Trading Energy Derivatives

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Abstract

This project presents a comprehensive analysis of a pairs trading strategy applied to energy derivatives, specifically focusing on crude oil, heating oil, and gasoline. The strategy employs mean reversion principles, capitalizing on the relative price movements between two correlated assets. To ensure the effectiveness of the strategy, we incorporate stationarity tests, rolling beta calculations, and a dynamic z-threshold for signal generation. Additionally, fundamental inventory data is integrated into the strategy to enhance predictive power and improve trade signals.

Through extensive grid searches, we identify optimal parameters, including the z-threshold and beta rolling window, for each asset pair. The strategy's performance is evaluated using key metrics, including annualized profit and loss (APL), Sharpe ratio, max drawdown, and return on drawdown (RoD). Our findings suggest that incorporating inventory-based signals, particularly the Midwest Inventory Signal, significantly enhances the strategy's profitability and risk management compared to the standard pairs trading approach. Overall, the strategy demonstrates strong potential for investors seeking to exploit market inefficiencies while managing risk in volatile energy markets.

Pairs Trading Strategy Overview

Pairs trading is a market-neutral strategy that involves identifying two correlated assets and trading them based on the relative movements of their prices. The main idea is that when the relationship between the two assets diverges beyond a certain threshold, it may be an opportunity for mean reversion. The strategy profits from the convergence of the spread between the two assets over time.

To implement this strategy, we start by ensuring that the pairs of assets we are interested in are stationary. We perform stationarity tests on the time series to ensure that they do not exhibit a long-term trend, which would make mean reversion ineffective. We check the stationarity of the asset pairs using statistical tests such as the Augmented Dickey-Fuller (ADF) test.

Stationarity, Beta Rolling and Z-Threshold

Stationarity:

The ADF test is used to check for unit roots in the time series, ensuring that the asset prices do not exhibit a trend. A stationary series will fluctuate around a constant mean, which is crucial for the pairs trading strategy to function effectively. The ADF test is essential because it ensures that any deviation in the asset pair prices is temporary and will eventually revert to the mean, a fundamental assumption for the pairs trading strategy.

Beta Rolling:

For pairs trading, we need to account for the relative relationship between the two assets over time. This is done by rolling the beta coefficient, which measures the sensitivity of one asset to changes in the other. The beta is computed using a rolling window, typically 30-90 days, depending on the strategy parameters. This rolling beta allows us to capture the dynamic relationship between the two assets and adjust for changing market conditions.

Z-Threshold:

The z-threshold plays a critical role in generating trading signals. It is used to define the points at which the spread between the two assets is considered extreme enough to trigger a trade. When the z-score exceeds the z-threshold, it indicates that the spread is significantly wide, suggesting an opportunity to place a short position. Conversely, when the z-score is below the negative z-threshold, the spread is considered narrow, indicating a potential for a long position. By combining the z-threshold with the rolling beta, we create a dynamic trading signal that adjusts to the changing relationship between the asset pairs, enhancing the strategy's responsiveness and effectiveness in capturing mean-reverting movements.

In the strategy, the z-threshold is calculated as the number of standard deviations away from the rolling mean of the spread. It ensures that only significant deviations from the mean are considered for entering trades, thus avoiding noise or insignificant price movements.

Grid Search for Optimal Z Threshold and Beta Rolling

In our strategy, we perform a grid search by varying the z threshold (the number of standard deviations beyond which we trigger a trade) and the beta rolling window The idea is to find the optimal parameters for each asset pair that maximizes the profitability of the strategy without overfitting.

Here are the results from the grid search for all three pairs:

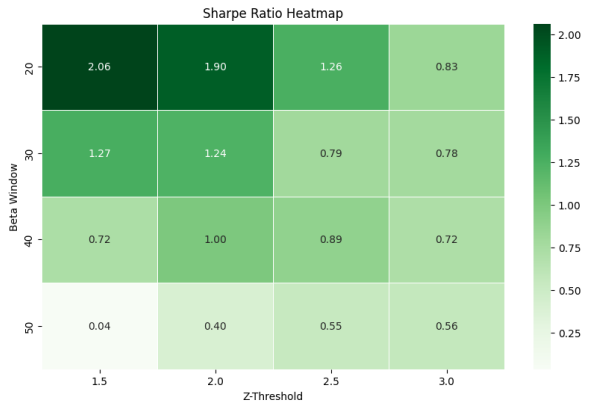

Figure 1: Grid Search Results for Crude and RBOB

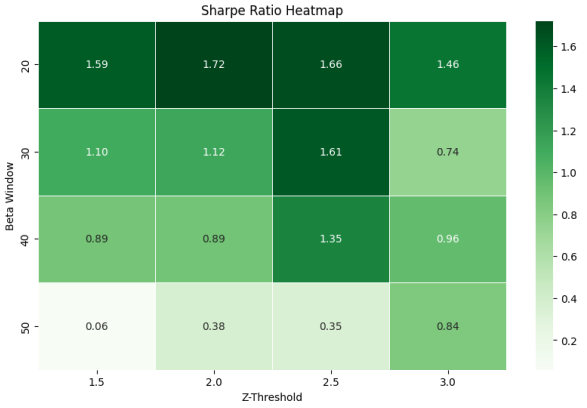

Figure 2: Grid Search Results for Crude and Heating Oil

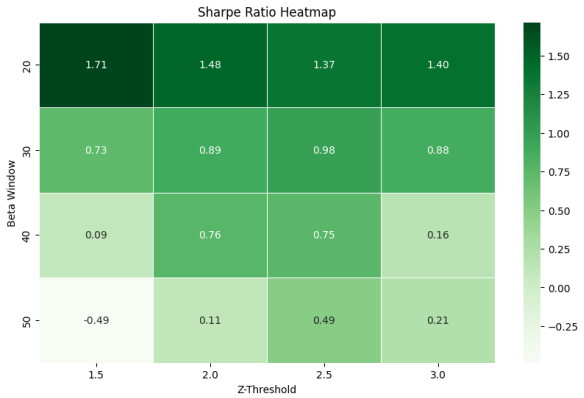

Figure 3: Grid Search Results for Heating Oil and RBOB

From the grid search, we select the optimal values that perform best on out-of-sample data but are not overly optimized for the training set. For example, for Pair 1, the optimal z threshold is 2.5, and the beta rolling window is 30 days.

Grid Search Results and Analysis

The heatmaps for the three asset pairs reveal the following trends:

- **Effect of Beta Window:** A decrease in the beta window generally leads to higher Sharpe ratios. Shorter rolling windows (e.g., 30 or 40 days) capture more relevant and dynamic relationships between the asset pairs, improving the performance of the strategy.
- **Effect of Z-Threshold:** Sharpe ratios are higher when both the z-threshold and beta window are low. This indicates that more sensitive thresholds (lower z-values) in combination with smaller beta windows enhance the risk-adjusted returns of the strategy.
- **Overall Trend:** The highest Sharpe ratios are achieved with low beta windows (30 or 40 days) and low z-thresholds (1.5 or 2), suggesting that a more responsive strategy yields better performance. Larger beta windows and higher z-thresholds, on the other hand, result in lower Sharpe ratios, indicating reduced effectiveness.

These insights suggest that a strategy with shorter beta windows and tighter z-thresholds is likely to optimize the Sharpe ratio, making the strategy more responsive to market dynamics.

Example Graph for Pair 1 with Optimal Parameters (From Heatmap)

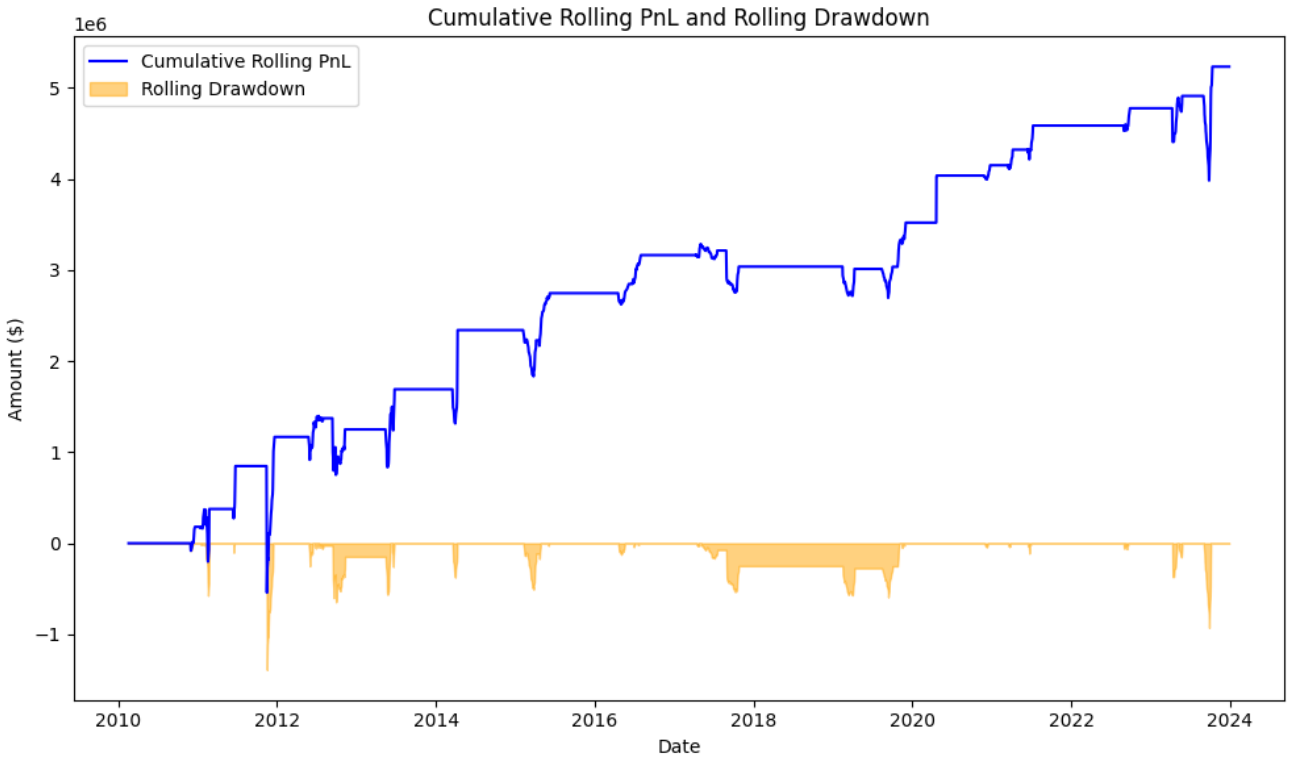

Figure 4: Strategy Performance for Pair 1 with Optimal Parameters

Performance Metric	Value
APL ($)	375,817.0185
Sharpe Ratio	0.7920
Max Drawdown ($)	-1,389,355.2982
RoD	0.2705

Table 1: Performance Metrics for Pair 1

Analysis of Performance Metrics

- **APL ($)**: The Annualized PnL (APL) of $375,817.02 demonstrates that the strategy generates positive returns over time. This is a strong indicator of profitability and suggests that the strategy is capable of capitalizing on market opportunities effectively.

- **Sharpe Ratio**: The Sharpe ratio of 0.7920 indicates a decent risk-adjusted return. While this value is not exceptionally high, it does suggest that the strategy generates positive returns relative to the level of risk taken. A Sharpe ratio above 0.7 is generally considered good, but there may be room for improvement in terms of risk management.

- **Max Drawdown ($)**: The maximum drawdown of $-1,389,355.30 is a significant figure. It represents the largest peak-to-trough decline during the backtest period, indicating that the strategy experienced substantial losses at its worst point. This is an important metric for assessing risk tolerance, and while the strategy is profitable, the magnitude of drawdowns suggests that there is exposure to significant risk during volatile market conditions.

- **RoD (Return on Drawdown)**: The Return on Drawdown (RoD) of 0.2705 suggests that for every dollar of drawdown, the strategy generated $0.27 in profit. While this value is positive, it is relatively modest. This highlights the importance of managing drawdowns in future improvements to the strategy, as higher RoD would imply better risk-reward efficiency.

Overall, the performance metrics indicate that the strategy is profitable but comes with notable drawdowns. The strategy's Sharpe ratio is good, but efforts to reduce the drawdown could enhance its risk-adjusted returns and make it more robust during periods of high volatility.

Fundamental Factors and Correlation Analysis

We have gathered fundamental factors data from the EIA website, including stock data for the entire U.S., PADD 1, PADD 2, and Cushing, OK regions. These factors represent critical indicators that can affect crude oil, heating oil, and gasoline prices.

To incorporate this into the strategy, we performed a correlation heatmap to analyze the relationship between these fundamental factors and the asset prices of crude oil, heating oil, and gasoline. We then ran linear regression to compute the R-squared values for each factor, indicating the strength of the relationship.

Key Insights:

- For crude oil, heating oil, and RBOB, the top factors with the highest R-squared values were: **- Weekly Midwest (PADD 2) Ending Stocks excluding SPR of Crude Oil. - Weekly U.S. Ending Stocks excluding SPR of Crude Oil and Petroleum Products.**

Regression Results

From the correlation and regression analysis, we identified the top two factors that had the strongest relationship with each asset. These factors are used to build additional signals to improve the strategy's performance.

Asset	Factors	R^2	Correlation
CRUDE	Weekly Midwest (PADD 2) Ending Stocks excluding SPR of Crude Oil (Thousand Barrels)	0.69	-0.83
	Weekly U.S. Ending Stocks excluding SPR of Crude Oil and Petroleum Products (Thousand Barrels)	0.65	-0.81
	Weekly U.S. Ending Stocks excluding SPR of Crude Oil (Thousand Barrels)	0.59	-0.77
	Weekly Cushing, OK Ending Stocks excluding SPR of Crude Oil (Thousand Barrels)	0.44	-0.66
Heating Oil	Weekly U.S. Ending Stocks of Crude Oil (Thousand Barrels)	0.51	-0.72
	Weekly Midwest (PADD 2) Ending Stocks excluding SPR of Crude Oil (Thousand Barrels)	0.51	-0.71
	Weekly U.S. Ending Stocks excluding SPR of Crude Oil and Petroleum Products (Thousand Barrels)	0.45	-0.67
	Weekly Cushing, OK Ending Stocks excluding SPR of Crude Oil (Thousand Barrels)	0.44	-0.66
RBOB	Weekly U.S. Ending Stocks excluding SPR of Crude Oil and Petroleum Products (Thousand Barrels)	0.53	-0.72
	Weekly Midwest (PADD 2) Ending Stocks excluding SPR of Crude Oil (Thousand Barrels)	0.5	-0.71
	US Weekly stoccks Excluding spr of crude oil	0.42	-0.65

Figure 6: Regression Results for Crude, Heating Oil, and RBOB

Incorporating Fundamental Data for Signal Generation

The core of the strategy is based on **quantile-based signal generation**. The signals are generated from the changes in inventory levels of two key factors: - **Long position**: If the inventory decreases significantly, falling within the lowest 20% quantile. - **Short position**: If the inventory increases significantly, falling within the highest 20% quantile.

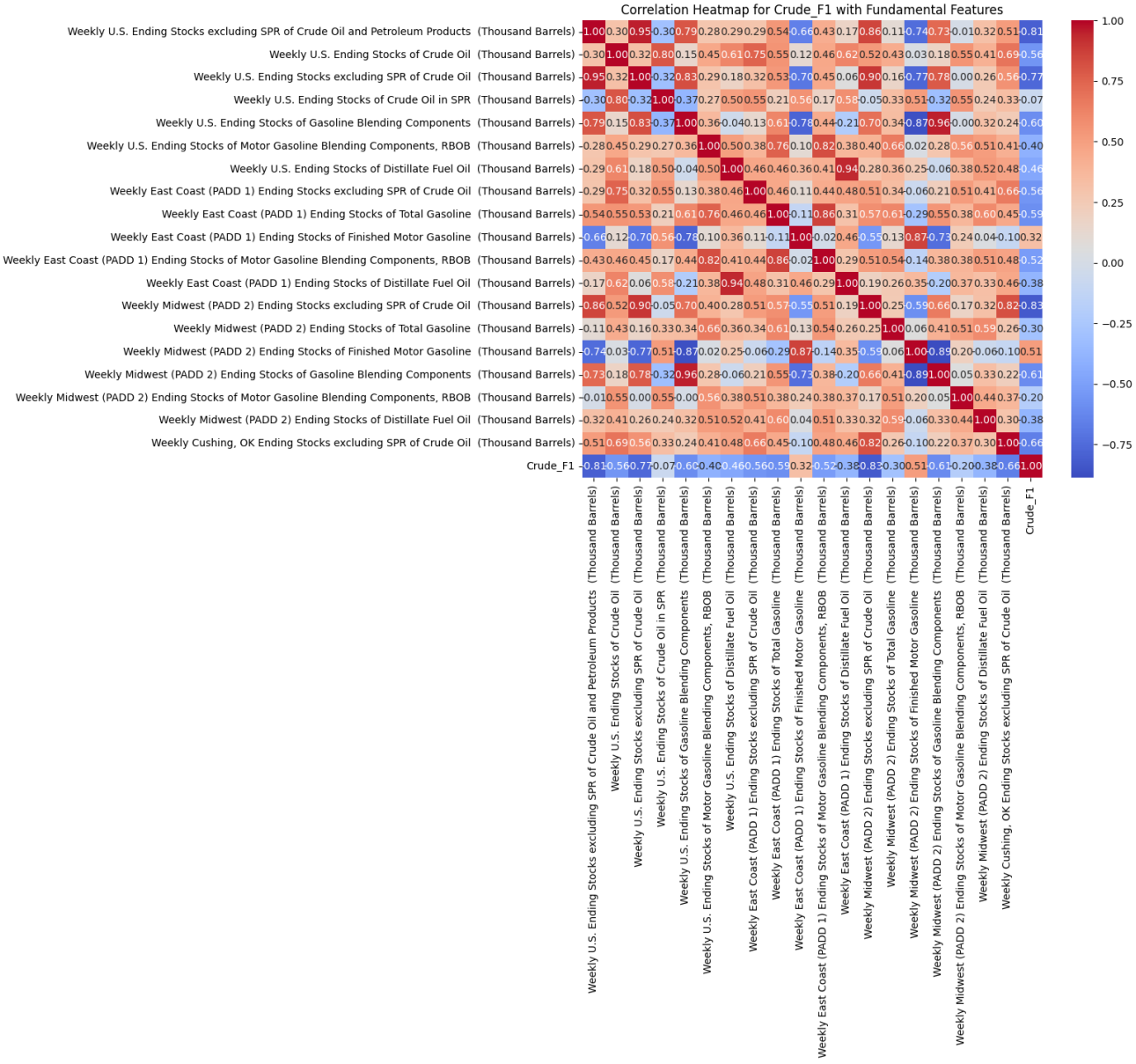

Figure 5: Correlation Heatmap for Fundamental Factors and Crude Prices

These signals are derived from the following data: - **Weekly U.S. Ending Stocks excluding SPR of Crude Oil and Petroleum Products**. - **Weekly Midwest (PADD 2) Ending Stocks excluding SPR of Crude Oil**.

By incorporating these quantile-based signals, the strategy aims to enhance the mean-reversion approach. The assumption is that significant shifts in inventory levels often signal opportunities for price adjustments, which can be exploited for profitable trading positions.

In this framework: - **Inventory decrease**: A sharp reduction in inventory suggests a potential price increase, triggering a long position. - **Inventory increase**: A significant rise in inventory suggests a potential price decline, triggering a short position.

The strategy leverages these signals to improve entry and exit points, particularly in response to shifts in inventory data. By doing so, it helps in capturing price movements driven by changes in supply dynamics, thus increasing the robustness and predictive power of the mean-reversion strategy. This approach ensures that trading decisions are made in alignment with fundamental shifts in inventory, enhancing the model's ability to navigate market volatility.

Performance Metrics

After implementing the strategy with these additional signals, we backtested it and calculated the following performance metrics:

Signal Type	APL($)	Sharpe Ratio	Max Drawdown($)	RoD
Combined Signals	52,342.7293	0.2466	-630,084.0687	0.0831
US Inventory Signal	209,821.4617	0.7001	-928,311.2091	0.2260
Midwest Inventory Signal	259,141.9127	0.9021	-646,454.2065	0.4009

Table 2: Performance Metrics for Combined and Individual Signals

Analysis:

- **Combined Signals:** The performance of the strategy using the combined signals is somewhat modest, with an Annualized P&L (APL) of $52,342.73 and a Sharpe ratio of 0.2466. The max drawdown of $-630,084.07 is relatively significant, indicating that the strategy can face periods of considerable loss, but it still achieves a reasonable Return on Drawdown (RoD) of 0.0831. This suggests that while the strategy is not risk-free, it can generate positive returns under certain market conditions.

- **US Inventory Signal:** The strategy utilizing only the US Inventory Signal exhibits improved performance, with a higher APL of $209,821.46 and a Sharpe ratio of 0.7001. The max drawdown of $-928,311.21 is higher than the combined signals, but it is accompanied by a more substantial RoD of 0.2260, indicating that the strategy is better at generating returns relative to the drawdowns compared to the combined approach.

- **Midwest Inventory Signal:** The Midwest Inventory Signal strategy demonstrates the best performance among the three. With an APL of $259,141.91 and a Sharpe ratio of 0.9021, it outperforms both the combined and US inventory signals. The max drawdown is lower than the US inventory signal at $-646,454.21, and the RoD of 0.4009 shows that the Midwest Inventory Signal is the most robust signal in terms of risk-adjusted return.

In conclusion, the Midwest Inventory Signal offers the best tradeoff between performance and risk, making it the most effective signal in improving the strategy's profitability while managing drawdowns effectively. The US Inventory Signal, while still strong, offers a lower risk-adjusted return compared to the Midwest Inventory Signal. Combining the signals provides a balanced approach, but the individual performance of each signal shows that incorporating the Midwest Inventory Signal would likely yield the best results.

Stability and Model Parameter Analysis

We analyzed the stability of the strategy by varying the model parameters, particularly the **z threshold** and **beta rolling window**. By performing a robustness check with different parameter values, we ensured that the strategy was not overfitted to a specific configuration and could maintain profitability in different market regimes.

The strategy's parameters were adjusted dynamically based on market conditions to ensure that it could adapt to varying environments, thus improving its overall stability. In particular, by scaling the strategy using 10 contracts, we achieved better risk management, as it helped to stabilize the performance while mitigating the impact of individual trade fluctuations.

Summary for Potential Investors

Investment Idea:

The strategy seeks to exploit relative price movements between pairs of assets (crude oil, heating oil, and gasoline) based on mean reversion principles. By incorporating fundamental data, particularly inventory data, we improve the strategy's predictive power and its ability to identify profitable trading opportunities.

Comparison of Strategy Performance: Standard vs. Inventory-Based Signals

This section compares the performance of the standard pairs trading strategy (for Crude and RBOB) with the version incorporating additional signals derived from inventory data. The performance metrics show how the additional signals affect the profitability and risk of the strategy.

Performance Comparison for Crude and RBOB

Signal Type	APL ($)	Sharpe Ratio	Max Drawdown ($)	RoD
Standard Strategy (Pair 1)	375,817.02	0.7920	-1,389,355.30	0.2705
Combined Signals (US & Midwest)	52,342.73	0.2466	-630,084.07	0.0831
US Inventory Signal	209,821.46	0.7001	-928,311.21	0.2260
Midwest Inventory Signal	259,141.91	0.9021	-646,454.21	0.4009

Table 3: Performance Metrics for Standard and Enhanced Signals (Crude & RBOB)

Analysis

- **Standard Strategy (Pair 1):** The standard strategy (without any additional inventory-based signals) achieves an **APL** of $375,817.02, with a **Sharpe Ratio** of 0.7920. While the strategy generates solid returns, the **max drawdown** of $1,389,355.30 highlights significant risk exposure. The **RoD** of 0.2705 indicates a moderate return relative to the drawdown, suggesting a balanced but somewhat risky strategy.

- **Combined Signals (US & Midwest Inventory):** The strategy using the **combined signals** (from both US and Midwest inventories) provides an **APL** of $52,342.73, which is lower than the standard strategy. The **Sharpe Ratio** of 0.2466 is significantly lower, reflecting reduced risk-adjusted returns. While the strategy is still profitable, the **max drawdown** of $630,084.07 is more manageable than the standard strategy, but the **RoD** of 0.0831 suggests a less efficient risk-to-return ratio.

- **US Inventory Signal:** Using only the **US Inventory Signal**, the strategy achieves a much higher **APL** of $209,821.46 and a **Sharpe Ratio** of 0.7001, which is considerably better than the combined signals approach. However, the **max drawdown** increases to $928,311.21, indicating higher volatility. The **RoD** of 0.2260 suggests that, relative to drawdown, this strategy performs better than the combined signals strategy.

- **Midwest Inventory Signal:** The **Midwest Inventory Signal** shows the best performance across all metrics, with an **APL** of $259,141.91 and a **Sharpe Ratio** of 0.9021. This strategy provides the highest **risk-adjusted return** and the lowest **max drawdown** ($646,454.21), making it the most robust signal. Additionally, the **RoD** of 0.4009 is the highest, indicating the best risk-reward efficiency among all strategies tested.

Conclusion

In conclusion, the **Midwest Inventory Signal** offers the best performance, providing the highest profitability with the most efficient risk management. The **US Inventory Signal** also improves performance compared to the combined signals approach, especially in terms of profitability and risk-adjusted returns. The **combined signals strategy**, while still profitable, lags behind in terms of **Sharpe ratio** and **RoD**.

Overall, the results suggest that incorporating inventory-based signals—especially the **Midwest Inventory Signal**—greatly enhances the strategy's ability to capture profitable opportunities while managing risk more effectively. Therefore, investors should consider the **Midwest Inventory Signal** as the preferred choice for optimizing returns and minimizing risk.