Using a Simulator to Develop Execution Algorithms

Robert Almgren

quantitativebrokers

University of Edmonton
July 7, 2016
Outline

1. Rates trading is becoming electronic futures first, then cash
2. Business of algo execution new in futures and fixed income
3. How to get good results understanding of market microstructure
4. How do we improve toward that result? use a market simulator
5. How do we build and use a simulator?
Pit trading → electronic

Pit

position traders → HFT & Market Makers

floor brokers → algorithmic brokers (QB)
CME rates futures shift to electronic

**Futures**

**Eurodollar**

**Treasury**

**Options**

All CME futures pits closing by July 2 2015

Produced by QB from CME data
Quantitative Brokers

Algorithmic execution and cost measurement

No prop trading or market making

Interest rate products, starting with futures

Equities, FX already well served

Futures on CME, Eurex, LIFFE, Montréal, ICE

Cash Treasuries live May 2015

Basis trading futures vs cash

Good execution depends on

Microstructure expertise
BUY 129 GEH6 BOLT

Exec = 98.806 Cost to strike = -0.31 tick = -$3.92 per lot

Midpoint liquidity

Benchmark = Arrival price

Cointegration signal (indicating down move)

Order book (direct + implied)

Our fills

Our limit orders

Midpoint fills
Passive fills
Cumulative exec
Market trades
Limit orders
Cumulative VWAP
Cointegration
Microprice
Bid-ask

Executed and working quantity

Cumulative market volume

Filled quantity
Aggressive quantity

Strike 98.8075
Sweep 98.8100

GEH6

Chicago time

09:22 09:24 09:26 09:28 09:30 09:32 09:34
SELL 362 ZNU3 BOLT

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

- Passive fills
- Aggressive cross based on signal
BUY 165 GEM4 BOLT

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

Butterfly middle leg midpoint liquidity

Cointegration signal indicates up move: aggressive buy

Aggressive fills
Midpoint fills
Cumulative exec
Market trades
Limit orders
Cumulative VWAP
Cointegration
Microprice
Bid–ask
Example bond execution

SELL $7MM CT5 BOLT

Exec = 100-23.11  Cost to strike = -0.93 tick = -$72.54 per lot

On-the-run 5-yr note

EDT on Fri 01 Jul 2016
Multi-asset

Buy spread in this region

Frankfurt

SELL 350 FGBLU6 LEGGER

CEST on Fri 01 Jul 2016

Chicago

BUY 200 ZNU6 LEGGER

CEST on Fri 01 Jul 2016

Frankfurt

SELL 350 FGBLU6 LEGGER

CEST on Fri 01 Jul 2016

Chicago

BUY 200 ZNU6 LEGGER

CEST on Fri 01 Jul 2016
Differences between rates futures and equities

• No market fragmentation (futures)
  simple routing, good market data
• Trading rules more complicated
  match algorithms
  implied quoting
• Large tick size (bid-ask spread)
• High degree of interrelation
  cointegration
  multidimensional algorithms
  basis trading, substitutions, etc
• Round the clock trading
  Information events
OTTAWA – The Bank of Canada today announced that it is lowering its target for the overnight rate by one-quarter of one percentage point to 1/2 per cent. The Bank Rate is correspondingly reduced by the same amount. The deposit rate is 3/4 per cent.

Total CPI inflation in Canada has been around 1 per cent in recent months, reflecting year-over-year price declines for consumer energy products. Core inflation has been close to 2 per cent, with disinflationary pressures from economic slack being offset by transitory effects of the past depreciation of the Canadian dollar and some sector-specific factors. Setting aside these transitory effects, the Bank judges that the underlying trend in inflation is about 1.5 to 1.7 per cent.

The downward revision reflects further downgrades of business investment plans in the energy sector, as well as weaker trade activity, particularly in advanced economies and China. The Bank anticipates that real GDP will grow by just over 1 per cent in 2015 and about 3 1/2 per cent in 2016 and 2017. With this revised growth profile, the output gap is expected to close more quickly than projected in April, and is expected to be solid in the fourth quarter, led by a rebalancing to a more sustainable growth path. This has pulled down prices of certain commodities producing regions, consumer confidence remains high and labour markets continue to improve.

In the third quarter, the U.S. economy is expected to strengthen over the second half of 2015, averaging about 3 per cent and the deposit rate is 1 1/2 per cent. The Bank Rate is correspondingly reduced by the same amount. The deposit rate is 3/4 per cent.

The Bank expects growth in Canada to accelerate to about 3 per cent for the year, and the Bank of Canada increases the target for the overnight rate by one-quarter of one percentage point to 1/2 per cent. The Bank Rate is correspondingly reduced by the same amount.

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Intraday forecast curves

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<td>FOMC Meeting Announcement</td>
<td>FOMC Meeting Announcement</td>
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Large tick markets

Pro rata match algos
short term interest rates (STIR)

One-dimensional spectrum of futures products in CME, Eurex, LIFFE

Interest rate futures are "large-tick"

Produced by QB from various market data
Slippage measurement

Live or die by transaction costs
Look at main determinants of good slippage
Algorithm Performance Comparison

April 2013 through Feb 2016

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<th>Market</th>
<th>Bid/Ask</th>
<th>Bulge Bracket Banks</th>
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$9.5MM in 34 months: 77 bp annual improvement in return

All Eurodollar outrights

Cumulative volume fraction

Slippage to arrival price in ticks

CCP: mean = 0.53

QB: mean = 0.37

Thu 15 Aug 2013 to Fri 31 Jan 2014

$2MM savings in 6 months

Produced by QB from internal data
Size is not most important variable for rates

For rates products, order size is not most important factor in slippage
For rates, slippage is largely controlled by ability to forecast price motion (and passive fills).

Price change during execution

Slippage to Arrival Price
Size matters more for non-rates

Slippage cost to midpoint as fraction of minimum price increment

Parent order size in lots

Natural gas futures

For non-rates products, slippage depends on order size (market impact)

Produced by QB from CME and internal data
Impact cost model

SP500 futures

ES from Thu 02 Jan 2014 to Thu 02 Oct 2014

Slippage as fraction of min px incr

Executed size in lots

Produced by QB from CME and internal data
What does performance depend on?

Passive fills
Short term price signals
Reliable performance in different mkt conds
How to develop and improve algos?

1. Pure theory and quant modeling
2. Experiment with real client orders
3. Simulator
A potent mixture of in-house, futures commission merchant, and boutique brokerage-provided algorithms now play a part in commodity trading advisors’ and managed futures funds’ trading activities. Tim Bourgaize Murray examines why a new cadre of simulation tools is helping to organize—and perhaps re-mold—these buy-side specialists’ order flow.

“S"kate to where the puck is going to be, not where it has been,” Wayne Gretzky once told an interviewer. As the Great One described it, what cuts certain players a level above isn’t native instinct alone, so much as endless practice seeing the ice and, frankly, the hard work of getting to where a scoring opportunity will be, before it reveals itself.

Gretzky’s advice is one of Robert Almgren’s favorite lines—but not because the co-founder of Quantitative Brokers (QB) is a hockey fan. Instead, he says a similar idea applies to the business of algorithmic futures execution: the more you see, the more you expect to perform.

“We do perform reviews on all algos internally using our own simulator, and are always keen to compare these results with those of the provider. If they cannot provide a simulator, it takes a lot longer to see if we believe their story.” Murray Steel, AHL

Many of the valuations they say they are putting into these algos internally using our own simulator, and are always keen to compare these results with those of the provider. If they cannot provide a simulator, it takes a lot longer to see if we believe their story. Murray Steel, AHL

Managed Futures’ ALGO CHASE

SALIENT POINTS

• Managed futures specialists are increasingly taking advantage of boutique agency brokers’ algorithms, citing their ability to be opportunistic and adjust to markets’ behavior, as well as faster speed to implementation and greater alpha realized through price slippage.

• Rates futures, particularly, are ripe for these applications given their correlation and the characteristics of the complex environments within which they’re traded, and are well-serviced by Quantitative Brokers (QB), among other independent shops. Hedge fund AHL and CTA Revolution Capital Management are among QB’s users for rates.

• Another value-added feature at smaller shops like QB is their simulation environments, which mimic the matching engine logic of relevant futures exchange venues and can test new adjustments to algorithms with real-time market data before putting the algos into production.

• Sources expect a greater variety of such brokers to crop up in coming years, while sell-side futures commission merchants (FCMs), sensing greater competition, are also expected to mature their offerings and continue bundling futures algos with other execution and clearing services.
Computational fluid dynamics
Computational fluid dynamics

Complete simulation is impossible
Discretize to capture key features:
• Conservation of mass, momentum, etc
• Positivity of density, etc
• Vortex dynamics
• Chemical reactions
• 2-D, 3-D, axisymmetric, etc
• Nonlocal effects (incompressible flow)
Computational market simulation
Complete simulation is impossible
(Human reaction is very complicated)

Key features to include:
queue position and match algorithms
price movement

Features to neglect for simplicity:
market impact

(Literature on agent-based markets)
‘They were obliged to have him with them,’ the Mock Turtle said: ‘no wise fish would go anywhere without a porpoise.’

‘Wouldn’t it really?’ said Alice in a tone of great surprise.

‘Of course not,’ said the Mock Turtle: ‘why, if a fish came to me, and told me he was going a journey, I should say “With what porpoise?”’

‘Don’t you mean “purpose”?’ said Alice.

‘I mean what I say,’ the Mock Turtle replied in an offended tone.
Market simulator

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

The one most natural way to build a simulator
What did not work

No real market data: no price signals

Algo being tested

Dummy algos

Random order sizes and times

Dummy algos

CME Test Environment

ZI Agents

ZI Agents

ZI Agents

ZI Agents

(Santa Fe zero-intelligence market algorithm)
Simulating and analyzing order book data: 
The queue-reactive model

Weibing Huang¹,², Charles-Albert Lehalle³ and Mathieu Rosenbaum¹

Through the analysis of a dataset of ultra high frequency order book updates, we introduce a model which accommodates the empirical properties of the full order book together with the stylized facts of lower frequency financial data. To do so, we split the time interval of interest into periods in which a well chosen reference price, typically the midprice, remains constant. Within these periods, we view the limit order book as a Markov queuing system. Indeed, we assume that the intensities of the order flows only depend on the current state of the order book. We establish the limiting behavior of this model and estimate its parameters from market data. Then, in order to design a relevant model for the whole period of interest, we use a stochastic mechanism that allows to switch from one period of constant reference price to another. Beyond enabling to reproduce accurately the behavior of market data, we show that our framework can be very useful for practitioners, notably as a market simulator or as a tool for the transaction cost analysis of complex trading algorithms.

4 Conclusion and perspectives

In this work, we have modeled market participants intelligence through their average behaviors towards various states of the LOB. This enabled us to analyze the different order flows and to design a suitable market simulator for practitioners, allowing notably to investigate the transaction costs of complex trading strategies. To our knowledge, our model is the first one where such pre-trade cost analysis is possible in a simple and efficient way.

Another important public information, the historical order flow, is not considered in this approach. Market order flows have been shown to be autocorrelated in several empirical studies, see for example Toth, Palit, Lillo, and Farmer (2011b). Thus, adding such feature in our framework would probably be relevant. Another possible direction for future research would be to explain the shape of the estimated intensity functions in a more sophisticated way. For example, it would be interesting to design some agent based model where these repetitive patterns of the LOB dynamics would be reproduced, providing an even better understanding of the nature of these intensity curves.
Simulating and Analyzing Order Book Data: The Queue-Reactive Model

Weibing HUANG, Charles-Albert LEHALLE, and Mathieu ROSENBAUM

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KEY WORDS: Ergodic properties; Execution probability; High frequency data; Jump Markov process; Limit order book; Mechanical volatility; Market impact; Market microstructure; Market simulator; Queuing model; Transaction costs analysis; Volatility.

4. CONCLUSION AND PERSPECTIVES

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Other simulators

The PLAT Project has developed a trading simulation that merges automated clients with real-time, real-world stock market data. This simulation has been used for three competitions.

The Penn-Lehman Automated Trading Project

Michael Kearns and Luis Ortiz, University of Pennsylvania

The Penn-Lehman Automated Trading Project is a broad investigation of algorithms and strategies for automated trading in financial markets. The PLAT Project’s centerpiece is the Penn Exchange Simulator (PXS), a software simulator for automated stock trading that merges automated client orders for shares with real-world, real-time order data. PXS automatically computes client profits and losses, volumes traded, simulator and external prices, and other quantities of interest. To test the effectiveness of PXS and of various trading strategies, we’ve held three formal competitions between automated clients.

We also actively use PXS as a platform for developing novel, principled automated trading strategies (clients). The real-data, real-time nature of PXS lets us examine computationally intensive, high-frequency, high-volume trading strategies (although this last property always presents the challenges of estimating the market impact—the effect on prices). We’re particularly interested in developing clients that make predictive use of limit order book data, including those using statistical modeling and machine learning. We hope that, over time, the project will generate a library of clients with varying features (trading strategy, volume, frequency, and so on) that can serve to create realistic simulations with known properties.
Merge real market data

Market data
(real-time or historical)
Quote volume at each level
and number of orders
(CME does not give detailed order info)

Simulator
(artificial market)

Algorithm

Orders

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
NYU MS Students, May 2012

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.
Assumption: that in a FIFO market, trades in Xetra are more likely to be cancelled when they are newly submitted. It is reasonable in Algorithmic Trading Patterns in Xetra Orders (2012).
Interleave algo orders with market

Interleave algo orders and market orders, respecting time priority and implementing exchange match rules.
Mkt data | Algo order | Book
---|---|---
quote=100 lot | 40 lot bid | 100
quote=150 lot | | 140
trade=30 lot (20%) | 8 lot fill | 190
quote=120 lot | | 152
quote=110 lot (10 lot cancel) | | 142
etc | | pro rata
cancel from back of queue
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

**Algorithm development**
- test new signals on historical orders
- multi-market legging trades

**Real-time splitting for testing**
- compare simulator executions with real
Signal development

1. Propose idea
   plausibility tests
2. Statistical tests on historical market data
   nonzero correlation with future price movement
3. Rerun actual orders executed
   show improvement in slippage
Signal evaluation

BUY 500 CLH4 BOLT

Exec = 99.68 Cost to strike = -6.47 tick = $84.72 per lot

Buy/sell signals based on short-term mean reversion and trading ranges

CST on Mon 10 Feb 2014

Produced by QB from CME and internal data
Splitting of actual orders in real time

- Client
- QB Algo’s
  - child orders
  - parent orders
  - quotes
  - trades
- QB simulation matching engine
  - quotes
  - trades
- Exchange matching engine
Comparison of simulator with real execution

Mon 04 Jan 2016 to Wed 06 Jul 2016

Produced by QB from CME and internal data
Simulator crosses spread because of extra volume on bid side

Buy 148 ZNH4, 2014-02-05

Remaining size at much lower price level following event
Pessimistic fill assumptions

Production receives passive fills at 10:37, simulator does not.

2014-01-27: Buy 56 GEU6
Main differences simulator/production:
• quote imbalance
• timing and latency
• random number sequences
• pessimistic fill model
Summary

Fixed income trading is becoming electronic

Need full range of algo execution tools:
- Transaction Cost Analysis (TCA) reporting
- Market microstructure analysis
- Algorithm optimization
- Market simulator
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. The information contained herein is based on sources that we believe to be reliable, but we do not represent that it is accurate or complete. Nothing contained herein should be considered as an offer to sell or a solicitation of an offer to buy any financial instruments discussed herein. All references to prices and yields are subject to change without notice. Past performance/profits are not necessarily indicative of future results. Any opinions expressed herein are solely those of the author. As such, they may differ in material respects from those of, or expressed or published by or on behalf of, Quantitative Brokers or its officers, directors, employees or affiliates. Quantitative Brokers, LLC, 2010.