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)

The HFT Arms Race: Market Design Perspective

- 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.

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

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3. Model: costs of the arms race
   - Harms liquidity (spreads, depth)
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4. Frequent Batch Auctions as a market design response
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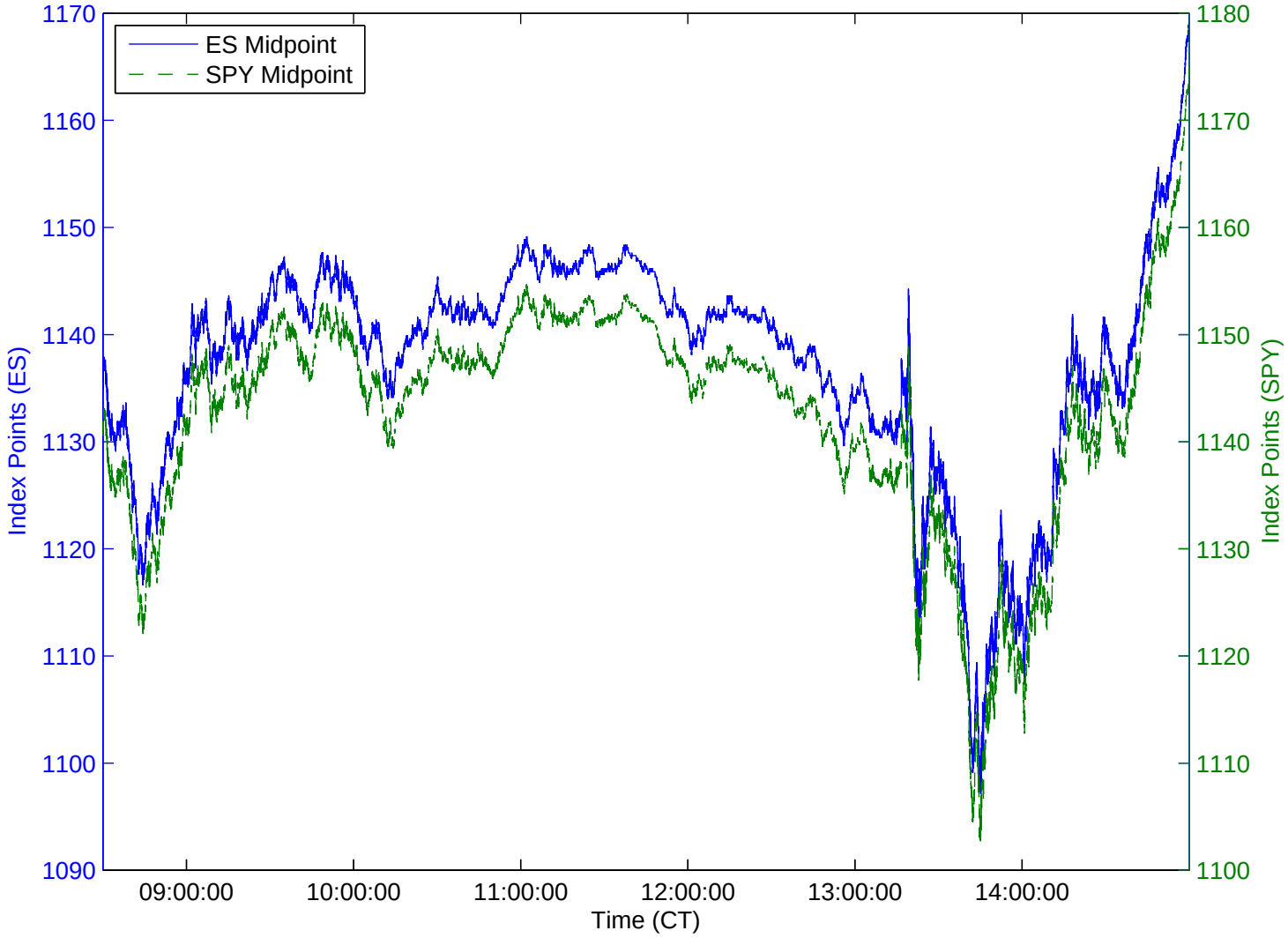
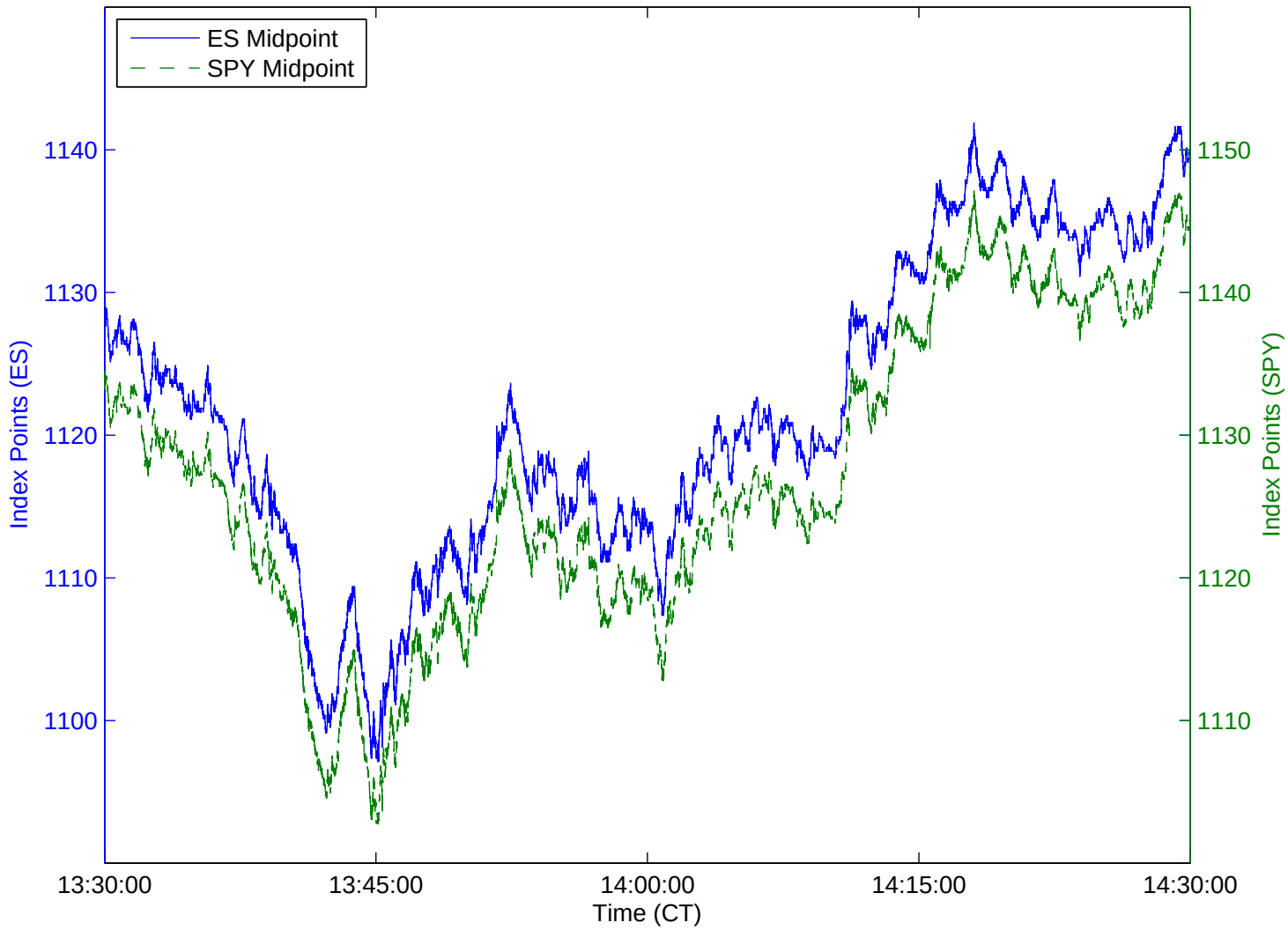
Market Correlations Break Down at High Frequency

ES vs. SPY: 1 Day



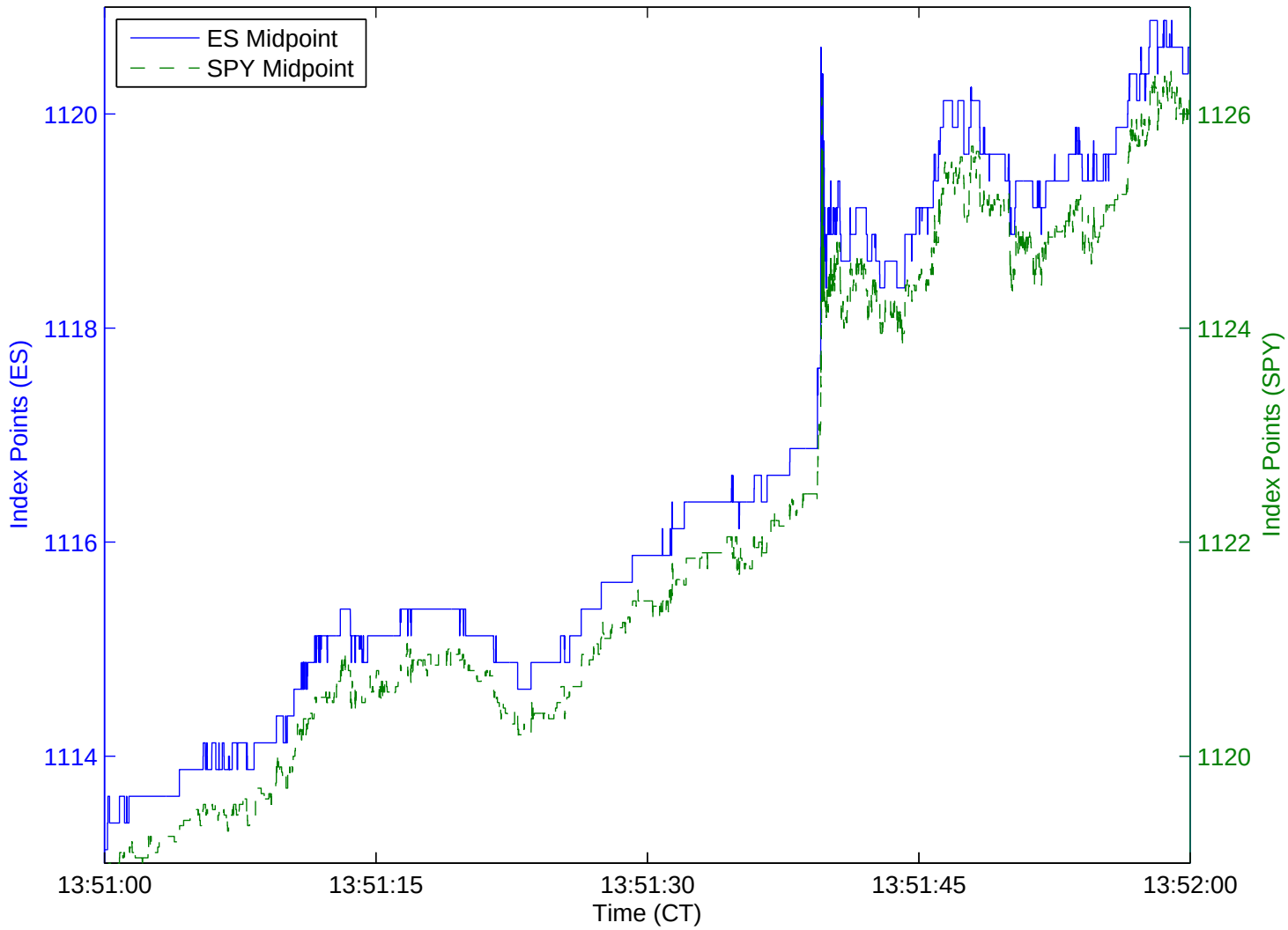
Market Correlations Break Down at High Frequency

ES vs. SPY: 1 hour



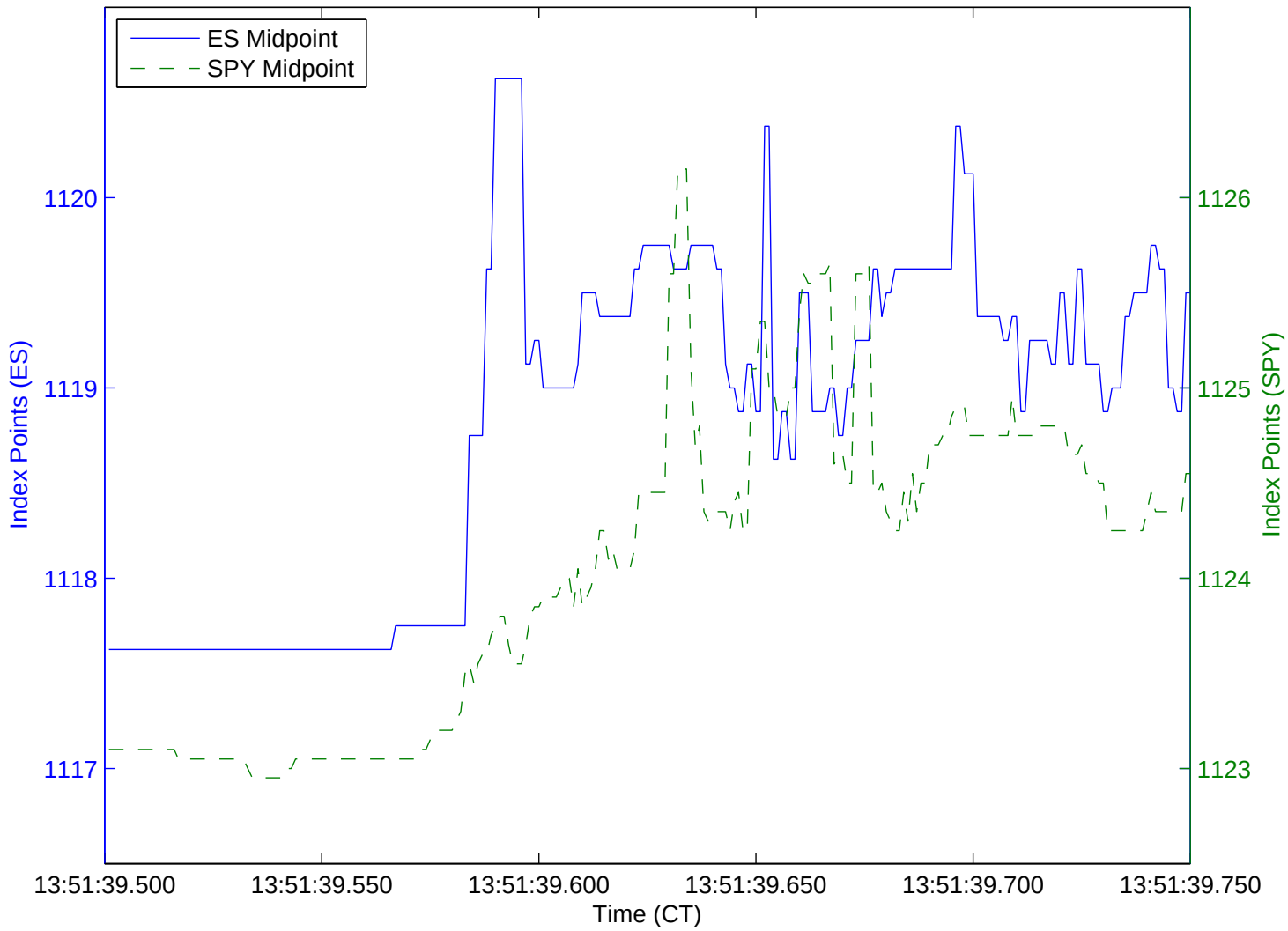
Market Correlations Break Down at High Frequency

ES vs. SPY: 1 minute

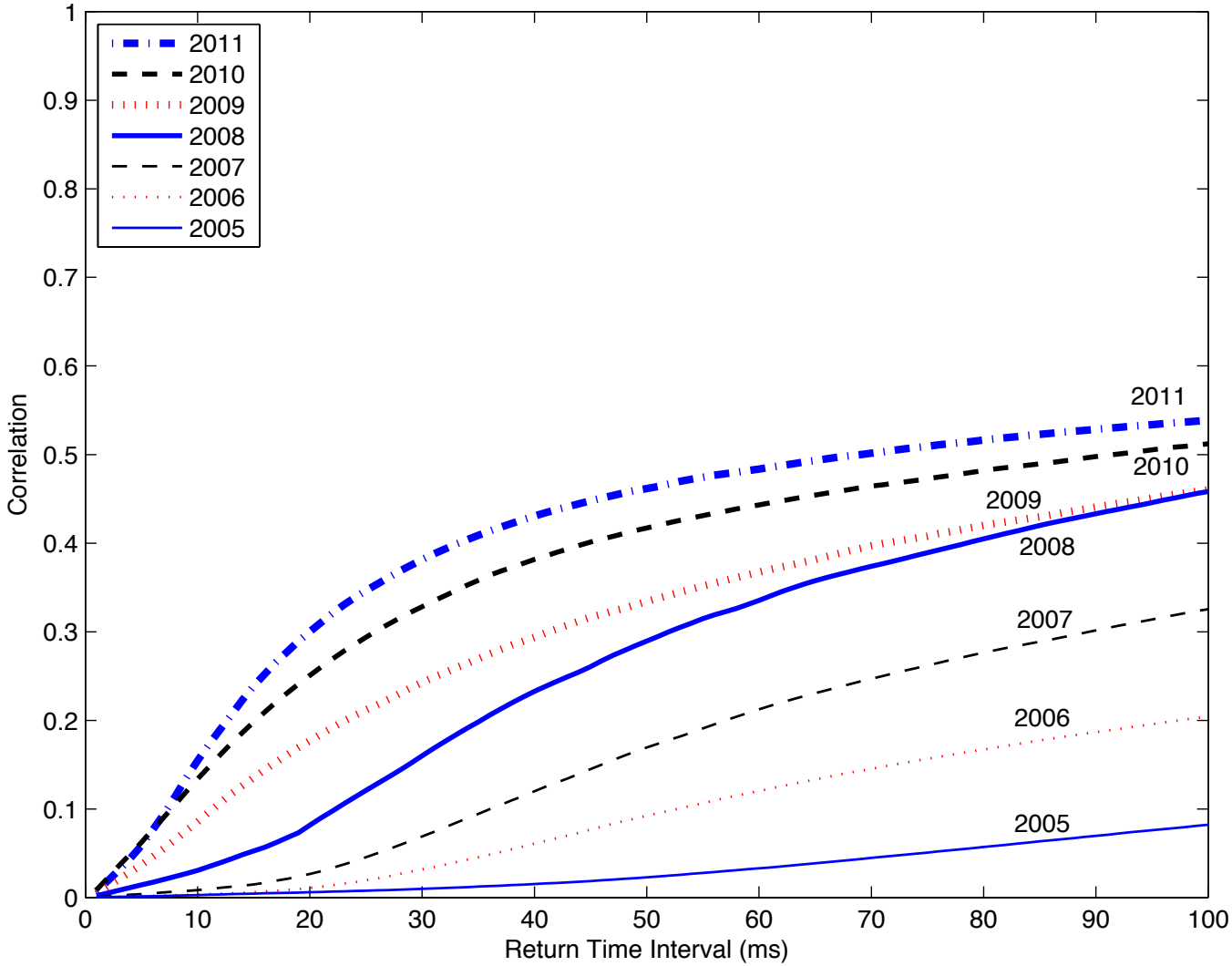


Market Correlations Break Down at High Frequency

ES vs. SPY: 250 milliseconds



Correlation Breakdown Over Time



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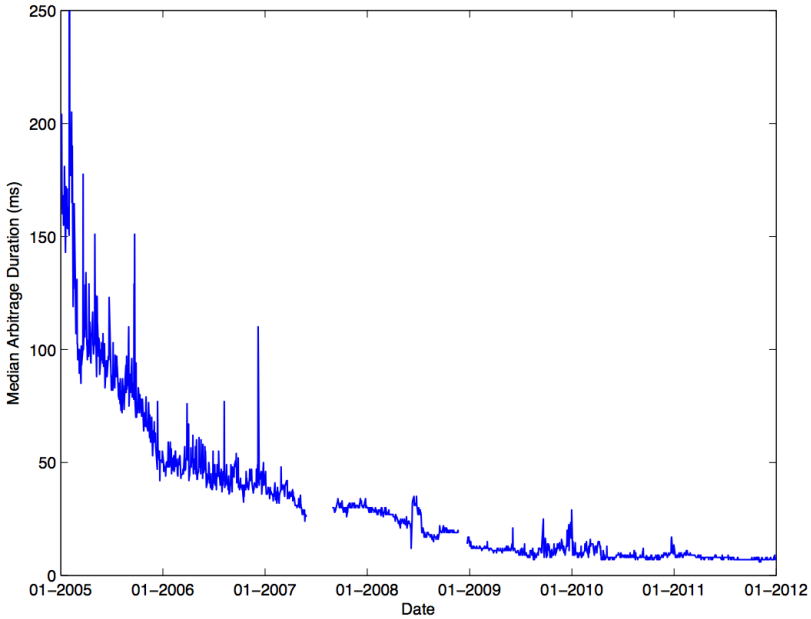
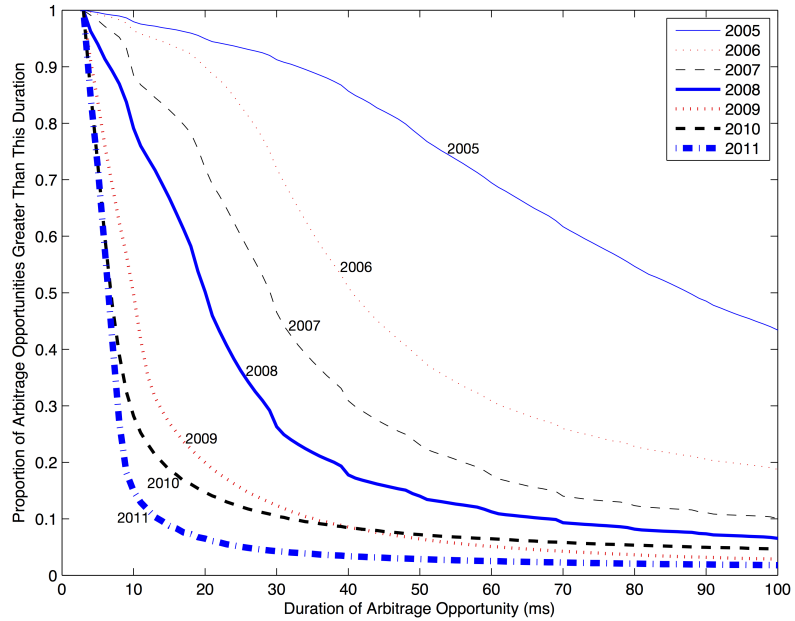
Arb Durations over Time: 2005-2011

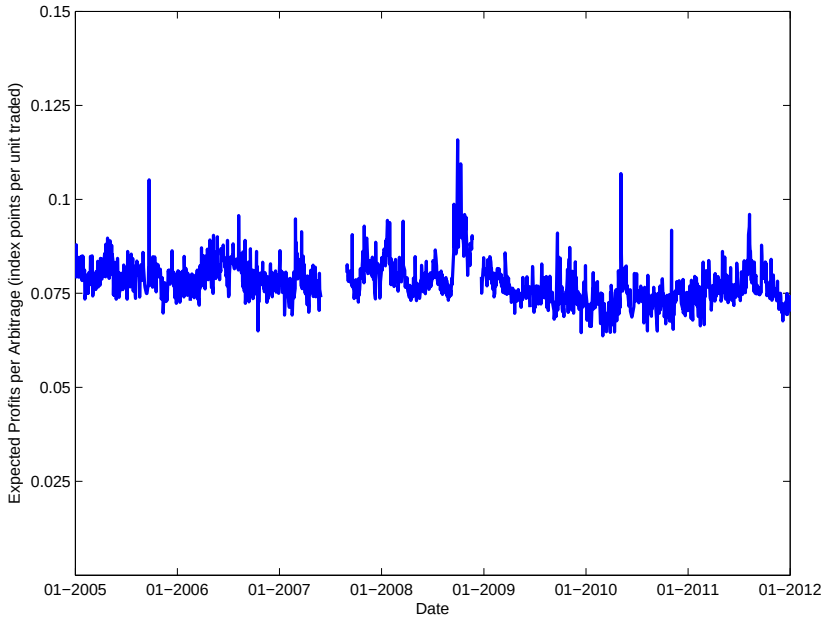


(a) Median over time

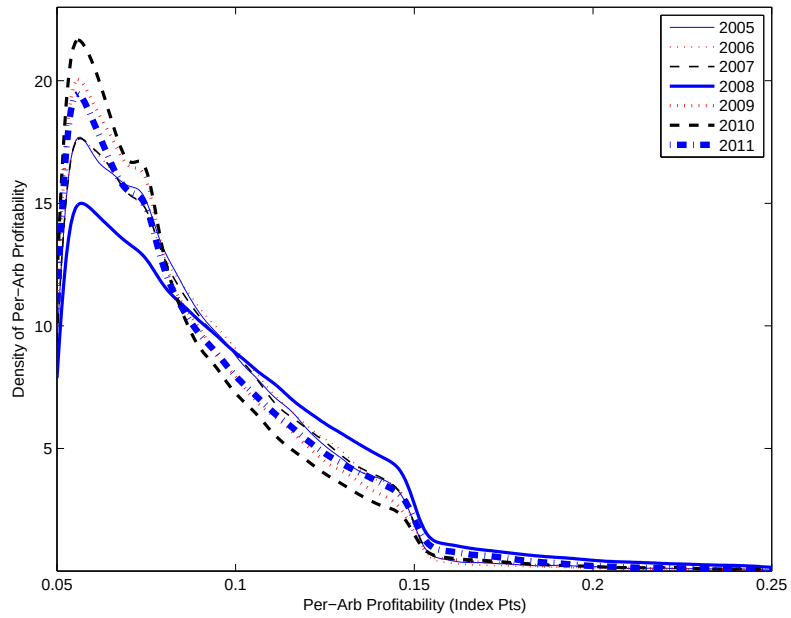


(b) Distribution by year

Arb Per-Unit Profits over Time: 2005-2011



(c) Median over time



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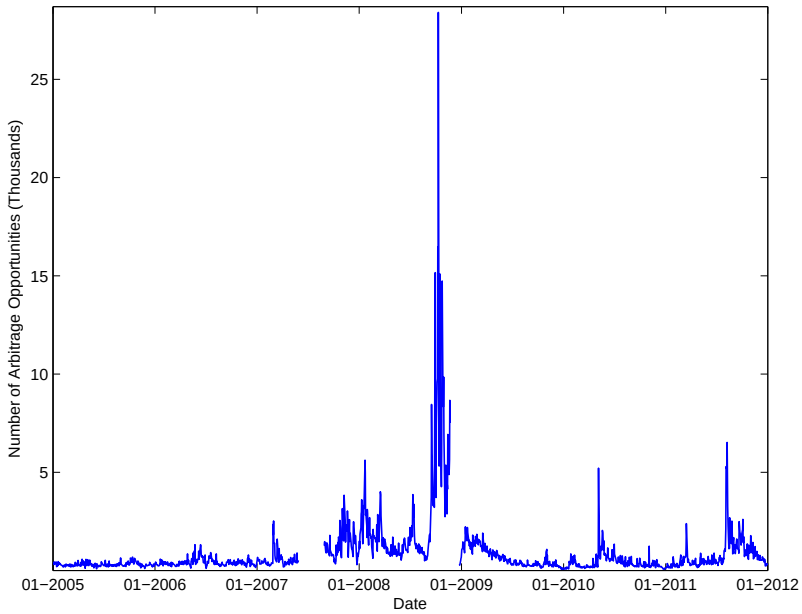
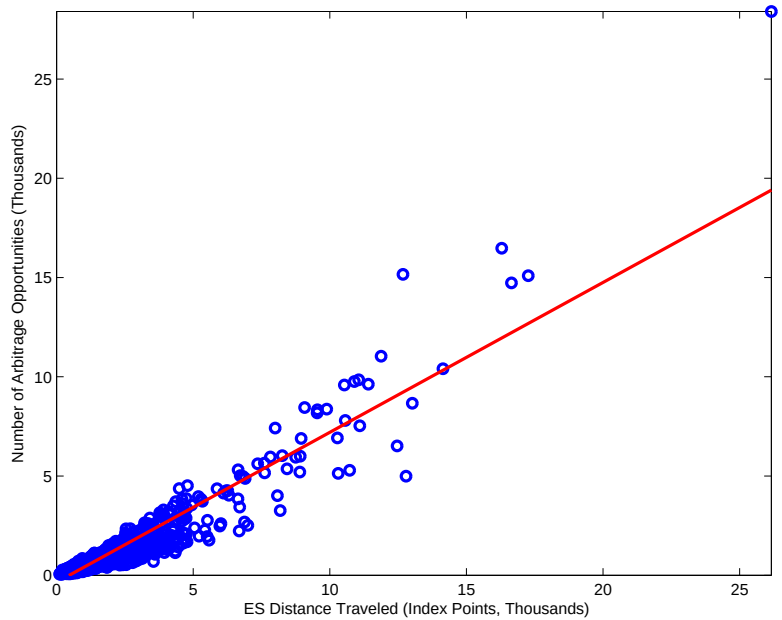
Arb Frequency over Time: 2005-2011



(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

E-mini S&P 500 Futures (ES) vs. SPDR S&P 500 ETF (SPY)
E-mini S&P 500 Futures (ES) vs. iShares S&P 500 ETF (IVV)
E-mini S&P 500 Futures (ES) vs. Vanguard S&P 500 ETF (VOO)
E-mini S&P 500 Futures (ES) vs. ProShares Ultra (2x) S&P 500 ETF (SSO)
E-mini S&P 500 Futures (ES) vs. ProShares UltraPro (3x) S&P 500 ETF (UPRO)
E-mini S&P 500 Futures (ES) vs. ProShares Short S&P 500 ETF (SH)
E-mini S&P 500 Futures (ES) vs. ProShares Ultra (2x) Short S&P 500 ETF (SDS)
E-mini S&P 500 Futures (ES) vs. ProShares UltraPro (3x) Short S&P 500 ETF (SPXU)
E-mini S&P 500 Futures (ES) vs. 500 Constituent Stocks
E-mini S&P 500 Futures (ES) vs. 9 Select Sector SPDR ETFs
E-mini S&P 500 Futures (ES) vs. E-mini Dow Futures (YM)
E-mini S&P 500 Futures (ES) vs. E-mini Nasdaq 100 Futures (NQ)
E-mini S&P 500 Futures (ES) vs. E-mini S&P MidCap 400 Futures (EMD)
E-mini S&P 500 Futures (ES) vs. Russell 2000 Index Mini Futures (TF)
E-mini Dow Futures (YM) vs. SPDR Dow Jones Industrial Average ETF (DIA)
E-mini Dow Futures (YM) vs. ProShares Ultra (2x) Dow 30 ETF (DDM)
E-mini Dow Futures (YM) vs. ProShares UltraPro (3x) Dow 30 ETF (UDOW)
E-mini Dow Futures (YM) vs. ProShares Short Dow 30 ETF (DOG)
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E-mini Dow Futures (YM) vs. 30 Constituent Stocks
E-mini Nasdaq 100 Futures (NQ) vs. ProShares QQQ Trust ETF (QQQ)
E-mini Nasdaq 100 Futures (NQ) vs. Technology Select Sector SPDR (XLK)
E-mini Nasdaq 100 Futures (NQ) vs. 100 Constituent Stocks
Russell 2000 Index Mini Futures (TF) vs. iShares Russell 2000 ETF (IWM)
Euro Stoxx 50 Futures (FESX) vs. Xetra DAX Futures (FDAX)
Euro Stoxx 50 Futures (FESX) vs. CAC 40 Futures (FCE)
Euro Stoxx 50 Futures (FESX) vs. iShares MSCI EAFE Index Fund (EFA)
Nikkei 225 Futures (NIY) vs. MSCI Japan Index Fund (EWJ)
Financial Sector SPDR (XLF) vs. Constituents
Financial Sector SPDR (XLF) vs. Direxion Daily Financial Bull 3x (FAS)
Energy Sector SPDR (XLE) vs. Constituents
Industrial Sector SPDR (XLI) vs. Constituents
Cons. Staples Sector SPDR (XLP) vs. Constituents
Materials Sector SPDR (XLB) vs. Constituents
Utilities Sector SPDR (XLU) vs. Constituents
Technology Sector SPDR (XLK) vs. Constituents
Health Care Sector SPDR (XLV) vs. Constituents
Cons. Discretionary Sector SPDR (XLY) vs. Constituents
SPDR Homebuilders ETF (XHB) vs. Constituents
SPDR S&P 500 Retail ETF (XRT) vs. Constituents
Euro FX Futures (6E) vs. Spot EURUSD
Japanese Yen Futures (6J) vs. Spot USDJPY
British Pound Futures (6B) vs. Spot GBPUSD
Australian Dollar Futures (6B) vs. Spot AUDUSD
Swiss Franc Futures (6S) vs. Spot USDCHF
Canadian Dollar Futures (6C) vs. Spot USDCAD
Gold Futures (GC) vs. miNY Gold Futures (QO)
Gold Futures (GC) vs. Spot Gold (XAUUSD)
Gold Futures (GC) vs. E-micro Gold Futures (MGC)
Gold Futures (GC) vs. SPDR Gold Trust (GLD)
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E-micro Gold Futures (MGC) vs. Spot Gold (XAUUSD)
Market Vectors Gold Miners (GDX) vs. Direxion Daily Gold Miners Bull 3x (NUGT)
Silver Futures (SI) vs. miNY Silver Futures (QI)
Silver Futures (SI) vs. iShares Silver Trust (SLV)
Silver Futures (SI) vs. Spot Silver (XAGUSD)
miNY Silver Futures (QI) vs. iShares Silver Trust (SLV)
miNY Silver Futures (QI) vs. Spot Silver (XAGUSD)
Platinum Futures (PL) vs. Spot Platinum (XPTUSD)
Palladium Futures (PA) vs. Spot Palladium (XPDUSD)
Eurodollar Futures Front Month (ED) vs. (12 back month contracts)
10 Yr Treasury Note Futures (ZN) vs. 5 Yr Treasury Note Futures (ZF)
10 Yr Treasury Note Futures (ZN) vs. 30 Yr Treasury Bond Futures (ZB)
10 Yr Treasury Note Futures (ZN) vs. 7-10 Yr Treasury Note
2 Yr Treasury Note Futures (ZT) vs. 1-2 Yr Treasury Note
2 Yr Treasury Note Futures (ZT) vs. iShares Barclays 1-3 Yr Treasury Fund (SHY)
5 Yr Treasury Note Futures (ZF) vs. 4-5 Yr Treasury Note
30 Yr Treasury Bond Futures (ZB) vs. iShares Barclays 20 Yr Treasury Fund (TLT)
30 Yr Treasury Bond Futures (ZB) vs. ProShares UltraShort 20 Yr Treasury Fund (TBT)
30 Yr Treasury Bond Futures (ZB) vs. ProShares Short 20 Year Treasury Fund (TBF)
30 Yr Treasury Bond Futures (ZB) vs. 15+ Yr Treasury Bond
Crude Oil Futures Front Month (CL) vs. (6 back month contracts)
Crude Oil Futures (CL) vs. ICE Brent Crude (B)
Crude Oil Futures (CL) vs. United States Oil Fund (USO)
Crude Oil Futures (CL) vs. ProShares Ultra DJ-UBS Crude Oil (UCO)
Crude Oil Futures (CL) vs. iPath S&P Crude Oil Index (OIL)
ICE Brent Crude Front Month (B) vs. (6 back month contracts)
ICE Brent Crude (B) vs. United States Oil Fund (USO)
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ICE Brent Crude (B) vs. iPath S&P Crude Oil Index (OIL)
Natural Gas (Henry Hub) Futures (NG) vs. United States Nat Gas Fund (UNG)

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  - Even if they are all equally fast!
- 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

Model: Additional Remarks

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 improvments (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

Model: Additional Remarks

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 inequilibrium 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 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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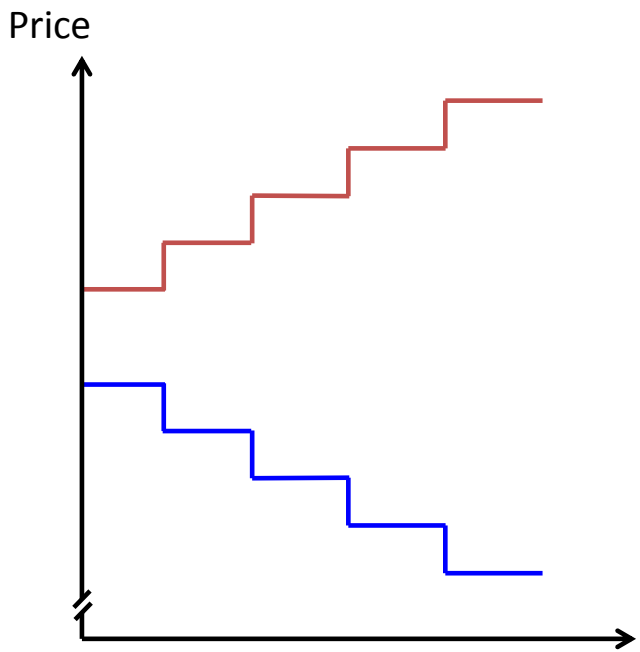
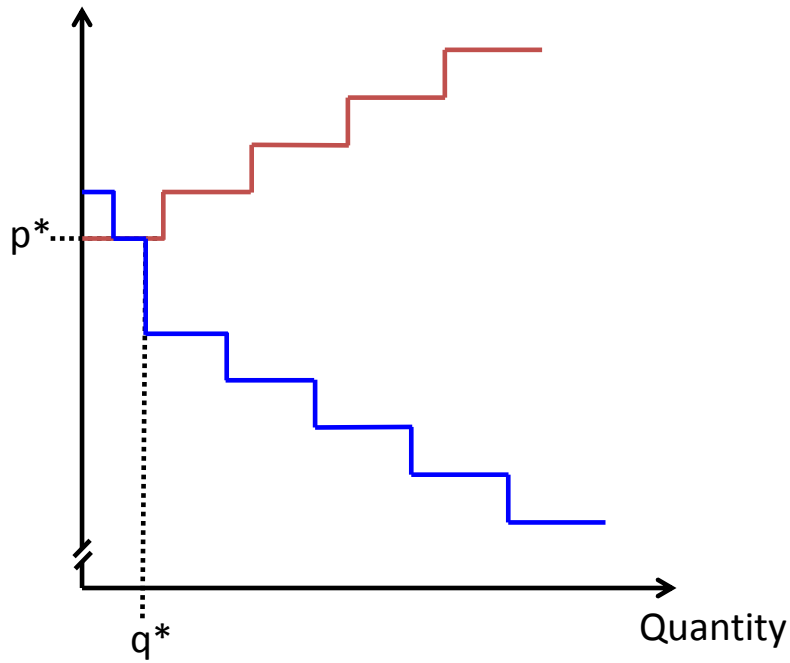
Frequent Batch Auctions: Definition

- During the batch interval (eg 1 second), traders submits 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

Why and How Batching Eliminates the Arms Race

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 $\rightarrow$ Technical arbitrage opportunities $\rightarrow$ Arms Race. Arms Race is a "constant" of the market design.
3. 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
   - Costs: investors must wait a small amount of time to trade, law of unintended consequences