The High-Frequency Trading Arms Race: Frequent Batch Auctions as a Market Design Response

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▶ Not tunnels, but microwaves (first 10ms, then 9ms, now 8.5ms).
▶ Analogous races occurring at level of microseconds and nanoseconds, estimated at $bn’s per year (also substantial human capital)
We examine the HFT “Arms Race” from the perspective of market design.

- We assume that HFT’s are optimizing with respect to market rules as they’re presently given.
- But, ask whether these are the right rules.
  - Avoids much of the “is HFT good or evil?” that seems to dominate the discussion of HFT.

Central point: HFT arms race is a symptom of a basic flaw in modern financial market design: continuous-time trading.

Proposal: replace continuous-time limit order books with discrete-time frequent batch auctions.

- Frequent batch auctions: uniform-price sealed-bid double auctions conducted at frequent but discrete time intervals, e.g., every 1 second or 100ms.
Frequent Batch Auctions

A simple idea: replace (continuous-time) limit-order books with (discrete-time) frequent batch auctions

1. Continuous limit-order books don’t actually “work” in continuous time: market correlations break down at high frequency
2. Correlation breakdown $\Rightarrow$ Technical arbitrage opportunities $\Rightarrow$ Arms Race. Arms Race is a “constant” of the market design.
3. Model: costs of the arms race
   - Harms liquidity (spreads, depth)
   - Socially wasteful
4. Frequent Batch Auctions as a market design response
   - Benefits: eliminates arms race, enhances liquidity, enhances market stability
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Market Correlations Break Down at High Frequency
ES vs. SPY: 1 Day
Market Correlations Break Down at High Frequency

ES vs. SPY: 1 hour

![Graph showing the comparison between ES Midpoint and SPY Midpoint over time. The graph displays the index points for both indices from 13:30:00 to 14:30:00, with significant variations indicating a breakdown in correlations at high frequency.]
Market Correlations Break Down at High Frequency

ES vs. SPY: 1 minute

[Graph showing ES and SPY index points over time]
Market Correlations Break Down at High Frequency

ES vs. SPY: 250 milliseconds
Correlation Breakdown Over Time

![Graph showing correlation breakdown over time with data points for different years.]
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2. **Correlation breakdown** → **Technical arbitrage opportunities** → **Arms Race. Arms Race is a “constant” of the market design.**

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Arb Durations over Time: 2005-2011

(a) Median over time

(b) Distribution by year
Arb Per-Unit Profits over Time: 2005-2011

(c) Median over time

(d) Distribution by year
Arb Frequency over Time: 2005-2011

(e) Median over time

(f) Frequency vs. Volatility
Arms Race is a “Constant” of the Market Design

- Results suggest that the arms race is a mechanical “constant” of the continuous limit order book.
  - Rather than a profit opportunity that is competed away over time
- Competition does increase the speed requirements for capturing arbs (“raises the bar”)
- Competition does not reduce the size or frequency of arb opportunities
- These facts both inform and are explained by our model
Total Size of the Arms Race Prize

- Estimate annual value of ES-SPY arbitrage is $75mm (we suspect underestimate, details in paper)
- And ES-SPY is just the tip of the iceberg in the race for speed:
  1. Hundreds of trades very similar to ES-SPY: highly correlated, highly liquid
  2. Fragmented equity markets: can arbitrage SPY on NYSE against SPY on NASDAQ! Even simpler than ES-SPY.
  3. Correlations that are high but far from one can also be exploited in a statistical sense. Example: GS-MS
  4. Race to top of book (artifact of minimum tick increment)

We don’t attempt to put a precise estimate on the total prize at stake in the arms race, but common sense extrapolation from our ES-SPY estimates suggest that the sums are substantial
## Technical Arbitrage: Other Highly Correlated Pairs

**Partial List**

<table>
<thead>
<tr>
<th>Futures Pair</th>
<th>ETFs</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-mini S&amp;P 500 Futures (ES) vs. SPDR S&amp;P 500 ETF (SPY)</td>
<td>Australian Dollar Futures (6B) vs. Spot AUDUSD</td>
</tr>
<tr>
<td>E-mini S&amp;P 500 Futures (ES) vs. iShares S&amp;P 500 ETF (IVV)</td>
<td>Swiss Franc Futures (65) vs. Spot USDCHF</td>
</tr>
<tr>
<td>E-mini S&amp;P 500 Futures (ES) vs. Vanguard S&amp;P 500 ETF (VOO)</td>
<td>Canadian Dollar Futures (6C) vs. Spot USDCAD</td>
</tr>
<tr>
<td>E-mini S&amp;P 500 Futures (ES) vs. ProShares Ultra (2x) S&amp;P 500 ETF (SSO)</td>
<td>Gold Futures (GC) vs. miNY Gold Futures (QO)</td>
</tr>
<tr>
<td>E-mini S&amp;P 500 Futures (ES) vs. ProShares UltraPro (3x) S&amp;P 500 ETF (UPRO)</td>
<td>Gold Futures (GC) vs. Spot Gold (XAUUSD)</td>
</tr>
<tr>
<td>E-mini S&amp;P 500 Futures (ES) vs. ProShares Short S&amp;P 500 ETF (SH)</td>
<td>Gold Futures (GC) vs. E-micro Gold Futures (MGC)</td>
</tr>
<tr>
<td>E-mini S&amp;P 500 Futures (ES) vs. ProShares Ultra (2x) Short S&amp;P 500 ETF (SDS)</td>
<td>Gold Futures (GC) vs. SPDR Gold Trust (GLD)</td>
</tr>
<tr>
<td>E-mini S&amp;P 500 Futures (ES) vs. ProShares UltraPro (3x) Short S&amp;P 500 ETF</td>
<td>Gold Futures (GC) vs. iShares Gold Trust (IAU)</td>
</tr>
<tr>
<td>E-mini S&amp;P 500 Futures (ES) vs. 500 Constituent Stocks</td>
<td>miNY Gold Futures (QO) vs. E-micro Gold Futures (MGC)</td>
</tr>
<tr>
<td>E-mini S&amp;P 500 Futures (ES) vs. 9 Select Sector SPDR ETFs</td>
<td>miNY Gold Futures (QO) vs. Spot Gold (XAUUSD)</td>
</tr>
<tr>
<td>E-mini S&amp;P 500 Futures (ES) vs. E-mini Dow Futures (YM)</td>
<td>miNY Gold Futures (QO) vs. SPDR Gold Trust (GLD)</td>
</tr>
<tr>
<td>E-mini S&amp;P 500 Futures (ES) vs. E-mini Nasdaq 100 Futures (NQ)</td>
<td>miNY Gold Futures (QO) vs. iShares Gold Trust (IAU)</td>
</tr>
<tr>
<td>E-mini S&amp;P 500 Futures (ES) vs. E-mini S&amp;P MidCap 400 Futures (EMD)</td>
<td>E-micro Gold Futures (MGC) vs. SPDR Gold Trust (GLD)</td>
</tr>
<tr>
<td>E-mini S&amp;P 500 Futures (ES) vs. Russell 2000 Index Futures (TF)</td>
<td>E-micro Gold Futures (MGC) vs. iShares Gold Trust (IAU)</td>
</tr>
<tr>
<td>E-mini Dow Futures (YM) vs. SPDR Dow Jones Industrial Average ETF (DIA)</td>
<td>Market Vectors Gold Miners (GDX) vs. Direxion Daily Gold Miners Bull 3x (NUGT)</td>
</tr>
<tr>
<td>E-mini Dow Futures (YM) vs. ProShares Ultra (2x) Dow 30 ETF (ODM)</td>
<td>Silver Futures (SI) vs. miNY Silver Futures (QI)</td>
</tr>
<tr>
<td>E-mini Dow Futures (YM) vs. ProShares UltraPro (3x) Dow 30 ETF (UDOW)</td>
<td>Silver Futures (SI) vs. iShares Silver Trust (SLV)</td>
</tr>
<tr>
<td>E-mini Dow Futures (YM) vs. ProShares Short Dow 30 ETF (DOG)</td>
<td>Silver Futures (SI) vs. Spot Silver (XAGUSD)</td>
</tr>
<tr>
<td>E-mini Dow Futures (YM) vs. ProShares Ultra (2x) Short Dow 30 ETF (DODX)</td>
<td>miNY Silver Futures (QI) vs. iShares Silver Trust (SLV)</td>
</tr>
<tr>
<td>E-mini Dow Futures (YM) vs. 30 Constituent Stocks</td>
<td>miNY Silver Futures (QI) vs. Spot Silver (XAGUSD)</td>
</tr>
<tr>
<td>E-mini Nasdaq 100 Futures (NQ) vs. ProShares QQ Trust ETF (QQQ)</td>
<td>Platinum Futures (PL) vs. Spot Platinum (XPTUSD)</td>
</tr>
<tr>
<td>E-mini Nasdaq 100 Futures (NQ) vs. Technology Sector SPDR (XLK)</td>
<td>Palladium Futures (PA) vs. Spot Palladium (XPDUSD)</td>
</tr>
<tr>
<td>E-mini Nasdaq 100 Futures (NQ) vs. 100 Constituent Stocks</td>
<td>Eurodollar Futures Front Month (ED) vs. (12 back month contracts)</td>
</tr>
<tr>
<td>Russell 2000 Index Futures (TF) vs. iShares Russell 2000 ETF (IWM)</td>
<td>10 Yr Treasury Note Futures (ZN) vs. 5 Yr Treasury Note Futures (ZF)</td>
</tr>
<tr>
<td>Euro Stoxx 50 Futures (FESX) vs. Xetra DAX Futures (FDAX)</td>
<td>10 Yr Treasury Note Futures (ZN) vs. 30 Yr Treasury Bond Futures (ZB)</td>
</tr>
<tr>
<td>Euro Stoxx 50 Futures (FESX) vs. CAC 40 Futures (FCE)</td>
<td>10 Yr Treasury Note Futures (ZN) vs. 7-10 Yr Treasury Note</td>
</tr>
<tr>
<td>Euro Stoxx 50 Futures (FESX) vs. Xetra DAX Futures (FDAX)</td>
<td>2 Yr Treasury Note Futures (ZT) vs. 1-2 Yr Treasury Note</td>
</tr>
<tr>
<td>Nikkei 225 Futures (NIFTY) vs. MSCI Japan Index Fund (EWI)</td>
<td>5 Yr Treasury Note Futures (ZT) vs. iShares Barclays 1-3 Yr Treasury Fund (SHY)</td>
</tr>
<tr>
<td>Financial Sector SPDR (XLF) vs. Constituents</td>
<td>30 Yr Treasury Bond Futures (ZB) vs. iShares Barclays 20 Yr Treasury Fund (TLT)</td>
</tr>
<tr>
<td>Financial Sector SPDR (XLF) vs. Direxion Daily Financial Bull 3x (FAS)</td>
<td>30 Yr Treasury Bond Futures (ZB) vs. ProShares UltraShort 20 Yr Treasury Fund (TBT)</td>
</tr>
<tr>
<td>Energy Sector SPDR (XLE) vs. Constituents</td>
<td>30 Yr Treasury Bond Futures (ZB) vs. ProShares Short 20 Year Treasury Fund (TBF)</td>
</tr>
<tr>
<td>Industrial Sector SPDR (XLI) vs. Constituents</td>
<td>30 Yr Treasury Bond Futures (ZB) vs. 15+ Yr Treasury Bond</td>
</tr>
<tr>
<td>Cons. Staples Sector SPDR (XLP) vs. Constituents</td>
<td>Crude Oil Futures Front Month (CL) vs. (6 back month contracts)</td>
</tr>
<tr>
<td>Materials Sector SPDR (XLB) vs. Constituents</td>
<td>Crude Oil Futures (CL) vs. ICE Brent Crude (B)</td>
</tr>
<tr>
<td>Utilities Sector SPDR (XLU) vs. Constituents</td>
<td>Crude Oil Futures (CL) vs. United States Oil Fund (USO)</td>
</tr>
<tr>
<td>Technology Sector SPDR (XLK) vs. Constituents</td>
<td>Crude Oil Futures (CL) vs. ProShares Ultra Di-UBS Crude Oil (UCO)</td>
</tr>
<tr>
<td>Health Care Sector SPDR (XLV) vs. Constituents</td>
<td>Crude Oil Futures (CL) vs. iPath S&amp;P Crude Oil Index (OIL)</td>
</tr>
<tr>
<td>Cons. Discretionary Sector SPDR (XLY) vs. Constituents</td>
<td>ICE Brent Crude Front Month (B) vs. (6 back month contracts)</td>
</tr>
<tr>
<td>SPDR Homebuilders ETF (XHB) vs. Constituents</td>
<td>ICE Brent Crude (B) vs. United States Oil Fund (USO)</td>
</tr>
<tr>
<td>SPDR S&amp;P 500 Retail ETF (XRT) vs. Constituents</td>
<td>ICE Brent Crude (B) vs. ProShares Ultra Di-UBS Crude Oil (UCO)</td>
</tr>
<tr>
<td>Euro FX Futures (6E) vs. Spot EURUSD</td>
<td>ICE Brent Crude (B) vs. iPath S&amp;P Crude Oil Index (OIL)</td>
</tr>
<tr>
<td>Japanese Yen Futures (6J) vs. Spot USDJP</td>
<td>Natural Gas (Henry Hub) Futures (NG) vs. United States Nat Gas Fund (UNG)</td>
</tr>
<tr>
<td>British Pound Futures (6B) vs. Spot GBPUSD</td>
<td></td>
</tr>
</tbody>
</table>
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▶ Takeaway: in a continuous limit order book, any time there is public information, there is a race to respond. This race harms liquidity provision.
Model: Key Idea

- This technical cost of providing liquidity – liquidity-providing HFTs getting “picked off” by other HFTs in the race to respond to symmetrically observable public news – is incremental to the usual fundamental costs of providing liquidity
  - Asymmetric information, inventory costs, search costs
- In a competitive market, picking off costs get passed on to investors
  - Thinner markets, wider bid-ask spreads
- Ultimately, in equilibrium of our model, all of the $ spent in the arms race come out of the pockets of investors
  - Arms-race prize = expenditures on speed = cost to investors
The Arms-Race is a “Constant”

- Comparative static: the negative effects of the arms race do not depend on either
  - the cost of speed (if speed is cheap, there will be more entry)
  - the magnitude of speed improvements (seconds, milliseconds, microseconds, nanoseconds, ...)

- The problem we identify is an equilibrium feature of continuous limit order books
  - not competed away as HFTs get faster and faster
  - ties in nicely with empirical results
Role of HFTs

- In our model, HFTs endogenously perform two functions:
  - **Useful**: liquidity provision / price discovery
  - **Rent-seeking**: picking off other HFTs’ stale quotes

- HFTs are indifferent between these two roles in equilibrium of our model.

- The rent-seeking seems like zero-sum activity among HFTs (all good fun!)
  - we show that it ultimately harms real investors

- Frequent batching preserves the useful function but eliminates the rent seeking function (or at least reduces)
What’s the Market Failure?

Chicago question: isn’t the arms race just healthy competition? what’s the market failure?
What’s the Market Failure?

Our model yields two responses

1. Model shows that the arms race can be interpreted as a prisoners’ dilemma
   ▶ If all HFTs could commit not to invest in speed, they’d all be better off
   ▶ But, each individual HFT has incentive to deviate and invest in speed

2. Model shows that a violation of the efficient market hypothesis is built in to the market design
   ▶ Violations of the weak-form EMH are intrinsic to the continuous limit order book market design
   ▶ You can make money from purely technical information (and HFTs do!)
   ▶ Core issue: continuous markets process messages in serial (i.e., one-at-a-time)
   ▶ Even for public / technical info (e.g., a jump in ES): somebody is always first to react
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Frequent Batch Auctions: Definition

- During the batch interval (e.g., 1 second), traders submit bids and asks as price-quantity pairs
  - Just like standard limit orders
- At the conclusion of each batch interval, the exchange “batches” all of the received orders, and computes market-level supply and demand curves
- If supply and demand intersect, then all transactions occur at the same market-clearing price (“uniform price”)
  - Bids and asks of exactly the market-clearing price may get rationed (pro-rata)
  - If there is a range of market-clearing prices, choose the midpoint (knife-edge case)
- Information policy: orders are not visible during the batch interval. Aggregate demand and supply are announced at the end.
  - Analogous to current practice under the continuous limit-order book
Frequent Batch Auctions: Illustrated

(a) Case 1: No Trade

(b) Case 2: Trade
There are two reasons why batching eliminates the arms race:

1. Batching reduces the value of a tiny speed advantage
   - If the batch interval is 1 second, a 1 millisecond speed advantage is only $\frac{1}{1000}$th as useful

2. Batching transforms competition on speed into competition on price
   - Ex: the Fed announces policy change at 2:00:00.000pm ...
     - Continuous market: competition manifests in a race to react. *Someone is always first.*
     - Batched market: competition simply drives the price to its new correct level for 2:00:01.000. Lots of orders reach the exchange by the end of the batch interval.
Computational Benefits of Frequent Batching

- **Overall**
  - Continuous-time markets implicitly assume that computers and communications technology are infinitely fast.
  - Discrete time respects the limits of computers and communications. Computers are fast but not infinitely so.

- **Algorithmic traders**
  - Continuous: Always uncertain about current state; temptation to trade off robustness for speed
  - Discrete: Everyone knows state at time $t$ before decision at time $t + 1$

- **Exchanges**
  - Continuous: Computational task is mathematically impossible; latencies and backlog unavoidable
  - Discrete: Computation is easy

- **Regulator**
  - Continuous: Audit trail is difficult to parse; who knew what when? in what order did events occur across markets?
  - Discrete: Simple audit trail; state at $t$, $t + 1$, ...
Costs and Benefits of Frequent Batching

- **Benefits**
  - Enhanced liquidity
    - Narrower spreads
    - Increased depth
  - Eliminate socially wasteful arms race
  - Computational / market stability benefits of batching

- **Costs**
  - Investors must wait until the end of the batch interval to transact
  - Unintended consequences
Summary

- We take a market design perspective to the HFT arms race. What incentivizes HFTs to invest billions in tiny speed advantages? Can we improve financial market design?
- Propose a simple idea: replace (continuous-time) limit-order books with (discrete-time) frequent batch auctions.

1. Show that continuous-time markets are a fiction: market correlations break down at high frequency
2. Correlation breakdown → Technical arbitrage opportunities → Arms Race. Arms Race is a “constant” of the market design.
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   - Costs: investors must wait a small amount of time to trade, law of unintended consequences