Competing on Speed

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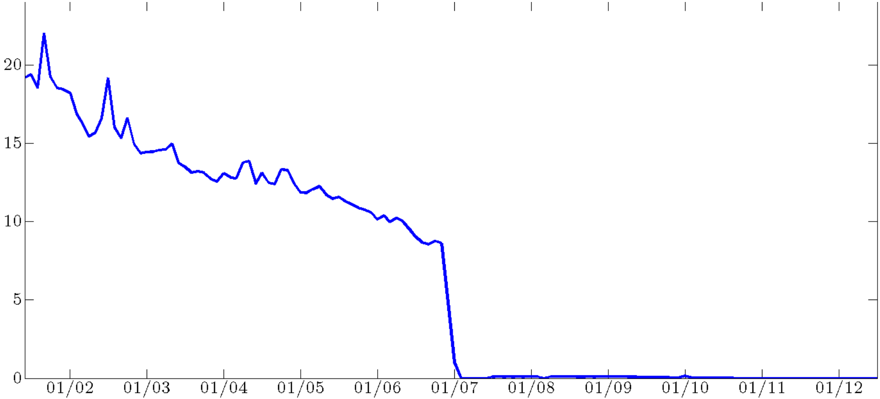
June 7, 2013

1.a Speed ↗

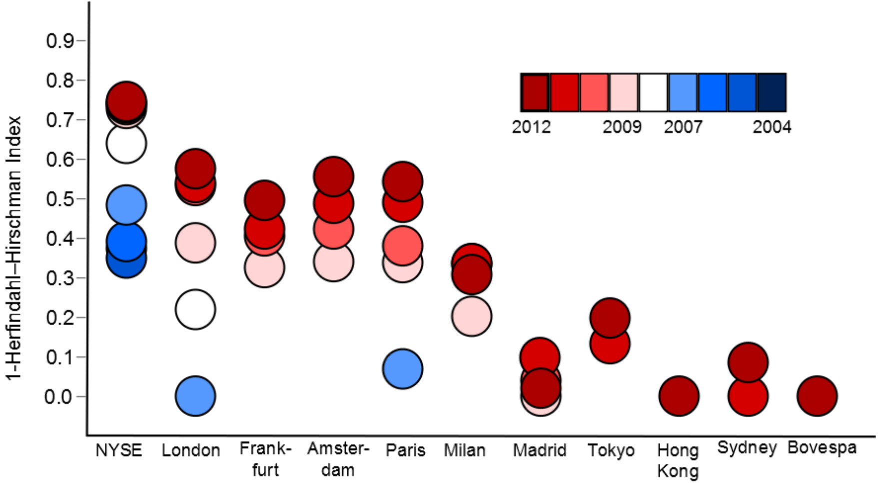


Avg. Execution Speed NYSE in seconds (Source: SEC Rule 605)

1.b Speed ↗

Arctic Fibre shaves 60ms London-Tokyo, cutting through icebergs

2. Fragmentation ↗



Issue & Analytical Approach

Financial Markets Organization

- Why do exchanges compete on speed?
- Both execution speed and fragmentation increased, is there a relationship?

Normative:

- Social value of exchanges speed investments?
- Is fragmentation socially desirable?
- Optimal Regulation?

Key insight

- **All investors value speed, but not equally $\Rightarrow$ Speed acts as (vertical) differentiation factor**
- Emphasis on liquidity and gains from trade, abstracts from asymmetric info, liquidity externalities

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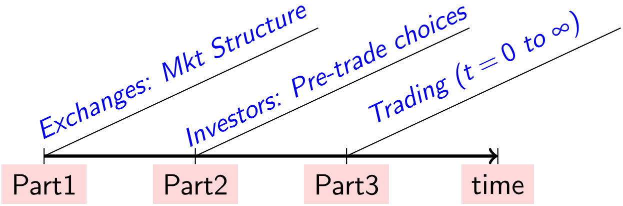
Main Findings

- **Speed-Enhancing Investments**
  - Accelerate fragmentation
  - Welfare effects are positive in single exchange economies and ambiguous otherwise
- **Fragmentation**:
  - Incentivizes trading speeds
  - Enhances "market quality" (evidence in O'Hara Ye 2011) and investor participation, but not necessarily higher welfare
- **Regulations** that protect executions (*SEC's trade-through*) distort competition, increase fragmentation and may have *negative welfare effects*

Model Structure and Presentation Plan



1. Trading Model
2. Outcomes in Consolidated Market
3. Outcomes in Fragmented Markets
4. Calibration and Empirical Implications

1. Trading in one market (time 0 to ∞)

Micro foundations of Speed Demand

- Two assets: cash (yields r). Illiquid asset yields μ per unit of time, total supply $\bar{a}$. Holdings a in $\{0,1\}$.
- Mass one continuum of investors. Fraction $\bar{a}$ initially endowed with 1 unit asset. Flow utility

$$u_{\sigma,\varepsilon_t}(a_t) = (\mu + \sigma\varepsilon_t)\, a_t$$

  - time-varying type ε in $\{+,-\}$, times$\sim \exp(\gamma)$, $\Pr_{\{\varepsilon=+\}} = 1/2$
  - fixed type $\sigma \in [0,\bar{\sigma}]$ CDF G (can see as brokers' "clienteles")
- Trading
  - Contact rate (speed) is ρ (i.e. "latency" ρ^{-1})
  - Conditional on contact, market is Walrasian

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- **Value function** $(\sigma, \varepsilon(t))$ holding a: $V_{\sigma,\varepsilon(t)}(a,t) =$

$$\mathbb{E}_t \left[\underbrace{\int_t^T e^{-r(s-t)} u_{\sigma,\varepsilon(s)}(a) ds}_{\text{Flows until contact}} + \underbrace{e^{-r(T-t)} \left(V_{\sigma,\varepsilon(T)}(a_T^*, T) - p_T (a_T^* - a) \right)}_{\text{Cont. value at time-T contact}} \right]$$

- **Optimal holdings** have recursive structure (similar to Lagos Rocheteau (EMA 2009)):

$$a^*(p; \sigma, \varepsilon) = \arg \max_{a \in \{0,1\}} \{ \bar{u}(a; \sigma, \varepsilon) - rpa \}$$

$$\bar{u}(a; \sigma, \varepsilon) \equiv \frac{(r+\rho) u_{\sigma,\varepsilon}(a) + \gamma \mathbb{E}_\varepsilon [u_{\sigma,\varepsilon'}(a)]}{r+\rho+\gamma}$$

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- **Supply:** $\bar{a} \leq 1/2$. Since 1/2 investors have $\varepsilon = +1$, supply is short.
- **Investors**: Let $\hat{\sigma} > 0$ type indifferent on buying when $\varepsilon = 1$
  - "*Active*" $\sigma \geq \hat{\sigma}$: buy when $\varepsilon = 1$, sell when $\varepsilon = -1$
  - "*Transient*/Small" $\sigma < \hat{\sigma}$: sell initial holdings and leave
- **Demand Functions**: $a^* = 0$ when $\varepsilon = -1$ or $\sigma < \hat{\sigma}$; $a^* = 1$ when $\varepsilon = +1$ and $\sigma \geq \hat{\sigma}$
- **Market Clearing**: $\frac{1}{2} \int_\sigma \sum_\varepsilon a^* (p; \sigma, \varepsilon)\, dG(\sigma) = \bar{a}$
- **Equilibrium**: $(p, \hat{\sigma})$ solving demand system and market clearing.

Define "effective speed" $s \equiv \frac{\rho}{r+\gamma+\rho}$

Result: Trading Equilibrium

- **Allocations**: Fraction of active traders with mis-allocated assets converges to $\frac{\gamma}{4}\frac{(1-s)}{\gamma+rs}$
- **Clearing Price**:

$$p = \frac{\mu}{r} + \frac{\hat{\sigma}}{r}\left(\frac{r+\gamma s}{r+\gamma}\right)$$

  - With full (limited) participation $\hat{\sigma} = (>) G^{-1}(1-2\bar{a})$.
  - p constant a.s. given ε stationarity
  - **Walrasian Limit:** $\rho \to \infty$ + free access $\Rightarrow$ $p \to p_W = \frac{1}{r}\left[\mu + G^{-1}(1-2\bar{a})\right]$

- Key difference wrto literature: $(\hat{\sigma}, s)$ endogenous
  - *Investors characteristics, State of technology, Competitive structure, Regulation*

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Participation Value with speed s

- Autarchy ("get and hold"): $W_{out} = \bar{a}\frac{\mu}{r}$
- $W(\sigma, \hat{\sigma}, s) \equiv \frac{\bar{a}}{2}\sum_{\varepsilon} V_{\sigma,\varepsilon}(1; s) + \frac{1-\bar{a}}{2}\sum V_{\sigma,\varepsilon}(0; s)$
- Solve system of Bellmans to find explicit $V_{\sigma,\varepsilon}(a)$, then...

Result: Participation Value with Speed s

- Ex ante net participation value is the sum of the value of transient ownership and trading repeatedly:

$$W(\sigma, \hat{\sigma}, s) - W_{out} = \frac{s\bar{a}\hat{\sigma}}{r} + \frac{s}{2r}\max(0; \sigma - \hat{\sigma})$$

- The value of trading is **super-modular** in (s, σ)

- Temporary ("small") traders only capture $\frac{s\bar{a}\hat{\sigma}}{r}$
- Now exchanges think how to extract rents (W ~ sufficient info)

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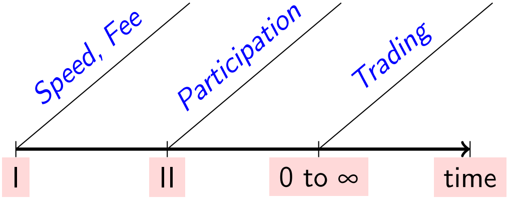
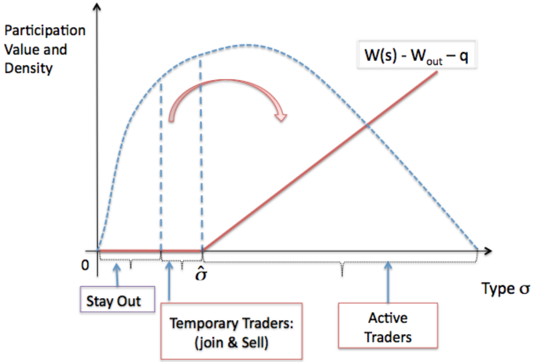
2. Consolidated Market



Investor Participation

- Pre-trade decision: $\mathscr{P} : [0, \bar{\sigma}] \longrightarrow \{0, 1\}$
- q: market access fee (membership, co-location, data feed...)
- If σ joins, enjoys $W(\sigma, \hat{\sigma}, s) - q$
    - Marginal investor $W(\hat{\sigma}, \hat{\sigma}, s) - W_{out} = q$
    - Then, mass active traders: $1 - G(\hat{\sigma})$

Participation Choice: One Market



Single Exchange Problem

$$\max_{q,s}\left\{\underbrace{q}_{\text{Fee}}\times\underbrace{[1-G(\hat{\sigma}(q,s))]}_{\text{Demand}}-\underbrace{C(s)}_{\text{Cost}}\right\}$$

- **Assumption 1**: $G(\sigma)\sim 1-\exp\left(-\frac{\sigma}{\nu}\right)$, $\nu>0$
- Let $\underline{\rho}>0$ be "default speed"
- **Assumption 2**: Speed cost is $c\times\max\{0,\rho-\underline{\rho}\}$, $c>0$
  - Recall $s=\frac{\rho}{r+\gamma+\rho}$, so cost is convex in s

Solution

$$\hat{\sigma}_{con}=\nu,\qquad s_{con}=1-\sqrt{2rc(\gamma+r)\left(\frac{e}{\nu}\right)}$$

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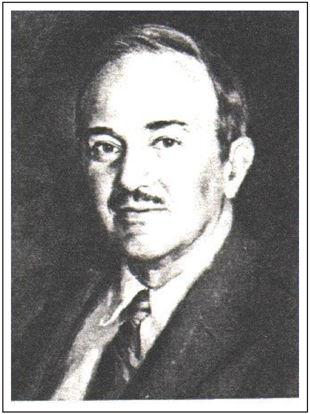
3. Fragmented Markets

$s_1 = s_2$

J. Bertrand

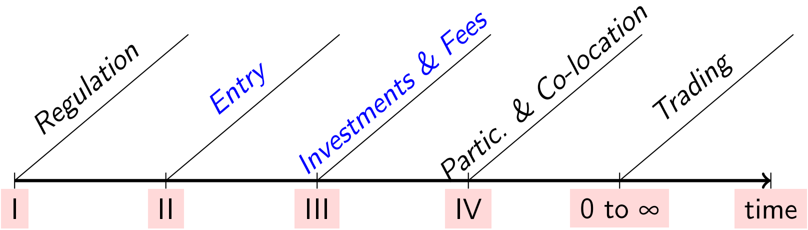
$s_1 \neq s_2$



E. Chamberlin

Pre-trade Decisions

- Two venues: wlog $s_1 < s_2$, fees (q_1, q_2)
- Pre-trade decision: $\mathscr{P} : [0, \bar{\sigma}] \longrightarrow \{0, 1, 2\}$
  - OTC dealer vs. exchange, Fiber optics vs. microwave, co-location?
- New: $\hat{\sigma}_{12}$ indifferent between 1 and 2
- Key: Investors' choices depends on price formation regulations



Vertically diff. duopoly Subgame Perfect Nash Equilibrium (e.g., Shaked Sutton, EMA 1983)

- First Stage: Market 1 owns $\underline{s}$. Market 2 solves

$$\max_{s_2}\left\{\left(1-G\left(\hat{\sigma}_{12}\right)\right)q_2\left(s_2\right)-C\left(s_2\right)\right\}$$

- Second stage: Markets compete in fees (q_1, q_2), given speeds

Investor Protection

Regulation on Price Formation $\tau \in \{seg, prot\}$

- **Segmentation**: 2 asset markets, 2 liquidity markets
- **Price Protection**: 1 asset market, 2 liquidity markets ('gates')

Example (*SEC's trade-trough*): Buy C @ NYSE. If $p_{NYSE} > p_{Nasdaq}$, then unless $p_{NYSE} \searrow$, buy order @ NYSE is routed to NASDAQ.

Economic Area	Reg. Agency	Regulation	Year	Investor Protection Model
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Canada	IIROC, CSA	OPR	2011	Trade-through (full book)
Europe	ESMA	MiFID	2007	Principles-based
Japan	FSA, FIEA	FIEA	2007	Principles-based
South Korea	FSC	FSCMA	2011	Principles-based
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IMPLICATIONS: MARKET ORGANIZATION

Proposition: Price protection and competition

Price protection **increases the profits of the slow venue** and decreases total active participation

- $\hat{\sigma}^{prot} > \hat{\sigma}^{seg}$: All temporary traders will join slow market $\Rightarrow$ demand less elastic for slow venue
- Ex-Post venue competition less intense $\Rightarrow$ total investor participation $\searrow$

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Entry: Endogenous fragmentation

- Two potential entrants, simultaneous entry game (see paper)
- Entry cost κ. Market i's net profit is $\pi_i^T - \kappa$, $T \in \{seg; prot\}$

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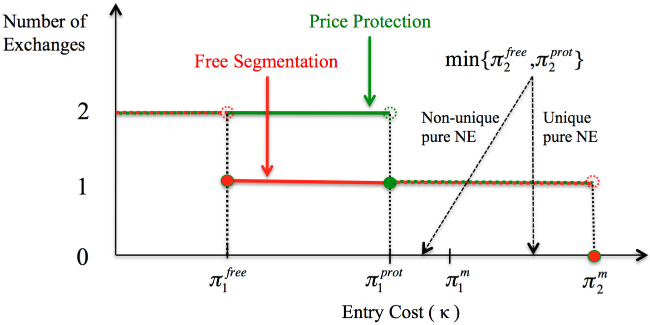
Price protection helps entry and thus expands the ex-ante number of markets



- Rationalizes U.S. experience Post Reg NMS (2007)

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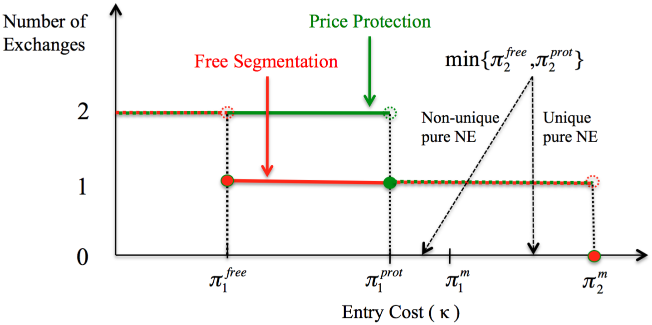

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Fragmentation and Market Quality

Proposition: Speed and Market Quality

- Consolidated market: Participation same as with exogenous speed
- Fragmented market: Participation fast venue alone is **higher** than monopolist case ($\hat{\sigma}_{12} < \hat{\sigma}_M$)
- The fast venue chooses **higher speed** than monopolist

Intuition: Scale and differentiation $s_2 > s_M$

- Two-way feedback: trading technologies $\longleftrightarrow$ fragmentation
- Measurable Market Quality (Liquidity, Participation, Volumes) higher under fragmentation (as reported in O'Hara Ye (2011) for U.S., Degryse et at. (2011) for Europe)

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What is the Social Value of...

1. **Endogenous speed?**
2. **Exchange competition?**
3. **Price Protection?**

Welfare (pre-trading)

$$\mathscr{W} \equiv \underbrace{\sum_i \int_\sigma (W(\sigma, \hat{\sigma}_i, s_i) - W_{out}) dG(\sigma)}_{\text{Partic. gains \& Allocation efficiency}} - \underbrace{\sum_i (\kappa + C(s_i))}_{\text{Entry+Speed Investment}}$$

- See paper for efficient market design

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Does faster trading increase welfare?

Summary of Results

Consolidated Trading:

- Social welfare always higher with speed investments
- Speed can be socially excessive

Fragmented Trading:

- There exists unique default speed $\underline{s}_0$ s.t. investments increase welfare iff $\underline{s} < \underline{s}_0$
- When differentiation costs are high (e.g., cost of technology is high) participation may be "excessive"

Policies?

1. Consolidated: never optimal to ban speed-enhancing investments in this environment
2. Fragmented: taxing may be welfare improving

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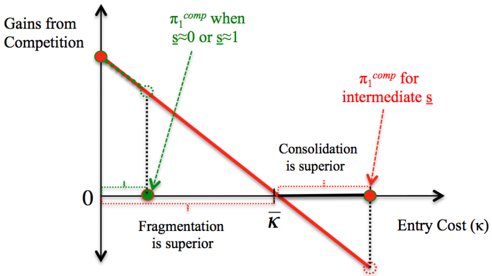
Should we Encourage Exchange Competition?

Proposition. Social Value of Competition

Consolidation is superior iff $\kappa \leq \pi_1$ *and* $\kappa > \mathscr{W}_{Frag} - \mathscr{W}_{Monop}$



- Old. Without liquidity externalities and entry costs fragmentation is always best (Bertrand outcome)
- New. Suboptimal Fragmentation unlikely when differentiation is difficult $\underline{s} \approx 0$, or $\underline{s} \approx 1$, or c high, or type heterogeneity low

Does Price Protection add Value?

- Model: Affects participation, speed choices, and importantly, entry.

Price Protection and Welfare

Entry affected?

- Yes: First order effect (more participation, more speed). Sign depends on entry costs.
- No: Small negative effect (total participation $\searrow$)

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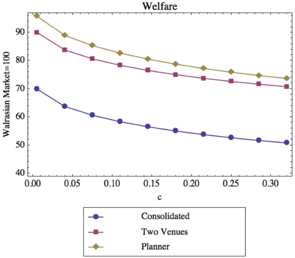
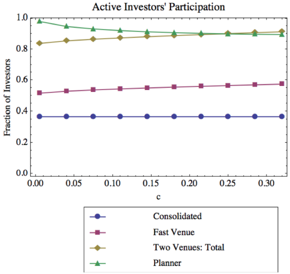
4.Calibration

Parameter	Notation	Baseline Value*
Interest rate	r	2.5%
Holding cash flow	μ	2.44
Default contact rate	$\underline{\rho}$	2.95×10^5
Short-run contact rate market 2	$\underline{\rho}_2$	1.18×10^6
Long-run contact rate consolidated market	ρ_{con}	5.90×10^6
Switching intensity temporary types	γ	$73,710$
Marginal cost of speed investments	c	7.6×10^{-9}
Asset supply	$\bar{a}$	0.47
Average investor type (baseline value)	ν	0.5

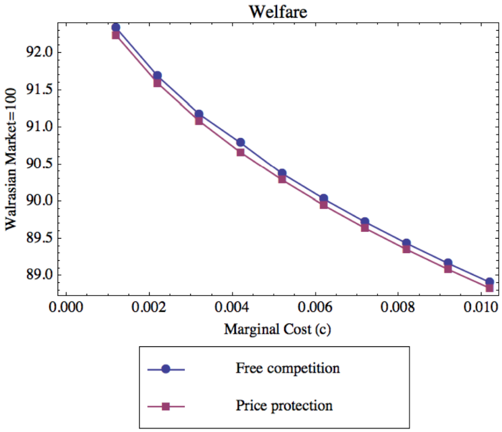
*The values of parameters $\{r, \mu, \underline{\rho}, \underline{\rho}_2, \rho_{con}, \gamma\}$ correspond to annual rates.

Welfare I: Regulation-Free Market

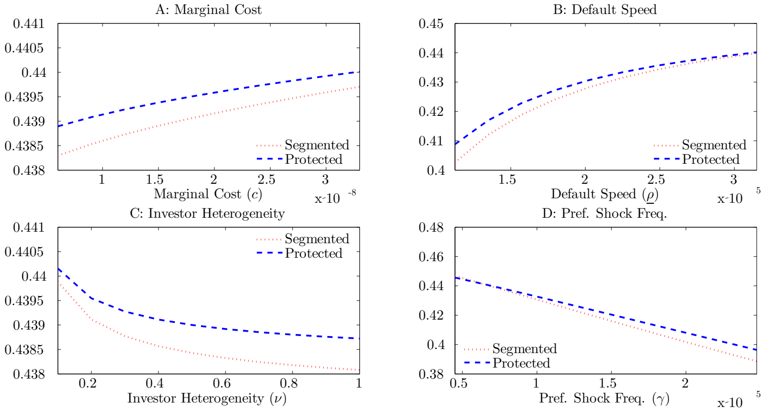




Welfare II: Entry-neutral price protection



Trading Fragmentation (1-HHI)



Asset prices are bad proxy for welfare

Table III: Short-Run Price Decomposition (Walrasian Price=100)

	Limited Participation Distortion	Illiquidity Discount	Price Protection Distortion	Price
Consolidated	18.98	-4.05		114.94
Slow Venue	0.38	-0.33		100.06
Fast Venue	1.78	-0.18		101.60
VWAP	1.32	-0.28		101.09
National Best	0.38	-0.33	0.16	100.21

Table IV: Long Run Price Decomposition (Walrasian Price=100)

	Limited Participation Distortion	Illiquidity Discount	Price Protection Distortion	Price
Consolidated	18.98	-0.25		118.73
Slow Venue	0.82	-0.41		100.40
Fast Venue	2.62	-0.04		102.58
VWAP	2.04	-0.29		101.88
National Best	0.82	-0.41	0.19	100.60

Extension: Generalized Portfolio Holdings

- Pref. shocks $\varepsilon_i \in \{\varepsilon_l, \varepsilon_h\}$, π prob ε_h. Let $\theta_{i\sigma} = \mu + \varepsilon_i \sigma$

$$u_{i\sigma}(a) = \theta_{i\sigma} u(a)$$

- Adjusted utility

$$\overline{u}_{i\sigma}(a) = \left(\mu \frac{(r+\rho)\varepsilon_i \sigma + \gamma(2\pi - 1)\sigma}{r+\gamma+\rho} \right) u(a) = \overline{\theta}_{i\sigma} u(a)$$

- Optimal portfolio holdings

$$a_{i\sigma} = (u')^{-1} \left(\frac{rp}{\overline{\theta}_{i\sigma}} \right)$$

- Example: $u(a) = \frac{a^{1-\xi}}{1-\xi}$. Assume A1 and let $\mu = 0$, then equilibrium price

$$p = \frac{v}{r} \left[\frac{\kappa(s, \pi, \xi)}{\overline{a}} \Gamma \left(1 + \frac{1}{\xi} \right) \right]$$

- where κ known function and Γ is the Gamma Function

A Few Related Papers

- **Search Frictions.** and asset prices: Duffie Garleanu Pedersen (2005, 2007), Weill (2007, 2008), Lagos Rocheteau (2009), Vayanos Tang (2008),...
- **Theory of Fragmentation.** Mendelson (1987), Pagano (1989), Madhavan (1995),...
- **Liquidity Level & Risk.** Amihud Mendelson (1986), Constantinides (1986), Vayanos (1998), Lo et al. (2004); Pastor Stambaugh (2004), Eisfeldt (2004), Acharya Pedersen (2005)
- **Competition between exchanges**. Santos Scheinkman (2001, margins), Foucault Parlour (2000, listing fees), Pagnotta Philippon (2012, Speed)
- **Vertically differentiated oligopolies.** Gabsewisz and Thisse (1979), Shaked and Sutton (1982, 1983),...

Final Remarks

- We provide a positive and normative analysis of trading speed and fragmentation in financial markets
  - Positive. Accounts for US and European experiences after Reg. NMS & MifID.
  - Testable implications for market organization, volumes, prices...
  - Normative. Several regulation insights. First normative analysis of investor protection
- Stresses poor mapping between price levels and welfare: tensions PRIMARY-SECONDARY markets
- Tractable model for regulation/policy analysis

THANKS !