Enhancing Cryptocurrency Pairs Trading

An Integrated Framework Combining Cointegration and Causal Inference

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Summary: This research introduces a novel two-stage framework integrating cointegration screening with Granger-causality filtering for cryptocurrency pairs trading. The methodology demonstrates significant improvements over traditional approaches, with a 61.7% return and 3.18 Sharpe ratio at 5-minute intervals. The modular Python implementation enables robust backtesting and parameter optimization.

Key Innovations

- **Causal Enhancement:** First formal integration of Granger-causality filtering with cointegration, improving returns by 14.8 percentage points (pp) at 5-minute intervals
- **Volatility-Adaptive Sizing:** Position scaling $\propto 1/\sigma_i$ reduces drawdowns by 29-32%
- **Latency-Constrained Execution:** Actionable 1-4 bar lag window ensures tradability
- **Modular Architecture:** 8-component Python system enables walk-forward validation

Methodology

Two-Stage Framework

1. **Cointegration Screening**
   - Johansen trace test ($p < 0.05$) on high-frequency data
   - Spread calculation: $Z_{ij,t} = \frac{P_{i,t}}{\beta P_{j,t}}$
   - Validation: Half-life (1-252 days), $\sigma_Z > 0.01$
2. **Granger-Causality Filtering**
   - VECM specification: $\Delta Y_t = \alpha\beta' Y_{t-1} + \sum_{i=1}^{4} \Gamma_i \Delta Y_{t-i} + \varepsilon_t$
   - Unidirectional causality (Wald test, $p < 0.05$)
   - Practical latency: 1-4 bars

Trading Engine

- **Entry**: $|Z| > 2.0\sigma$
- **Exit**: $|Z| < 0.5\sigma$ (methodology compliant)
- **Stop-loss**: $|Z| > 3.0\sigma$ OR 5-day hold
- **Costs**: 4 basis points (bps) fee + 5 bps slippage

System Architecture

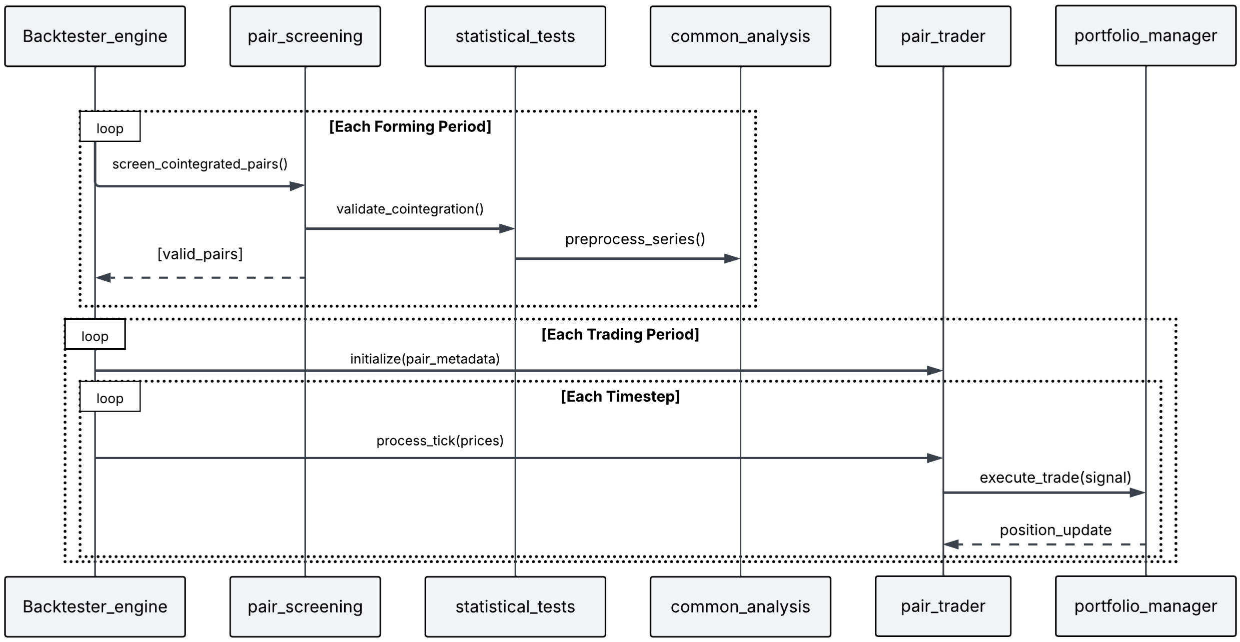

Figure 1: Modular implementation with data flow

Vector Error Correction Model (VECM)

The VECM framework captures both short-term dynamics and long-term equilibrium between cointegrated assets:

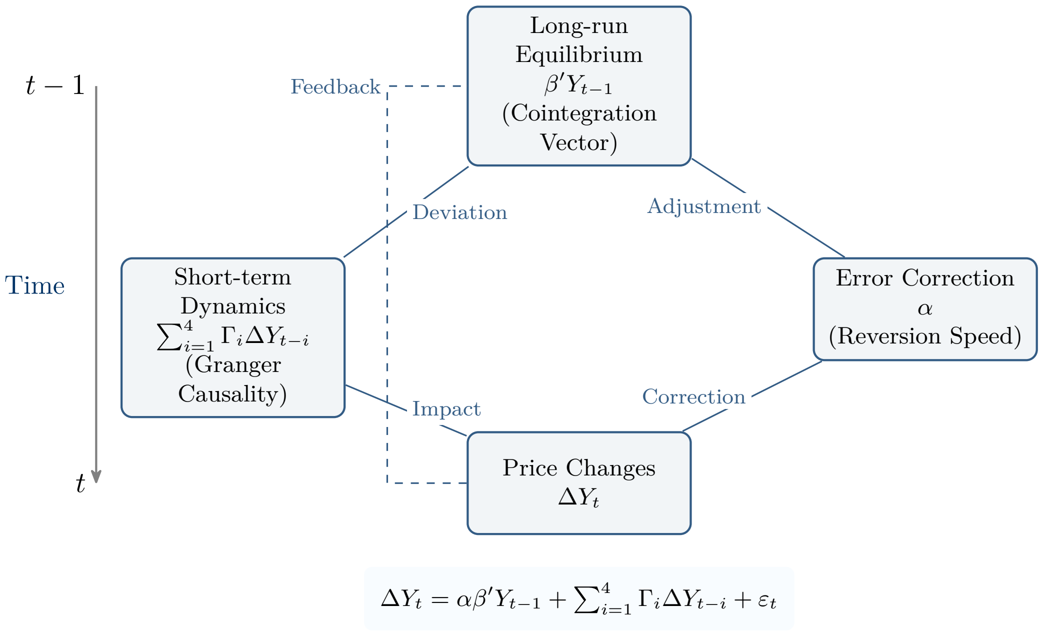

Figure 2: VECM components and relationships

Understanding the VECM Components The VECM model helps us understand how cryptocurrency pairs interact over time:

1. **Long-term Relationship** (β): - Measures how two cryptocurrencies move together - β is the "hedge ratio" for position sizing - *Example: ETH/BTC* β *= 0.04*

2. **Short-term Adjustments** (Γ): - Shows immediate reactions between coins - Reveals leader-follower relationships - *Example: BTC moves → ETH follows in 5 min*

3. **Correction Speed** (α): - Measures how quickly prices return to equilibrium - Negative values indicate mean reversion - *Example:* α *= -0.18 (18% correction per period)*

Preliminary Results

Performance Metrics (5-minute interval)

Metric	Filtered	Unfiltered	Improvement
Total Return	61.7%	46.9%	+14.8 pp
Avg Return/Trade	0.26%	0.19%	+36.8%
Sharpe Ratio	3.18	2.54	+25.2%
Max Drawdown	3.7%	5.2%	-28.8%
Success Rate	81%	73%	+8 pp

Table 1: Performance comparison with vs. without Granger filtering

Interval Comparison

Metric	1-minute	5-minute	60-minute
Total Return	52.4%	**61.7%**	14.2%
Avg Trade Duration	18.4 h	**22.1 h**	35.7 h
Stop-Loss Triggers	15.3%	**13.1%**	13.6%
Calmar Ratio	12.5	**16.7**	1.8

Table 2: Performance across different time intervals

Key Findings

- **5-minute interval optimal:** Balances signal quality and execution efficiency
- **Granger filtering critical:** Reduces time-expired trades by 42% and increases success rate to 81%
- **Volatility scaling essential:** Drawdowns 29-32% lower than fixed allocation
- **Statistical significance:** Diebold-Mariano (DM) tests confirm outperformance ($p < 0.01$)

Conclusion and Next Steps

The integrated cointegration-causality framework demonstrates substantial improvements over traditional statistical arbitrage:

- **Robust Alpha Generation:** 61.7% returns with 3.18 Sharpe at optimal frequency
- **Risk Mitigation:** 3.7% max drawdown through adaptive sizing
- **Actionable Implementation:** Modular Python system enables parameter optimization

Validation Roadmap:

1. Extended backtesting (2019-2024) across market regimes
2. Integration of regime-switching models
3. Live paper trading implementation

For full methodology and replication code: `https://github.com/ivalenzuelan/pairtrading-framework`