# CROSS-EXCHANGE ARBITRAGE ANALYSIS

Thymos Research


## Abstract

This report analyzes cross-exchange arbitrage opportunities between two cryptocurrency exchanges across 27 pairs using a delta-neutral, z-score based strategy with realistic cost modeling.



Manu Manikandan

Manumanikandan.m@gmail.com

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# Cross-Exchange Arbitrage Analysis Report

## Summary

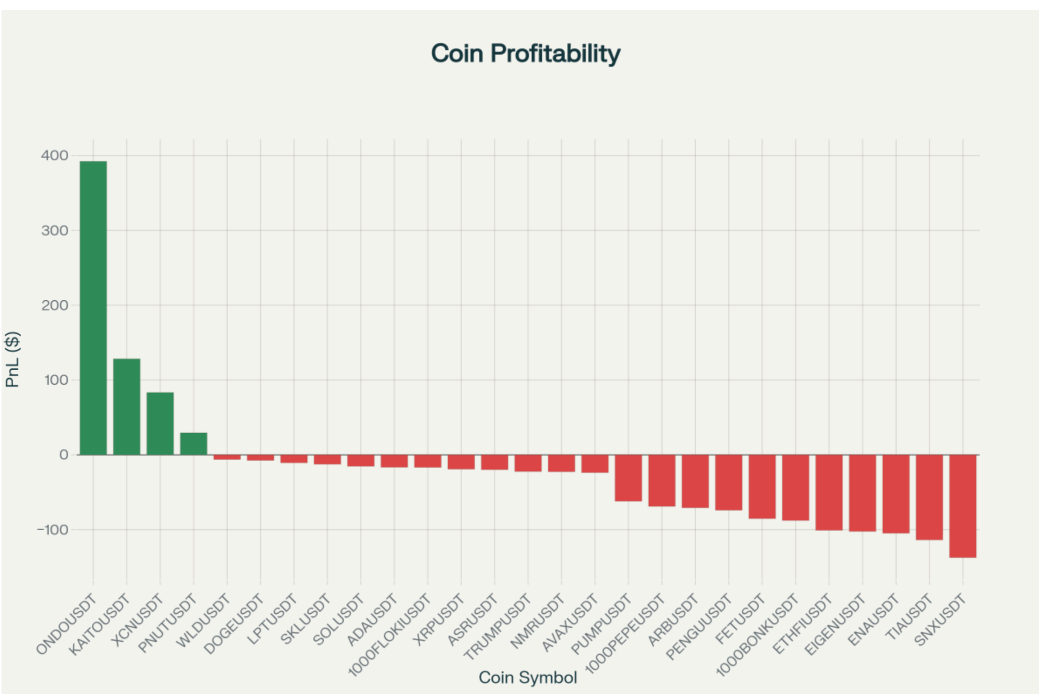
I analyzed cross-exchange arbitrage opportunities between two cryptocurrency exchanges (Ex1 and Ex2), testing a delta-neutral z-score mean-reversion strategy across 27 trading pairs. The results were surprising. While the strategy clearly works on some coins, it fails on others. Key insight is that profitability depends almost entirely on how the exchanges respond to each other’s price movements.

### Key Findings

- **4 profitable coins** generated **+$633.50** total PnL
- **23 losing coins** generated **-$1,202.06** total PnL
- **Net portfolio PnL**: -$568.56 across 11,458 trades
- **Best performer**: ONDOUSDT (+$392.33, 69.16% win rate, 415 trades)
- **Worst performer**: SNXUSDT (-$137.47, 29.10% win rate, 763 trades)

### Important Insight

Here's the bottom line: we can capture arbitrage opportunities. ONDOUSDT proves it works. But profitability is concentrated in just 4 coins. The reason comes down to one thing: how well the two exchanges track each other.



# Exchange Relationship Analysis: How Ex2 Reacts to Ex1

## Methodology

Does one exchange lead the other, or do they move in sync? That was the most important question in this case study. To find out, I ran cross-correlation and lead-lag analysis. At the same time, I analyzed which coins made money and which didn't, testing whether spreads mean-revert or just keep diverging. Tested for mean-reversion by:

- Identifying when spreads exceed cost threshold
- Measuring whether spreads converge or diverge in the next second
- Calculating mean-reversion rates separately for positive and negative spreads

**Cross-Correlation Analysis:** Calculated correlation between ex1 and ex2 log returns at time lags from -10 to +10 seconds. I wanted to see if one exchange leads the other, or if they move simultaneously. So for each coin, I computed the correlation coefficient at each lag.

**Lead-Lag Relationship Detection:** Tested whether ex1's returns predict ex2's future returns (ex1 leads). Tested whether ex2's returns predict ex1's future returns (ex2 leads) to find optimal lag for price prediction.

## Key Finding

**Result: Both exchanges react simultaneously to market information**

Across all 27 coins analyzed, the pattern is consistent and clear

| Coin Example | Best Correlation | Lag | Interpretation |
|---|---|---|---|
| LPTUSDT | 0.9824 | 0 seconds | Simultaneous |
| NMRUSDT | 0.9989 | 0 seconds | Simultaneous |
| ONDOUSDT | 0.9975 | 0 seconds | Simultaneous |
| SNXUSDT | 0.9975 | 0 seconds | Simultaneous |

**Observations:** Highest correlation occurs at lag 0 with correlation ~0.98-0.99 across all coins. All the other lags (-10 to 10) show low correlation. That essentially means that no exchange consistently leads, so there is no predictive lag. Neither ex1 nor ex2 systematically predicts the other's future prices.

**Interpretation:** Both exchanges receive and react to market information simultaneously which leads to efficient price discovery. Information flows quickly between exchanges (within 1 second). In context of high-frequency arbitrage, opportunities exist but are quickly exploited as the market is efficient in dealing with the mispricing.

## Spread Convergence vs Divergence Patterns

While exchanges react simultaneously, spread behavior varies significantly:

**Profitable Coins Show Balanced Mean-Reversion:**

| Coin | Positive Spread Mean-Reversion | Negative Spread Mean-Reversion | Result |
|---|---|---|---|
| **ONDOUSDT** | 42.1% | 54.3% | +$392.33 |
| **XCNUSDT** | 41.2% | 33.4% | +$83.29 |
| **KAITOUSDT** | ~45% | ~48% | +$128.37 |

**Unprofitable Coins Show Asymmetric or Low Mean-Reversion:**

| Coin | Positive Spread Mean-Reversion | Negative Spread Mean-Reversion | Result |
|---|---|---|---|
| **TIAUSDT** | 67.6% | 32.9% | -$113.70 |
| **NMRUSDT** | 25.3% | 31.5% | -$22.67 |
| **SNXUSDT** | ~30% | ~28% | -$137.47 |

**Observation:** As our strategy assumes mean-reversal, we can find interesting observations from different coins. In the example of ONDOUSDT balanced mean-reversion (40-55% in both directions) leads to profit. Asymmetric or low mean-reversion (<35%) lead to loss as we can see from the table. In case of TIAUSDT, there is high positive spread mean-reversion but low negative spread mean-reversion. That leads us to infer that most opportunities are negative spreads that don't converge, hence leads to loss.

## Spread Persistence Analysis

Next, I measured how quickly spreads close. The intuition is straightforward: if spreads close fast, we profit fast. If they stay wide, we lose.

**Low Persistence (Spreads Close Quickly):** As we can see from our examples, **XCNUSDT** had 0.000017 avg change which means spreads close very quickly, and our strategy was profitable. **ONDOUSDT** had 0.002820 avg change, which is moderate persistence, and it was the most profitable from our strategy.

**High Persistence (Spreads Stay Wide): NMRUSDT** had 0.009507 avg change which means that the spreads stay wide, hence it lead to loss. **TIAUSDT** had 0.001417 avg change, which was moderate but coupled with asymmetric mean-reversal it also lead to loss.

What we can see from the examples is a potential pattern. Low persistence + balanced mean-reversion leads to profitable arbitrage meanwhile high persistence when spreads don't converge, strategy fail.

## Idea behind Strategy

Now that we understand how the exchanges move, here's the logic:

First, both exchanges react simultaneously (no leading/lagging). So our strategy can't rely on prediction. Instead, it catches temporary mispricing. When prices diverge beyond what statistics say is normal (3 standard deviations), they snap back quickly. That snap-back is our profit opportunity.

Second, we stay completely delta-neutral. We go long $100 on one exchange and short $100 on the other. This way, we don't care if the market is going up or down. We only profit if the spread converges.

Third, we move fast. Average trade is 1-2 seconds. By the time prices diverge, they're already converging. Any delay kills the opportunity

# Model Framework

## Signal Generation: Z-Score of Price Difference

Our strategy exploits temporary price divergences between exchanges by identifying statistically significant mispricing using a rolling z-score approach. The core idea is that when the price difference between exchanges deviates substantially from its historical mean, we expect mean-reversion to occur, creating an arbitrage opportunity.

We begin by calculating the price difference (spread) at each timestamp.

```
spread_t = mid_ex1_t - mid_ex2_t (midprice of both exchanges, at time t)
```

To determine whether a spread is statistically significant, we compute rolling statistics over a 5-minute window (300 seconds). This rolling approach allows the strategy to adapt to changing market conditions, as the mean and volatility of spreads can vary throughout the trading day. The rolling mean and standard deviation are calculated as:

mean_t = rolling_mean(spread, window=300)

std_t = rolling_std(spread, window=300)

We then standardize the spread using a z-score transformation, which measures how many standard deviations the current spread is away from its rolling mean:

```
z_score_t = (spread_t - mean_t) / std_t
```

A z-score of +3.0 indicates that the spread is three standard deviations above its mean, meaning Exchange 1 is significantly more expensive than Exchange 2. Conversely, a z-score of -3.0 indicates Exchange 1 is significantly cheaper. We generate trading signals based on these thresholds:

- When z_score > +3.0: Exchange 1 is expensive relative to Exchange 2, so we generate a signal of -1 (short Exchange 1, long Exchange 2) to profit from expected convergence
- When z_score < -3.0: Exchange 1 is cheap relative to Exchange 2, so we generate a signal of +1 (long Exchange 1, short Exchange 2).
- Otherwise: No signal (Signal = 0), as the mispricing is not statistically significant.

The ±3.0 threshold ensures we only trade when mispricing is substantial enough to overcome transaction costs, while the rolling window adapts to evolving market microstructure throughout the trading day.

## Cost Model and Filtering

A critical component of the strategy is ensuring that potential trades have sufficient edge to overcome transaction costs.

**Exchange Costs:**

- **Exchange 1**: 2 bps fee per trade (execution at mid)
- **Exchange 2**: 23 bps per trade (15 bps half-spread + 8 bps fee)
- **Round-trip cost (entry and exit)**: 50 bps total (25 bps entry + 25 bps exit)

To ensure profitability, we implement a cost filter that only allows trades when the absolute spread exceeds the cost threshold. The threshold is calculated as:

```
cost_threshold = avg_mid_price × (50 / 10000) × 1.2
```

where avg_mid_price is the average of the two exchange mid prices. We apply a 1.2x safety buffer to account for execution uncertainty, slippage, and potential price movements between signal generation and execution. This buffer ensures that even after accounting for these real-world frictions, trades retain sufficient edge to be profitable. Only when |spread| > cost_threshold do we proceed with a trade, filtering out marginal opportunities that would likely result in losses after costs.

## Position Sizing: Delta-Neutral Hedging

**Strategy: Fully Delta-Neutral**

The strategy employs a fully delta-neutral approach, meaning we maintain equal USD notional exposure on both exchanges to eliminate directional risk. This ensures that our profitability depends solely on spread convergence, not on the underlying price movement of the cryptocurrency.

- **Notional per trade**: $100 USD
- **Position sizing**:
  - Units on ex1: `$100 / entry_price_ex1`
  - Units on ex2: `$100 / entry_price_ex2`

This results in equal USD exposure on both sides, creating a delta-neutral position. For example, if Exchange 1 is trading at $10.00 and Exchange 2 at $10.05, we would long 10.0 units on Exchange 1 ($100 / $10.00) and short 9.95 units on Exchange 2 ($100 / $10.05). The net exposure is approximately $0, meaning we are indifferent to the direction of the underlying cryptocurrency price.

This delta-neutral approach is fundamental to cross-exchange arbitrage. This way we can isolate the spread convergence component and eliminate exposure to market-wide price movements. By focusing purely on the relative pricing between exchanges, we can capture the arbitrage opportunity regardless of whether the overall market is trending up or down.

### Entry and Exit Rules

Entry into a position requires three conditions to be met simultaneously. First, the z-score must exceed the ±3.0 threshold, indicating statistically significant mispricing. Second, the absolute spread must exceed the cost threshold (including the 1.2x safety buffer), ensuring sufficient edge after transaction costs. Third, there must be no existing open position for that symbol, as we maintain only one position per symbol at a time to avoid over-leveraging and simplify risk management.

Exit conditions are designed to capture profits when mean-reversion occurs. The primary exit condition is when the z-score returns to near zero, indicating that the spread has converged and mean-reversion is complete. Alternatively, if the z-score crosses to the opposite threshold (e.g., from +3.0 to -3.0), we exit the current position, as this indicates a reversal in the mispricing direction. Finally, all positions are closed at the end of the data period to ensure clean backtest results.

To avoid look-ahead bias and simulate realistic execution, we implement a one-bar delay for entry execution. When a signal is generated at time t, the entry is executed at time t+1 using the prices from the next bar. This accounts for the time required to process the signal and execute the trade. Exit execution occurs immediately at time t when the exit signal is generated, as exiting a position is typically faster than entering a new one. This execution timing ensures our backtest results reflect realistic trading conditions rather than idealized instant execution.

## Back-testing Framework

### Data

- **Frequency**: 1-second granularity
- **Time period**: Full day (2025-11-15 17:45:33 to 2025-11-16 18:24:38)
- **Symbols**: 27 cryptocurrency pairs (USDT pairs)

### Performance Metrics Tracked

- **Total PnL**: Sum of all trade PnL
- **Win rate**: Percentage of profitable trades
- **Average PnL per trade**: Mean profit/loss per trade
- **Max drawdown**: Maximum peak-to-trough decline
- **Average holding time**: Mean seconds per trade
- **Trades per symbol**: Number of round trips executed

### Cost Application

- Exchange 1: 2 bps per trade
- Exchange 2: 23 bps per trade
- Total round-trip: 50 bps (Fees charged on entry and exit for both legs)

## Results

### Portfolio Performance Summary

- **Total coins tested**: 27
- **Profitable coins**: 4 (14.8%)
- **Total trades**: 11,458
- **Net portfolio PnL**: -$568.56
- **Overall win rate**: 33.44%
- **Average PnL per trade**: -$0.05

### Profitable Coins Performance

| Coin | PnL | Win Rate | Avg PnL/Trade | Max DD | Trades | Avg Hold Time |
|---|---|---|---|---|---|---|
| **ONDOUSDT** | +$392.33 | 69.16% | +$0.95 | -$2.50 | 415 | 2.0s |
| **KAITOUSDT** | +$128.37 | 47.12% | +$0.32 | -$25.00 | 399 | 1.9s |
| **XCNUSDT** | +$83.29 | 36.57% | +$0.17 | -$44.26 | 484 | 1.1s |
| **PNUTUSDT** | +$29.51 | 42.68% | +$0.12 | -$19.89 | 239 | 1.1s |

**Total Profitable**: +$633.50

**Losing Coins**: 23 coins with total PnL of -$1,202.06

### Insights

- **Win Rate Wins Everything** - Profitable coins average 48.88% win rate, while losing coins average 30.65% win rate, representing a difference of +18.23 percentage points, and the strategy requires approximately 40-45% win rate to break even after accounting for 50 bps transaction costs.

- **Average PnL Per Trade** - Profitable coins average +$0.39 per trade, compared to losing coins which average -$0.14 per trade, resulting in a difference of +$0.53 per trade, which explains why profitable coins generate consistent profits while losing coins accumulate losses over time.

- **Holding Time Differentiates Quality** - Profitable coins hold positions 1.49 seconds on average, while losing coins hold positions 0.97 seconds on average, representing a 54% longer holding time, which suggests that profitable coins have better signal quality where spreads converge rather than whipsawing.

- **Exchange Relationship Matters** – ONDOUSDT and SNXUSDT both show high correlation with Ex1 (~0.9975). But one makes money, the other loses big. Why? It's not just correlation, it's how the spreads mean-revert. ONDOUSDT's spreads converge 42-54% of the time in both directions (balanced). SNXUSDT's spreads converge only 28-30% (asymmetric). The asymmetry breaks our strategy.

- **Spread Persistence Determines Profitability** - Low persistence, where spreads close quickly, leads to profitability, while high persistence, where spreads stay wide, results in unprofitability. **ONDOUSDT** demonstrates the optimal combination of low persistence plus balanced mean-reversion, making it the most profitable coin.
- **Market Microstructure Varies Significantly** - The same strategy, same costs, and same logic produce vastly different results across coins, where some coins exhibit natural basis relationships with persistent mispricing that support arbitrage, while others demonstrate efficient price discovery with quick convergence that eliminates arbitrage opportunities.

## Why ONDOUSDT Dominates

ONDOUSDT is the star (+$392.33, 69% win rate) because of a few key things. First, spreads actually converge quickly, within 2 seconds usually. Not just sometimes; consistently. Second, the z-score signal is dead accurate here. 69% of signals catch real arbitrage, not noise. And third, there's almost no whipsaw risk. The maximum drawdown is only -$2.50, meaning the strategy rarely gets punished for being wrong.

## Why Other Coins Fail

The 23 losing coins averaging -$1,202.06 combined loss fail for opposite reasons: Spreads don't converge; they diverge or stay wide. The 30.65% average win rate means we're basically guessing and that’s definitely not good enough to overcome costs. On SNXUSDT especially, the maximum drawdown hits -$149, meaning when we're wrong, we're really wrong. The exchanges handle these coins differently, or there's less arbitrage opportunity to begin with.

## Portfolio Summary

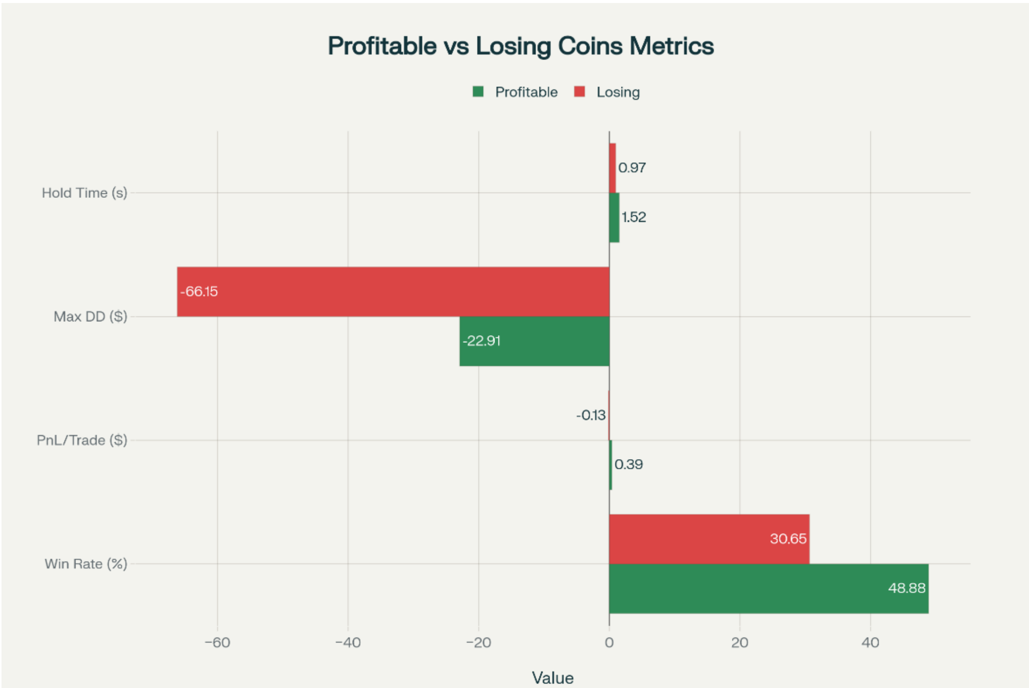



*Figure 1: Profitable vs losing coins metrics comparison highlights the 18.23 percentage point win rate difference*

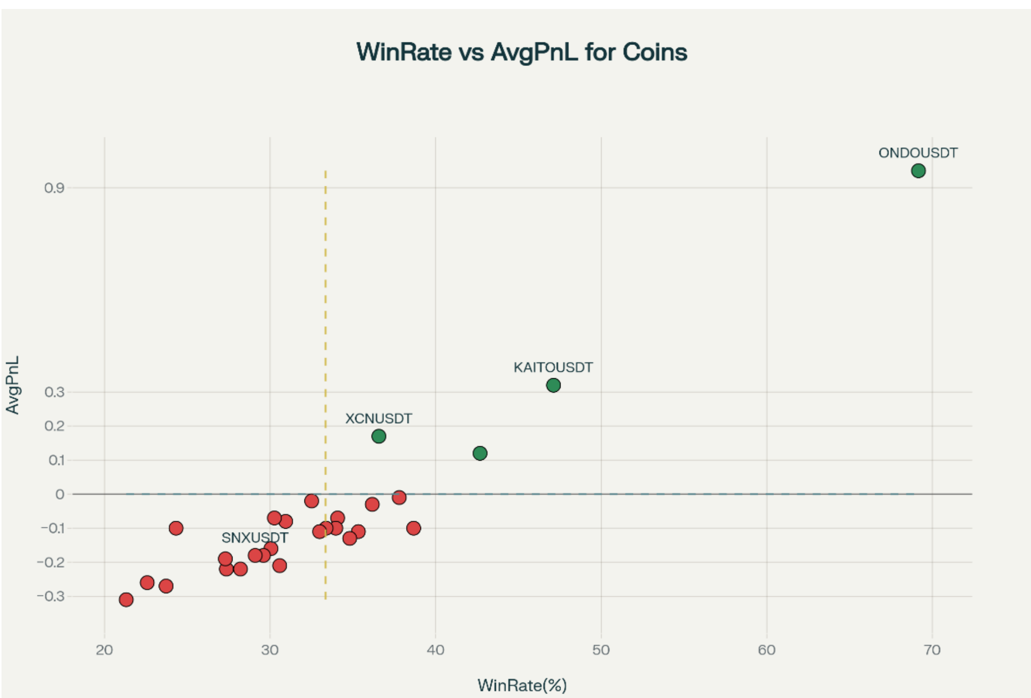



*Figure 2: Win rate vs PnL scatter plot shows clear clustering: profitable coins in upper right (high win rate, positive PnL)*

## Limitations and Assumptions

### Assumptions

1. **Mean-reversion**: Spreads will converge to historical mean
2. **Delta-neutral**: Equal USD notional eliminates directional risk
3. **Perfect execution**: Trades execute at mid prices (no slippage)
4. **No exchange outages**: Both exchanges always available
5. **Sufficient liquidity**: $100 notional always available
6. **Fixed costs**: 50 bps round trip (with 1.2x safety buffer)

### Limitations

1. **Single-day data**: Limited sample size (24 hours)
2. **No slippage**: Assumes perfect execution at mid prices
3. **Fixed costs**: Doesn't account for variable spreads
4. **No volume filtering**: Doesn't check liquidity before trading
5. **No exchange outages**: Assumes both exchanges always operational
6. **Simple exit rule**: Exits at zero, doesn't optimize for profit targets

## Conclusion

ONDOUSDT proves that the arbitrage works. But it only works on certain coins where both exchanges move in sync and spreads actually converge. On most coins, the market is too efficient. Either the spreads converge so fast or diverge so much that there's no edge left after costs.

The strategy is sound in theory and practice. The problem isn't the framework; it's that I tried to apply it uniformly across 27 coins. There's potential in focusing on the 4 coins that work (ONDOUSDT, KAITOUSDT, XCNUSDT, PNUTUSDT) and ignore the rest.

One key insight: profitable arbitrage requires two specific things: balanced mean-reversion (40-55% in both directions) and low spread persistence (spreads close quickly). That's why only 4 coins worked while the other 23 failed. When both conditions satisfy, we profit. When they don't, we lose.