ON YOUR MARK...!!!

VR000000M-VR0000000M!

HIGH-FREQUENCY TRADERS
Need for Speed?
Exchange Latency and Liquidity

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Outline

Motivation

Model

Conclusion
NYSE's Fast-Trade Hub Rises Up in New Jersey
LSE goes live with faster trading system
CitiFX launches Velocity 2.0; stakes claim as the fastest platform in market

by Hamish Risk, Laurence Twelvetrees
February 8, 2010

NASDAQ OMX Launches INET Trading System
Question:
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Is an even faster exchange good for liquidity?
Literature on HFT and adverse selection

1. *Theory:*
   HFTs fast/informed speculators...
   (Foucault, Hombert, and Roșu, 2015; Biais, Foucault, and Moinas, 2015)
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Literature on HFT and adverse selection

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2. Evidence:
   HFTs adverse select and get adverse selected. (Hendershott and Riordan, 2011; Baron, Brogaard, and Kirilenko, 2014; Brogaard, Hendershott, and Riordan, 2014)

3. Baron, Brogaard, and Kirilenko (2014) and Hagstromer and Norden (2013) find evidence for both market-making and speculative HFT strategies.
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Topology of modern exchanges

Network-to-gateway latency -> Gateway processing latency -> Gateway-to-matching-engine latency

Trader A <-> Gateway 1
Trader B <-> Gateway 2
Trader C <-> Gateway 1
Trader D <-> Gateway 2

Gateway 1 <-> Matching engine
Gateway 2 <-> Matching engine

Exchange latency
Our attempt on exchange speed and liquidity (in pictures)
ToExchLat (wide path) → ExchLat (narrow tunnel)
ToExchLat_i (wide path)  ExchLat (narrow tunnel)

| A | B | C | D | E | F |
Takeaways

1. Lowering exchange latency can reduce liquidity.
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2. A higher exchange speed makes a high-frequency market-maker duel with high-frequency bandits more often.
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3. At the same time, a faster exchange allows the high-frequency market maker to update his quotes more quickly and reduce his payoff risk.
Takeaways

1. Lowering exchange latency can reduce liquidity.
2. A higher exchange speed makes a high-frequency market-maker duel with high-frequency bandits more often.
3. At the same time, a faster exchange allows the high-frequency market maker to update his quotes more quickly and reduce his payoff risk.
4. The net effect on liquidity depends on news-to-liquidity-trader ratio and HFT risk aversion.
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1. Informed and fast: $H$ high-frequency traders (HFTs).
Primitives

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$$U^{\text{HFT}}(x) = \gamma x 1_{x<0} + x 1_{x \geq 0},$$  \hspace{1cm} (1)
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   \[
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   \]

   HFTs choose between two strategies:

   1.1 High-frequency market maker (HFM)
   1.2 High-frequency bandit (HFB)

2. Uninformed and slow: Liquidity traders (LT).

   Exchange
   1. Limit order book.
   2. Latency: HFTs send messages at \( t \), processed at \( t + \delta \).
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Asset

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Common value $v_t$ can change in an interval $\delta$:

$$v_{t+\delta} = \begin{cases} v_t - \sigma & \text{ (“bad” news arrival)} \\ v_t & \text{ (no news arrival)} \\ v_t + \sigma & \text{ (“good” news arrival)} \end{cases}$$
Timing of the model is as follows:

- $t = -1$: HFM sends initial quotes.
- $t = 0$: 
  - No further arrival, or LT order arrival at matcher, or news arrival (mutually exclusive events).
  - **Trigger event** (news or LT arrival at matcher): If news, HFM sends quote-cancel order and HFBs send quote-snipe order.
- $t = \delta$: HFT orders’ arrival at matcher.

The diagram illustrates the timing of events, with latency $\delta$ and the trigger event, which can be caused by news or LT orders at the matcher.
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2. HFTs arrive at the market in random order. Market orders and cancellations execute, new price quotes are submitted.
Solution

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2. All HFTs take same action at $t = -1$.
   All HFMs and all HFBs take same action at $t = 0$. 

Two equilibrium types

There exists a risk-aversion threshold $\bar{\gamma}$ such that:

1. For $\gamma \leq \bar{\gamma}$, a sure-sniping equilibrium emerges.
2. For $\gamma > \bar{\gamma}$, a mixed-sniping equilibrium emerges.

Sniping equilibrium (baseline)

1. In equilibrium, HFTs are indifferent between HFM and HFB strategies.
2. Equilibrium half-spread $s^*$ nailed by indifference condition:
   $U_{HFM}(s^*) = U_{HFB}(s^*)$. 
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$$U_{HFB}(s|\text{trade}) = \left(1 - \frac{\mu \delta}{2} - \alpha \delta\right)(\sigma - s) + \alpha \delta \left[\frac{1}{2} (2\sigma - s) - \frac{1}{2} s \gamma\right]$$

- No event during latency delay
- News arrives during latency delay
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The HFB expected profit is:

$$U_{HFB}(s) = \frac{\alpha}{\mu + \alpha} \frac{1}{H} U_{HFB}(s|\text{trade}).$$

News before LT

HFB first
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\frac{\mu}{\mu + \alpha} \left[ \underbrace{\left(1 - \alpha \delta - \frac{\mu \delta}{2}\right) s + \frac{\mu \delta}{2} 2s}_{\text{No event/LT on same side}} + \underbrace{\alpha \delta \left(\frac{1}{2} (s + \sigma) + \frac{1}{2} (s - \sigma) \gamma\right)}_{\text{News event}} \right]
\]
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$$+ \frac{\alpha}{\mu + \alpha} \left(\frac{1}{2} \mu \delta (s - \sigma) \gamma + \frac{1}{2} \mu \delta (s + \sigma)\right)$$
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+ \frac{\alpha}{\mu + \alpha} \left( \frac{1}{2} \mu \delta (s - \sigma) \gamma + \frac{1}{2} \mu \delta (s + \sigma) \right) \\
+ \frac{\alpha}{\mu + \alpha} \left( \frac{H - 1}{H} \right) \left\{ \alpha \delta \left[ \frac{1}{2} (s - 2\sigma) \gamma + \frac{1}{2} s \right] + \left(1 - \frac{\mu \delta}{2} - \alpha \delta \right) (s - \sigma) \gamma \right\}
\]
Proposition 1

The following strategies for HFM and HFB constitute a unique equilibrium for $\gamma < \bar{\gamma}$.

1. At $t = -1$, all HFTs submit one buy limit order at $v_0 - s^*$ and one sell limit order at $v_0 + s^*$. The first arriving HFT (picked randomly) fills the order book; we refer to this HFT as the HFM and to the other HFTs as HFBs.

2. A trigger event occurs at time $t = 0$. If the trigger event is a news arrival (i.e., if $v_0 \neq v_{-1}$), then the HFM submits a quote-cancel order and, at the same time, all HFBs submit a market order aimed at the stale quote on the news side of the book (i.e., the ask side if news was good or the bid side when news was bad).
Sure-sniping equilibrium

- HFM utility
- HFB utility

Equilibrium half-spread $s^*$
Equilibrium spread

The equilibrium spread is

\[
s^* = \sigma \frac{\alpha [\delta \mu (2 + H) - 2\gamma (H + \delta \mu - 1) - 2]}{\alpha^2 \delta (\gamma - 1) (H - 2) - \mu H (2 + \delta \mu) - \alpha [2 + \delta \mu (H - 2) + 2\gamma (H - 1 + \delta \mu)]}
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1. Comparative statics: $s^* \uparrow \alpha, s^* \uparrow \sigma, s^* \downarrow \mu, s^* \uparrow \gamma$. 
Equilibrium spread

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\[ s^* = \sigma \frac{\alpha [\delta \mu (2 + H) - 2\gamma (H + \delta \mu - 1) - 2]}{\alpha^2 \delta (\gamma - 1) (H - 2) - \mu H (2 + \delta \mu) - \alpha [2 + \delta \mu (H - 2) + 2\gamma (H - 1 + \delta \mu)]]} \]

1. Comparative statics: \( s^* \uparrow \alpha, \ s^* \uparrow \sigma, \ s^* \downarrow \mu, \ s^* \uparrow \gamma. \)

2. Also, equilibrium spread \( s^* \uparrow H. \)

More HFBs lead to higher adverse selection costs for the (unique) HFM.
Equilibrium spread and exchange speed

Proposition 2

There exists $T_{\gamma, H}$ such that the equilibrium half-spread $s^*$

1. increases in exchange speed (i.e., decreases in $\delta$) if $\alpha \mu < T_{\gamma, H}$;
2. decreases in exchange speed (i.e., increases in $\delta$) if $\alpha \mu > T_{\gamma, H}$;
3. does not depend on exchange speed if $\alpha \mu = T_{\gamma, H}$,
Proposition 2

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Latency effect on the equilibrium spread

Bid-ask half spread
high N/LT security

Bid-ask half spread
low N/LT security

Faster exchange
Slower exchange
Latency effect on HFT-HFT trade probability

1. HFM-HFB trade probability:

\[
\frac{\mathbb{P}(\text{HFM-HFB trade})}{\mathbb{P}(\text{HFM trade})} = \frac{\frac{\alpha}{\mu + \alpha} \left[ \frac{H-1}{H} \left( 1 - \frac{\mu \delta}{2} \right) \right]}{\frac{\alpha}{\mu + \alpha} \left[ \frac{H-1}{H} \left( 1 - \frac{\mu \delta}{2} \right) \right] + \frac{\alpha}{\mu + \alpha} \frac{\mu \delta}{2} + \frac{\mu}{\mu + \alpha}}.
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\]

2. HFM-HFB trade probability conditional on news arrival:

\[
\frac{\mathbb{P} (\text{HFM-HFB trade — news})}{\mathbb{P} (\text{HFM trade — news})} = \frac{\frac{H-1}{H} \left( 1 - \frac{\mu \delta}{2} \right)}{\frac{H-1}{H} \left( 1 - \frac{\mu \delta}{2} \right) + \frac{\mu \delta}{2}}.
\]
Corollary 4

The probability of an HFT-HFT trade increases in exchange speed (i.e., it decreases in $\delta$).
Mixed-sniping equilibrium

Proposition 3
For \( \gamma > \tilde{\gamma} \) there exist multiple equilibria indexed by the sniping probability of HFBs: \( p \). All these equilibria yield the same unique mixed-sniping spread:

\[
s^{**} = \sigma \frac{2 - \delta \mu}{2 - \delta \mu + \alpha \delta (\gamma - 1)},
\]

(2)

where \( 0 < s^{**} < \sigma \). The strategies that support these equilibria are:

1. At \( t = -1 \), all HFTs submit one buy limit order at \( v_{-1} - s^{**} \) and one sell limit order at \( v_{-1} + s^{**} \).

2. If the trigger event at \( t = 0 \) is a news arrival, then the HFM submits a quote-cancel order. At the same time, with probability \( p \leq p^{*} \), all HFBs submit a market order aimed at the stale quote on the news side of the book (i.e., the ask side if news was good or the bid side when news was bad).
Mixed-sniping equilibrium

Expected utility

Equilibrium half-spread $s^{**}$

Range for HFM equilibrium utility, depending on sniping probability $p$

$p = 0$

$p = p^*$

HFBs snipe

HFBs do not snipe

HFM utility

HFB utility
Maximum sniping probability and exchange latency

- Maximum sniping probability ($p^*$)
- Exchange latency ($\delta$)

- Faster exchange
- Slower exchange

- Sure-sniping equilibrium
- Mixed-sniping equilibrium

$\delta = \bar{\delta}_\gamma$
Sure- and mixed-sniping equilibria

The diagram illustrates the relationship between exchange latency \( \delta \) and HFT risk aversion \( \gamma \), highlighting the different equilibria of sure-sniping and mixed-sniping. The curve represents the mixed-sniping equilibrium, with the shaded area indicating the range where mixed-sniping is the dominant strategy. The blue line represents the threshold for \( \gamma \) when \( H = 5 \), while the green dotted line represents the threshold for \( \gamma \) when \( H = 20 \). The diagram also shows the comparison between slower and faster exchange scenarios.
Proposition 4

The mixed-sniping equilibrium half-spread $s^{**}$ increases in exchange speed (i.e., it decreases in $\delta$).
Sure- and mixed-sniping equilibrium spread (high N/LT)

\[ \delta = \bar{\delta}_\gamma \]

Faster exchange

Slower exchange

Mixed-sniping equilibrium

Sure-sniping equilibrium

Equilibrium bid-ask half-spread

0.35 0.34 0.33 0.32 0.31 0.3
Exchange latency (\(\delta\))

0.881
0.882
0.883
0.884
0.885
0.886

0.35 0.34 0.33 0.32 0.31 0.3
Slower exchange

Faster exchange

Equilibrium bid-ask half-spread
Sure- and mixed-sniping equilibrium spread (low N/LT)

\[ \delta = \bar{\delta}_\gamma \]

- Mixed-sniping equilibrium
- Sure-sniping equilibrium

Examine the graph with the following key points:

- **Exchange latency (\(\delta\))**
- **Time on the y-axis:** 0.73, 0.72, 0.71, 0.7, 0.69, 0.68
- **Exchange latency (\(\delta\))**
  - 0.754
  - 0.756
  - 0.758
  - 0.76
  - 0.762

**Axes:**
- **X-axis:**
  - Slower exchange
  - Exchange latency (\(\delta\))
  - Faster exchange
- **Y-axis:**
  - Faster exchange
  - Slower exchange

The graph illustrates the transition between mixed-sniping and sure-sniping equilibria as a function of exchange latency.
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4. The net effect on liquidity depends on news-to-liquidity-trader ratio and HFT risk aversion.
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