

**QF621 Quant Trading Strategies**

**Group Project Report**

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Table of Contents

[**1. Objective** 4](#_Toc201664791)

[**2. Fundamental Economic Justification - IVAN** 5](#_Toc201664792)

[**3. Strategy Implementation – Shobhit** 6](#_Toc201664793)

[**4. Backtest – Julian & Shobhit** 8](#_Toc201664794)

[**5. Performance Metrics - Shobhit** 10](#_Toc201664795)

[**6. Suggested Further Analysis** 11](#_Toc201664796)

[**7. Tools & Environment** 11](#_Toc201664797)

[**8. Next Steps** 11](#_Toc201664798)

[**9. Appendix** 11](#_Toc201664799)

[Appendix 12](#_Toc201664800)

### **1. Objective**

This project investigates the viability of high-frequency trading (HFT) strategies in the U.S. equity market using nanosecond-level quote data. The goal is to extract intraday alpha via simple, interpretable indicators such as Order Book Imbalance (OBI) and VWAP.

Key objectives:

* **Develop 3 HFT strategies** leveraging microstructure signals and volume-price dynamics.
* **Assess economic intuition** behind signals (e.g., OBI-VWAP bid pressure, mean-reversion, inverse volume traps).
* **Evaluate robustness** of performance out-of-sample (H2 2023).
* **Ensure realistic backtesting**, with trend/volatility filters and noise reduction.
* **Analyze performance metrics** such as Sharpe ratio, drawdowns, and strategy correlations.

Focus is on alpha generation, stability, and interpretability in fast-paced environments.

### **2. Fundamental Economic Justification**

* **Order Book Imbalance (OBI):**  
  Captures short-term supply/demand skew. Persistent imbalance reflects dominant buyer/seller interest, predicting directional price pressure.
* **VWAP (Volume Weighted Average Price):**  
  Represents consensus fair value. Mean-reversion logic assumes prices oscillate around this benchmark, enabling statistically favorable entry/exit points.
* **Inverted VWAP & Volume (Inverse-OBI-VWAP Strategy):**
  + **Inverted VWAP:**  
    Centered around the **median**, it filters out outliers and large trade noise, offering a more stable fair value estimate in HFT settings.
  + **Inverted Volume:**  
    High when current volume is **below** median—suggesting market **quietness** or spoofing. Combined with positive OBI, it flags potential traps or false signals.
* **Microstructure Justification:**
  + Detect **spoofing/iceberging traps** from large misleading quotes.
  + Use **bid/ask depth**, median-centered VWAP, and low-volume anomalies to avoid false breakouts.
  + Blend trend filters and volatility regimes to enter only when signal quality is high.

These features allow us to exploit short-term dislocations while filtering noisy, deceptive signals.

### **3. Strategy Implementation**

#### Initial Observations of OBI and VWAP indicators:

A screenshot of a graph

AI-generated content may be incorrect.

Our initial implementation centered on a pure Order Book Imbalance (OBI) signal, which ultimately proved ineffective. Across all tested tickers, the OBI-based strategy consistently underperformed. The root issue was the signal’s sensitivity—it responded too strongly to short-term noise in the order book, failing to offer reliable trade direction. Even after threshold tuning, the results remained unstable. One potential improvement, which we identify for future work, involves smoothing OBI using a rolling average to filter out volatility-driven noise.

In contrast, VWAP served as a more stable benchmark. Acting as a fair value anchor, it reflected the consensus market price over a short window. Given that traders often view VWAP as the “right” price, the strategy implicitly benefits from an anchoring bias—participants tend to trade toward it, leading to natural mean reversion. We found that integrating VWAP with OBI significantly improved results by grounding the signal in both market depth and volume-based price dynamics.

##### Key Improvements:

Our initial strategy, relying solely on Order Book Imbalance (OBI), proved **unprofitable** across all tested tickers due to its noisy nature. Adjusting the OBI threshold did not yield a reliable signal for positive returns.

To address this, we integrated OBI with Volume Weighted Average Price (VWAP). Combining these indicators significantly **improved strategy outcomes**, leading to positive returns for select SPY tickers (e.g., ZION on DirectX).

Our baseline strategy assigns a **buy signal** when both indicators point to upward momentum (bid pressure > 0.5 and VWAP > mid-price), and vice versa for a sell signal.

Further analysis involved filtering for tickers that showed positive returns between May 10th and 11th, which resulted in 46 tickers. We then extended our analysis to these tickers over a two-week period, with similar results. We also developed and will discuss two additional strategies in later sections.

#### Chosen Strategies

Our group decided to attempt 3 distinct strategies:

Strategy 1: OBI and VWAP

Basic high-frequency trading strategy that combines order book analytics and VWAP-based signals. Naively taking OBI and VWAP as short term price signals.

Strategy 2: Inverse OBI and VWAP

This strategy tries to predict a break out to short term trend

This strategy aims to predict short-term trend breakouts by exploiting reversal opportunities. It is designed for markets where low volume and order book imbalances suggest trend exhaustion rather than continuation. By inverting both volume and VWAP trends, the strategy systematically bets against the prevailing sentiment at potential turning points, specifically when volume is low and the VWAP is near the midpoint.

Strategy 3: Mean Reversion

#### This strategy is designed for environments where prices frequently revert to a mean, such as in liquid equities, ETFs, and certain futures markets. It combines VWAP anchoring, volatility and volume filters, and robust risk controls to systematically capture short-term price reversals while minimizing exposure to trending or illiquid conditions. This serves as a practical and research-friendly template for mean-reversion trading in modern electronic markets.

#### Trading Rules and Environment

* **Trading Window:** Trading is restricted to an intraday session from 9:55 AM to 3:36 PM.
* **Asset Focus:** Each strategy trades a single stock at any given time.
* **Execution Model:** Execution assumes crossing the spread (buying at the ask, selling at the bid) to ensure immediate fills. This model incorporates two primary costs:
  + **Bid-Ask Spread:** The direct transaction cost incurred from crossing the spread.
  + **Adverse Selection:** The risk of informed counterparties executing against aggressive orders, potentially leading to unfavorable trade prices.
* **Capital Allocation:** Each strategy is allocated a capital of $300,000.

#### Trading Cost Assumptions

* **Shorting**: Assumes sufficient liquidity is available to borrow shares.
* **Financing**: All positions are funded from the initial capital; no margin or leverage is used.
* **Commissions**: Not considered as part of this backtest
* **Market Depth**: Analysis deferred to a separate section.
* **Spread**: Crossed orders are assumed to fill instantly at quoted prices. The model assumes fills occur strictly at the quoted bid or ask.

#### OBI-VWAP Strategy Overview

The OBI-VWAP strategy is a foundational high-frequency trading model that integrates order book microstructure with price-volume trends to generate trading signals. It combines two key elements: Order Book Imbalance (OBI), which captures real-time supply and demand pressure, and Volume Weighted Average Price (VWAP), which serves as an anchor for price mean reversion.

VWAP is computed over a rolling window using mid-price and volume data. The strategy constructs adaptive bands around VWAP based on recent price variance and volume profiles. These bands help assess whether the current price is relatively cheap or expensive compared to recent trading activity, providing a dynamic benchmark for trade decisions.

OBI is derived by calculating the ratio of bid size to total depth (bid + ask). A bid pressure greater than 0.5 indicates buying dominance, while a lower value signals selling pressure. The strategy interprets these imbalances to anticipate short-term directional movements.

Trade signals are straightforward: a long position is entered when bid pressure exceeds 0.5 and the mid-price is below VWAP, suggesting upside momentum from both microstructure and valuation signals. A short position is taken when the reverse conditions hold. The strategy avoids trading when signals are mixed or fall outside of the defined intraday session.

#### Inverse OBI VWAP Strategy Overview

The Inverse OBI VWAP Strategy is a quantitative trading strategy that inverts traditional order book and volume signals since we are using quote data for VWAP instead of the traditional trade volume weighted VWAP. Our aim is to capture **start of a trend when volume is low and a short term trend has not started, by using OBI as an indicator the strategy capitalizes on** opportunities in entering based on a sudden bid or ask imbalance. Unlike standard momentum or trend-following approaches, this strategy assumes that **high volume may signal exhaustion and potential reversals** rather than continuations.

##### KeyComponents

* **Inverse Volume Signal:**  
  Instead of treating high volume as confirmation of trend, the strategy inverts the volume metric. It computes an "inverted volume" by reflecting the current volume around its rolling median, then normalizes it. High values of this inverted volume are interpreted as potential reversal signals.
* **Adjusted Order Book Imbalance (Adjusted OBI):**  
  The strategy calculates a sophisticated OBI metric, combining:
  + Raw order book imbalance,
  + Price-level weighting (giving more weight to orders near the mid price),
  + Time-decay weighting (using exponential moving averages),
  + The normalized, inverted volume.
* **VWAP and Inverse VWAP:**  
  VWAP (Volume Weighted Average Price) is calculated as a reference. The strategy also computes an "Inverse VWAP" by reflecting the VWAP around its rolling median, which serves as a contrarian price anchor.
* **Signal Generation:**
  + **Long Signal:** Triggered when OBI is strongly positive, the mid price is below the Inverse VWAP, and the inverted volume is high.
    - **Order book** is imbalanced on bid volume
    - **Inverted VWAP** are relatively low i.e. high relative VWAP
    - **Volume** is less than the rolling window aggregate
  + **Short Signal:** Triggered when OBI is strongly negative, the mid price is above the Inverse VWAP, and the inverted volume is high.
  + **No Trade:** Otherwise, or outside of trading hours.
* **Risk Management:**
  + **Trade Reversal:** Positions are reversed when the signal flips direction.

#### Mean Reversion Strategy Overview

The Mean Reversion Strategy class implements a classic **mean reversion trading strategy** that seeks to profit when prices deviate significantly from their recent average (VWAP) and are likely to revert.

##### Key Components

* **VWAP-Based Anchoring:**  
  The strategy calculates the **Volume Weighted Average Price (VWAP)** over a rolling window, using it as a reference point for fair value. The mid price’s deviation from VWAP is tracked and used as a primary signal.
* **Volatility and Volume Filters:**
  + **Volatility:** Rolling mean of absolute mid price changes is used to measure market volatility.
  + **Volume Ratio:** Compares current volume to its rolling mean to ensure signals are only acted on when there is sufficient market activity.
* **Mean Reversion Score:**
  + Computes a mean reversion score as the normalized difference between the current price deviation and its rolling mean, divided by volatility.
  + This score highlights when price deviations are extreme relative to recent history and volatility, indicating a higher probability of reversion.
* **Signal Generation:**
  + **Long Signal:** Triggered when the mean reversion score is significantly negative (price is well below VWAP and likely to revert up), volume is above average, and volatility is above a minimum threshold.
  + **Short Signal:** Triggered when the mean reversion score is significantly positive (price is well above VWAP and likely to revert down), with similar volume and volatility conditions.
  + **No Trade:** Otherwise, or outside of trading hours.
* **Risk Management:**
  + **Max Hold Time:** Positions are forcibly closed if held for too long, to avoid stale trades.

#### Other Implementations common to all strategies:

**Performance Tracking**

* The strategy tracks account balance, open positions, entry prices, unrealized P&L, and other metrics at each step.
* After the backtest, it logs key performance metrics: total return, Sharpe ratio, max drawdown, win rate, and average profit per trade.

**Position Sizing:** Uses aggressive risk-based sizing, risking a fixed fraction of the portfolio per trade, capped by a maximum position size.

**Stop Loss & Take Profit:** Positions are closed if unrealized P&L breaches specified percentage thresholds.

### **4. Backtest – Julian & Shobhit**

#### Data Preprocessing

For this strategy, only quote data was used. Trade data was deliberately excluded due to its coarser granularity. Although we would like to study the incorporation this data especially in providing more investor data such as VWAP on traded prices instead of quote. The dataset was filtered on two dimensions:

* Exchange Code: Only quotes from selected exchanges were included, ensuring market consistency and depth.
  + Testing was done on NASDAQ, NYSE, DirectX Edge, BATS, NASDAQ OMX Stock Exchange. This gave some variation in terms of most liquid exchanges and some broker exchanges
* Quote Condition: We restricted the dataset to quotes marked with condition "R", representing regular double-sided quotes. This exclusion criteria effectively filtered out cancelled, indicative, or non-actionable quotes, helping preserve the integrity of the simulated order book.
  + It is found that majority of quote conditions is two sided “R” in TAQ data. Although we acknowledge that in live trading there may be many market makers that may be cancelling orders.

This preprocessing step ensures the backtest operates on realistic and executable quotes.

#### Execution Logic

The backtest adopts a simplified but conservative execution model. We assume that all trades are filled immediately at the prevailing bid (for sell orders) or ask (for buy orders), with a trade size of one lot. This reflects:

* A market-taking strategy,
* Minimal market impact assumptions,
* Intraday-only activity (no overnight holdings),
* One lot per trade, thereby controlling inventory risk and emulating high-frequency position turnover.

This logic, while idealized, allows for a controlled assessment of signal efficacy.

#### Backtesting Framework

Each strategy is assigned a notional capital of $100,000. To isolate performance attribution, only one strategy is active at a time. The dataset is divided into:

* **In-sample period:** H1 2023
* **Out-of-sample period:** H2 2023

For both, one week of trading data was randomly selected. This ensures that strategy performance is not overly dependent on a specific market regime, while also capturing general stability across time.

#### Realism and Practical Considerations

To ground the backtest in practical constraints:

* **Trade frequency** is reviewed to ensure that the number of trades is consistent with realistic HFT throughput. We can compare with the total daily volume that the strategy is run. Since the traded volumes is less than X% of average daily volume, we can assume that the market impact is not significant. Furthermore we can quantify MI.
* **Slippage** is not yet modelled but is recognized as a key next step, especially for assessing fill uncertainty in fast-moving markets. We could include a percentage chance of filling order instead of filling every time
* **Brokerage fees** will be incorporated into Sharpe ratio calculations to provide a more accurate measure of risk-adjusted performance.
* **Traded VWAP** was not considered and instead the mid price was used as an estimate. This fails to account for the volume traded and cases when there are no trades even if a bid-ask is quoted. Further limitations of VWAP is as follows:
  + As a **lagging indicator** based on cumulative volume and price, VWAP reacts slowly to sharp intraday price moves, making it less useful during high volatility.
  + VWAP **resets at the start of each trading day**, which eliminates continuity across sessions—unsuitable for strategies considering inter-day momentum or mean reversion.
  + In **range-bound or noisy markets**, price frequently crosses VWAP, often generating **false signals** and whipsaws.

### **5. Performance Metrics - Shobhit**

**Evaluated Metrics:**

* Total returns, max drawdown, Sharpe ratio.
* Trades per minute, average spread.
* Returns over time to show volatility of PNL
* Show correlation to single stock / SPY
* Position Netting, Internal Trade Crossing, Diversification
  + There was no combined portfolio AUM targeting so no benefit in position netting
  + There was internal trade crossing, so we managed to save some trade costs in commissions, spread and market impact cost.
  + There is diversification cost since the two strategies are not fully correlated so there is reduced max drawdown and volatility in P&L.

**Comparative Analysis:**

* Exchange Comparison: NASDAQ, NYSE, DirectX vs broker-dealer venues.
  + Verified that strategy not only works in most liquid exchanges but also large brokerages (i.e. Direct X, BATS)
    - Performance metric table / chart
* Temporal Analysis: In/out-of-sample by week/month.
* Ticker Analysis: SPY components and small-cap tickers.

**Key Questions:**

* Can alpha be achieved without exchange priority?
* What drives returns for select tickers?
* Is nanosecond-level quote data reliable?
* Is it realistic to execute high frequency trades in a day? What proportion of traded volume are our trades?
* What about phantom liquidity?
  + In cases where traders place immediate or cancel orders

### **6. Suggested Further Analysis**

**Enhancements:**

* Expand universe of stocks besides the highest market cap
  + Very high liquidity could reduce performance although large caps like JPM still has positive returns
  + Searched entire spy 500. We could continue to look at Russell 200
* Hyper parameter tuning
  + Optimizing OBI / VWAP threshholds
  + Using SMA for OBI,
* Look at seasonality within the day and check if we can restrict some intra-day periods to get more alpha
* Market impact estimation.
  + Is volume a factor?
    - Are these the lowest volume or is the trade size significant when we are trading
  + Could we use a % filled rate to test if strategy still does well when we can’t take bid/ask whenever executed

Blue sky analysis:

* Slippage and latency modeling.
* Regime-dependent performance evaluation.

### **7. Tools & Environment**

* **Language**: Python 3.11+
* **Libraries**: polars, matplotlib, pandas\_market\_calendars
* **Structure**: Modular scripts for strategy, comparison, and analysis.

### **8. Next Steps**

* Expand stock universe and increase testing duration.
* Further evaluate performance across timeframes and venues.
* Hyper parameter tuning of threshholds of VWAP
* Change OBI to rolling average
* Improve signal filtering and execution assumptions.
* Include trading data to get trading VWAP
* Incorporate percent change to fill order to simulate slippage

### **9. Appendix**

**Key Scripts:**

* main.py: Core backtest logic.
* compare\_exchanges.py: Exchange comparison.
* compare\_months.py: Monthly performance tests.
* compare\_dates.py: Random date analysis.

**Data Directory:**

* Positive return tickers.
* Filtered ticker lists.
* Performance metric outputs.

**Realism Checks:**

* Trade frequency analyzed for feasibility.
* Slippage not yet incorporated—future improvement.
* To include trading broker fees in sharpe ratio.
* What VWAP is not able to do

VWAP is a widely used intraday benchmark, but it carries several important limitations. As a lagging indicator based on cumulative price and volume data, VWAP responds slowly to sudden price movements and is not suitable for fast-paced or volatile market conditions. Its utility is restricted to intraday trading because it resets daily and does not retain context from previous sessions, making it ineffective for swing or multi-day strategies. VWAP is also not predictive, and it merely reflects where trading has occurred, not where price is likely to go, and does not account for momentum, volatility, or external catalysts like news. In range-bound or choppy markets, prices frequently cross VWAP without meaningful direction, leading to frequent false signals and whipsaws.