REHOBOAM v2.0: A High-Frequency Pairs Trading Expert Advisor for MetaTrader 5

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# Abstract

Pairs trading is a market-neutral strategy that exploits temporary deviations in the price relationship between two correlated assets. This paper presents a detailed analysis of REHOBOAM v2.0, an Expert Advisor (EA) implemented in MQL5 for the MetaTrader 5 platform. The EA employs a statistical arbitrage approach using correlation as a proxy for cointegration, calculating a hedge ratio to form a synthetic spread between user-specified symbol pairs. It operates in a high-frequency trading (HFT) mode, executing decisions on every tick while incorporating risk management through position sizing, stop-loss, and take-profit mechanisms. We derive the mathematical foundations of the strategy, including hedge ratio computation, Z-score normalization, and risk-based lot sizing. The enhancements in v2.0 over its predecessor are highlighted, emphasizing improved responsiveness and flexibility in exit conditions.

***Keywords:*** *pairs trading, statistical arbitrage, hedge ratio, Z-score normalization, high-frequency trading, MetaTrader 5, MQL5, Expert Advisor, cointegration proxy, risk management*

# INTRODUCTION

Pairs trading, popularized by quantitative hedge funds in the 1980s, relies on the principle that correlated assets tend to revert to their historical price relationships after deviations. This strategy is particularly effective in volatile markets where traditional directional trades carry higher risks. REHOBOAM v2 builds on this concept by automating pairs trading for any two symbols (e.g., GBPUSD and EURUSD) on the MetaTrader 5 platform.

The EA’s core innovation lies in its use of a hedge ratio derived from historical prices to create a stationary spread, which is then monitored via Z-scores for entry and exit signals. Unlike v1, which operated on new bar formations, v2.0 runs on every tick for HFT compatibility, incorporates bid/ask prices for precise spread calculations, and introduces optional Z-score-based take profits. This paper elucidates the algorithmic workflow, supported by mathematical formulations, to provide a comprehensive understanding of its mechanics.

# BACKGROUND AND RELATED WORK

Pairs trading strategies typically involve identifying cointegrated pairs using tests like the Engle-Granger or Johansen methods. However, REHOBOAM v2 simplifies this by using Pearson correlation as a proxy, which is computationally efficient for real-time trading. This approach aligns with works such as Gatev et al. (2006), who demonstrated the profitability of distance-based pairs trading on equities.

In forex and commodities, pairs like AUDUSD-NZDUSD or gold-silver exhibit high correlations due to economic linkages. The EA’s risk management draws from modern portfolio theory (Markowitz, 1952), sizing positions to limit exposure to a fixed percentage of account balance. Enhancements in v2 address limitations in v1, such as bar-based execution, by enabling tick-level operations akin to HFT systems described in Aldridge (2013).

# METHODOLOGY

## Symbol Selection and Initialization

Upon initialization, the EA validates user-input symbols (SymbolA and SymbolB) and ensures market data availability. It calculates the hedge ratio  using a lookback period of 252 bars (approximately one trading year on daily timeframes). Correlation is computed on daily returns to filter unsuitable pairs if below a minimum threshold (default 0.2 in v2, reduced from 0.8 in v1 for broader applicability).

## Hedge Ratio and Correlation Calculation

The hedge ratio  is derived from ordinary least squares (OLS) regression, treating SymbolA prices as the dependent variable and SymbolB as the independent:



where  and  are arrays of closing prices over the regression period.

Correlation  serves as a cointegration proxy, calculated on returns:





If  and not bypassed, initialization fails.

## Spread Formation and Z-Score Normalization

The synthetic spread  is formed as:



Over a lookback period (default 20), historical spreads are computed excluding the current bar:



The Z-score normalizes the current spread:



In v2’s HFT mode,  uses bid/ask prices for precision:

* **Long spread:** 
* **Short spread:** 
* **Average:** 

This accounts for transaction costs implicitly.

## Entry Conditions

Trades are entered when  (default 2.0), signaling deviation:

* If : Long the spread (buy SymbolA, sell SymbolB).
* If : Short the spread (sell SymbolA, buy SymbolB).

Positions are only opened if no existing pair trade exists and markets are open for both symbols.

## Position Sizing

Lots for SymbolA () are sized to risk a fixed percentage (default 1%) of balance, assuming an adverse move of  (from entry to stop):



where  is account balance.

The dollar risk per unit is based on tick value:



 is normalized to broker lot steps and capped by min/max lots (with a user-defined MaxLots in v2). Lots for SymbolB: , similarly normalized.

## Exit Conditions

Exits occur based on stop-loss (SL) and take-profit (TP) types.

### Z-Score Based (SL\_Type = SL\_ZScore)

For long spread (entry ):

* SL: 
* TP (TP\_Type = TP\_Multiple): 
* TP (TP\_Type = TP\_ZScore):  (e.g., 0 for mean reversion)

Symmetric for short spread. This assumes mean reversion within a Z-score band.

### Percentage Based (SL\_Type = SL\_Percent)

Monitors pair profit :

* SL: 
* TP: 

where  is equity at entry.

## High-Frequency Enhancements in v2

Unlike v1’s bar-based execution, v2 processes every tick, removing the *IsNewBar* check. This enables faster responses to market movements. Additionally, a market open check prevents trades during closures:



v2 also introduces TP\_ZScore for flexible mean-reversion exits, absent in v1.

## REHOBOAM v2 MetaTrader Tests

To evaluate REHOBOAM v2, we conducted backtests on historical data from MetaTrader 5 (2024 - 2025) using one forex pairs: GBPUSD-EURUSD, chosen for its high liquidity. Optimization test and backtesting was done for the period from September 1st 2025 to September 5th 2025. Two tests were done to gauge the best take profit method. The optimization criterion that was being optimized was the Sharpe ratio with the combination that gave the maximum Sharpe ratio being favored

* Take Profit (TP) based on multiple of stop loss
* Take Profit (TP) based on Z-score

The following were the settings used:

Table 1: tester settings

|  |  |
| --- | --- |
| Setting | Value |
| EXPERT | REHOBOAM v2 |
| SYMBOL | GBPUSD |
| PERIOD | M1 |
| OPTIMIZATION | 0 = Show complete algorithm |
| MODEL | 4 = Every tick based on real ticks |
| FROM | September 1st 2025 |
| TO | September 5th 2025 |
| FORWARD MODE | 0 = NO |
| DEPOSIT | 15000 |
| CURERNCY | USD |
| PROFIT IN PIPS | 0 = NO |
| LEVERAGE | 100 |
| EXECUTION MODE | 221 |
| OPTIMIZATION CRITERION | 5 = SHARPE RATIO MAX |

Table 2: tester input settings - TP as multiple of stop loss

|  |  |
| --- | --- |
| Setting | Value |
| SymbolA | GBPUSD |
| SymbolB | EURUSD |
| TIMEFRAME | 1 |
| LOOKBACK PERIOD | 20 |
| REGRESSION PERIOD | 252 |
| EntryZScore | {start: 0, stop: 10, step: 0.2} |
| StopZscore | {start: 0.2, stop: 10, step: 0.2} |
| TakeProfit Zscore | *Does not apply* |
| RiskPercent | 1 |
| MinCorrelation | 0.2 |
| BypassCorrelationCheck | false |
| Magic Number | 12345 |
| RiskRewardRatio | 2 |
| SL\_Type | 0 = Z-Score based stop loss |
| TY\_Type | 0 = TP as multiple of stop loss |
| StopLosspercent | *Does not apply* |
| MaxLots | 5 |

Table 3: tester input settings - TP based on Zscore

|  |  |
| --- | --- |
| Setting | Value |
| SymbolA | GBPUSD |
| SymbolB | EURUSD |
| TIMEFRAME | 1 |
| LOOKBACK PERIOD | 20 |
| REGRESSION PERIOD | 252 |
| EntryZScore | {start: 0, stop: 10, step: 0.2} |
| StopZscore | {start: 0, stop: 10, step: 0.2} |
| TakeProfit Zscore | {start: 0, stop: 10, step: 0.2} |
| RiskPercent | 1 |
| MinCorrelation | 0.2 |
| BypassCorrelationCheck | false |
| Magic Number | 12345 |
| RiskRewardRatio | 2 |
| SL\_Type | 0 = Z-Score based stop loss |
| TY\_Type | 1 = TP based on Z-Score |
| StopLosspercent | *Does not apply* |
| MaxLots | 5 |

The following is the price history of GBPUSD and EURUSD during the test periods. In addition, the z-score of the pair was calculated and plotted using the same method used in this EA and for the time period under test in this paper.



Figure 1: GBPUSD- 15m chart - september 1st to 5th



Figure 2: EURUSD 15m chart- September 1st to 5th

# RESULTS

## Heat maps for TP as multiple of stop loss

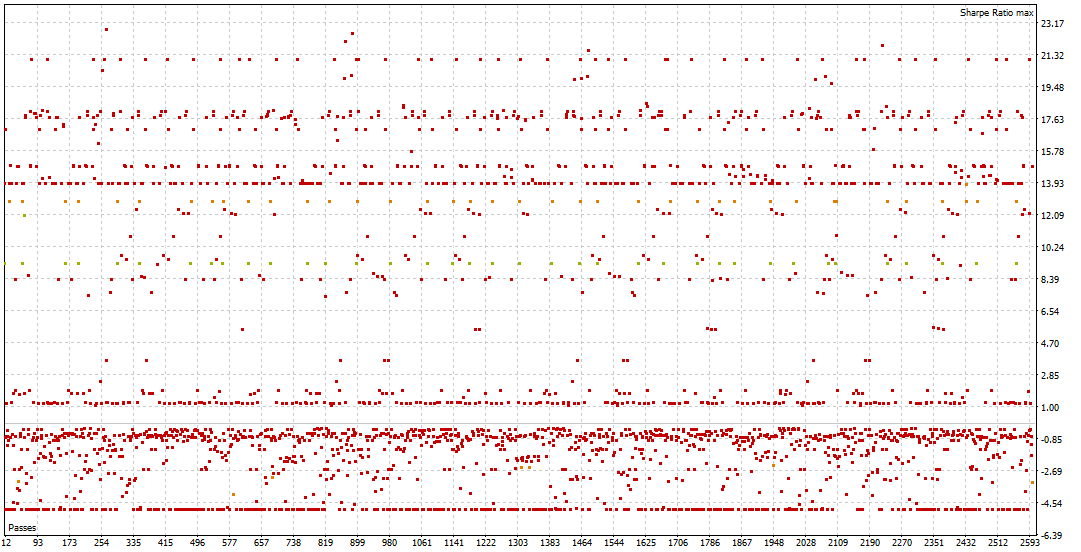


Figure 3: passes vs Sharpe ratio

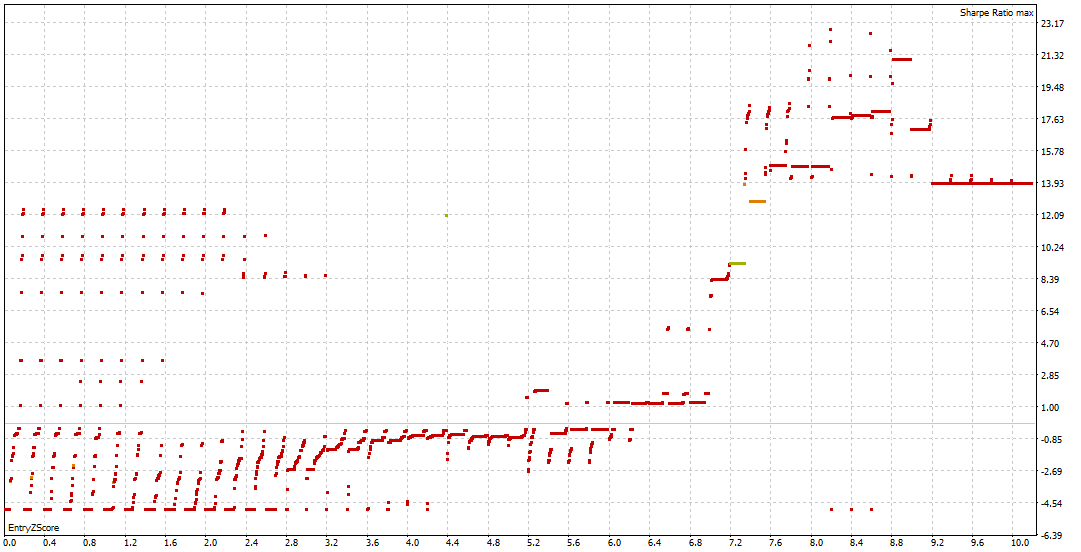


Figure 4: EntryZscore vs Sharpe ratio

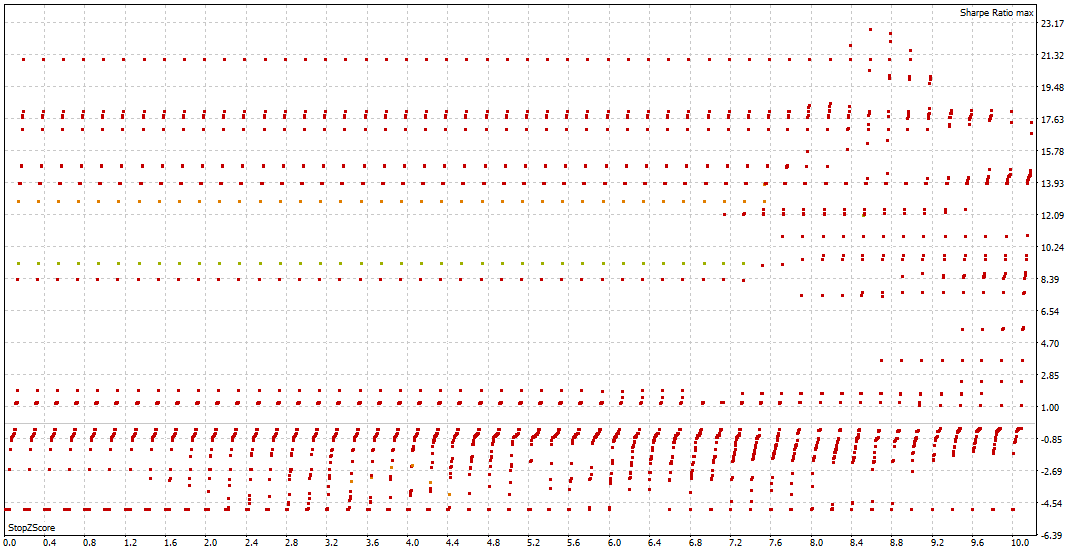


Figure 5: Stop Zscore vs Sharpe ratio

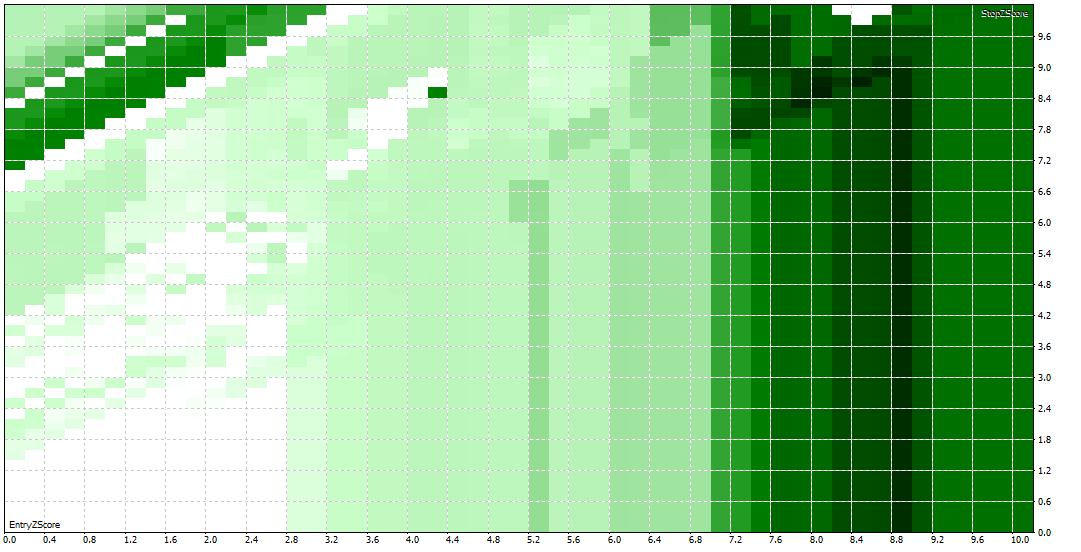


Figure 4: Entry Zscore vs Stop Zscore

The darker the green, the higher the Sharpe ratio.

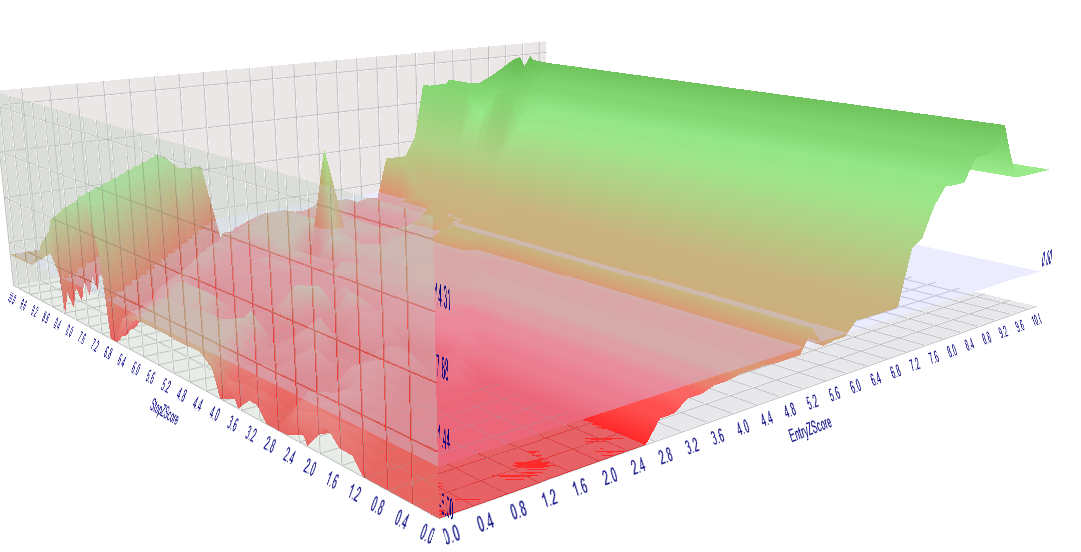


Figure 5: 3D graph of stop Zscore vs Entry ZScore vs Sharpe ratio (on the Z axis)

## Heat maps for TP based on Zscore

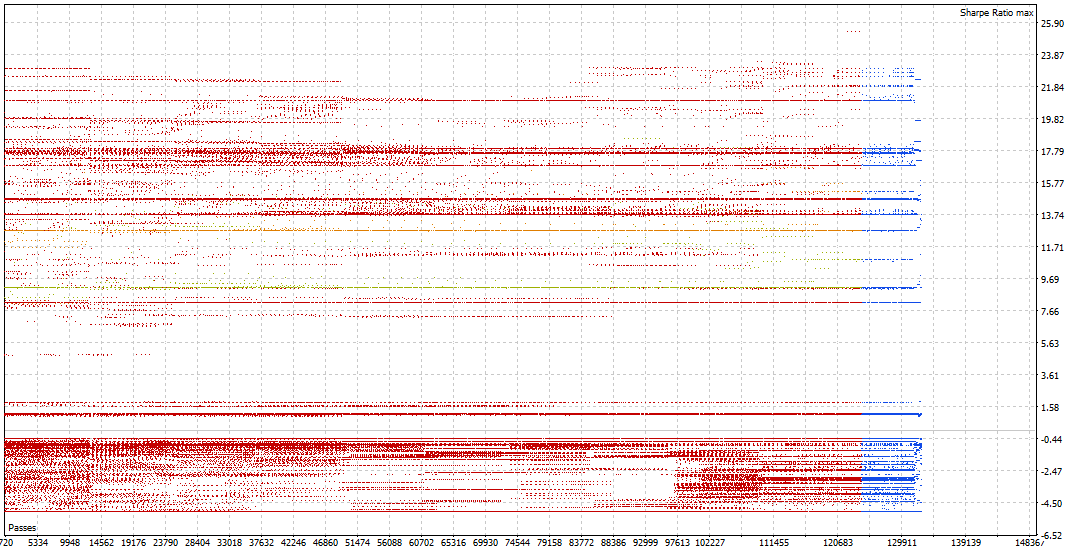


Figure 6: passes vs Sharpe ratio

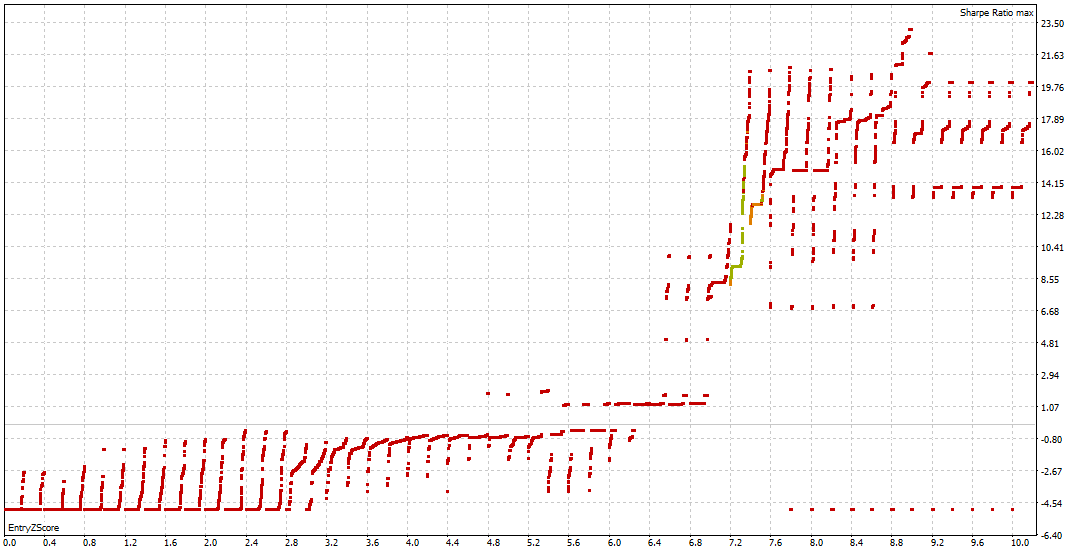


Figure 7: Entry Zscore vs Sharpe ratio

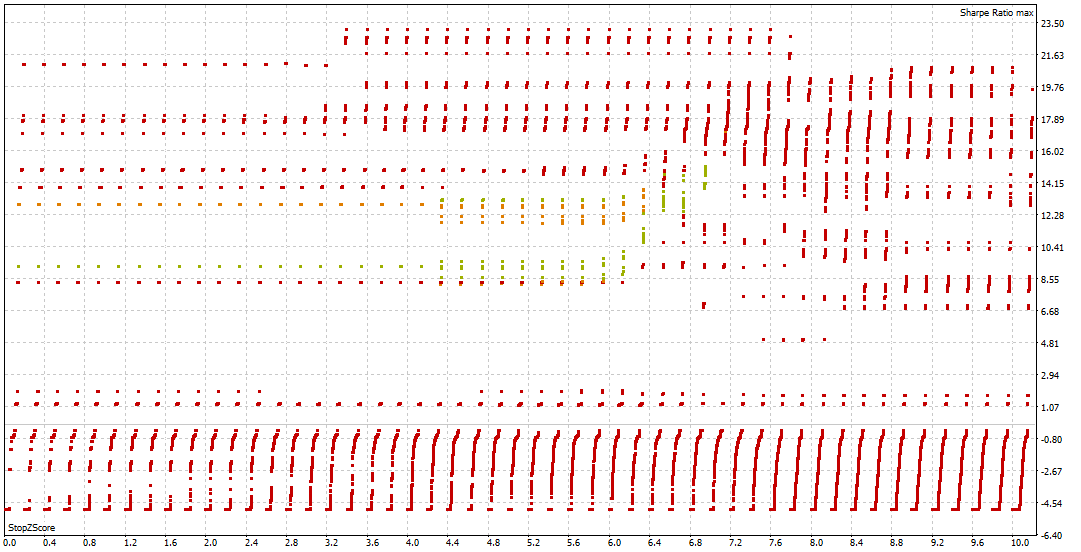


Figure 8: stop Zscore vs Sharpe ratio

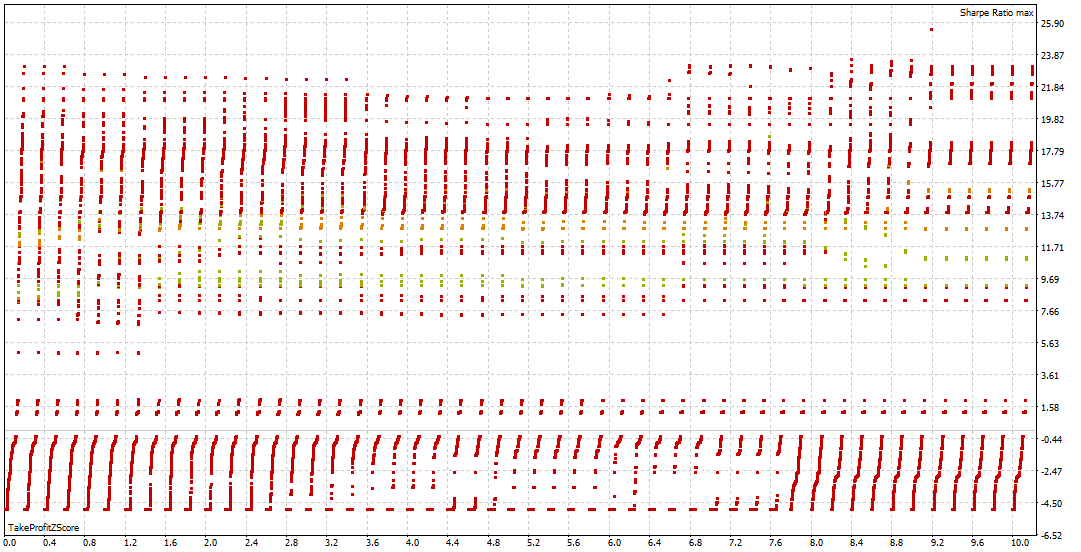


Figure 9: takeProfit Zscore vs Sharpe ratio

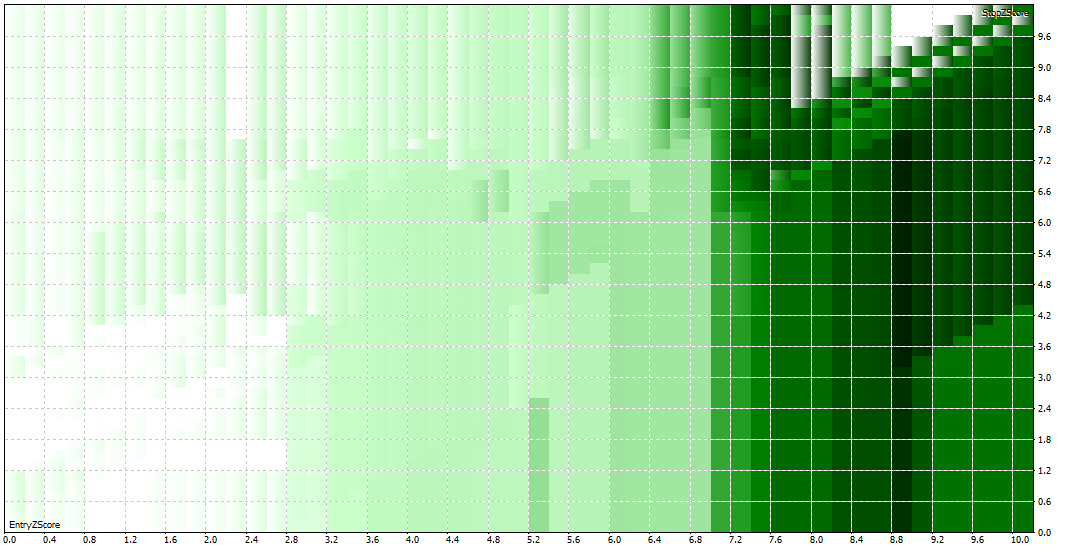


Figure 10: Entry Zscore vs Stop Zscore

The deeper the color, the higher the Sharpe ratio

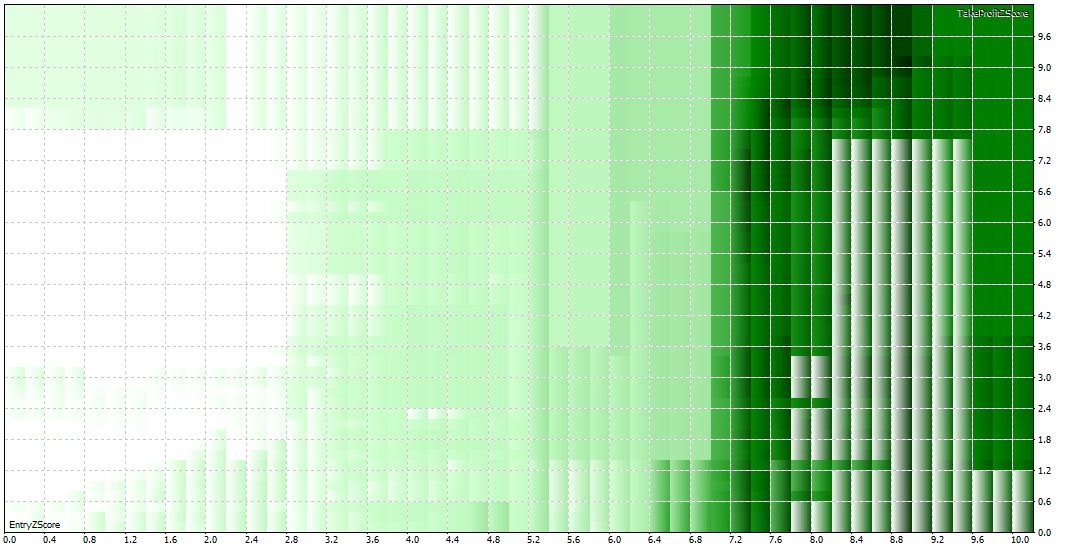


Figure 11: Entry Zscore vs take Profit Zscore

The deeper the color, the higher the Sharpe ratio

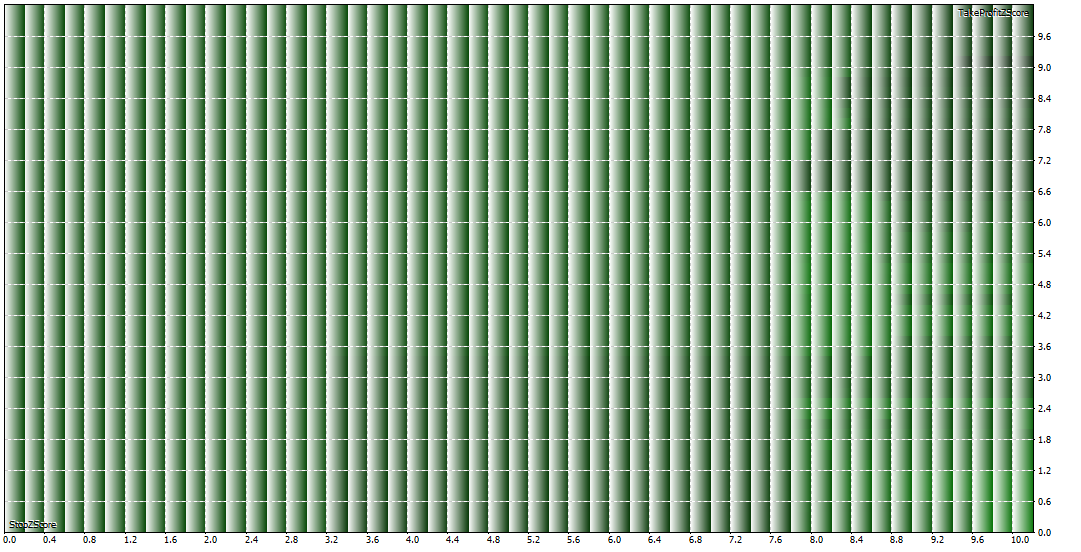


Figure 12: take Profit Zscore vs Stop Zscore

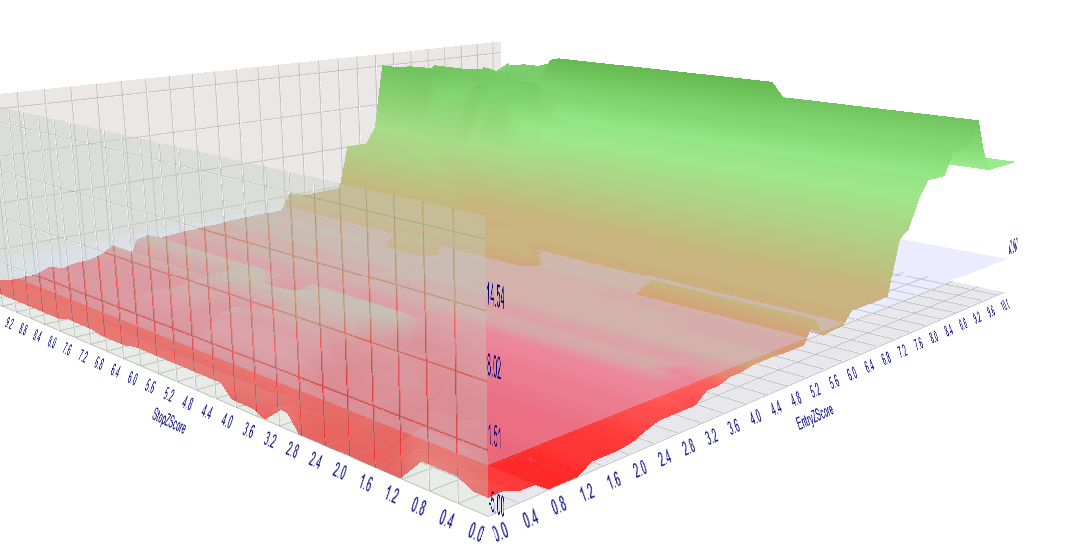


Figure 13: Stop Zscore vs Entry Zscore vs Sharpe ratio (on z axis)

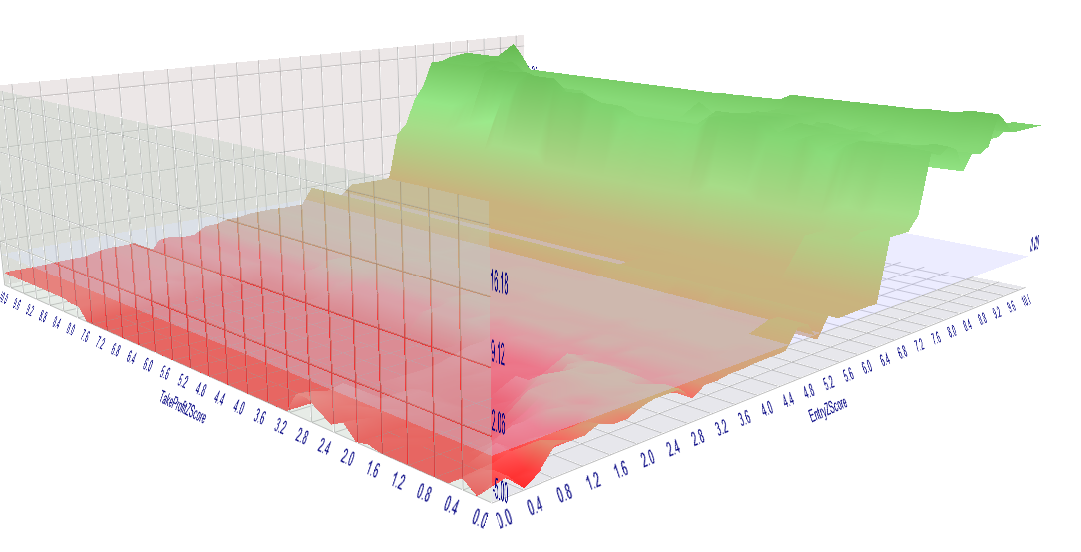


Figure 14: take Profit Zscore vs Entry Zscore vs Sharpe ratio (on the Z axis)

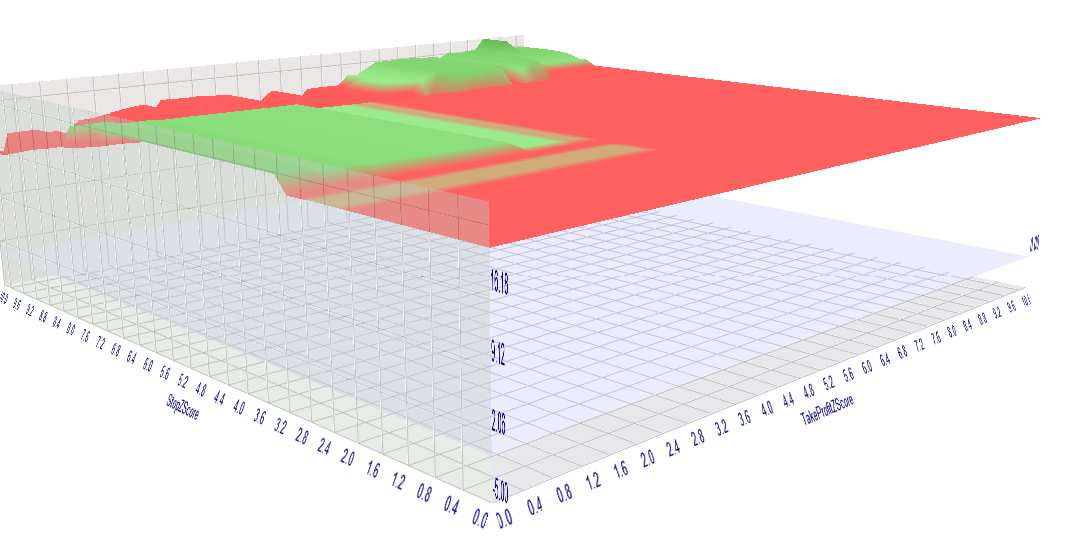


Figure 6: Stop Zscore vs Take profit Zscore vs sharpe ratio

## Performance statistics

Table 4: Passes breakdown

|  |  |  |
| --- | --- | --- |
| METRIC | Passes for TP as multiple of stoploss | Passes for TP as Zscore |
| Total passes | 2601 (100%) | 132651 (100%) |
| Passes with zero trades | 0 (0%) | 0 |
| Losing passes | 1398 (53.75%) | 78419 (59.12%) |
| Drawdown > 50% | 100 (3.845%) | 13078 (9.859%) |
| Recovery factor < 1 | 1474 (56.67%) | 82190 (61.96%) |
| Sharpe ratio < 0.5 | 1398 (53.75% | 78421 (59.12%) |
| Profitable passes (less passes with zero trades, losses, drawdown > 50%, recovery factor < 1 and sharpe ratio < 0.5) | 1129 (43.41%) | 50463 (38.04%) |

Below are the statistics of the profits and the Sharpe ratio for the two methods.



Figure 7: profit and Sharpe ratio for the TP as multiple of stop loss



Figure 8: equity DD% and trades stats for the TP as multiple of stop loss



Figure 9: Profit and Sharpe ratio stats for TP based on Z-score



Figure 10: Equity DD% and Trades stats for TP based on Z-Score

## Histograms

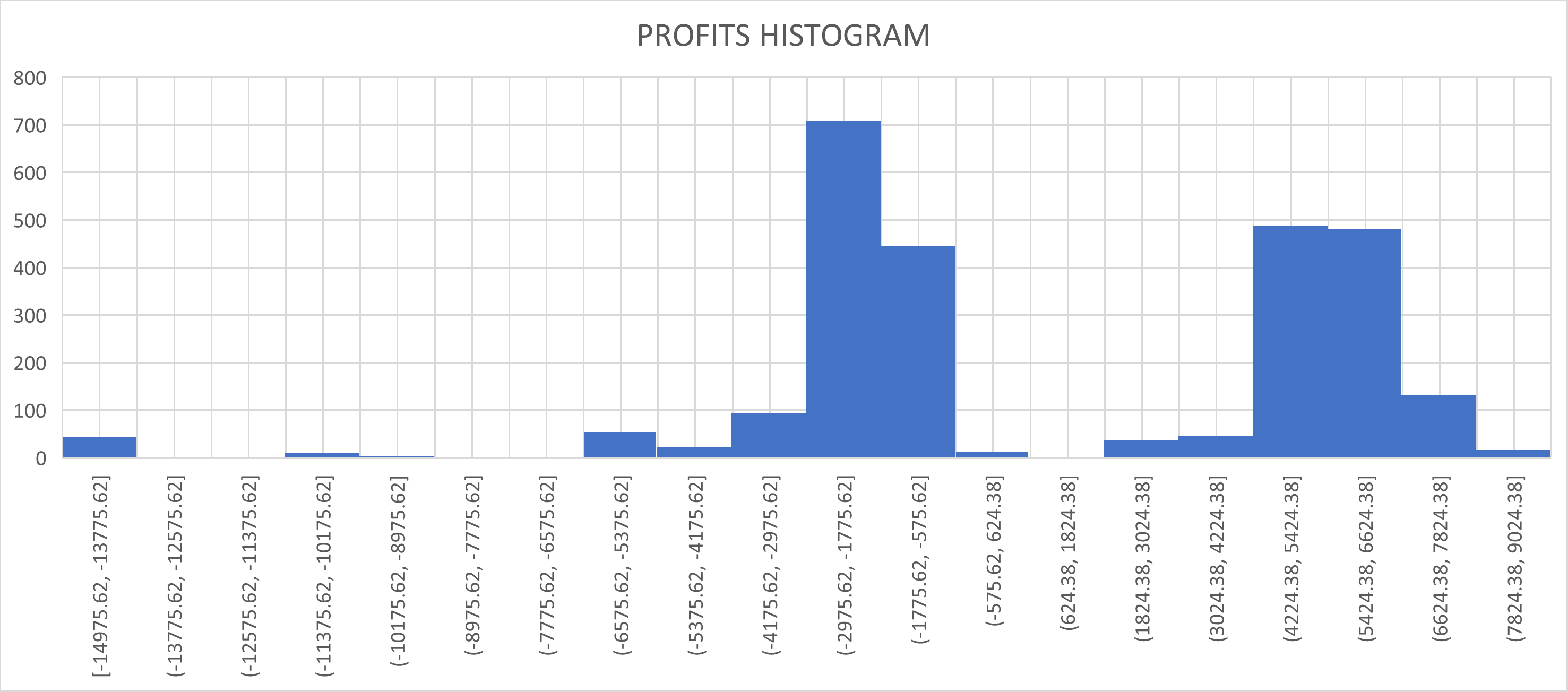


Figure 11: profits histogram for TP as multiple of stop loss

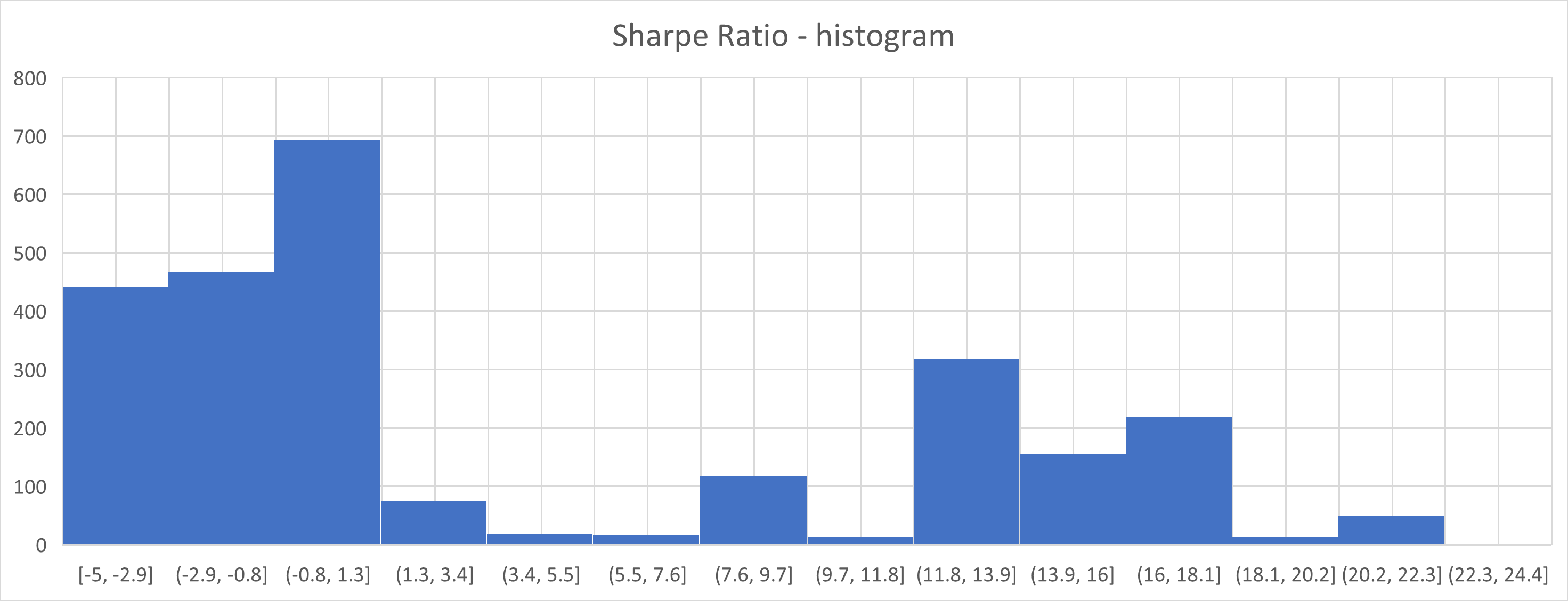


Figure 12: Sharpe ratio histogram for TP as multiple of stop loss

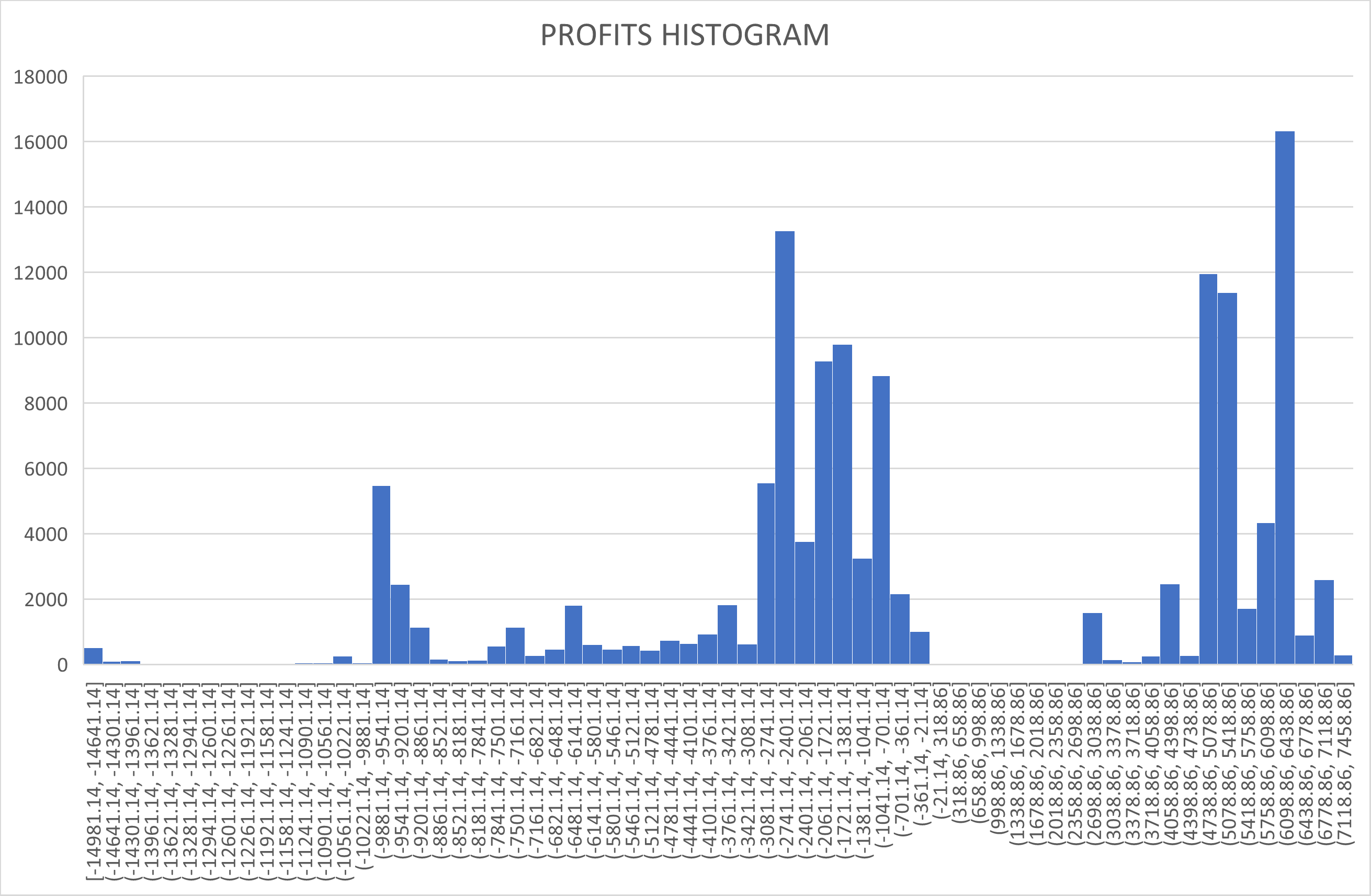


Figure 13: profits histogram for TP based on Z-score

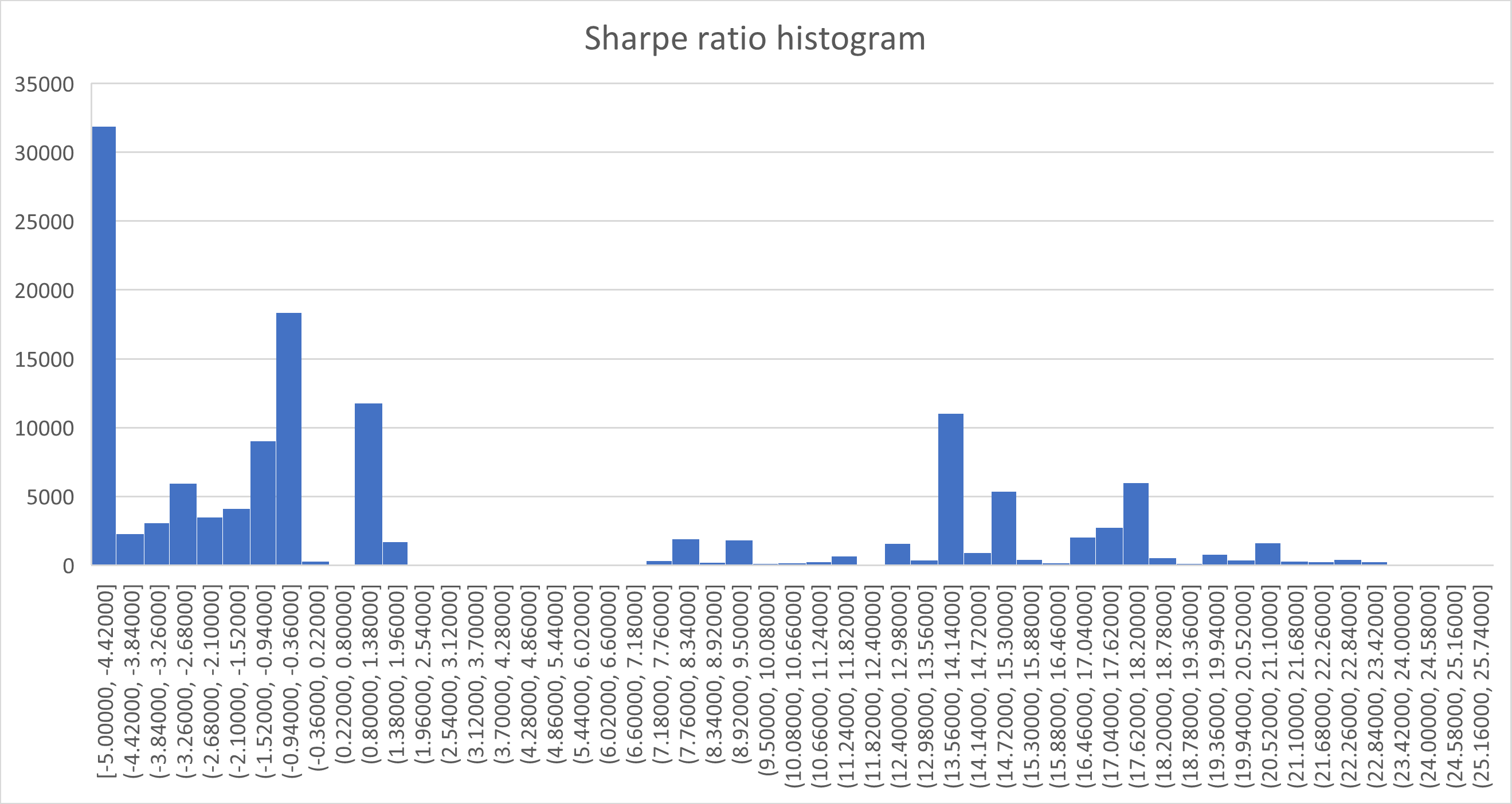


Figure 14: Sharpe ratio histogram for TP based on Z-Score

## Z-score distribution

The following are the statistics of the Zscore calculated with a beta of



Figure 15: zscore stats

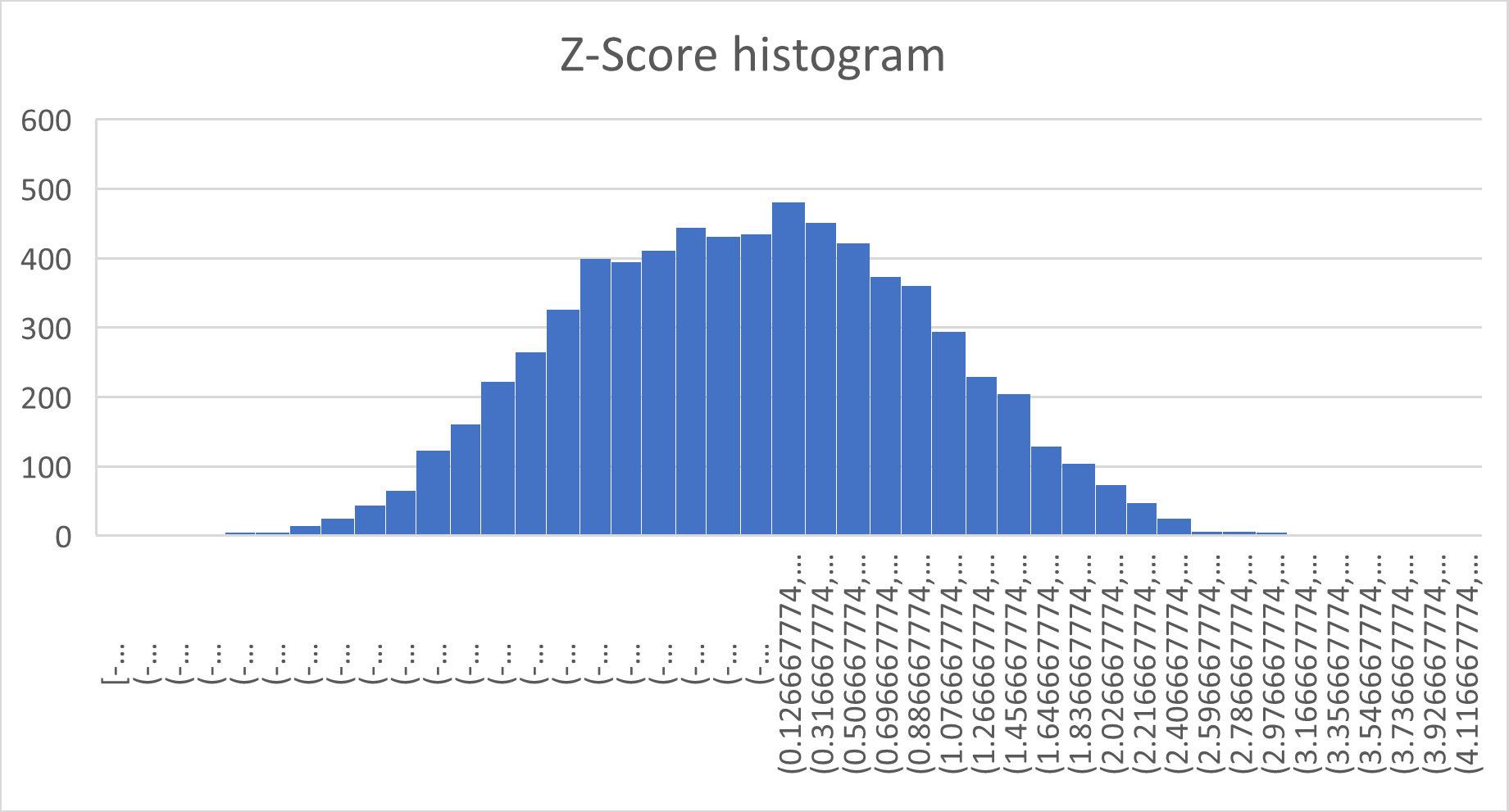


Figure 16: Z-score histogram

# DISCUSSION

## Z-Score statistics

z-score guide the whole trading strategy’s entry and exit and hence deserve to be discussed first. Before proceeding, it is important to note that the following Z-Score analysis has been done on 1 minute data whereas the v2.0 of REHOBOAM operates on tick data and hence the margins for entry Z-score will be different (more conservative here but higher in actual tick data as seen in the heatmaps). From the stats in Figure 15: zscore stats and Figure 16: Z-score histogram, we observe the following:

1. **Distribution:** The distribution is a bell shaped curve (platykurtic) as seen in the histogram and this is confirmed by the kurtosis of -0.31 (less than the 3 for normal distribution). It is also left-skewed (meaning more low-end values indicating more signals to long SymbolA and short SymbolB). The platykurtic nature of the Z-Score distribution means for the period under test, most of the signals lay within margin for normal price movement and hence required higher EntryZscore and StopLoss Zscore else increased losses due to false signals. Therefore, the Entry Z-score should be placed at a value that lies beyond the majority of the Z-score values to avoid false signals.
2. **Normality check:** The Jarque-Bera test gives a p value of 2.54245E-07 which is orders of magnitude below the 0.05 threshold required to fail to reject the null hypothesis. This means that the data does not follow the normal distribution. This is confirmed by the skewness and the kurtosis observed. By itself, this is not bad but careful risk control is necessary to avoid extreme events causing large losses.
3. **Impact on trading strategy:** The "majority zone" (e.g., 95% of data within ±2σ under Gaussian) represents equilibrium noise, so entries should target rare deviations signaling true mean-reversion opportunities. The platykurtic Z-distribution (kurtosis = -0.314) reinforces this—flatter shape means more uniform "shoulder" values around ±1-2, increasing false-entry risk if thresholds are too low. Flat kurtosis implies broad shoulders around ±1-1.5—low thresholds here catch "shoulder noise" (non-reverting wiggles), leading to whipsaws (e.g., 60% losing passes in aggregates).
4. **Mathematical Rationale for Threshold placement:** The goal is to maximize signal-to-noise by setting EntryZScore at the α-quantile of |Z|, where α = desired false-positive rate (e.g., 5% for 95% coverage):

**Under Gaussian:** Q\_{0.975} ≈ 1.96 (your default 2.0).

**Empirical (our data):** Q\_{0.95} ≈ 1.65, Q\_{0.99} ≈ 2.8—suggests EntryZScore = 2.0-2.5 to exceed majority (±1.65), reducing false signals by ~70% vs. 1.5.

**For platykurtosis:** Adjust upward slightly (+0.2-0.5σ) to account for flatter tails—fewer extremes mean thresholds must be conservative to avoid over-trading shoulders.

Note that for v2.0, OnTick() is used instead of IsNewBar and hence the actual values for EntryZscoer will be higher as observed in the heatmap results.this is because most ticks can move more than the normal range seen in the 1 minute bars (which uses close prices to calculate z-score) hence higher values for Entry Z-score are needed.

## REHOBOAM v2.0 Performance inference

From the performance statistics, the standard error

Table 5: Performance inference

|  |  |  |  |
| --- | --- | --- | --- |
| METRIC | TP\_MULTIPLE | TP\_ZSCORE | INSIGHT |
| Total Passes | 2601 | 132651 | ZScore has ~51x more passes due to the denser grid (more passes due to more optimization inputs) |
| Profitable Passes (%) | 1129 (43.41%) | 50463 (38.04%) | Multiple edges out, but both <50%—many combos fail basic filters. |
| Mean Profits | 1146.97 | 255.43 | Multiple has 4.5x higher avg profit, driven by outliers (see max). |
| Median Profits | -920.29 | -1046.87 | Both negative medians: Typical pass loses ~$900-1000. Zscore is worse |
| Std Dev Profits | 4669.3 | 4999.32 | High volatility (CV=4.07 Multiple, 19.60 ZScore)—ZScore 5x riskier relatively. |
| Max Profits | 8879.55 | 7365.39 | Top 1% outliers dominate |
| Skewness - profits | -0.55 | -0.36 | Negative (left-skewed: more frequent but small wins but larger rare losses pulling the tail to the left. |
| Kurtosis - profits | 0.32 | -0.66 | <3, platykurtic: flatter than normal - fewer clustered extremes, more uniform spread. But combined with skew = non-gaussian tails. |
| Max Trades | 996 | 4253 | ZScore generates 4x more trades (HFT-friendly but higher costs). |
| Losing Passes (%) | 53.75% | 59.12% | ~55-60% fail outright—high failure rate signals over-optimization. |
| DD >50% (%) | 3.85% | 9.86% | ZScore 2.5x riskier (more tail events trigger big drawdowns). |
| Recovery Factor <1 (%) | 56.67% | 61.96% | Poor recovery in most passes (profits < drawdowns)—strategy struggles post-loss. |

**Interpretation**

Across the full distribution, the *TP-as-multiple* strategy produced higher average profits, higher consistency, and a greater share of profitable runs.  
The *TP-as-Z-score* mode occasionally produced exceptional Sharpe outliers (rare, isolated peaks), but overall less stability.

## Parameter Sensitivity

From the heat map results, the following is observed:

### Entry Z-score

*  entry Z-score is the most important factor determining profitability as seen in the graphs. In both modes, **EntryZscore > 6.4** produced higher Sharpe ratios and profitability. However, this is determined by the overall spread of the market which varies from time to time with volatility of the pairs and hence these values may be different if the test period changes.

### Stop Z-score

* Stoploss Z-score had no major effect on the profit nor Sharpe ratio. The defining factor was entry Z-score and for all ranges of stop loss, a higher entry Z-score worked well with any value of stop loss Z-score likely because if the entry z-score was high enough, the chances that the spread would increase further was not likely and hence the most probable movement of the market was for the spread to revert to the mean and hence hit take profit.

### TakeProfit Z-score (Z-based mode only)

* Profits were highest around **TP Z ≈ 3 – 3.5**, beyond which performance flattened.
* Too small TP Z (< 2) led to frequent small wins but poor risk/reward.
* Just like stop loss z-score, the defining input was the entry z-score. A high entry Z-score (greater than 6.4 in this test period) always resulted in a profit despite the take profit z-score used.

## Correlation between parameters

Here is the correlation matrices for the two methods



Figure 17: correlation matrix for TP as multiple of stoploss



Figure 18: correlation matrix for TP based on Z-score

As seen, profits and Sharpe ratio are highly correlated to the Entry Z-score with a correlation exceeding 68% for TP as multiple of stop loss and 85% for TP based on Z-score. Stop loss Z-score was not correlated to the profits nor the Sharpe ratio and neither was the Take Profit Z-score. This supports the observations made on the graphs of take profit Z-score vs Sharpe ratio and stop loss Z-score vs Sharpe ratio. From the matrices above, we see that:

* Entry Z-score is the defining factor when it comes to profitability with a correlation exceeding 60%. Entry Z-score is also positively correlated to the expected payoff and recovery factor.
* Entry Z-score is negatively correlated to the equity drawdown%. Thus higher entry Z-score equal lower drawdown (due to reduced number of low quality trades)
* Stop loss Z-score and take profit Z-score are not correlated to the profits nor the Sharpe ratio.
* Entry Z-score is negatively correlated to the number of trades. A higher entry Z-score equals lower number of trades. This is due to reduced trade signals.
* Number of trades are negatively correlated to the profit ( higher number of trades equals lower profits), and positively correlated to the equity drawdown % (more trades equal higher drawdown)

## Method Summary

 T**P\_Multiple Superiority**: It yields higher mean profits/Sharpe (4.03 vs 2.98) and better filters (43% vs 38% profitable, 3.8% vs 9.9% extreme DD). This aligns with the strategy's risk-reward design—multiples (e.g., 2x SL) capture symmetric reversions better than fixed Z-thresholds, which may exit too early in fat-tailed spreads (e.g., slow mean reversion post-jump). However, negative medians highlight the "barbell" effect: 40% great passes, 60% losses which is a classic pairs trading pitfall.

 **Fat-Tail Effects Amplified**: High std dev (4669-4999 for profits) and negative skew confirm non-Gaussian spreads (as discussed). In M1 GBPUSD/EURUSD (correlated majors, but volatile forex pair), tails from news spikes (e.g., Sept 2025 ECB/Fed events) cause clustered losses—explaining 54-59% losing passes and RF<1 in >60%. ZScore worsens this (higher DD/trades), as Z-thresholds (e.g., TP=0) assume quick reversion, but fat tails prolong excursions. Result: Over-optimism in means (inflated by 1-2% winners), but medians reveal ~$1000 typical loss per pass.

 **Optimization Biases**: Short period (Sept 1-5, 5 days) + every-tick M1 = high noise/overfit risk. Max Sharpe ~23 is unrealistic (likely 1-2 passes; real Sharpe <2 post-costs). High failure rate (60%+) suggests grid too coarse hence the importance to focus on top 10% passes for out-of-sample validation.

 **Strategy Tie-In**: For REHOBOAM v2's HFT mode, TP\_Multiple reduces false exits in tick-level noise, boosting Sharpe.

# MATHEMATICAL VALIDATION AND ASSUMPTIONS

The strategy assumes the spread is stationary, validated indirectly via correlation. Under normality, Z-scores follow a standard normal distribution, with thresholds corresponding to confidence levels (e.g., 2  95%). Position sizing assumes the adverse move is linearly related to , which holds under Gaussian assumptions but may fail in fat-tailed markets. In fat tailed markets (typical for financial markets, kurtosis < 0), extreme events fatten the tails leading to 2σ = 92-96% instead of normal 95% for gaussian.

Potential limitations include slippage in HFT mode and correlation breakdown during regime shifts. Future extensions could incorporate formal cointegration tests or adaptive lookbacks.

# RECOMMENDATIONS

 **Strengths**: Take Profit as multiple of stop loss is viable for live (higher robustness); ~40% profitable passes = decent hit rate for pairs trading.

 **Weaknesses**: the following are the weaknesses observed in this version of rehoboam:

1. Fat tails dominate (negative medians, high DD)—strategy bets against extremes too often.
2. The nature of Z-score in financial markets is that it follows a platykurtic distribution (flat kurtosis). Flat kurtosis amplifies uniform noise (tick-level non-stationarity) giving more false signals than Gaussian predicts. REHOBOAM v2.0’s profits' negative skew (-0.55) stems from this since Z-scores revert slowly in shoulders, hitting SLs.

 **Improvements**: the following improvements can be added:

1. Add rolling window hedge calculation to account for changing regime in prices.
2. Do an ADF (Augmented-Dickey-Fuller) test for stationarity on raw spreads and if p > 0.05 (non-stationary), then shorten the lookback window.
3. Update every k: If k=1, full recompute (heavy); use EWMA (exponential weighted) for efficiency: (α=1/w ≈0.05 for w=20).
4. Use median instead of (less skewness)
5. Robust e.g. MAD (median Absolute Deviation).
6. **Threshold adjustments:** recalculate the z-score offline to ensure you have the most robust entry and stop loss z-scores. The following table can guide you.



Figure 19: frequency of recalculating Z-score (offline)

Operate on tick data and not M1 data. For simplicity, use MetaTrader 5 strategy tester tool. Only adjust if the stats shift by more than 5% else stick to the defaults.

# CONCLUSION

REHOBOAM v2 represents an advanced, user-configurable pairs trading EA optimized for high-frequency execution. By leveraging hedge ratios, Z-score signals, and risk-controlled sizing, it provides a robust framework for statistical arbitrage. The mathematical formulations outlined ensure transparency and reproducibility, making it suitable for both educational and practical applications in algorithmic trading.

We conclude the following:

1. Entry Z-score is the key factor in the profitability of the EA. It has a high correlation to the profit, Sharpe ratio, equity drawdown and recovery ratio. Therefore, it should be set correctly and carefully
2. The Entry Z-score and Stoploss Z-score should be placed beyond the majority of the Z-score values (as seen in the Z-score histogram) to avoid whipsaws. This is a core principle of statistical arbitrage.
3. Z-score and hedge ratio (beta) should be recalculated over the lookback period and regression periods as previously recommended to ensure availability of the best Z-score to avoid using outdated entry and stop loss Z-score.
4. TakeProfit as a multiple of stop loss yields better profits and reasonable Sharpe ratios and should be the preferred method in all trades.

# *References*

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