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*

I. 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.

II. 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).

III. METHODOLOGY

A. 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 β 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).

B. Hedge Ratio and Correlation Calculation

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

$$\beta = \frac{\mathrm{Cov}(P_A, P_B)}{\mathrm{Var}(P_B)}$$

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

Correlation ρ serves as a cointegration proxy, calculated on returns:

$$r_{A,i} = \frac{P_{A,i} - P_{A,i+1}}{P_{A,i+1}}, r_{B,i} = \frac{P_{B,i} - P_{B,i+1}}{P_{B,i+1}}$$

$$\rho = \frac{\mathrm{Cov}(r_A, r_B)}{\sigma_{r_A} \cdot \sigma_{r_B}}$$

If $\rho < MinCorrelation$ and not bypassed, initialization fails.

C. Spread Formation and Z-Score Normalization

The synthetic spread S is formed as:

$$S_t = P_{A,t} - \beta \cdot P_{B,t}$$

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

$$\mu_S = \frac{1}{N}\sum_{i=1}^{N} S_{t-i}, \sigma_S = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(S_{t-i} - \mu_S)^2}$$

The Z-score normalizes the current spread:

$$Z_t = \frac{S_t - \mu_S}{\sigma_S}$$

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

- **Long spread:** $S_{\text{long}} = \text{Ask}_A - \beta \cdot \text{Bid}_B$
- **Short spread:** $S_{\text{short}} = \text{Bid}_A - \beta \cdot \text{Ask}_B$
- **Average:** $S_t = (S_{\text{long}} + S_{\text{short}})/2$

This accounts for transaction costs implicitly.

D. Entry Conditions

Trades are entered when $|Z_t) \geq \text{EntryZScore}$ (default 2.0), signaling deviation:

- If $Z_t \leq \text{-EntryZScore}$: Long the spread (buy SymbolA, sell SymbolB).
- If $Z_t \geq \text{EntryZScore}$: Short the spread (sell SymbolA, buy SymbolB).

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

E. Position Sizing

Lots for SymbolA (L_A) are sized to risk a fixed percentage (default 1%) of balance, assuming an adverse move of $2\sigma_S$ (from entry to stop):

$$\text{RiskAmount} = \begin{cases} (\text{RiskPercent}/100) \cdot B & \text{if SL\_ZScore} \\ (\text{StopLossPercent}/100) \cdot B & \text{if SL\_Percent} \end{cases}$$

where B is account balance.

The dollar risk per unit is based on tick value:

$$L_A = \frac{\text{RiskAmount}}{2\sigma_S \cdot (\text{TickValue}_A / \text{TickSize}_A)}$$

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

F. Exit Conditions

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

a. Z-Score Based (SL_Type = SL_ZScore)

For long spread (entry $Z_e < 0$):

- SL: $Z_t \leq Z_e - (\text{StopZScore} - \text{EntryZScore})$
- TP (TP_Type = TP_Multiple):
  $Z_t \geq Z_e + \text{RiskRewardRatio} \cdot (\text{StopZScore} - \text{EntryZScore})$
- TP (TP_Type = TP_ZScore): $Zt \geq TakeProfitZScore$ (e.g., 0 for mean reversion)

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

b. Percentage Based (SL_Type = SL_Percent)

Monitors pair profit $\Pi = \sum \text{PositionProfit}$:

- SL: $\Pi \leq (\text{StopLossPercent}/100) \cdot E$
- TP: $\Pi \geq (\text{StopLossPercent}/100) \cdot E \cdot \text{RiskRewardRatio}$

where E is equity at entry.

G. 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:

$$\text{MarketOpen} = \left(\text{TradeMode}_A \neq \text{DISABLED}\right) \wedge \left(\text{TradeMode}_B \neq \text{DISABLED}\right)$$

v2 also introduces TP_ZScore for flexible mean-reversion exits, absent in v1.

H. 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

IV. RESULTS

A. Heat maps for TP as multiple of stop loss

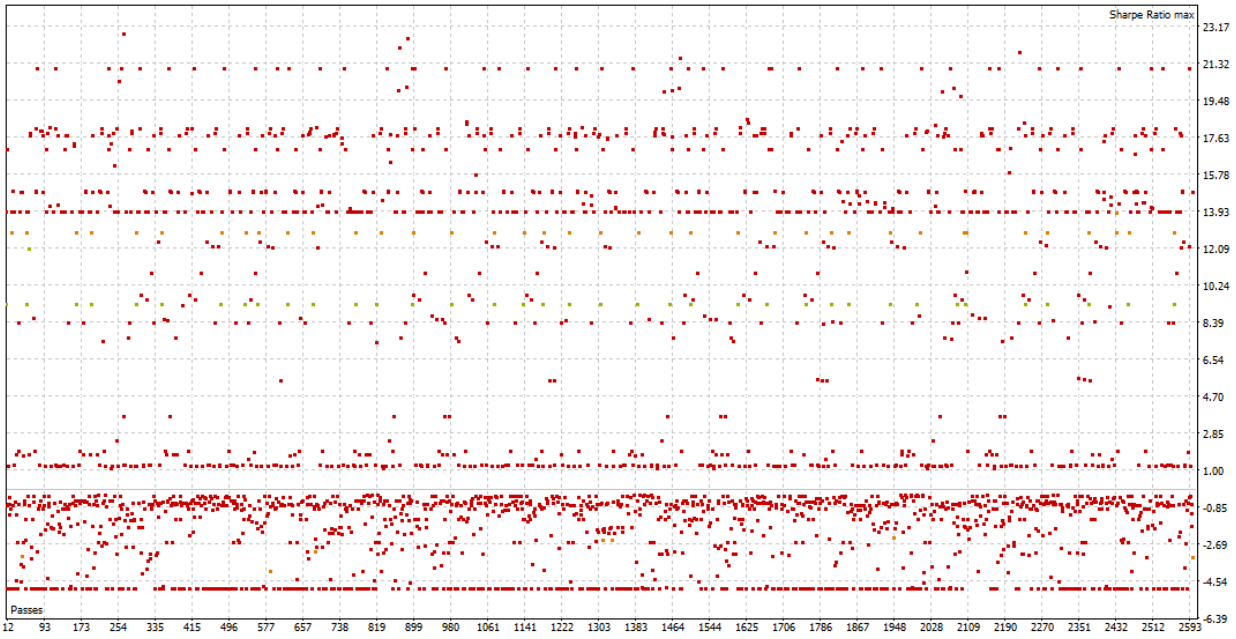

Figure 3: passes vs Sharpe ratio

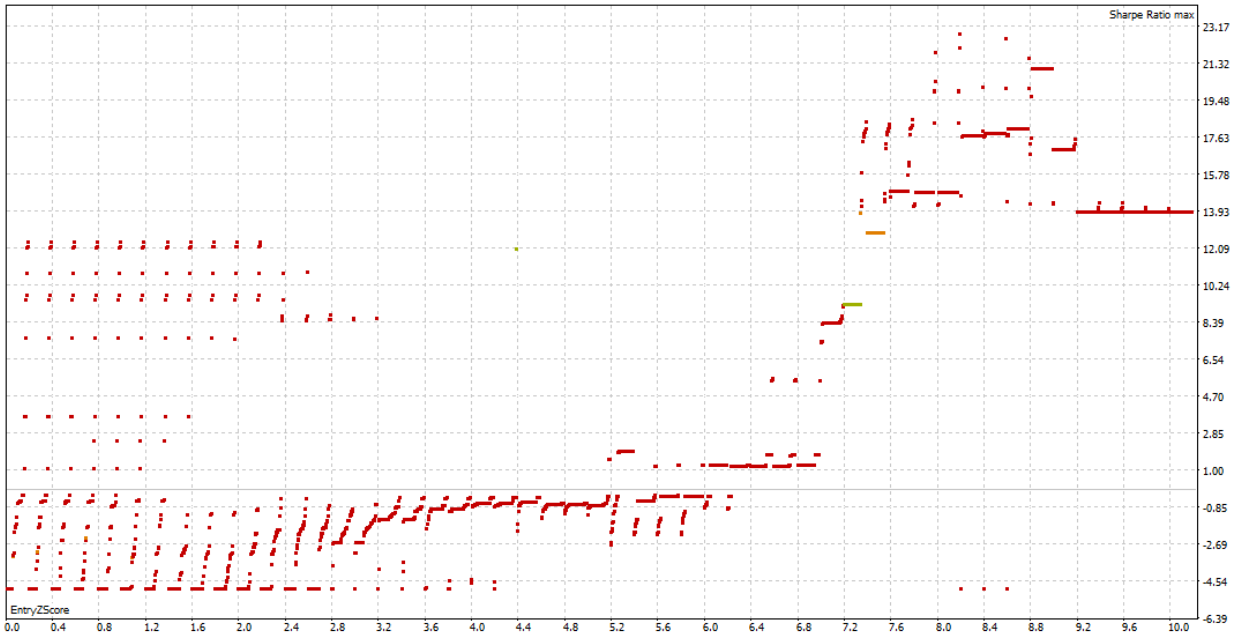

Figure 4: EntryZscore vs Sharpe ratio

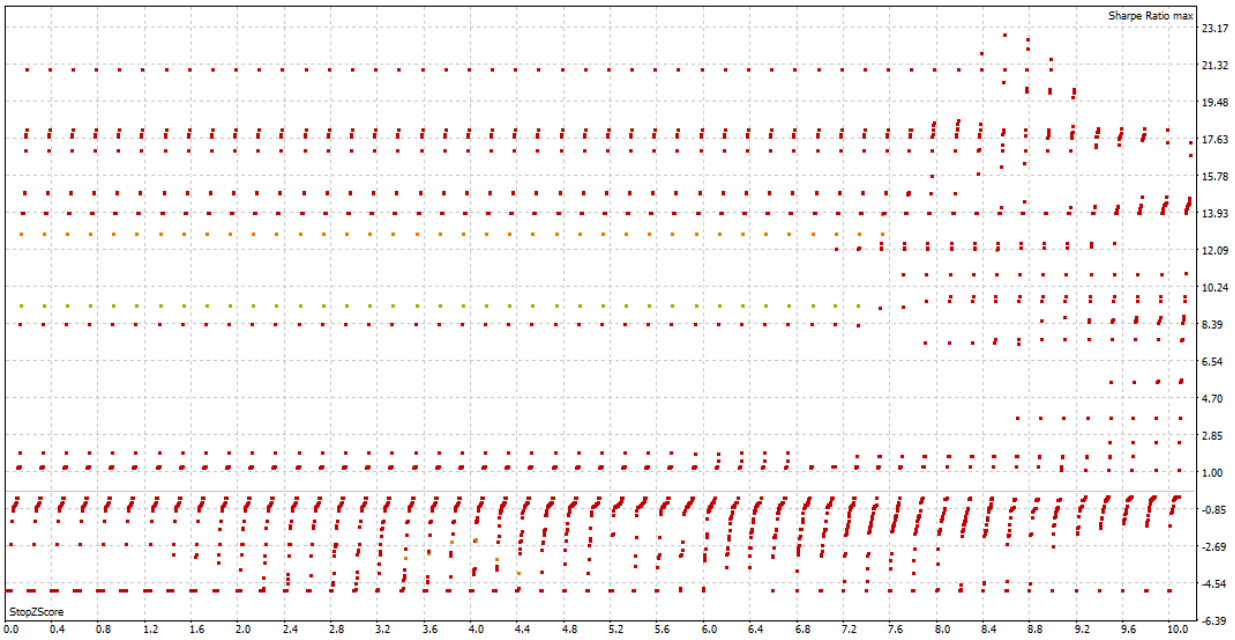

Figure 5: Stop Zscore vs Sharpe ratio

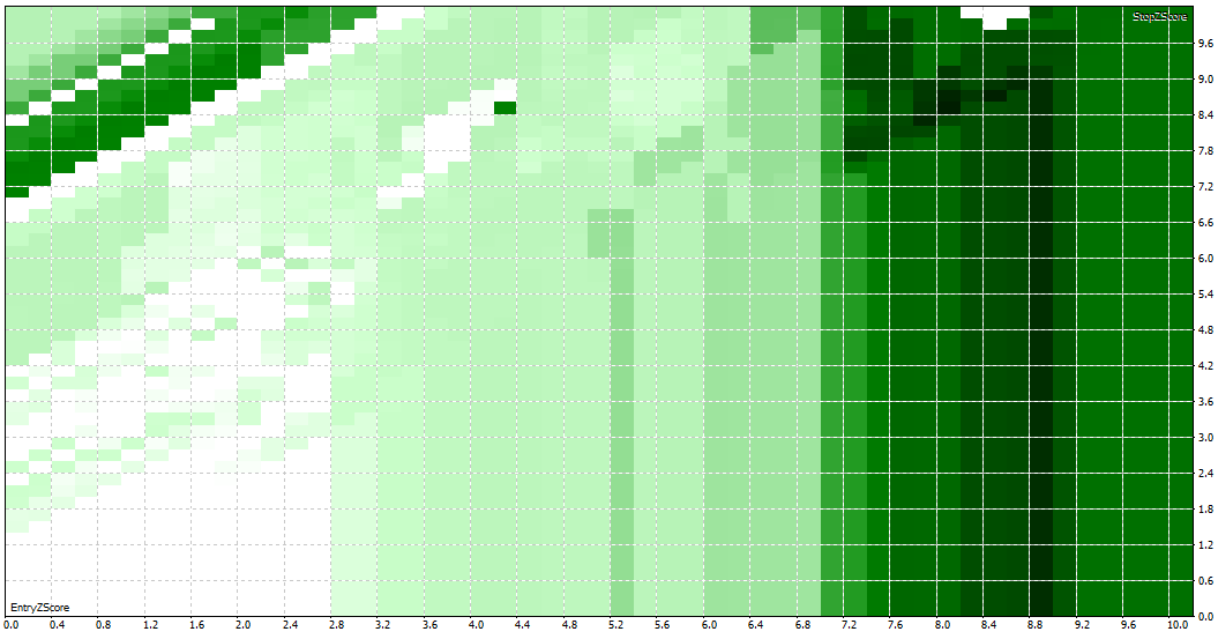

Figure 4: Entry Zscore vs Stop Zscore

The darker the green, the higher the Sharpe ratio.

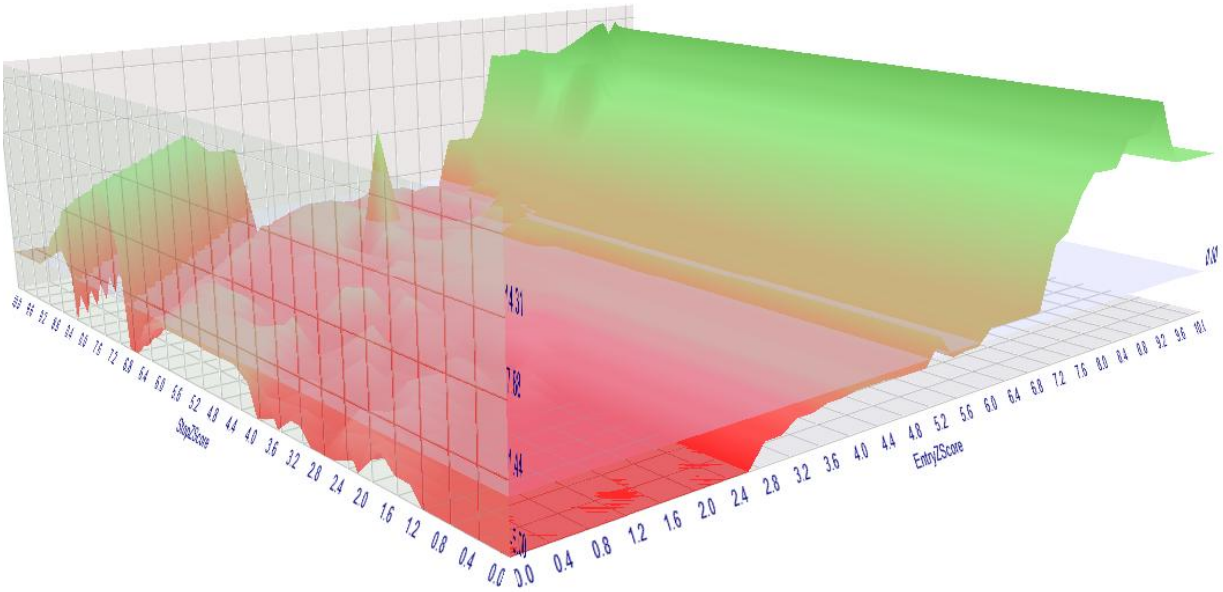

Figure 5: 3D graph of stop Zscore vs Entry ZScore vs Sharpe ratio (on the Z axis)

B. Heat maps for TP based on Zscore

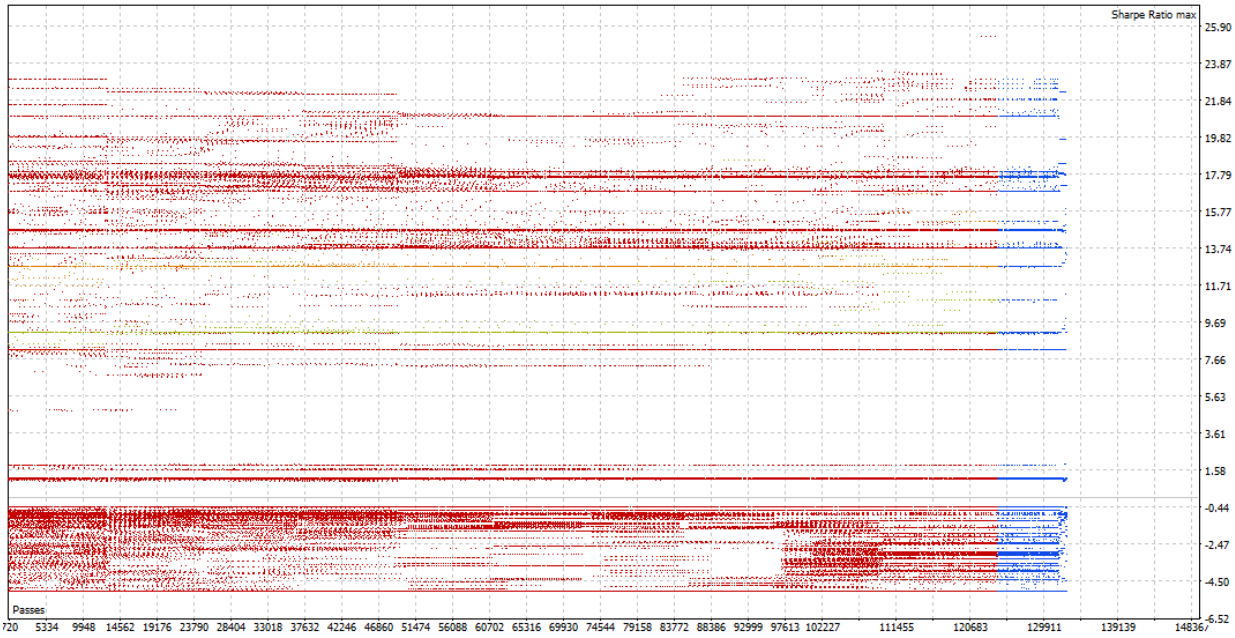

Figure 6: passes vs Sharpe ratio

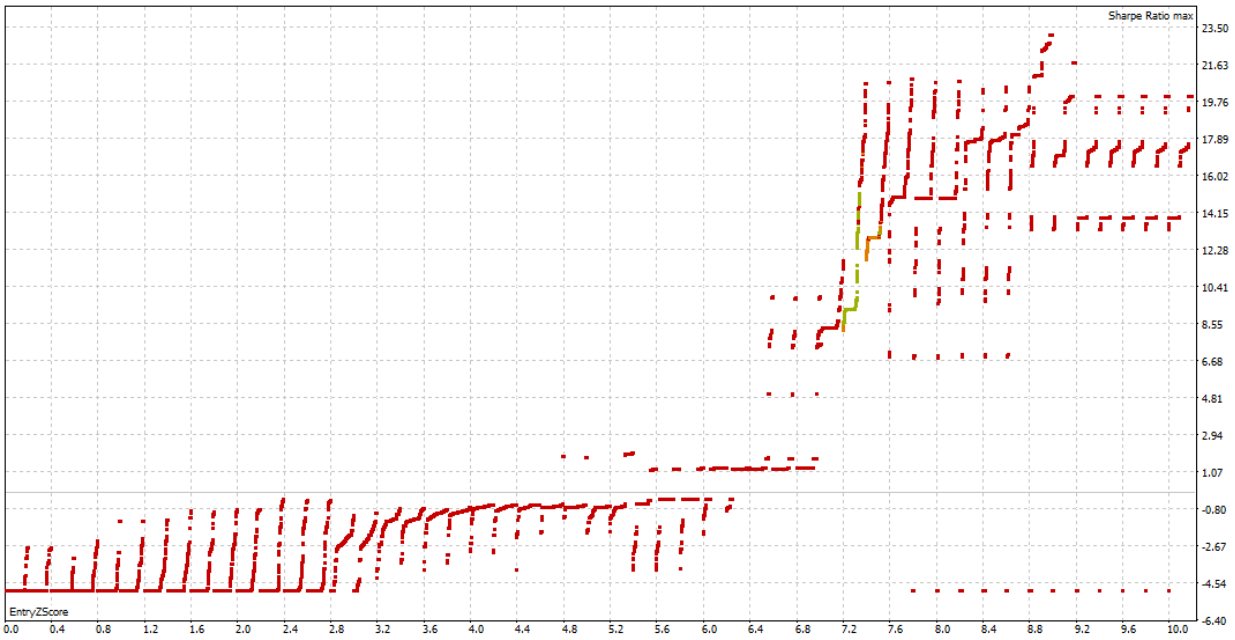

Figure 7: Entry Zscore vs Sharpe ratio

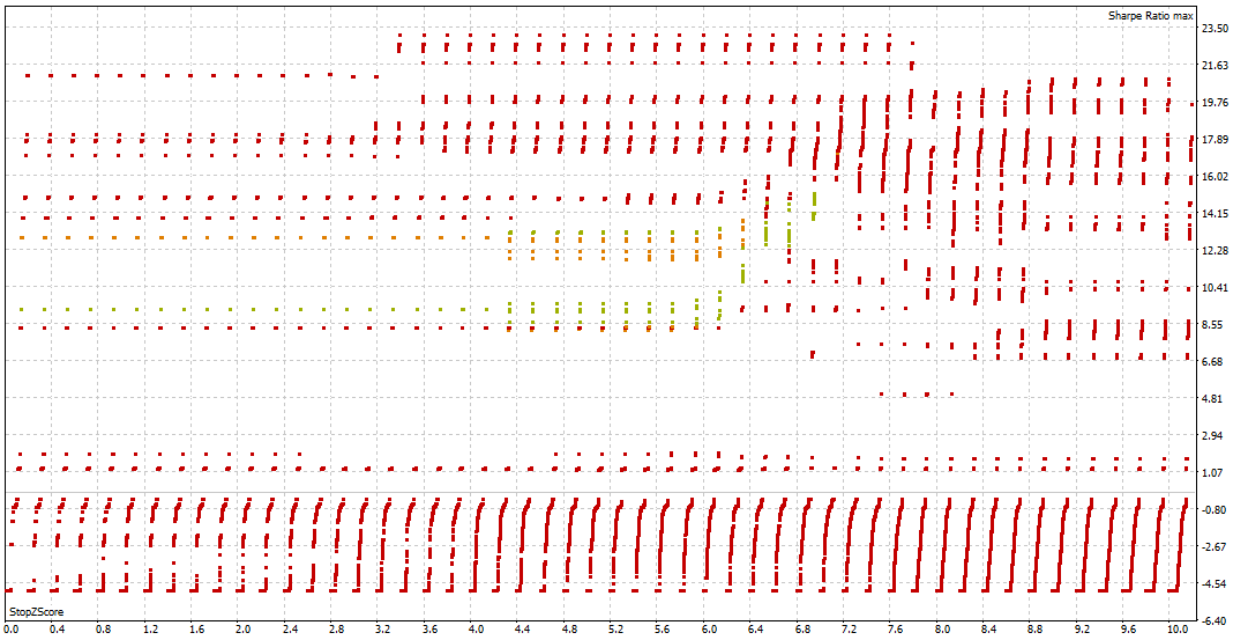

Figure 8: stop Zscore vs Sharpe ratio

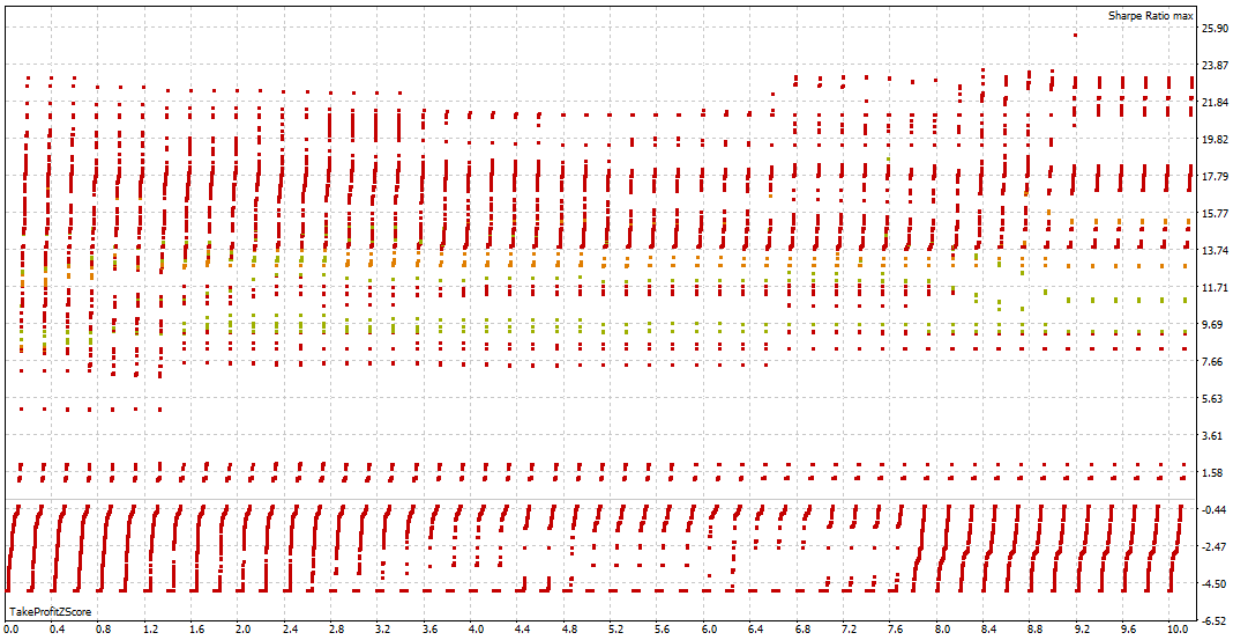

Figure 9: takeProfit Zscore vs Sharpe ratio

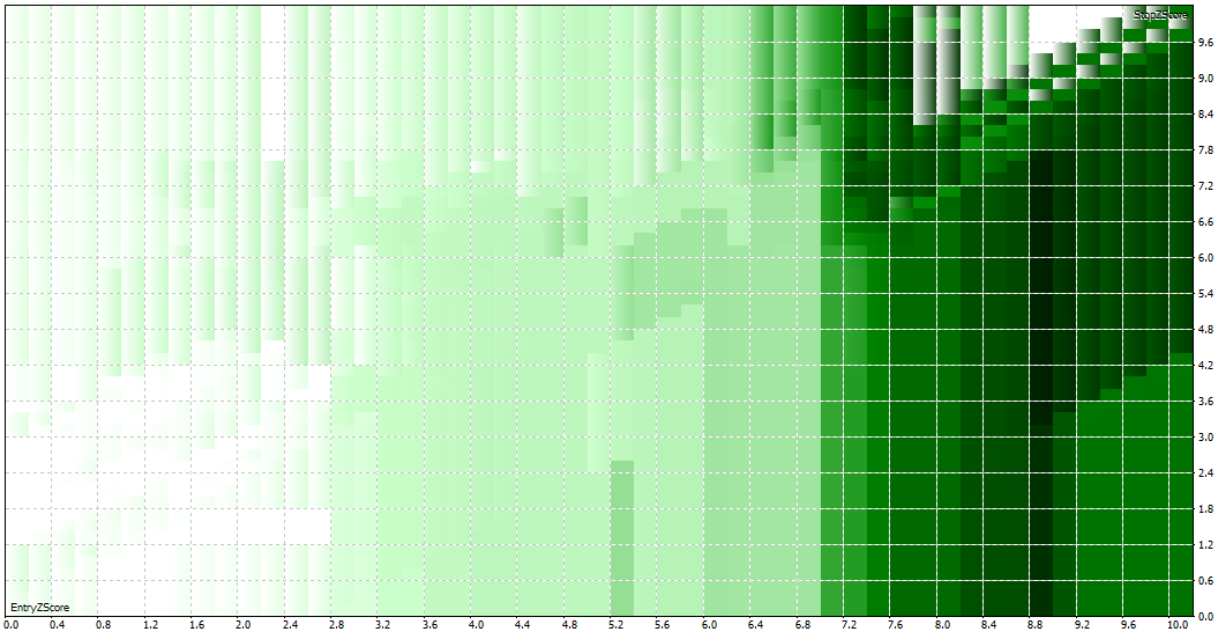

Figure 10: Entry Zscore vs Stop Zscore

The deeper the color, the higher the Sharpe ratio

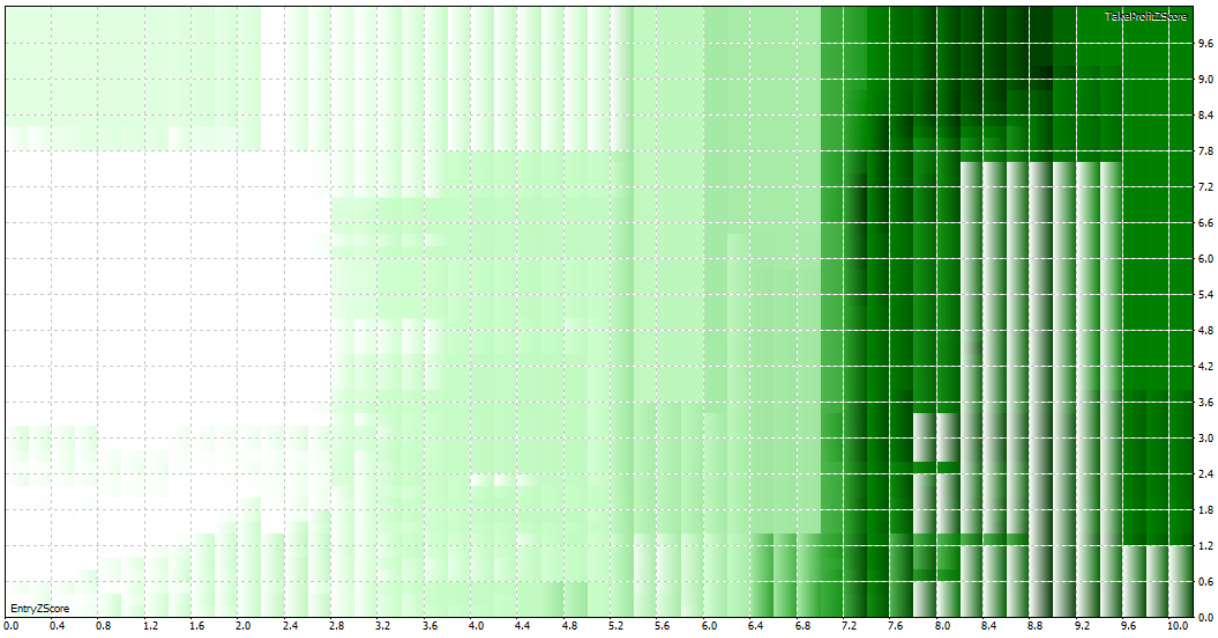

Figure 11: Entry Zscore vs take Profit Zscore

The deeper the color, the higher the Sharpe ratio

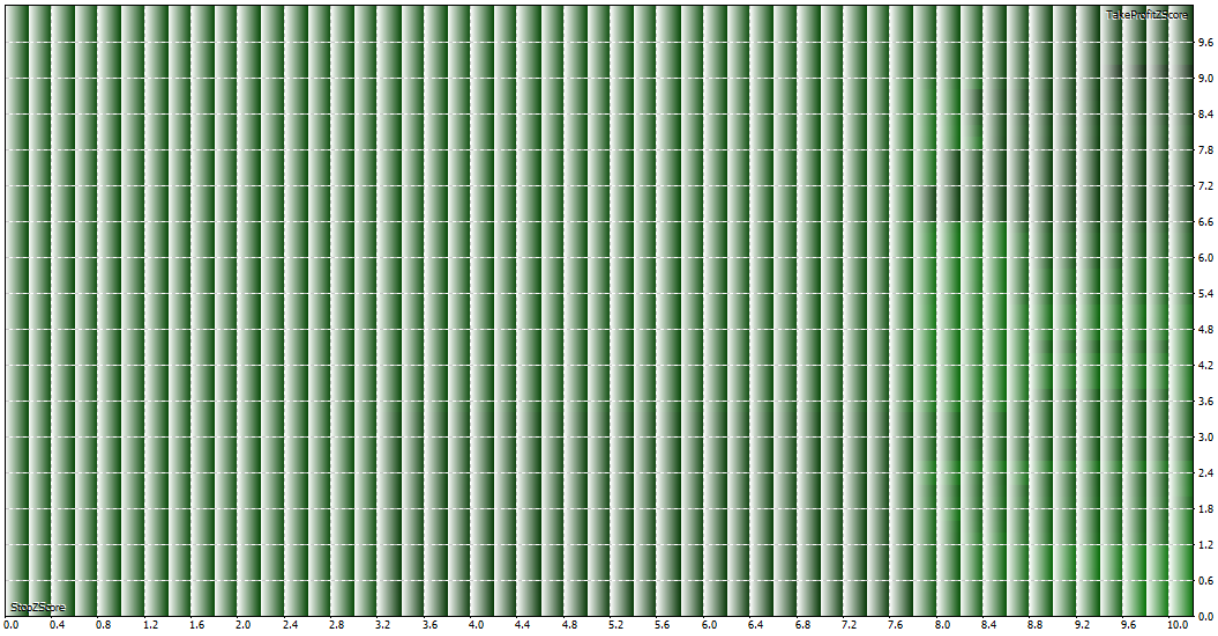

Figure 12: take Profit Zscore vs Stop Zscore

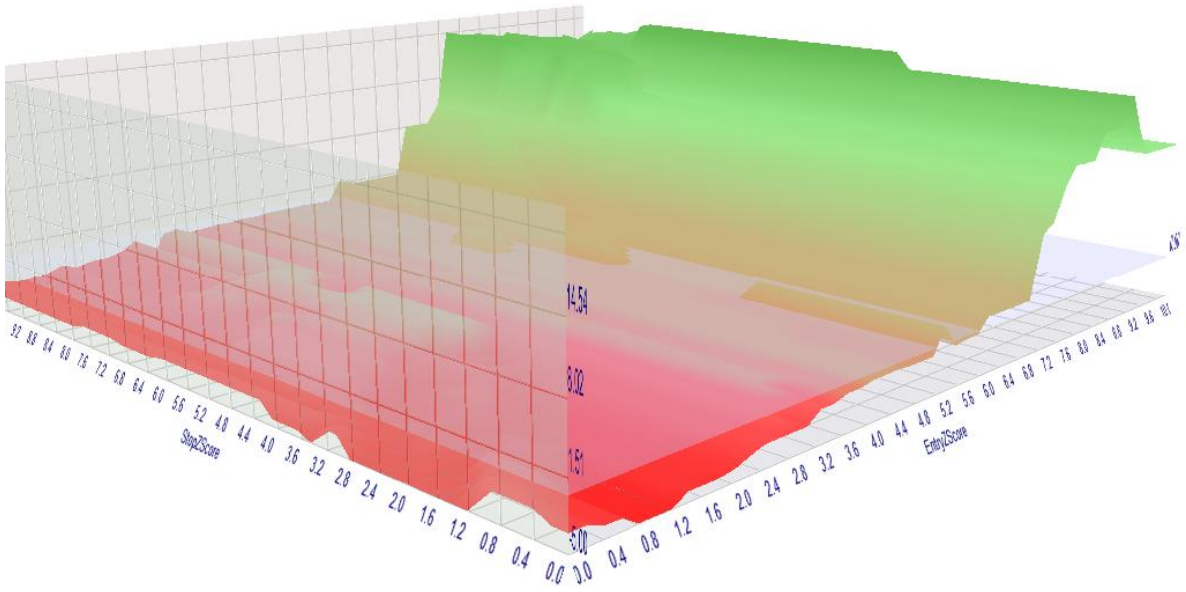

Figure 13: Stop Zscore vs Entry Zscore vs Sharpe ratio (on z axis)

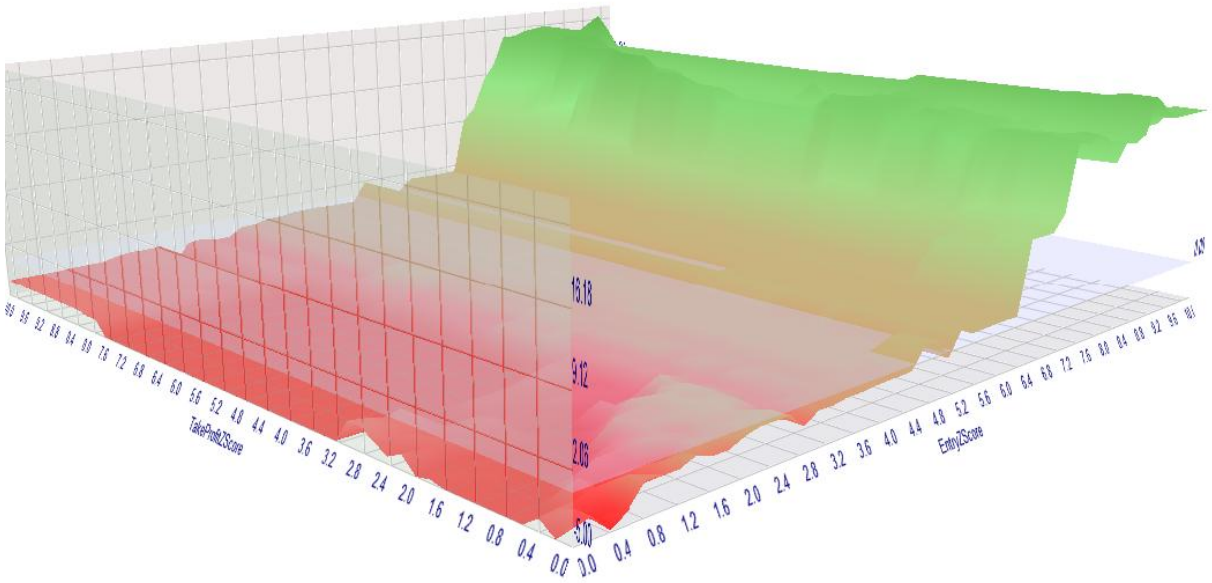

Figure 14: take Profit Zscore vs Entry Zscore vs Sharpe ratio (on the Z axis)

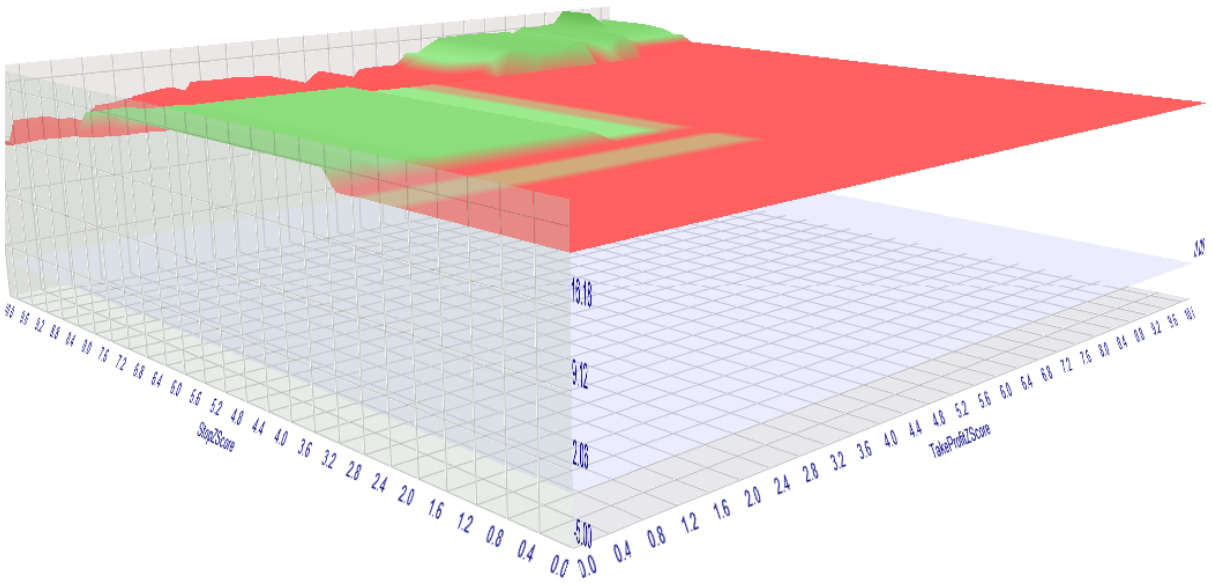

Figure 6: Stop Zscore vs Take profit Zscore vs sharpe ratio

C. 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.

Profit		***Sharpe Ratio***	
Mean	1146.962076	Mean	4.031675559
Standard Error	91.57232583	Standard Error	0.158463355
Median	-920.29	Median	-0.368113
Mode	6387.8	Mode	-5
Standard Deviation	4670.188617	Standard Deviation	8.081631123
Sample Variance	21810661.72	Sample Variance	65.31276161
Kurtosis	0.323942941	Kurtosis	-1.129941365
Skewness	-0.55406391	Skewness	0.660654032
Range	23855.17	Range	27.763985
Minimum	-14975.62	Minimum	-5
Maximum	8879.55	Maximum	22.763985
Sum	2983248.36	Sum	10486.38813
Count	2601	Count	2601
Largest(1)	8879.55	Largest(1)	22.763985
Smallest(1)	-14975.62	Smallest(1)	-5
Confidence Level(95.0%)	179.5620505	Confidence Level(95.0%)	0.310727119

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

Equity DD %		*Trades*	
Mean	21.27121134	Mean	24.92810458
Standard Error	0.259113063	Standard Error	1.267931483
Median	16.9761	Median	16
Mode	15.5325	Mode	16
Standard Deviation	13.21476619	Standard Deviation	64.66450565
Sample Variance	174.6300455	Sample Variance	4181.498291
Kurtosis	19.3201125	Kurtosis	125.8416825
Skewness	4.160897685	Skewness	10.14243815
Range	94.1743	Range	992
Minimum	5.6853	Minimum	4
Maximum	99.8596	Maximum	996
Sum	55326.4207	Sum	64838
Count	2601	Count	2601
Largest(1)	99.8596	Largest(1)	996
Smallest(1)	5.6853	Smallest(1)	4
Confidence Level(95.0%)	0.508088797	Confidence Level(95.0%)	2.486257448

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

Profit		*Sharpe Ratio*	
Mean	255.4302164	Mean	2.980172146
Standard Error	13.72642923	Standard Error	0.023263443
Median	-1046.87	Median	-0.738061
Mode	6387.8	Mode	-5
Standard Deviation	4999.341907	Standard Deviation	8.472844799
Sample Variance	24993419.51	Sample Variance	71.78909899
Kurtosis	-0.659560327	Kurtosis	-0.910808604
Skewness	-0.362548274	Skewness	0.823690037
Range	22346.53	Range	30.450484
Minimum	-14981.14	Minimum	-5
Maximum	7365.39	Maximum	25.450484
Sum	33883073.64	Sum	395322.8153
Count	132651	Count	132651
Largest(1)	7365.39	Largest(1)	25.450484
Smallest(1)	-14981.14	Smallest(1)	-5
Confidence Level(95.0%)	26.9035524	Confidence Level(95.0%)	0.045595926

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

Equity DD %		*Trades*	
Mean	24.09735955	Mean	60.68959148
Standard Error	0.043692961	Standard Error	0.561281082
Median	17.1554	Median	18
Mode	15.5325	Mode	16
Standard Deviation	15.9135379	Standard Deviation	204.4257824
Sample Variance	253.2406885	Sample Variance	41789.90052
Kurtosis	4.814434867	Kurtosis	244.2401727
Skewness	2.351752453	Skewness	14.15842413
Range	96.0515	Range	4249
Minimum	3.8324	Minimum	4
Maximum	99.8839	Maximum	4253
Sum	3196538.841	Sum	8050535
Count	132651	Count	132651
Largest(1)	99.8839	Largest(1)	4253
Smallest(1)	3.8324	Smallest(1)	4
Confidence Level(95.0%)	0.085637412	Confidence Level(95.0%)	1.100100744

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

D. Histograms

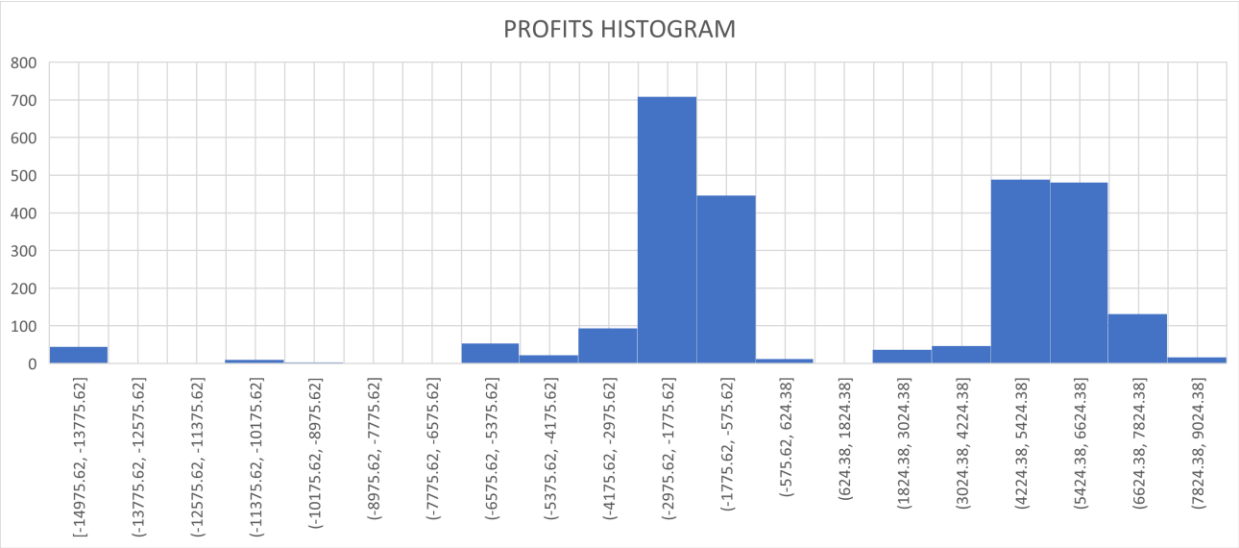

Figure 11: profits histogram for TP as multiple of stop loss

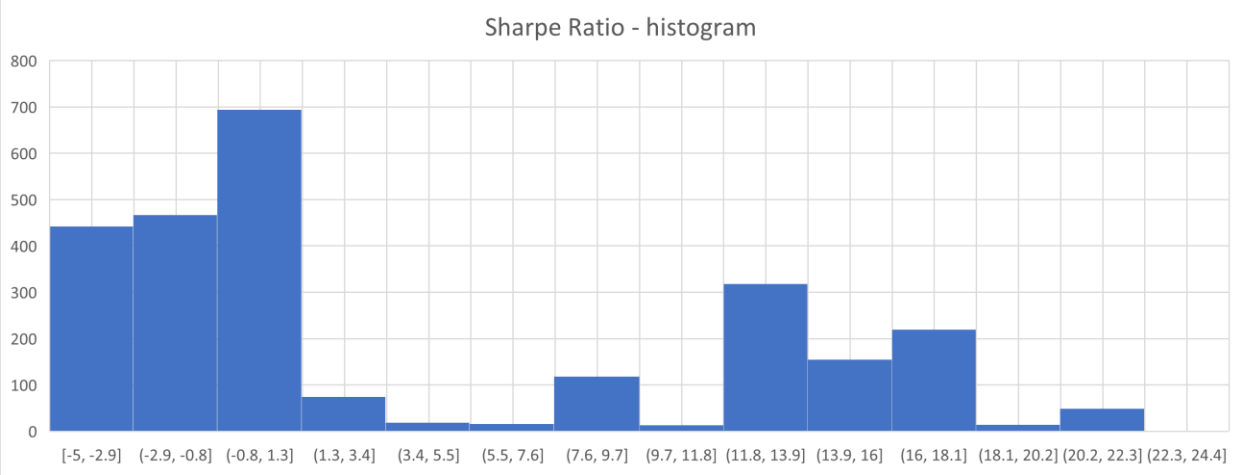

Figure 12: Sharpe ratio histogram for TP as multiple of stop loss

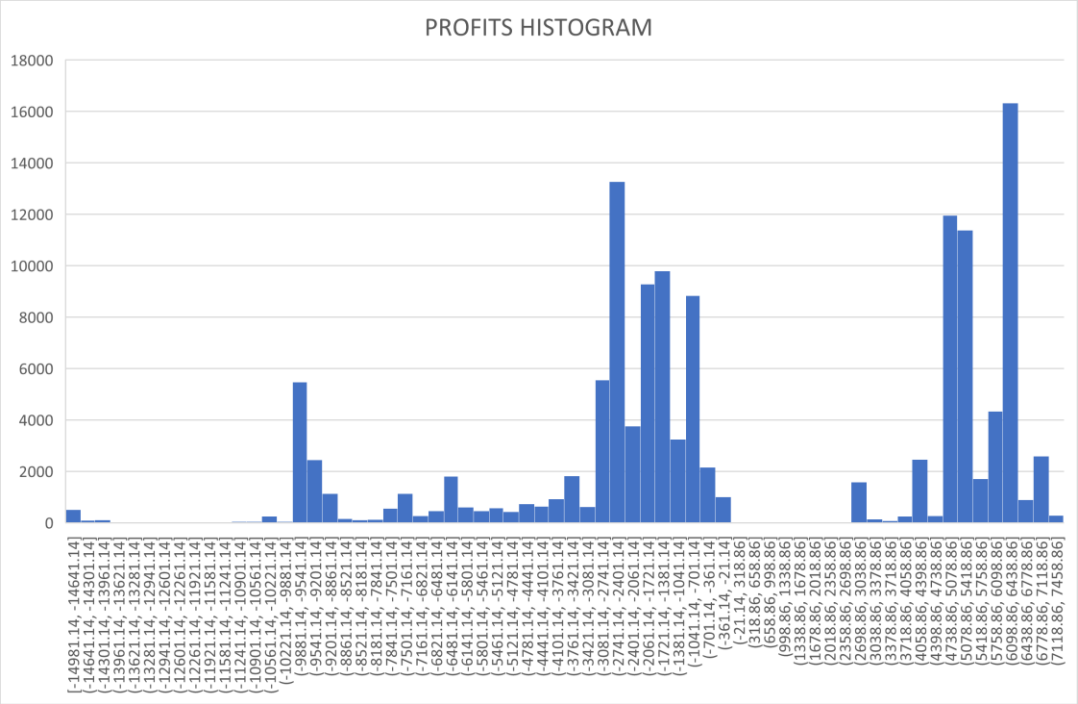

Figure 13: profits histogram for TP based on Z-score

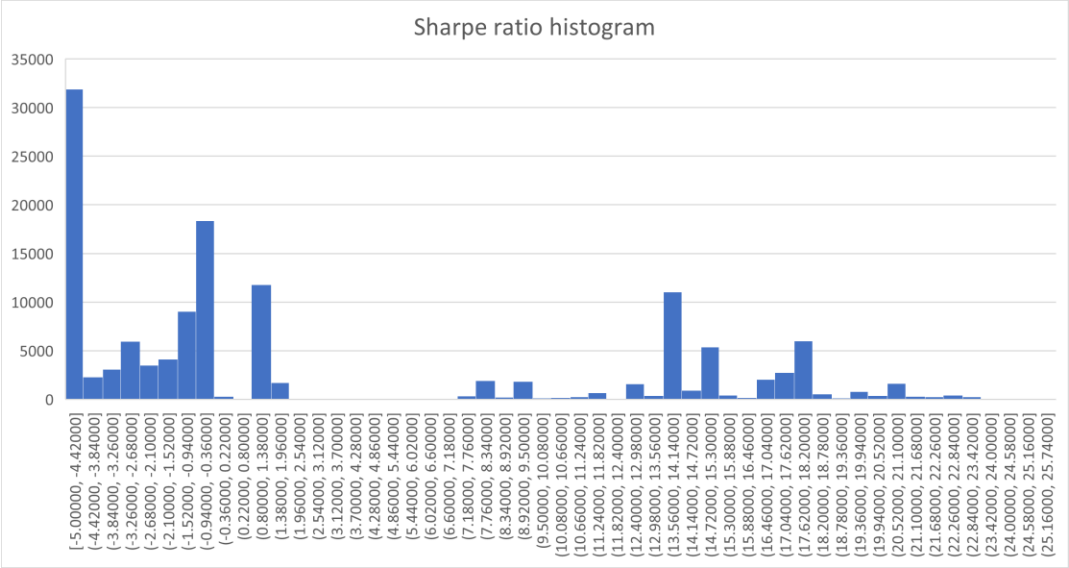

Figure 14: Sharpe ratio histogram for TP based on Z-Score

E. Z-score distribution

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

ZSCORE	
Mean	0.000150825
Standard Error	0.012585888
Median	0.003928657
Mode	#N/A
Standard Deviation	1.053537281
Sample Variance	1.109940803
Kurtosis	-0.314202001
Skewness	0.036400267
Range	7.984847264
Minimum	-3.863332226
Maximum	4.121515038
Sum	1.05683358
Count	7007
Largest(1)	4.121515038
Smallest(1)	-3.863332226
Confidence Level(95.0%)	0.024672149

Figure 15: zscore stats

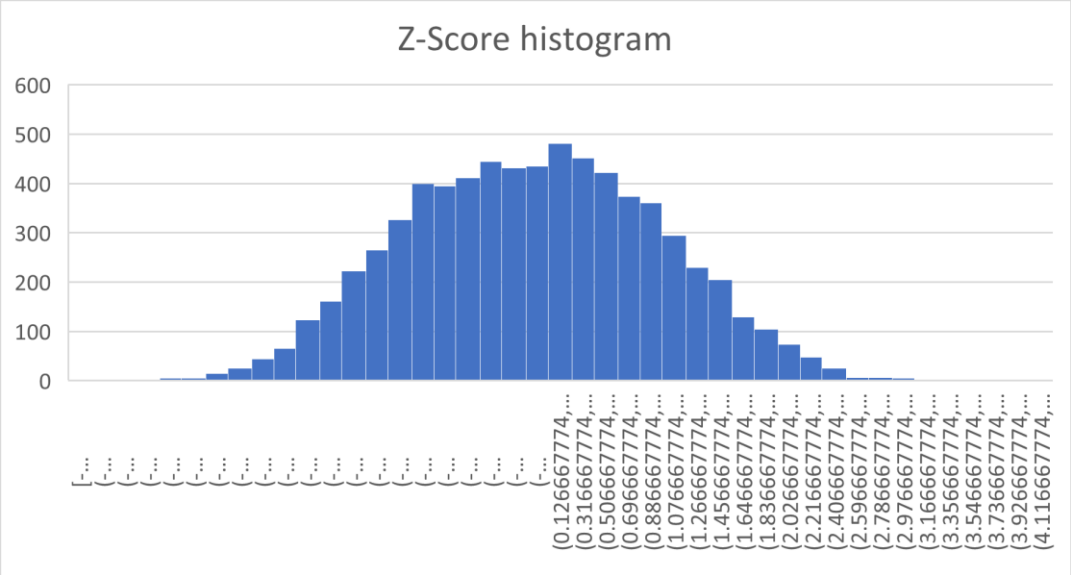

Figure 16: Z-score histogram

V. DISCUSSION

A. 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:

a) **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.

b) **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.

c) **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).

d) **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):

EntryZScore $= \boldsymbol{Q_{1-\alpha/2}}(|\boldsymbol{Z}|)$(upper quantile of absolute Z)

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.

B. 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.

C. Parameter Sensitivity

From the heat map results, the following is observed:

i) 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.

ii) 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.

iii) 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.

D. Correlation between parameters

Here is the correlation matrices for the two methods

	Profit	*Expected Payoff*	*Profit Factor*	*Recovery Factor*	*Sharpe Ratio*	*Equity DD %*	*Trades*	*EntryZScore*
Profit	1							
Expected Payoff	0.792243094	1						
Profit Factor	0.806383646	0.864500171	1					
Recovery Factor	0.929467676	0.885157156	0.892943778	1				
Sharpe Ratio	0.795736895	0.563796941	0.605375598	0.840742866	1			
Equity DD %	-0.659007408	-0.257262936	-0.327019042	-0.367119275	-0.355384471	1		
Trades	-0.376913536	0.00761851	-0.120095443	-0.107329215	-0.076533117	0.708106406	1	
EntryZScore	0.681758455	0.482103338	0.706655347	0.733624953	0.782912785	-0.391427515	-0.1482	1
StopZScore	0.228023101	0.141973369	0.08555072	0.137803411	0.109375985	-0.238998841	-0.20453	-1.05595E-17

Figure 17: correlation matrix for TP as multiple of stoploss

	Profit	*Expected Payoff*	*Profit Factor*	*Recovery Factor*	*Sharpe Ratio*	*Equity DD %*	*Trades*	*EntryZScore*	*StopZScore*
Profit	1								
Expected	0.692053	1							
Profit Fact	0.832523	0.857456426	1						
Recovery	0.925429	0.839205448	0.918225123	1					
Sharpe Ra	0.804677	0.518577909	0.650421124	0.855717824	1				
Equity DD	-0.77589	-0.220278628	-0.406307908	-0.484778976	-0.436975521	1			
Trades	-0.41877	-0.039434303	-0.177329995	-0.202098904	-0.17983733	0.608778072	1		
EntryZSco	0.857971	0.50147396	0.743923385	0.834203899	0.862875184	-0.583512382	-0.261295991	1	
StopZScor	0.021173	0.032706102	0.012265292	-0.011758797	-0.026777483	-0.076611805	-0.076059456	7.63886E-16	1
TakeProfit	0.040593	0.059745484	0.016252296	0.045547702	-0.000185214	-0.033798202	0.015691115	1.90131E-15	-4E-16

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)

E. 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.

VI. 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., $2^{\sigma} \approx 95\%$). Position sizing assumes the adverse move is linearly related to σ_S , 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.

I. 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:

  a) Fat tails dominate (negative medians, high DD)—strategy bets against extremes too often.

  b) 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:

  a) Add rolling window hedge calculation to account for changing regime in prices.

  b) Do an ADF (Augmented-Dickey-Fuller) test for stationarity on raw spreads and if p > 0.05 (non-stationary), then shorten the lookback window.

  c) Update every k: If k=1, full recompute (heavy); use EWMA (exponential weighted) for efficiency: $\mu_t = \alpha S_t + (1-\alpha)\mu_{t-1}$(α=1/w ≈0.05 for w=20).

  d) Use median instead of μ_s (less skewness)

  e) Robust σ_s e.g. MAD (median Absolute Deviation).

  f) **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.

Trading Style/Goal	Export/Recalc Frequency	Data Period to Export	Rationale
Live Trading (Daily HFT)	Weekly (e.g., every Friday)	Last 1-2 weeks (M1 or ticks)	Captures short-term shifts (e.g., weekly vol cycles) without daily noise. ~5-10% threshold tweak expected.
Backtesting/ Optimization	Daily or Every 2-3 days	Last 1 week (M1)	Quick iterations during dev—your Sept 1-5 test could be daily for fine-tuning (e.g., EntryZ from 2.0 → 2.2).
Long-Term Monitoring	Monthly (e.g., month-end)	Last 1-3 months (M1/ticks)	Detects regime changes (e.g., corr breakdown at MinCorrelation=0.2); major tweaks (e.g., +0.5σ).
High-Vol Events	Ad-Hoc (post-news, e.g., NFP)	1-3 days around event	Immediate response to tails (e.g., your range ±4 spikes → widen StopZ to 4.5).

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.

II. 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:

a) 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

b) 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.

c) 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.

d) TakeProfit as a multiple of stop loss yields better profits and reasonable Sharpe ratios and should be the preferred method in all trades.

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