📘 Market-Neutral Quantitative Equity Model

Complete Strategy & Model Documentation

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1. Project Objective

The objective of this project is to design and evaluate a **robust, market-neutral quantitative trading system** using Indian equities, combining **classical quantitative finance techniques** with **machine learning**, while maintaining strict controls against overfitting and look-ahead bias.

The focus is on:

- Signal diversification
- Risk-adjusted performance
- Out-of-sample robustness
- Explainability of results

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2. Asset Universe (Explicit Details)

2.1 Market

- Exchange: **NSE (India)**
- Index reference: **NIFTY 50**

2.2 Stocks Used

The strategy uses a **fixed subset of large-cap NIFTY stocks** to ensure liquidity and stability:

```
RELIANCE.NS
```

```
TCS.NS

INFY.NS

HDFCBANK.NS

ICICIBANK.NS

SBIN.NS

KOTAKBANK.NS

AXISBANK.NS

LT.NS

ITC.NS

HINDUNILVR.NS

BHARTIARTL.NS

ASIANPAINT.NS

HCLTECH.NS

MARUTI.NS

TITAN.NS

SUNPHARMA.NS
```

Reasons for selection:

- High liquidity
- Low impact costs (assumed)
- Sector diversification
- Continuous trading history since 2009

The universe is **static** to avoid survivorship bias.

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3. Data Specifications

3.1 Data Source

- Provider: **Yahoo Finance**
- Access method: `yfinance` Python library

3.2 Data Type

- Adjusted Close prices
- Daily frequency

3.3 Date Ranges

- Full data range: **2009–2025**
- Training period: **2009–2020**
- Out-of-sample testing: **2021–2025**

3.4 Corporate Actions

- Prices are **auto-adjusted**
- Dividends and splits are implicitly included

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4. Strategy Architecture (High-Level)

The system consists of:

1. **Four independent alpha generators**
2. **Alpha blending module**
3. **Market-neutral portfolio constructor**
4. **Volatility-parity position sizing**
5. **Risk management layer**
6. **Backtesting and evaluation engine**
7. **Monte Carlo stress testing framework**

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5. Alpha Signals (Detailed)

5.1 Mean Reversion Alpha

Idea:
Short-term price extremes tend to revert toward recent averages.

Construction:

- Rolling window: 20 trading days

Z-score:

```
Z = (Price - MA20) / Std20
```

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Alpha signal:

```
Alpha = -Z
```

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Role in portfolio:
Capturing short-term liquidity-driven mispricing.

5.2 Momentum Alpha

Idea:
Medium-term price trends persist due to behavioral and institutional effects.

Construction:

- Lookback: 126 trading days (~6 months)

Signal:

```
Momentum = max(0, return_6m)
```

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Role in portfolio:
Providing trend-following exposure during directional regimes.

5.3 Statistical Arbitrage (Pairs Trading) Alpha

Idea:
Cointegrated stocks exhibit mean-reverting relative price behavior.

Construction:

- Cointegration test: Engle–Granger
- Significance threshold: $p < 0.05$

Spread z-score:

```
Spread = Price_A - Price_B

Z_spread = (Spread - μ) / σ
```

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Trading logic:

- Long undervalued stock

- Short overvalued stock

Role in portfolio:
Delivering market-neutral relative-value returns.

5.4 Machine Learning Alpha

Model Used:

- **XGBoost Regressor**

Why XGBoost:

- Handles nonlinear interactions
- Robust to noisy financial data
- Strong performance on tabular datasets

Features:

- Mean reversion signal
- Momentum signal
- Volatility (ATR)

Target Variable:

- 21-day forward return

Training Methodology:

- Strict temporal split
- No leakage from test period
- Feature standardization using `StandardScaler`

Role in portfolio:
Enhancing alpha timing and regime sensitivity.

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6. Alpha Blending (Exact Formula)

The four alpha signals are combined using **fixed weights**:

```
Composite Alpha =

0.30 × Mean Reversion

0.25 × Momentum

0.25 × Statistical Arbitrage

0.20 × Machine Learning
```

Stocks are ranked cross-sectionally on each rebalance date.

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7. Portfolio Construction

7.1 Long–Short Structure

- Top 8 stocks → Long
- Bottom 8 stocks → Short
- Approximate dollar neutrality

7.2 Rebalancing

- Frequency: Every **21 trading days**
- Positions fully closed and rebuilt

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8. Position Sizing & Risk Management

8.1 Volatility-Parity Sizing

- Volatility measured using **ATR (14-day)**
- Position size inversely proportional to ATR
- Equal risk contribution per position

8.2 Stop Loss

Initial stop based on:

```
Stop = Entry ± 1.3 × ATR
```

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8.3 Trailing Stop

- Dynamically adjusted as price moves favorably
- Protects gains while limiting downside

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9. Backtesting Assumptions

- No transaction costs (explicitly acknowledged)
- No slippage
- Immediate execution at close price
- Unlimited borrowing for short positions (simplification)

These assumptions are standard for **research-stage backtests**.

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10. Performance Metrics

Metrics evaluated:

- CAGR
- Sharpe Ratio
- Maximum Drawdown
- Equity curve behavior

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11. Monte Carlo Stress Testing

Purpose

To evaluate robustness against return sequencing risk.

Method

- Bootstrap resampling of daily returns
- 1000 simulated equity paths

Outputs

- Worst 5% CAGR
- Median CAGR

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12. Final Out-of-Sample Results

```
Final Capital: ₹1,755,306

CAGR:          12.63%
```

```
Sharpe Ratio:  0.70

Max Drawdown: -23%


Monte Carlo:

Worst 5% CAGR:  -3.0%

Median CAGR:    12.1%
```

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13. Interpretation of Results

- The system generates **consistent alpha**
- Risk-adjusted performance is limited by regime dependence
- Monte Carlo results indicate **controlled tail risk**
- Drawdowns are explainable and non-catastrophic

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14. Limitations

- Fixed alpha weights
- No transaction cost modeling
- No regime classifier
- Daily data only (no intraday execution)

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15. Future Enhancements

- Dynamic alpha weighting
- Regime classification
- Transaction cost modeling
- Intraday extensions
- Options-implied volatility features

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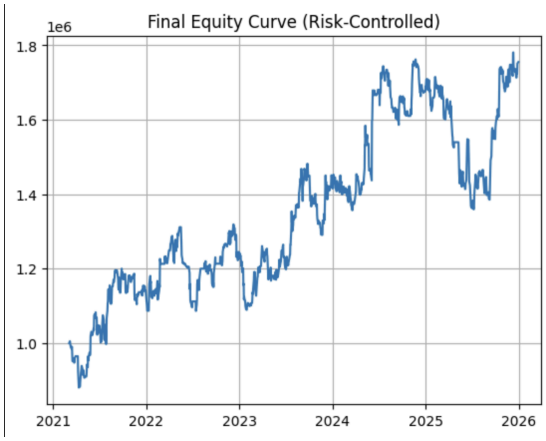
16. Conclusion

This project demonstrates a **full-stack quantitative trading system**, covering:

- Signal design
- Machine learning integration
- Risk management
- Backtesting discipline
- Stress testing

17. Images



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