Market Simulator for Interest Rates Trading

Robert Almgren

quantitativebrokers

Stevens HF Data, Oct 2013
Pit trading $\rightarrow$ electronic

Pit

- position traders
- floor brokers

Electronic

- HFT & Market Makers
- algorithmic brokers (QB)
QB = Agency algorithmic execution

Sell 97 June 2012 Eurodollar

Average execution price = 9883.56  Cost to strike = –$7.67 per lot

Our limit orders

Benchmark = Arrival price

Cointegration signal

Our fills

Order book (thin for Eurodollar)
Quantitative Brokers

Algo execution and cost measurement

No prop trading or market making

Interest rate products, starting with futures
Equities, FX already well served
Live on CME, Eurex, LIFFE rates products
IR swaps, cash Treasuries, etc

Good execution depends on microstructure expertise
“We think it creates a strong position in one of the most liquid and global asset classes,” an exchange spokesman told me. The U.S. Treasury bond market has more than $500 billion traded daily, which is almost three times bigger than the U.S. equities market with $150 billion in daily trading volume. In addition, Nasdaq sees some other big volume drivers ahead, such as the issuance of new Treasuries, fiscal uncertainty, continued migration of fixed income products to electronic platforms. It expects key headwinds to recede, such as the Federal Reserve’s QE program, the US debt ceiling and risk-on investing, which will lead to an increase in volume in U.S. Treasuries.
SELL 2210 GEH4 BOLT

Exec = 9962.50  Cost to strike = −0.50 tick = −$6.25 per lot

Wait for passive fills

All these examples could have been fully executed at take price
SELL 362 ZNU3 BOLT

Exec = 125–07.71  Cost to strike = −0.92 tick = −$14.33 per lot

Aggressive fills
Passive fills
Cumulative exec
Market trades
Limit orders
Cumulative VWAP
Microprice
Bid–ask

Aggressive cross based on signal

passive fills

2000 lots


Produced by QB from CME and internal data
BUY 165 GEM4 BOLT

Exec = 9955.88  Cost to strike = 0.25 tick = $3.14 per lot

Cointegration signal indicates up move: aggressive buy

Butterfly middle leg midpoint liquidity

Sweep 9956
Strike 9955¼
BML 500 lots

20000 lots
GEM4

GEM4


Done at 13:07:01

Executed and working quantity

Midpoint fills
Cumulative exec
Market trades
Limit orders
Cumulative VWAP
Cointegration
Microprice
Bid–ask
Algorithm Performance Comparison

<table>
<thead>
<tr>
<th>Market</th>
<th>Bid/Ask</th>
<th>Bulge Bracket Banks</th>
<th>Quantitative Brokers</th>
<th>QB Improvement</th>
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<td>AP</td>
<td>I-VWAP</td>
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<td>US 5-yr Note</td>
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<td>LIFFE Long Gilt</td>
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<td>4.13</td>
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<td>E-mini S&amp;P</td>
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<td>E-mini NASDAQ</td>
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<td>NYMEX Heating Oil</td>
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<td>NYMEX Crude Oil</td>
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<td>NYMEX Nat. Gas</td>
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<td>16.50</td>
<td>2.38</td>
<td>14.72</td>
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<td><strong>Weighted Average:</strong></td>
<td><strong>8.25</strong></td>
<td><strong>3.21</strong></td>
<td><strong>3.80</strong></td>
<td><strong>-1.68</strong></td>
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</table>
Size is not most important variable

1Q-year -- Mon 03 Jun 2013 to Fri 30 Aug 2013

Slippage cost to midpoint as fraction of minimum price increment

Size in lots
Slippage is largely controlled by ability to forecast price motion (and passive fills).

Price change during execution

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**Slippage to Arrival Price**

- GE (1360)
- ZT (181)
- ZF (1448)
- ZN (2670)
- ZB (1746)
- UB (160)
How to develop and improve algos?

1. Pure theory and quant modeling
2. Experiment with real client orders
3. Simulator
Special features of Interest Rates

1. Large tick
2. Large liquidity
3. Specialized matching algorithms
4. Event response
5. Interrelationships

These must be taken into account in designing a trade simulator
Large-tick markets

Market Microstructure Properties of Futures

% Time Bid–Ask Spread > 1 tick

Bid-ask spread nearly always equal to minimum increment

Quote size >> trade size

Displayed Liquidity/Average Trade Size

Energy-like

Treasury-like

STIRS

Produced by QB from CME, Eurex, and LIFFE market data
Quote reversion

Figure 1: Proportion of time market is not one-tick (log scale), displayed liquidity over average trade size (log scale), and quote reversion probability, averaged throughout July-August 2013. Symbols and colors indicate clusters.

Same grouping as for spread

Produced by QB from CME, Eurex, and LIFFE market data.
Pro rata order matching

Incoming market sell order

Best bid price

Incoming volume divided among all resting orders at best price

Used by CME for Eurodollars and Treasury calendar spreads
CME Eurodollar pro rata

1. First order at new level is filled first when filled, no new order
2. Remaining volume is allocated pro rata volumes rounded down to integral trade size 0-lots and 1-lots rounded down to zero
3. Remaining volume is allocated FIFO
Mixed time priority / pro rata

\[ f_j = \frac{(V - P_{j-1})^k - (V - P_j)^k}{V^k} \cdot \]

LIFFE

\( P_j = \) volume preceding order \( j \)

\( k=1: \) pro rata

\( k=\infty: \) time priority

Market order size as fraction of resting limit orders

2-year Treasury
& some Treasury calendar spreads

CME
Mixed FIFO/Pro Rata Match Algorithms

Robert Almgren and Eugene Krel

May 31, 2013

LIFFE algorithm requires infinite sequence to determine trade allocations

Market order size as fraction of resting limit orders
Market simulator

Provide an effective tool for developing and testing execution algorithms for interest rate products.

Capture essential features of main markets:
• matching algorithms and passive fill probabilities
• short term pricing signals

Will have limitations -- useful anyway

Does not embody model of market impact
What did not work

Algo being tested

No real market data: no price signals

CME Test Environment

Dummy algos

Random order sizes and times

Dummy algos

ZI Agents

(Santa Fe zero-intelligence market algorithm)
Merge real market data

Orders

Algorithm

Simulator (artificial market)

Market data (real-time or historical)

Fills

Market data
Criteria for simulator

• If no algo orders, reproduce market data
• If no market data, reproduce match engine
• Challenge: combine market data with orders
Interleave algo orders with market

Interleave algo orders and market orders, respecting time priority and implementing exchange match rules.
Project Report

Combining historical data with a market simulator for testing algorithmic trading

Huang, Wensheng
Su, Li
Zhu, Yuanfeng

Advisor
Dr. Robert Almgren

Abstract

In algorithmic trading field, it is very important to have a good market simulator to for back testing trading algorithms or trading strategies. Before trading algorithms or trading strategies are used in production environment, they are often required to be tested against historical data in a market simulator. One of the challenges is to merge the orders generated from algorithms or strategies into market quotes and trades. This project develops an algorithm to merge orders into historical data so that people can pragmatically back testing trading algorithms or strategies. This algorithm is applied to US Treasury Futures on CME and results are proved to be promising.
Huang, Su, and Zhu, NYU project 2012
Compare results on child orders (not full algo stack)

Huang, Su, and Zhu, NYU project 2012
QB Simulator Assumptions

• Child orders always joining back of the queue
• Child orders use pessimistic queue position model, where;
  • Market Trades - reduce quantity from front of queue
  • Market Quote decreases - reduce quantity from back of queue
• Child orders receive passive fills based on matching algorithm:
  • Aggressive child orders are fully executed at sweep price
  • Child orders cannot establish a new price level
• If a price level is traded through, child orders at that level are filled
• Hidden liquidity (BML) is recreated from QB calculations
• Implied quotes are treated equally to direct quotes
• Static latency of 2ms on market data and 8ms on execution
How to use simulator

**Historical**
- rerun scenarios for algo improvement
- backtests for potential clients

**Real-time**
- clients can connect to “test-drive” algos
- Real-time splitting for testing
- compare simulator executions with real
Splitting of actual orders in real time

Client → QB Algo’s → QB simulation matching engine → exchange matching engine

- Parent orders
- Child orders
- Quotes
- Trades
Challenges

Fill model
Market data latency
Latency on order entry
Impact of real orders executing in parallel
Maintaining consistent code versions
Random numbers within algorithm
Simulator slippage (min px incr) vs. Production slippage (min px incr)

Data points for different symbols:
- GE
- ZT
- ZF
- ZN
- ZB
- UB

Data range: Wed 16 Oct 2013 to Fri 18 Oct 2013

Produced by QB from CME and internal data
Micro details are hard to get right

Production
SELL 1984 ZFZ3 BOLT

Simulator
SELL 1984 ZFZ3 BOLT

CDT on Thu 17 Oct 2013

Produced by QB from CME and internal data
Summary

Simulator is built for specific purpose for specific products

Very useful tool in appropriate context

No attempt to solve general problems
Disclaimer

This document contains examples of hypothetical performance. Hypothetical performance results have many inherent limitations, some of which are described below. No representation is being made that any account will or is likely to achieve profits or losses similar to those shown. In fact, there are frequently sharp differences between hypothetical performance results and the actual results subsequently achieved by any particular trading program.

One of the limitations of hypothetical performance results is that they are generally prepared with the benefit of hindsight. In addition, hypothetical trading does not involve financial risk, and no hypothetical trading record can completely account for the impact of financial risk in actual trading. For example, the ability to withstand losses or to adhere to a particular trading program in spite of trading losses are material points which can also adversely affect actual trading results. There are numerous other factors related to the markets in general or to the implementation of any specific trading program which cannot be fully accounted for in the preparation of hypothetical performance results and all of which can adversely affect actual trading results.

The reader is advised that futures are speculative products and the risk of loss can be substantial. Futures spreads are not necessarily less risky than short or long futures positions. Consequently, only risk capital should be used to trade futures.

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