<table>
<thead>
<tr>
<th>Institution</th>
<th>Quarter</th>
<th>Investment</th>
<th>Speed Increase</th>
<th>Asset class</th>
<th>Notes</th>
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<tbody>
<tr>
<td>NYSE Euronext</td>
<td>Q4 2008</td>
<td>Universal Trading Platform</td>
<td>150-400 microseconds from 1.5 milliseconds</td>
<td>Bonds</td>
<td></td>
</tr>
<tr>
<td>NYSE Euronext</td>
<td>Q1 2009</td>
<td>Universal Trading Platform</td>
<td></td>
<td>Cash Equities</td>
<td>Based on Arca's Wombat. Replaces SuperDOT</td>
</tr>
<tr>
<td>NYSE</td>
<td>Q2 2009</td>
<td>Super Display Book System Platform</td>
<td>5 milliseconds (350 in 2007)</td>
<td>Cash Equities</td>
<td></td>
</tr>
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<td>Q3 2009</td>
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<td></td>
</tr>
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<td>NYSE, NYSE Arca, NYSE Amex</td>
<td>Q4 2009</td>
<td>Universal Trading Platform from 5 to 1.5 milliseconds</td>
<td>Cash Equities</td>
<td>Based on NYSE Liffe's LiffeConnect</td>
<td></td>
</tr>
<tr>
<td>Tokyo Stock Exchange</td>
<td>Q4 2009</td>
<td>Tdex+ System</td>
<td>to 6 milliseconds</td>
<td>Options</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Q1 2010</td>
<td>Arrowhead Platform</td>
<td>5 milliseconds from 2 seconds</td>
<td>Cash Equities</td>
<td>Developed by MilleniumIT</td>
</tr>
<tr>
<td></td>
<td>Q4 2011</td>
<td>Tdex+ System</td>
<td>5 milliseconds</td>
<td>Futures</td>
<td></td>
</tr>
<tr>
<td>Turquoise (LSE's)</td>
<td>Q4 2009</td>
<td>Millenium Exchange Platform</td>
<td>Latency of 126 microseconds</td>
<td>Derivatives</td>
<td></td>
</tr>
<tr>
<td>NASDAQ OMX (Nordic+Baltic)</td>
<td>Q1 2010</td>
<td>INET Platform</td>
<td>400 times faster to 126 microsecond (at the moment faster than BATS Global and NASDAQ OMX)</td>
<td>Cash equities</td>
<td></td>
</tr>
<tr>
<td>Johannesburg Stock Exchange</td>
<td>Q1 2011</td>
<td>Millenium Exchange Platform</td>
<td></td>
<td>Cash equities</td>
<td></td>
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<tr>
<td>London Stock Exchange</td>
<td>Q4 2010</td>
<td>Millenium Exchange Platform</td>
<td></td>
<td>Cash equities</td>
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<td>Singapore Stock Exchange</td>
<td>Q3 2011</td>
<td>Reach Platform</td>
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<td><strong>Inter-Market Connections</strong></td>
<td></td>
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</tr>
<tr>
<td><strong>Providers</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Spread Network</td>
<td>Q4 2011</td>
<td>Straightest cable from Chicago to NY (cable 100 miles shorter than previous ones)</td>
<td>Latency reduction from 18.5 to 15.5 milliseconds (13.3 at additional cost)</td>
<td>Reported cost $300M</td>
<td></td>
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<tr>
<td>Hibernia Atlantic</td>
<td>Q3 2011</td>
<td>Shortest cable from NY to London</td>
<td>Shaves 6 milliseconds from 65 milliseconds</td>
<td>Reported cost $300M</td>
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<td>Aviat Networks</td>
<td>Exp. Q2 2012</td>
<td>Microwave-based connection from Chicago to NY</td>
<td>claimed to be faster than Fiber-optics</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure: Similar industry dynamics in many economies

Source: Menkveld (2011)
<table>
<thead>
<tr>
<th>Economic Area</th>
<th>Reg. Agency</th>
<th>Regulation</th>
<th>Year</th>
<th>Investor Protection Model</th>
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<tr>
<td>USA</td>
<td>SEC</td>
<td>Reg.NMS</td>
<td>2005</td>
<td>Trade-through (top of the book)</td>
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<td>IIROC, CSA</td>
<td>OPR</td>
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</tr>
<tr>
<td>South Korea</td>
<td>FSC</td>
<td>FSCMA**</td>
<td>2011</td>
<td>To be determined</td>
</tr>
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Source: www.fidessa.com
* Currently under revision
** Revision of 2009 version

Example (SEC’s trade-trough): Stock C @ NASDAQ, NYSE. \( ask^{NY} > ask^{NA} \). Then, unless \( ask^{NY} \not> \), buy order @ NYSE is routed to NASDAQ.
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- Both execution speed and fragmentation increased significantly, is there a relationship?

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- Trading fragmentation?
- Protecting prices?

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- What is the social value of speed investments?
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• Key: Endogenize IO of financial markets by modeling connections between exchanges and investors decisions.
  - We abstract from (i) Liquidity externalities (ii) Asymmetric information & investors own speed investments (e.g. “HFT”)

MODEL OUTLINE

Regulation → Entry Game → Speed Investment → Fees & Affiliation → Trading
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I         | II         | III              | IV                 | 0 to ∞ | time
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Trading in one market (time 0 to ∞)

- Two assets: cash (yields $r$), illiquid asset in fixed per-capita supply $\bar{a}$. Asset holdings $a$ in $\{0,1\}$
- Mass one continuum of investors enjoy flow utility

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

- time-varying type $\varepsilon$ in $\{+, -\}$, times $\sim \exp(\gamma)$, $\Pr\{\varepsilon=+\} = \frac{1}{2}$
- fixed type $\sigma \in [0, \bar{\sigma}]$ CDF $G$ (can see as brokers’ “clienteles”)

- Trading a’-la Lagos-Rocheteau (Econometrica 2009)
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  - Contact rate (speed) is $\rho$ (i.e. “latency” $\rho_i^{-1}$).
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- Value function of type $\sigma, \epsilon(t)$ holdings $a$: $V_{\sigma,\epsilon(t)}(a, t) =$

$$
\mathbb{E}_t \left[ \int_t^T e^{-r(s-t)} u_{\sigma,\epsilon(s)}(a) ds + e^{-r(T-t)} \left( V_{\sigma,\epsilon(T)}(a^*_T, T) - p_T(a^*_T - a) \right) \right]
$$

- Flows until contact
- Cont. value at time-$T$ contact

- Wlog $\bar{a} \leq 1/2$ (supply is short, half the investors are $\epsilon = +1$)
- Marginal type $\hat{\sigma} > 0$ indifferent on buying when $\epsilon = 1$.
- Demand functions:
  - $a^* = 0$ when $\epsilon = -1$ or when $\sigma < \hat{\sigma}$
  - $a^* = 1$ when $\epsilon = +1$ and $\sigma \geq \hat{\sigma}$
- Participants: “Active traders” $\sigma \geq \hat{\sigma}$, “Temporary traders” $\sigma < \hat{\sigma}$
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Trading Equilibrium

- Characterized by \((\rho, \hat{\sigma})\) solving demand system and market clearing
- “Temporary Traders” \((\sigma < \hat{\sigma})\) sell their initial holdings \(\tilde{a}\) and leave
- “Active traders” \((\sigma \geq \hat{\sigma})\) buy when \(\varepsilon = 1\), sell when \(\varepsilon = -1\).
- The proportion of active traders with mis-allocated assets converges to \(\frac{1}{4} \frac{\gamma}{\gamma + \rho}\). Converge to Walrasian allocation when \(\rho \to \infty\).

- Effective speed \(s\) defined by \(s \equiv \frac{\rho}{r + \gamma + \rho}\).

\[
p = \frac{\mu}{r} + \frac{1}{r} \hat{\sigma} \left( \frac{r + \gamma s}{r + \gamma} \right)
\]

- Participation
- Effective Speed

- Key diff. wrto DGP prices: \((\hat{\sigma}, s)\) endogenously determined
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\[
\begin{align*}
\text{Participation} & \quad \text{Effective Speed}
\end{align*}
\]

- Key diff. wrto DGP prices: \((\hat{\sigma}, s)\) endogenously determined
Proposition: Participation Value with Speed $s$

The ex-ante value of participating for type $\sigma$, in a market with speed $r$ and price $p$ is the sum of the value of ownership and the value of trading repeatedly:

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

where outside option of any investor is $W_{out} = \frac{1}{r} \mu \bar{a}$, and The value of trading is super-modular in $(s, \sigma)$. 
## IO of the Security Exchange Industry

1. Investor Affiliation with Consolidated Trading (monopoly)
2. Affiliation with Fragmented Trading (duopoly)
   - 2.1 Participation Fees
   - 2.2 Trading Regulations
3. Speed Investment Choice
4. Entry Decisions
Single Market

• $q$: market access fee
• Investor $\sigma$ joining a market with speed $s$ enjoys $W(\sigma, \hat{\sigma}, s) - q$
• Participation decision: $\mathcal{P} : [0, \bar{\sigma}] \rightarrow \{0, 1\}$
• Marginal investor $W(\hat{\sigma}, \hat{\sigma}, s) - W_{out} = q$
• $\delta$: mass of temporary traders

Affiliation Choices with One Market

Net Value and Density

$\delta$
Join & Sell
Stay Out
0
$\hat{\sigma}$
Join & Trade

$W - W_{out} - q$
Fragmented Trading

- Two venues, 1 and 2, with \( s_1 \) and \( s_2 \) and fees \( q_1 \) and \( q_2 \)
- Wlog \( s_2 > s_1 \)
- Participation decision: \( \mathcal{P} : [0, \bar{\sigma}] \rightarrow \{0, 1, 2\} \)
- New: \( \hat{\sigma}_{12} \) is indifferent between market 1 and 2: 
  \( W(\hat{\sigma}_{12}, \hat{\sigma}_1, s_1) - q_1 = W(\hat{\sigma}_{12}, \hat{\sigma}_2, s_2) - q_2 \)
- Different prices? We consider two types of regulations.

Regulation on Price Formation \( \uparrow \in \{seg, prot\} \)

- Free Market Segmentation: multiple asset prices
- Price protection (“Reg. NMS”): single asset price (here: \( \text{ask} = \text{bid} = p \)
Fragmented Trading

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

- Free Market Segmentation: multiple asset prices
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Regulation and Marginal Investors

- **Limit case:** When $\bar{a} = 1/2$ all marginal types are the same and regulation is immaterial.
- When $\bar{a} < 1/2$, regulation affects marginal types

\[ \hat{\sigma}^{seg}_{12} = \frac{r}{\bar{a}} \frac{q_2 - q_1}{s_2 - s_1} \]
\[ \hat{\sigma}^{prot}_{12} = \frac{2r}{s_2 - s_1} (q_2 - z(\bar{a})q_1) \]

- $\hat{\sigma}^{seg}_{12}$ familiar from quality competition in IO. $\hat{\sigma}^{prot}_{12}$ specific to financial markets
- Regulation affects affiliation: under price protection more investors join the slow market (see paper)
Figure: Globally Fragmented Markets (source: Fidessa)

Assumption A1: $G(\sigma) \sim \exp(1/\nu) \Rightarrow \hat{\sigma}_m = \nu$

**Proposition**

1. Competition among exchanges increases participation.
2. Under A1 price protection increases the profits of the slow venue and decreases total active participation.
Entry

- Two potential entrants, simultaneous entry game (see paper)
- Entry cost \( \kappa \). Market \( i \)'s net profit is \( \pi_i^\tau - \kappa, \ \tau \in \{seg; prot\} \)

**Proposition: Price Protection and Entry**

Price protection helps entry and thus expands ex ante number of markets
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Speed Choices

• $C$ convex in $s$ and $C(s) = 0$ (recall $s = \frac{\rho}{r + \gamma + \rho}$). (let $\bar{a} = 1/2$)

• Monopolist program

$$\max_{q,s} q(1 - G(\hat{\sigma})) - C(s)$$

• Duopoly (SPNE): Market 1 owns $s$. Market 2 sets $s_2$ in 1st stage to solve

$$\max_{s_2} (1 - G(\hat{\sigma}_{12})) q_2(s_2) - C(s_2)$$
Proposition: Consolidated Market Structure

- Participation is the same as with exogenous speed
- Under A1 optimal effective speed is given by
  \[ s_M = 1 - (2rc(\gamma + r)e)^{1/2} v^{-1/2} \]
- Optimal speed level \( \rho \) concave in \( \gamma \)

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- Participation in the fast venue alone is higher than in the monopolist case (\( \hat{s}_{12} < \hat{s}_M \))
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**IMPLICATIONS: ASSET PRICES**

What affects Asset Price Levels?

1. **Endogenous speed?**
2. **Exchange competition?**
3. **Price Protection?**
Asset Supply and Prices: Does Speed matter?
Asset Supply and Prices: Does Speed matter?

Endogenous speeds may change demand curves slope

**Proposition: Asset Supply and Asset Price**

The Walrasian price decreases with the asset supply. For given speed, the monopoly and free duopoly prices are independent of asset supply. With *endogenous* speed, prices **increase** with the asset supply.
Does Exchange Competition Affect Asset Price Level?

**Definition: VWAP**

\[
\bar{p}^{seg} \equiv \left( \frac{\tau_1}{\tau_1 + \tau_2} \right) p_1^{seg} + \left( \frac{\tau_2}{\tau_1 + \tau_2} \right) p_2^{seg}
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\( \tau_i \): instantaneous transaction rate in market \( i \) (see paper)

**Proposition: Market Structure and Asset Prices**

With or without price protection, market competition reduce asset prices. For any asset characteristics:

1. \( p_M > p^{prot} \),
2. Under A1, \( p_M > \bar{p}^{seg} \)

**Intuition:** Monopolist restricts participation \( \implies \hat{\sigma}_1^M > \hat{\sigma}_1^{prot} \).

- **Interesting Empirical Prediction:** When markets open to competition, assets liquidity **increase**, but asset price levels **decrease**
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- **Test Example**: Canada 2011
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International Asset Pricing Implication. Fix asset features $\Rightarrow$ 
$p^{\text{JAPAN}} > p^{\text{EU}} > p^{\text{US}}$
### IMPLICATIONS: PARTICIPATION AND WELFARE

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<thead>
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<th>What is the Social Value of...</th>
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<tbody>
<tr>
<td>1. <strong>Endogenous speed?</strong></td>
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<td>3. <strong>Price Protection?</strong></td>
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**Welfare (pre-trading)**

\[
\mathcal{W} \equiv \sum_i \int_{\sigma} (W(\sigma, \hat{s}_i, s_i) - W_{out})dG(\sigma) - \sum_i (\kappa + C(s_i))
\]

- Partic. gains & Allocation efficiency
- Entry+Speed Investment

- See paper for efficient market design
IMPLICATIONS: PARTICIPATION AND WELFARE

What is the Social Value of...

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

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Does Speed increase Welfare?

- Abstract from entry (number of venues given) and protection

**Proposition**

1. **Consolidated Trading**: Social welfare always higher with endogenous speed
2. **Fragmented Trading**: under A1, there is a unique default speed $s_0$ s.t. welfare increases with endogenous speed iff $s < s_0$.

**Implications.** Taxing technology investments?

2. Fragmented Trading: may be welfare improving

**Intuition**: Limiting speed investments intensifies Bertrand fee competition.
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2. Fragmented Trading: may be welfare improving

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Should we Encourage Exchange Competition?

- Abstract from price protection. Assume A1 and let

\[
Gains_{comp}(\kappa) \equiv W_{comp} - W_{M} - \kappa
\]

**Proposition. Social Value of Competition**

- For \( \kappa \) low enough fragmentation always desirable
- Consolidation increases welfare when \( \kappa \) is such that \( Gains_{comp}(\kappa) = 0 \).

**Remark 1:** Without liquidity externalities and entry costs, fragmentation is always best (Bertrand outcome)
**Remark 2:** With positive entry costs market is natural monopoly without speed diff.
**Remark 3:** Very imperfect link between asset prices level and Welfare (often assumed)
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**Proposition. Social Value of Competition**

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Does Price Protection add Value?

- US: implemented by the SEC around 2007
- Model: affects participation and speed choices. More importantly, it can affect 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 ↓)

Remark 1: Price protection has always negative effect on price level, effect on welfare is ambiguous (likely positive in US, likely negative in Europe in light of MiFID II)

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Full Equilibrium (no reg.)
Figure: Price Protection Effects (low entry costs $\kappa$)
Some Related Literature


• Competition between exchanges: Santos Scheinkman (2001, margin requirements), Foucault Parlour (2000, listing fees)

• Vertically differentiated oligopolies pioneered by Gabszewisz and Thisse (1979), Shaked and Sutton (1982, 1983)
Final Remarks

• Paper provides a positive and normative analysis of trading speed in financial markets
• Stresses imperfect mapping between price levels and welfare
  • Trade-offs PRIMARY-SECONDARY Markets
• Accounts for US and European experiences after Reg. NMS & Mifid
• Testable implications for asset prices
• Useful to study regulations. First normative analysis of investor protection (i.e. Tobin tax on market structure)
• Future directions: information, investors own investments (Pagnotta & Philippon 2012)
THANKS !
Affiliation Choices with Free Segmentation

Net Value and Density

Market 1

$\delta_1$

Market 2

$\delta_2$

$W_1 - W_{out} - q_1$

$W_2 - W_{out} - q_2$

Type $\sigma$

$\hat{\sigma}_1$

$\hat{\sigma}_2$

$\hat{\sigma}_{12}$
Affiliation Choices with Protected Prices

Net Value and Density

\[ \delta_1 \]

Market 1

\[ W_2 - W_{out} - q_2 \]

Market 2

\[ W_1 - W_{out} - q_1 \]
Profits

Segmented Markets

\[
\max_{q_1} \pi_1^{seg} = \frac{q_1}{2\bar{a}} (G(\hat{\sigma}_{12}) - G(\hat{\sigma}_1))
\]

\[
\max_{q_2} \pi_2^{seg} = \frac{q_2}{2\bar{a}} (1 - G(\hat{\sigma}_{12}))
\]

Price-protected Markets

\[
\max_{q_1} \pi_1^{reg} = q_1 \left( G(\hat{\sigma}_{12}) + \frac{1 - G(\hat{\sigma}_1)}{2\bar{a}} - 1 \right)
\]

\[
\max_{q_2} \pi_2^{reg} = q_2 (1 - G(\hat{\sigma}_{12}))
\]
Investors

- Value function of type $\sigma, \varepsilon(t)$ holdings $a$:

$$V_{\sigma,\varepsilon(t)}(a, t) = $$

$$\mathbb{E}_t \int_t^T e^{-r(s-t)} u_{\sigma,\varepsilon(s)}(a) ds + e^{-r(T-t)} (V_{\sigma,\varepsilon(T)}(a_T, T) - p_T (a_T - a))$$

- When $p$ is constant, Bellman equation is time-independent

$$rV_{\sigma,\varepsilon}(a) = u_{\sigma,\varepsilon}(a) +$$

$$\frac{\gamma}{2} \left[ V_{\sigma,\varepsilon'}(a) - V_{\sigma,\varepsilon}(a) \right] + \rho \left[ V_{\sigma,\varepsilon}(a^*_\sigma, \varepsilon) - V_{\sigma,\varepsilon}(a) - p(a^*_\sigma, \varepsilon - a) \right]$$

- next find demand...
Finding the Value of Speed (1)

- Step 1: Finding steady-state Value functions
- Step 2: Computing ex-ante values with transition dynamics

- Values for types holding the assets

\[ rV_{\sigma,+}(1) = \mu + \sigma + \frac{\gamma}{2} [V_{\sigma,-}(1) - V_{\sigma,+}(1)] \]
\[ rV_{\sigma,-}(1) = \mu - \sigma + \frac{\gamma}{2} [V_{\sigma,+}(1) - V_{\sigma,-}(1)] + \rho (p + V_{\sigma,-}(0) - V_{\sigma,-}(1)) \]

- Values for types not holding the assets

\[ rV_{\sigma,-}(0) = \frac{\gamma}{2} [V_{\sigma,+}(0) - V_{\sigma,-}(0)] \]
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The paper

• **Idea**: All investors value speed, but not equally ⇒ Speed acts as vertical differentiation factor.

• Provides micro foundations for the value of speed
• Addresses exchanges incentives to invest in faster intermediation technologies
• Endogenizes entry decisions
• Provides simple dynamic model for role of price protection
• Delivers welfare and asset prices in equilibrium

We abstract from
• Asymmetric information
• Traders’ own speed investments (“HFT”)
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Results Sample

- Rationalizes experience US after Reg. NMS
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