A Theory of Stock Exchange Competition and Innovation: Will the Market Fix the Market?

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- This paper studies the incentives of exchanges to innovate to address latency arbitrage and the arms race for speed

SEC Chair Mary Jo White, June 2014

"Enhancing Our Equity Market Structure"

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Private vs. Social Returns to Market Design Innovation

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  - (e.g., Arrow 1962, Nordhaus 1969, Hirshleifer 1971, Mankiw Whinston 1986, ...)
- This paper's insight: incumbents' private innovation incentives misaligned with social *precisely because they earn rents from the arms race.*

1. **A Theory of Status Quo Competition Among Exchanges**
   - **Synthesized single exchange**
   - **Competitive trading fees**
   - **Economic profits from speed technology that are not dissipated**
2. Empirical Validation of the Theory
3. Incentives for Market Design Innovation

Institutional Background: Key Regulations

Two key regulations shape modern electronic stock exchange competition in the US:

- Unlisted Trading Privileges (UTP)
  - Any stock can be bought or sold on any exchange
  - Model: same asset trades on all exchanges, *perfectly fungible*
- Regulation National Market System (Reg NMS)
  - Order Protection Rule: roughly, on an order-by-order basis, transaction must execute at exchange(s) with best quote
  - Dissemination and Access Rules: exchanges must make quotes easily electronically accessible.
  - Model: *frictionless search and access*
- Contrast with
  - Futures exchanges (no fungibility), Uber/Lyft (no frictionless multi-homing), Pagano-style models (single-homing)

Model of the Status Quo: Plan

- Point of departure: Budish, Cramton and Shim (2015) model
- Add 3 things:
  1. Informed traders, Glosten-Milgrom style
  2. Multiple exchanges
     - Exchanges strategic
     - Trading across the multiple exchanges shaped by UTP, Reg NMS
  3. New solution concept, Order Book Equilibrium (see paper)
- (Note: model is of regular-hours trading. Not opening/closing auctions, nor role of listings.)

Model of the Status Quo: Game Timing

- **STAGE 1:** Exchanges set prices. Trading fees f_j, exchange-specific speed technology fees F_j.
- **STAGE 2:** Speed technology adoption. TFs choose where to buy ESST.
- **STAGE 3:** Infinitely repeated Trading Game:
  - Publicly observed state at start of trading game: value y, state of order books ω.
  - Period 1: Trading firms submit limit orders to exchanges
    - E.g., offer to buy q shares at $y - \frac{s}{2}$, sell q at $y + \frac{s}{2}$
    - Serial processing at each exchange. Updated ω public.
  - Period 2: Nature selects one of four events:
    1. λ_{invest} : an investor arrives and can trade on all exchanges
    2. $\lambda_{private}$: an informed trader privately observes a jump in y, and can trade on all exchanges; information about y then revealed
    3. λ_{public}: there is a publicly observed jump in y, and TFs engage in "sniping race" on all exchanges
    4. $1 - \lambda_{invest} - \lambda_{private} - \lambda_{public}$: nothing happens

Equilibrium Properties I: Single Synthesized Exchange

- In Stage 3, the seemingly fragmented exchanges "aggregate up" into a *single synthesized exchange*
  - Frictionless search and access -> all liquidity competed down to the same bid-ask spread across all exchanges
  - One-for-one relationship between depth and volume ensures the marginal unit of liquidity is equally attractive on all exchanges. (See Glosten 1994; Ellison Fudenberg 2003)

- Key economic point: frictionless search very different economically from "standard" platform competition (Rochet and Tirole 03, Armstrong 06)
  - E.g., can show strictly positive frictions leads to tipping
  - Analogy: Diamond (1971) search model. Large economic difference between 0 and ϵ

Equilibrium Properties II: Competitive Trading Fees

- Frictionless search and access -> Bertrand competition on trading fees
  - Investors are perfectly elastic w.r.t. spreads and trading fees.
  - Hence, if $f_j > f_k$, then any trading firm providing liquidity on j can more profitably provide on k.
- Contrast: models with single-homing -> network effects -> supra-competitive trading fees (e.g., Pagano 1989, Cantillon-Yin 2008)

Equilibrium Properties III: Will Trading Fees Go Negative?

- If exchanges make positive profits from selling ESST, will they dissipate these rents in competition for share by setting *negative* trading fees ($\mathbf{f} < 0$)?
  - In standard add-on pricing models firms that anticipate monopoly rents in an add-on good dissipate these rents in competition to sell the pre-add-on good
    - Ex: printers and cartridges, hotels and minibars
    - (see Ellison 2005, Gabaix-Laibson 2006)

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    - (see Ellison 2005, Gabaix-Laibson 2006)
- No. Difference here: *binding money pump constraint*.
  - Marginal costs to execute a trade are extremely low (modeled as zero). To dissipate rents would require negative prices.
  - But a negative price creates an obvious money pump: TFs will execute ∞ trades

Equilibrium Properties IV: Division of Latency Arb Rents

- Exchanges capture rents via positive ESST fees $\mathbf{F}^*$. These are not dissipated.
  - Intuition: even though stocks are fungible across exchanges, *latency sensitive trading opportunities are not*

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- Yet, even as price-setters in Stage 1, exchanges cannot extract *all* sniping rents:
  - Intuition: TFs can steer volume by providing good liquidity
  - Formally: "lone-wolf" deviation. We show that this is the most attractive deviation in Stage 2, so ruling it out is sufficient.
- Upper bound on total ESST revenues: $\frac{M}{(M-1)(N-1)}\Pi(s^*)$. ("30%")
- Model delivers *strictly interior split of latency arbitrage rents.*

1. A Theory of Status Quo Competition Among Exchanges
2. **Empirical Validation of the Theory**
3. Incentives for Market Design Innovation

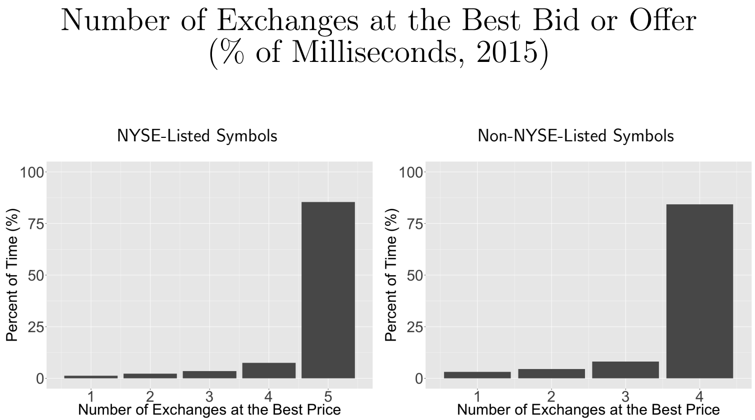
Empirical Validation of the Model

1. **Evidence on Stage 3 Trading Game**
   - **Stylized Fact #1: Many exchanges simultaneously at the best bid and best offer**
   - **Stylized Fact #2: Linear depth-volume relationship**
   - **Stylized Fact #3: Market shares interior and relatively stable**

2. Evidence on Exchange Trading Fees (f)

3. Evidence on Exchange-Specific Speed Technology Fees (F)

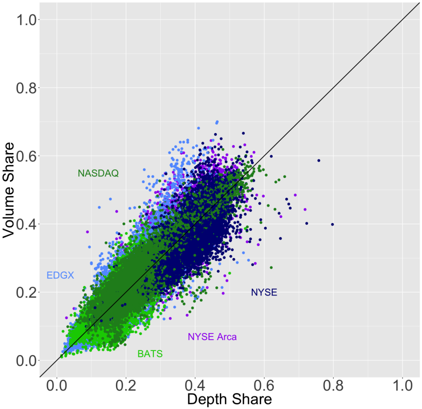
Fact #1: Many Exchanges at the Same Best Price



Data: NYSE TAQ. Top 5 exchanges, Top 100 symbols, all milliseconds in 2015.

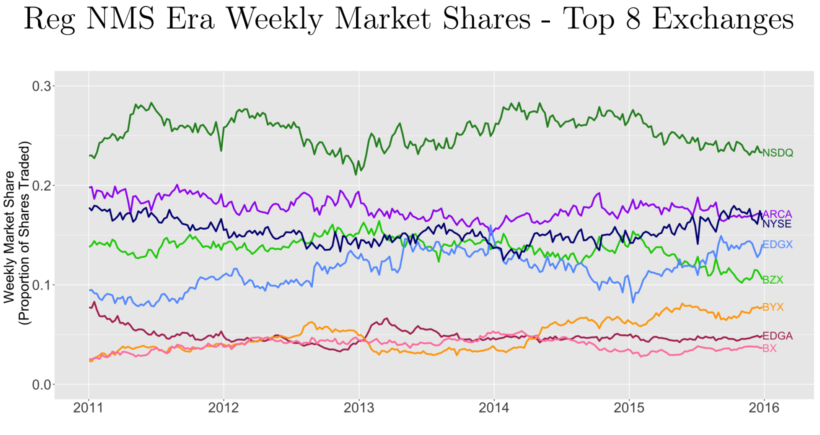
Fact #2: Linear Depth-Volume Relationship

Daily Volume Share vs. Depth Share – 2015



Data: NYSE TAQ. Top 5 exchanges, Top 100 symbols, all dates in 2015.

Fact #3: Exchange Shares Interior & Relatively Stable

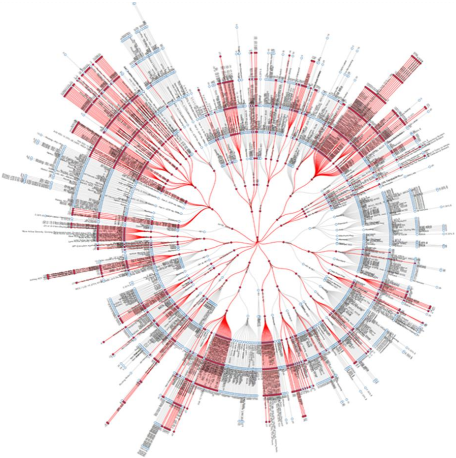


Data: NYSE TAQ. Top 8 exchanges, all symbols, from January 1, 2011 to December 31, 2015.

Empirical Validation of the Model

1. Evidence on Stage 3 Trading Game
2. **Evidence on Exchange Trading Fees (f)**
   - **Stylized Fact #4: Average trading fees are economically small**
   - **Stylized Fact #5: Money-Pump constraint binds**
3. Evidence on Exchange-Specific Speed Technology Fees (F)

Trading Fees: Complexity of Exchange Fees



Notes: From RBC Capital Markets, "Complexity of Exchange Pricing and Corresponding Challenges to Transparency and Routing," (February 2016). RBC's visual representation of exchange trading and routing fees by tier as of October 2015. Each path from the center node to an extreme node indicates a particular fee scenario, characterized by exchange, share price, transaction type (adding or removing liquidity), market participant type, market participant ADV, security listing exchange, other factors, and a fee or rebate. Red indicates rebate, blue indicates fee.

Trading Fees: Complexity of Exchange Fees

Bats BZX Exchange Fee Schedule

Effective April 12, 2017

Transaction Fees:

- Rebates indicated by parentheses ( ).
- The rates listed in the Standard Rates table apply unless a Member's transaction is assigned a fee code other than a standard fee code. If a Member's transaction is assigned a fee code other than a standard fee code, the rates listed in the Fee Codes table will apply.
- Footnotes provide further explanatory text or, where annotated to fee codes, indicate variable rate changes, provided the conditions in the footnote are met.
- Unless otherwise noted, all routing fees or rebates in the Fee Codes and Associated Fees table are for removing liquidity from the destination venue.

Standard Rates:

Category	Adding Liquidity	Removing Liquidity	Routing and Removing Liquidity
Securities at or above $1.00	($0.0020) ($0.0025)	$0.0030	$0.0030
Securities below $1.00	Free	0.30% of total dollar value	0.30% of total dollar value
Standard Fee Codes	B, V, Y	N, W, BB	X

[1] Add Volume Tiers

Applicable to the following fee codes: B, V and Y.

Tier	Rebate Per Share to Add	Member has an ADAV as a percentage of TCV ≥
Tier 1	($0.0025)	0.10%
Tier 2	($0.0028)	0.20%
Tier 3	($0.0029)	0.30%
Tier 4	($0.0030)	0.50%
Tier 5	($0.0031)	1.00%
Tier 6	($0.0032)	1.25%

Fee Codes and Associated Fees:

Apr 22, 2017 | Download CSV | Copy To Clipboard

Fee Code	Description	Fee/(Rebate)
10[10]	Routed to NYSE Arca, adds liquidity (Tape B)	(0.00220)
8[10]	Routed to NYSE MKT, adds liquidity	(0.00150)
9[10]	Routed to NYSE Arca, adds liquidity (Tapes A or C)	(0.00210)
A[10]	Routed to NASDAQ, adds liquidity	(0.00150)
AA[15]	Routed to EDGA using ALLB routing strategy	(0.00020)
AC[14]	Closing Auction, BZX listed security	0.00100
AL[14]	Closing Auction, Late-Limit-On-Close order, BZX listed security	FREE
AN[14]	Continuous Book Order that executed in the Opening or Closing Auction, BZX listed security	FREE
AO	Opening, IPO or Halt Auction, BZX listed security	0.00050
AP	Opening, IPO or Halt Auction, Late-Limit-On-Open order, BZX listed security	FREE
AX[16]	Routed to EDGX using ALLB routing strategy	0.00290
AY[17]	Routed to BYX using ALLB routing strategy	(0.00150)
B[1,2,3,4,7,12,13,14,19]	Displayed order, adds liquidity to BZX (Tape B)	(0.00250)
BA	Routed to NYSE Arca using Destination Specific routing strategy (Tape B)	0.00270
BB[3,8,14]	Removes liquidity from BZX (Tape B)	0.00300
BJ	Routed to EDGA using TRIM or TRIM2 routing strategy	(0.00020)
BO	Routed using Destination Specific routing strategy unless otherwise specified	0.00300
BY	Routed to BYX using Destination Specific, TRIM, TRIM2 or SLIM routing strategy	(0.00150)
CL	Routed to listing market closing process	0.00100
D	Routed to NYSE using Destination Specific, RDOT, RDOX, TRIM or SLIM routing strategy	0.00265
F[10]	Routed to NYSE, adds liquidity	(0.00150)
G	Routed to NYSE Arca using Destination Specific routing strategy (Tapes A or C)	0.00290
HA[1,5,7]	Non-displayed order, adds liquidity	(0.00170)
HI[5,7]	Non-displayed order that receives price improvement, adds liquidity	FREE
J	Routed to NASDAQ using Destination Specific or INET routing strategy	0.00290
N[3,8]	Removes liquidity from BZX (Tape C)	0.00300
NA[10]	Routed to EDGX, NYSE, NYSE Arca, NYSE MKT or Nasdaq; adds non-displayed liquidity	FREE
NB[18]	Routed to any exchange not covered by Fee Code NA, adds non-displayed liquidity	0.00300
O	Routed to listing market opening or re-opening cross	0.00150
OO	BZX Opening or Re-opening, non-BZX listed security	0.00050
P[10]	Routed to EDGX, adds liquidity	(0.00200)
R	Re-routed by NYSE using RDOT, RDOX or Post to Away routing strategy	0.00300
RA[10]	Routed to EDGA, adds liquidity	0.00050
RB[10]	Routed to NASDAQ BX, adds liquidity	0.00200
RN	Routed to NASDAQ using ROOC routing strategy, adds liquidity	(0.00150)
RP[7]	Non-displayed order, adds liquidity using Supplemental Peg	(0.00170)
RY[10]	Routed to BYX, adds liquidity	0.00180
S	Directed ISO	0.00330
SW[9]	Routed using Parallel T or SWPA/B routing strategy	0.00330
SX	Routed using SLIM routing strategy (except to BYX or NYSE)	0.00260
TV	Routed to NASDAQ BX using TRIM or TRIM2 routing strategy	(0.00100)
V[1,2,3,4,7,19]	Displayed order, adds liquidity to BZX (Tape A)	(0.00200)
VI	Displayed order subject to price sliding that receives price improvement, adds liquidity	FREE
W[3,8]	Removes liquidity from BZX (Tape A)	0.00300
X[8]	Routed to a displayed market to remove liquidity using Parallel D, Parallel 2D, ROUT, ROUX or Post to Away routing strategy	0.00300
Y[1,2,3,4,7,19]	Displayed order, adds liquidity to BZX (Tape C)	(0.00200)
Z	Routed to a dark liquidity venue (except through SLIM)	0.00280
ZA[7,11]	Retail Order, adds liquidity	(0.00320)
ZR[8]	Retail Order, removes liquidity	0.00300

Fact #4: Average Trading Fees are Small

Estimate of average regular-hours trading fees ("f")
(3 major exchange families)

Exchange Family	f
NYSE	\$0.000128
NASDAQ	0.000105
BATS	0.000089

Data: Exchange 10-K and S-1 filings, exchange fee schedules, NYSE TAQ, and other sources. Please see Appendix B.

Fact #5: Money Pump Constraint Binds

U.S. Equity Exchange Trading Fees Per Share ("f")

		Taker Fee		Maker Fee		Total fee per share per side	
Exchange	Fee Type	Min	Max	Min	Max	Min	Max
NASDAQ	Maker-Taker	0.00300	0.00300	-0.00325	-0.00150	-0.00013	0.00075
BATS BZX	Maker-Taker	0.00300	0.00300	-0.00320	-0.00200	-0.00010	0.00050
EDGX	Maker-Taker	0.00300	0.00300	-0.00320	-0.00200	-0.00010	0.00050
NYSE	Maker-Taker	0.00270	0.00270	-0.00220	-0.00140	0.00025	0.00065
NYSE Arca	Maker-Taker	0.00280	0.00300	-0.00270	-0.00200	0.00005	0.00050
BATS BYX	Taker-Maker	-0.00160	-0.00160	0.00140	0.00180	-0.00010	0.00010
EDGA	Taker-Maker	-0.00020	-0.00020	0.00030	0.00050	0.00005	0.00015
NASDAQ BX	Taker-Maker	-0.00150	-0.00040	0.00165	0.00200	0.00008	0.00080

Data: Data: Exchange fee schedules obtained via Internet Archive dated from February 28, 2015 to September 1, 2015.

Empirical Validation of the Model

1. Evidence on Stage 3 Trading Game
2. Evidence on Exchange Trading Fees (f)
3. **Evidence on Exchange-Specific Speed Technology Fees (F)**
   - **Stylized Fact #6: Exchanges earn significant revenue from ESST**
   - **Stylized Fact #7: ESST revenue has grown significantly in the Reg NMS era**

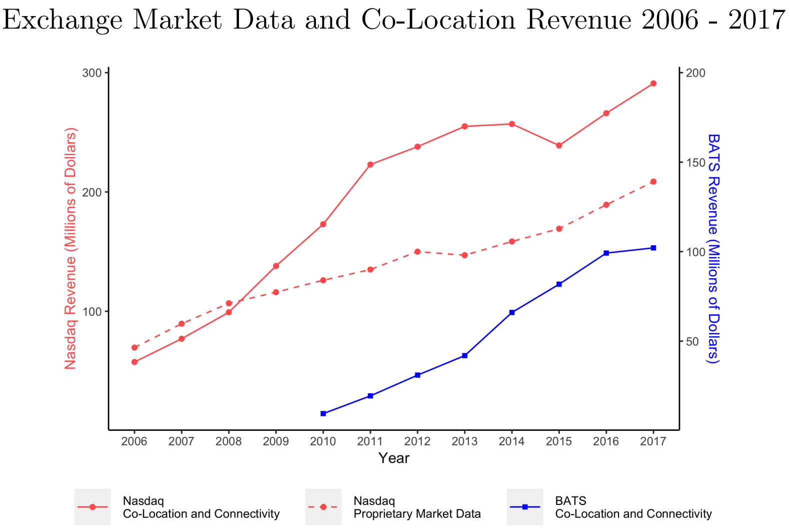
Fact #6: Exchanges Earn Significant Revenues from Speed Technology

Estimated Market Data and Co-Location Revenues for U.S. Equities Market in 2015 (Millions of Dollars)

	BATS	NASDAQ	NYSE	Total
Market Data Revenue	114.1	222.4 – 267.3	218.9 – 241.5	555.4 – 623.0
Co-Location/Connectivity Revenue	64.3	121.0 – 139.0	251.6 – 281.5	436.8 – 484.8
Market Data + Co-Location Revenue	178.4	343.3 – 406.4	470.5 – 523.0	992.2 – 1107.8
CTA/UTP Tape Revenue				317.0
Market Data + Co-Lo Revenue net of Tape Revenue				675.2 – 790.8

Data: Exchange 10-K and S-1 filings, CTA fee-change filing. Please see Appendix D.

Fact #7: Exchange Speed Technology Revenue has Grown Significantly since Reg NMS



Data: Exchange 10-K, S-1 and merger proxy filings. Please see Appendix D.

Empirical Validation: Summary of Main Results

- Overall fit is pretty good, especially for such a simple model.
- Also note that data is not consistent with other potential models of exchange competition (most not specifically tailored to US stock exchanges)
- Models with single-homing, network effects (Pagano 1989, Cantillon and Yin 2008, Pagnotta and Philippon 2018)
    - Exchanges will charge supra-competitive trading fees
    - Network effects often lead to tipping
- Models in which exchanges are meaningfully differentiated (Pagnotta and Philippon 2018, Baldauf and Mollner 2018)
    - Exchanges will charge supra-competitive trading fees
    - Differentiation leads to segmentation – who and what trade where
- Models in which tick-size frictions are central to understanding exchange fragmentation and competition (Chao, Yao and Ye 2019)

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Incentives for Market Design Innovation

- Now we study the incentives for market design innovation: "will the market fix the market?"
  - What are the private incentives for an exchange to adopt a new market design that eliminates latency arbitrage and the speed race?
  - Focus on frequent batch auctions ("Discrete") with very short time interval

- We analyze this question in 3 steps:
  1. "Continuous" vs. "Discrete"
  2. "Discrete" vs. "Discrete"
  3. Use analyses of Continuous vs. Continuous (status quo), Continuous vs. Discrete, and Discrete vs. Discrete to study the incentives to adopt. Consider both de novo and incumbents.

Frequent Batch Auctions ("Discrete")

- Time in discrete units
  - In context of competition among exchanges, time interval very fast, e.g. 1 millisecond or potentially even finer
  - Long enough for a computer to batch process if multiple TFs act at "the same time" in response to public information
  - Short enough that an investor does not care about delay per se, only the price they pay
- Orders are just as in continuous market
  - price, quantity, buy/sell
  - remain outstanding until either executed or canceled
- At end of each discrete interval, FBA processes new orders alongside outstanding orders from before using uniform-price auction.
  - Priority is price then (discrete) time
  - Information policy: at end of each time interval, publicly announce any trades and updated state of the order book

Continuous vs. Discrete: Model

- **STAGE 1**: Continuous and discrete choose trading fees f. Continuous chooses ESST fees F; discrete does not sell ESST
- **STAGE 2**: N TFs choose whether to purchase ESST on continuous. On discrete, no decision to make.
- **STAGE 3 [Repeated]**: Trading game, essentially as before
  - Only modeling difference: if multiple orders received at the same time (e.g., after public news), discrete processes these orders in batch, using a uniform-price auction, rather than serially. This eliminates latency arbitrage.
  - Same as before: Investors / Informed traders can trade on all venues before others act in response. Justified by fast discrete time interval (e.g., 1 millisecond).

Continuous vs. Discrete: Bid-Ask Spreads

- Recall: equilibrium spread for Continuous with fee of zero (or set of multiple competing Continuous) is characterized by

$$\lambda_{invest}\frac{s^*_{continuous}}{2} = (\lambda_{public} + \lambda_{private})L(s^*_{continuous})$$

where $L(s) \equiv Pr(J > \frac{s}{2})E(J - \frac{s}{2}|J > \frac{s}{2})$

- If a single Discrete exchange operated in isolation w/ trading fee of zero, equilibrium spread:

$$\lambda_{invest}\frac{s^*_{discrete}}{2} = (\lambda_{private})L(s^*_{discrete})$$

where $s^*_{discrete} < s^*_{continuous}$. Eliminating sniping reduces the spread. Like eliminating a tax on liquidity.

Continuous vs. Discrete: Equilibrium

Proposition: In *any* equilibrium of the multi-exchange game among a single Continuous and a single Discrete exchange:

Continuous vs. Discrete: Equilibrium

Proposition: In *any* equilibrium of the multi-exchange game among a single Continuous and a single Discrete exchange:

- Discrete gets 100% share: in every iteration of the trading game, exactly one unit of liquidity is provided on Discrete, and no liquidity is provided on Continuous
- Continuous earns zero profits
- Discrete charges strictly positive trading fees and earns expected per-trading-game profits that exceed $\frac{N-1}{N}\Pi^*_{continuous}$
- Intuition:
  - Eliminating latency arbitrage like eliminating a tax on liquidity
  - Frictionless search and access -> if two markets operate in parallel, one with a tax and one without, the one without the tax wins.
- Caveat: please do not take 100% literally (tick constraints, agency frictions. See Appendix E).

Discrete vs. Discrete

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Discrete vs. Discrete

Proposition: In *any* equilibrium of the multi-exchange game with at least two Discrete exchanges:

- At least one Discrete charges zero trading fees
- Volume split across Discrete exchanges that charge zero
- All exchanges and trading firms earn zero profits

- Interior equilibria just like C vs. C, also with Bertrand competition on fees ... but now no ESST fees.

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Exchange A \ Exchange B	C	D
C	A: NF_A^*; B: NF_B^*	A: 0; B: Π^D
D	A: Π^D; B: 0	A: (only ancillary revenues); B: (only ancillary revenues)

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  Technologically, we could do it. ***The big issue,*** *one of the big issues for us, when I talked about cost, the cost we would bear,* ***would be getting [the SEC] to approve it, which would take a lot of time and effort, and if we got it approved, it would immediately be copied by everybody else****. . . .* ***So we would have essentially no first-mover advantage*** *if we put it in there,* ***we would have no incentive to go through the lift of creating [the new market design].***

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- These gaps suggest it is possible that private-market forces alone may not solve the problem. Private $<<<$ social.
  - On the other hand, analysis suggests that if there is an entrant, will gain share.
  - Implication: "push".

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- Many directions for future research