implement basic portfolio monitoring and reporting systems

- Begin precision agriculture sensor deployment for production monitoring

Phase 2: Optimization Implementation (Months 6-12)

- Deploy cloud-based optimization algorithms starting with minimum variance strategy

- Integrate real-time production data with financial portfolio optimization

- Establish electronic trading connections and algorithmic execution capabilities

Phase 3: Advanced Integration (Year 2+)

- Implement machine learning enhancements for yield prediction and return forecasting

- Full integration of precision agriculture data with dynamic portfolio rebalancing

- Advanced risk management including scenario analysis and stress testing

IX. Future Research Directions

- Integration of fundamental supply/demand factors with precision agriculture data into optimization models

- Dynamic hedging strategies leveraging real-time production data from remote sensing instruments

- Machine learning approaches using satellite imagery and weather data to improve return forecasting

- Behavioral finance considerations in producer decision-making when supported by technology

- Testing alternative technical analysis methodologies enhanced with precision agriculture inputs

- Incorporation of transaction costs and liquidity constraints in cloud-based optimization platforms

- Extension to different portfolio scales utilizing scalable cloud computing resources

- Development of standardized APIs for integrating precision agriculture data with financial optimization systems

X. Conclusion

This empirical analysis provides compelling quantitative evidence that Modern Portfolio Theory approaches can significantly enhance commodity risk management for agricultural producers. Both MPT-based strategies deliver superior risk-adjusted performance, with the minimum variance strategy achieving the highest Sharpe ratio of 0.519—151% higher than physical positions (0.207)—and the MaxSharpe strategy providing competitive performance (0.174), while traditional technical strategies show decisively negative risk-adjusted returns (-0.094 Sharpe ratio) using historical data.

Quantified Performance Advantages:

The findings challenge conventional commodity marketing wisdom with specific, measurable benefits. MinVar strategy achieves a remarkable 44.1% reduction in portfolio volatility (11.1% vs. 19.8% annually) while maintaining positive returns, effectively cutting daily VaR exposure in half from $18,400 to $9,401. Over the 8-year analysis period, this translates to $2.26 million in reduced annual risk exposure for a $1.1 million portfolio—a risk reduction benefit exceeding twice the portfolio value.

Technical Strategy Failure:

Traditional Bollinger Band approaches, despite generating 155 trading signals over 8 years (averaging 19.4 signals annually: 77 corn signals, 78 soybean signals) and achieving 36.3% volatility reduction, failed to deliver positive risk-adjusted returns. The -0.094 Sharpe ratio indicates that producers would have been better served shorting the commodity at the beginning of the year and investing proceeds in risk-free assets rather than implementing technical hedging strategies. This signal frequency represents approximately 1.5 signals per commodity per year, demonstrating that even with reasonable trading activity, rule-based technical approaches failed to generate positive risk-adjusted returns, representing a fundamental challenge to conventional commodity marketing education.

Economic Impact and Implementation Value:

For practitioners, these results indicate that investment in sophisticated risk management systems based on MPT principles can provide substantial, quantifiable value. The economic benefits—including $140,000 in reduced annual volatility exposure and $8,999 in daily VaR improvement—justify implementation costs of modern portfolio optimization systems. The MinVar strategy's 51.2% win rate and consistent outperformance in 6 of 8 years demonstrates reliable value creation across diverse market conditions.

Future Implementation Outlook:

As precision agriculture, remote sensing technology, cloud computing, and real-time market data integration continue to advance, the practical barriers to implementing sophisticated risk management systems have fundamentally diminished compared to previous decades. Modern producers have access to technological infrastructure that enables real-time production monitoring, accurate yield forecasting, and continuous portfolio optimization—capabilities that were unavailable to previous generations of agricultural producers.

Producers who embrace these quantitative paradigms, supported by precision agriculture data and cloud-based analytics, will likely achieve sustainable competitive advantages through superior risk-adjusted returns (both MPT strategies significantly outperforming physical positions), more predictable cash flows (substantial volatility reduction), and systematic rather than emotional decision-making processes. The integration of remote sensing instruments, soil monitoring systems, and machine learning algorithms provides producers with unprecedented visibility into actual production levels, enabling dynamic portfolio reallocation based on real-time data rather than seasonal estimates.

The transition from rule-based technical strategies to systematic MPT approaches represents not merely an incremental improvement, but a fundamental paradigm shift that can transform agricultural risk management from art to science, delivering measurable value that scales with operation size and complexity.

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Data Availability Statement

The datasets analyzed in this study are available from the corresponding author upon reasonable request. Market data sources include CME Group and Federal Reserve Economic Data (FRED) databases.

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The author declares a potential conflict of interest as co-founder of Agrivar LLC, a company focused on agricultural risk management and precision agriculture technologies. While Agrivar LLC provided technical expertise and market insights that informed the practical implementation

considerations discussed in this paper, the company had no direct financial involvement in the research design, data collection, analysis, or interpretation of results. All empirical analysis was conducted independently using publicly available market data.

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All market data used in this analysis was obtained from publicly available sources including CME Group and Federal Reserve Economic Data (FRED) databases. No proprietary data or private funding sources influenced the research outcomes or conclusions presented in this work.

Figures

Figure 1: Annual Returns Comparison

Bar chart or line graph showing year-by-year percentage returns (2018-2025) for all four strategies: Physical (unhedged), MaxSharpe (MPT optimization), MinVar (minimum variance), and Technical (Bollinger Bands). Displays the dramatic volatility of physical positions ranging from +28.51% to -17.98%, contrasted with the more stable performance of MPT strategies, particularly MinVar's consistent risk management across all market conditions.

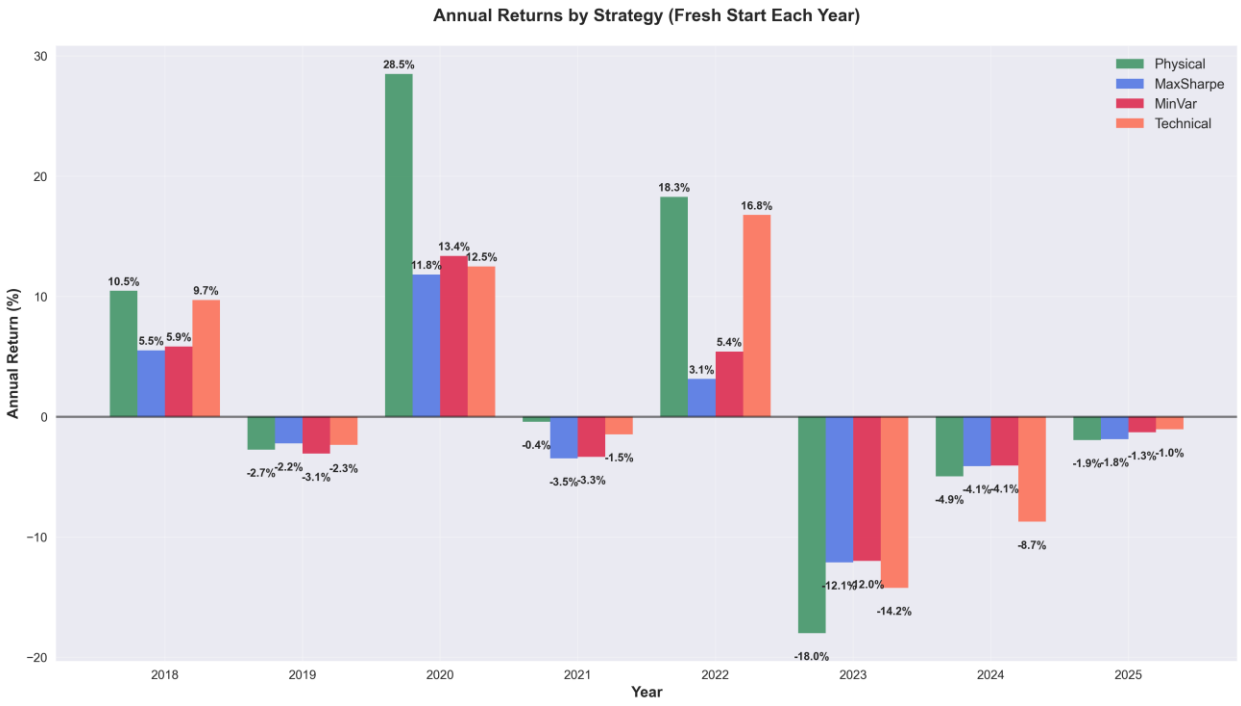


Figure 2: Sharpe Ratio Analysis

Bar chart comparing risk-adjusted performance (Sharpe ratios) across all strategies. Shows MinVar's dominant performance at 0.519, Physical strategy at 0.207, MaxSharpe at 0.174, and Technical strategy's negative performance at -0.094. Visual representation clearly demonstrates that technical strategies destroy value on a risk-adjusted basis while MinVar provides superior risk-adjusted returns.

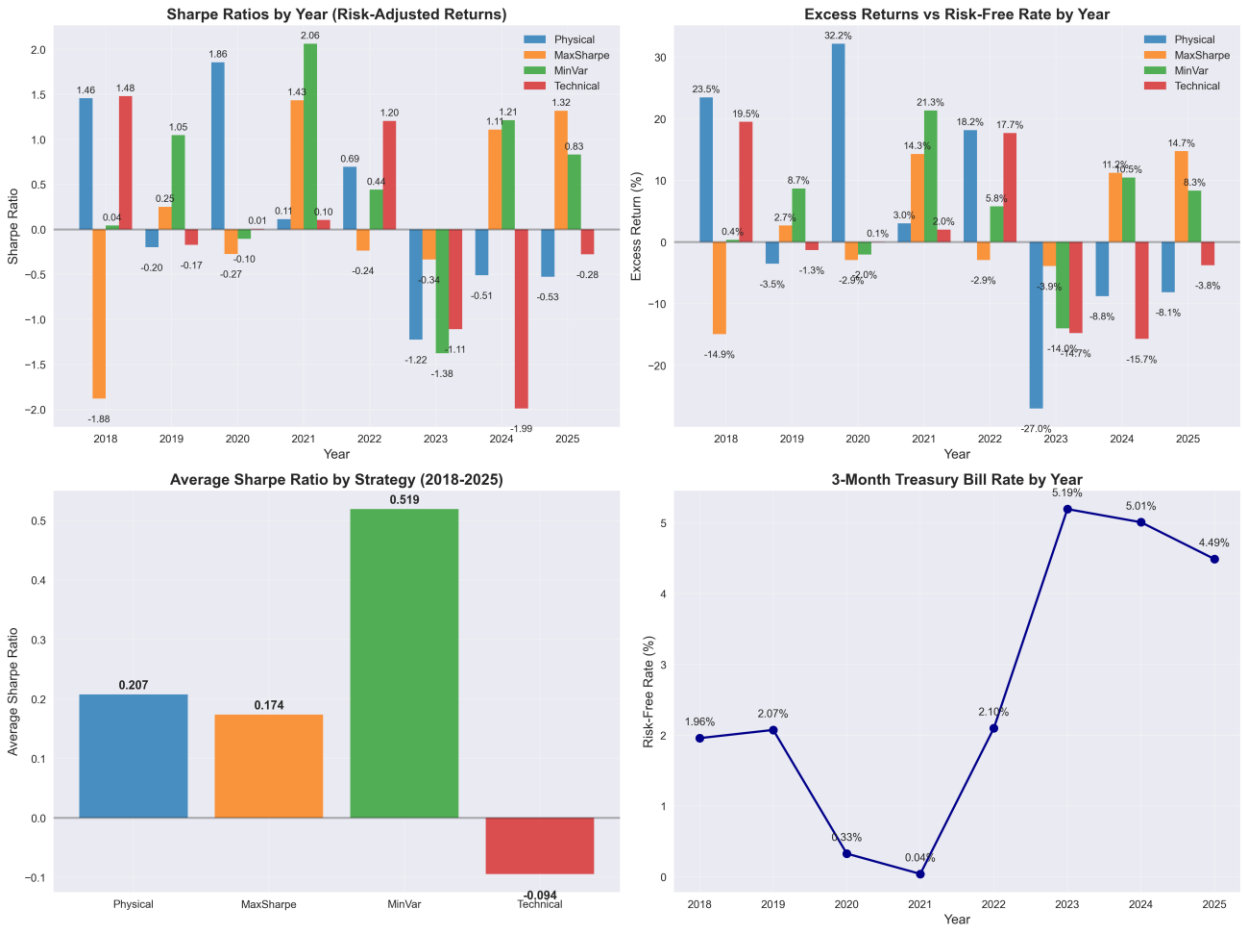


Figure 3: Value at Risk Analysis

Comparative chart shows daily 90% Value at Risk for each strategy in both percentage and dollar terms. Illustrates substantial risk reduction achieved by MPT strategies: MinVar (-0.71%, $9,401) and MaxSharpe (-0.68%, $8,970) compared to Physical strategy (-1.38%, $18,400). Technical strategy (-0.82%, $10,809) shows minimal improvement over unhedged positions.

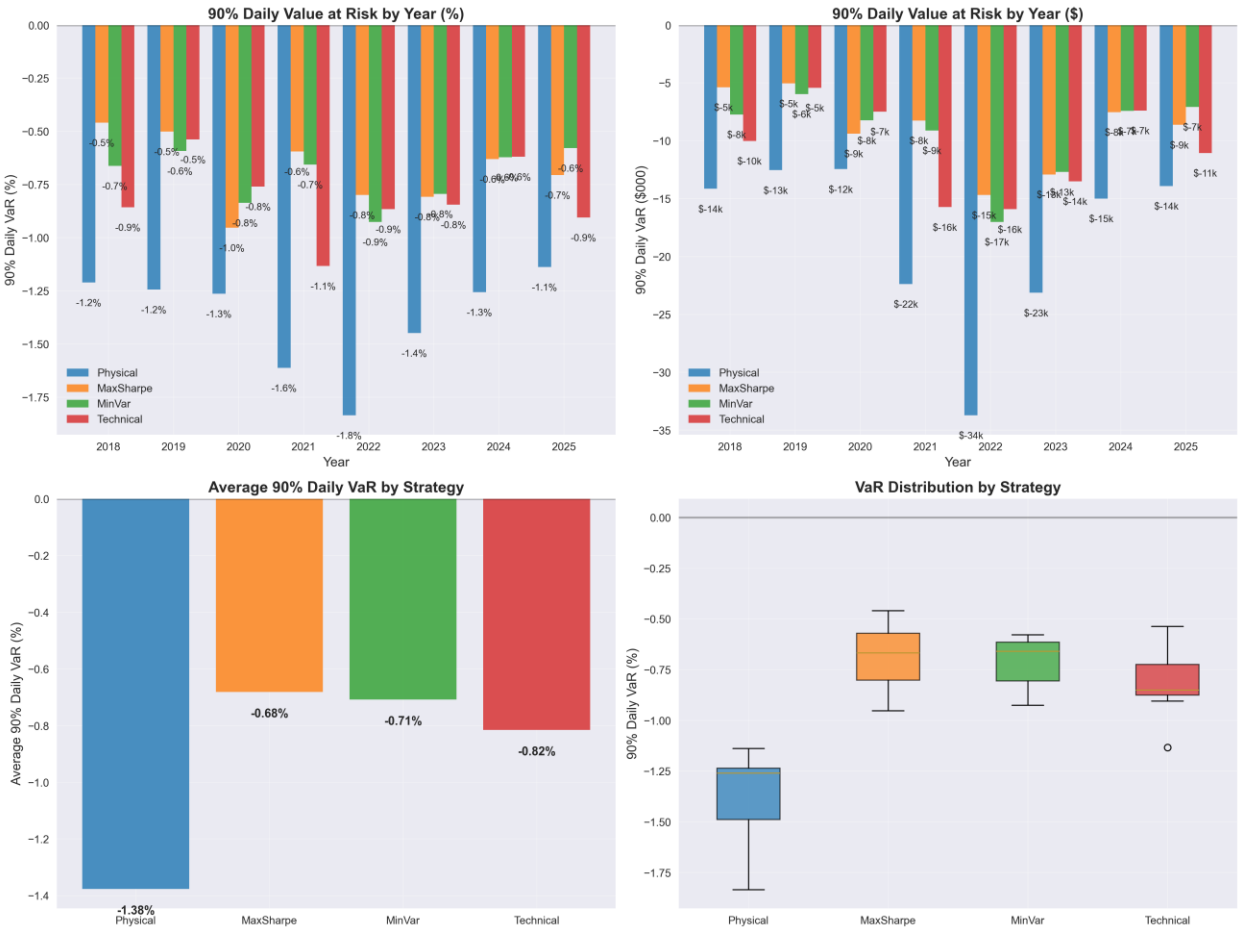


Figure 4: Risk-Return Scatter Plot

Scatter plot with volatility (risk) on x-axis and average annual returns on y-axis. Each strategy plotted as distinct point showing risk-return positioning. MinVar appears in optimal upper-left quadrant (low risk, positive returns), Physical strategy in high-risk area, and Technical strategy in suboptimal moderate-risk, poor-return position. Clearly demonstrates efficient frontier concepts and MinVar's superior positioning.

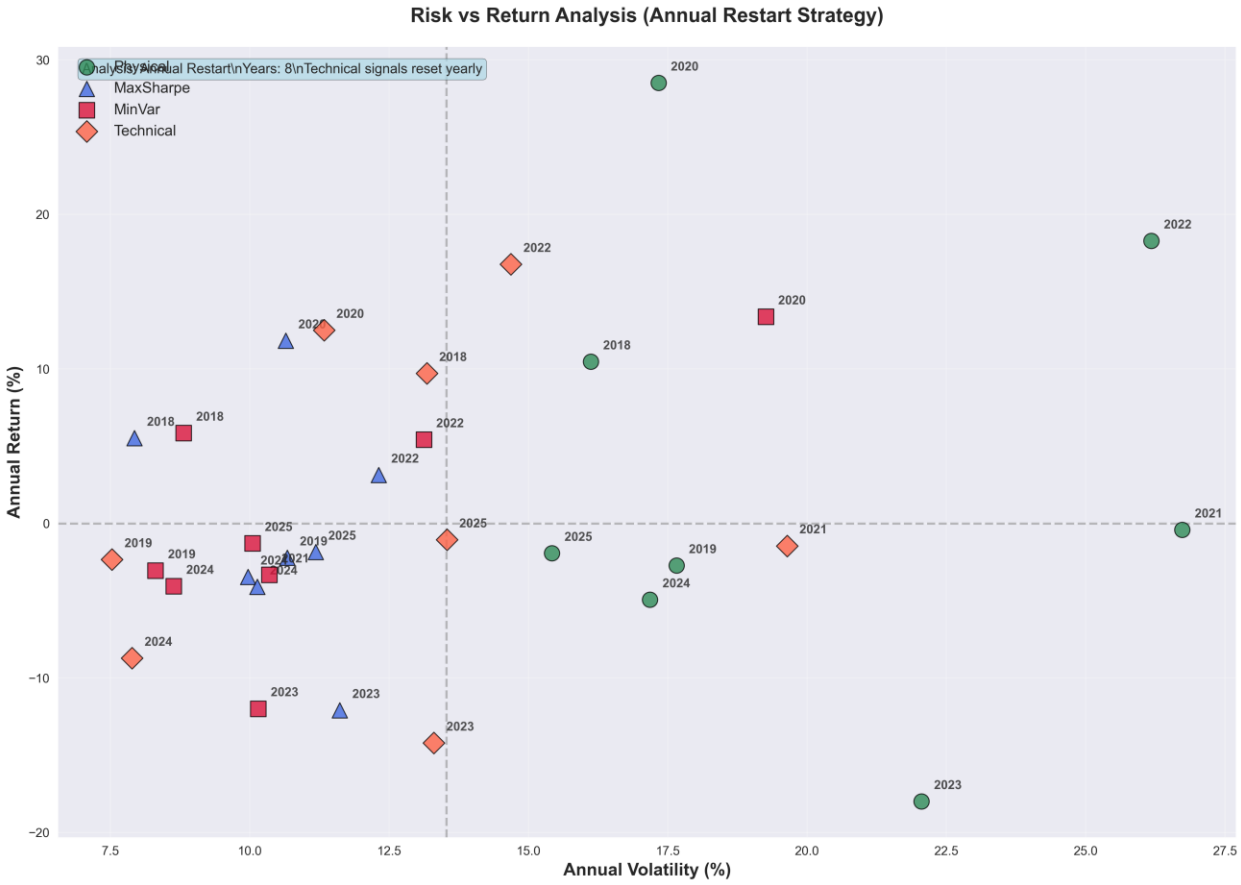
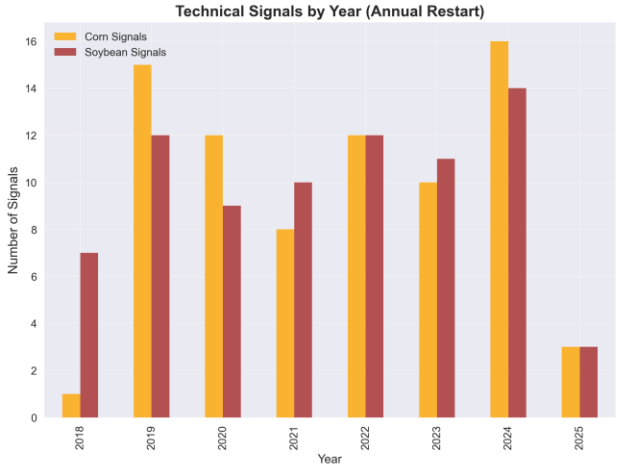
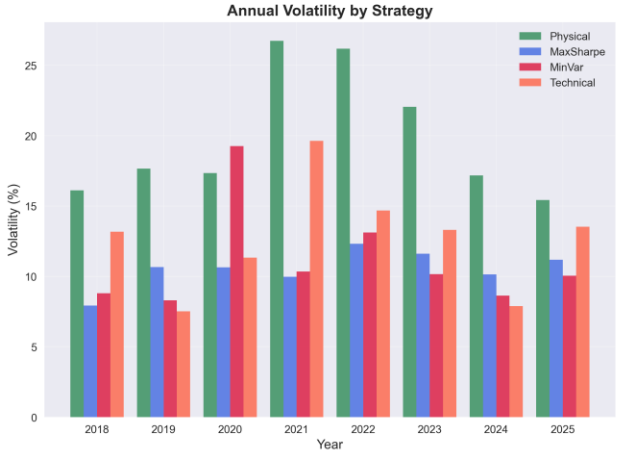


Figure 5: Comprehensive Strategy Performance Dashboard

Multi-panel comparison chart displays all key performance metrics side-by-side: annual returns, Sharpe ratios, volatility measures, VaR statistics, and win rates. Uses consistent color coding for each strategy across all metrics. Provides comprehensive visual evidence of MinVar's excellence across multiple performance dimensions and highlights the systematic underperformance of traditional technical approaches.


Technical Signals by Year (Annual Restart)
Corn Signals
Soybean Signals
Number of Signals
Year
2018
2019
2020
2021
2022
2023
2024
2025


Annual Return Distribution by Strategy
Annual Return (%)
Physical
MaxSharpe
MinVar
Technical


Annual Volatility by Strategy
Physical
MaxSharpe
MinVar
Technical
Volatility (%)
Year


Win Rate by Strategy (% Positive Trading Days)
Win Rate (%)
50.8%
53.0%
53.4%
46.4%
Physical
MaxSharpe
MinVar
Technical