ON YOUR MARK....!!!
Need for Speed?
Exchange Latency and Market Quality

Albert J. Menkveld    Marius A. Zoican

VU University Amsterdam and Tinbergen Institute

Midway Market Design Workshop
University of Chicago
July 9-11, 2014
Outline

Motivation

Model

Evidence

Conclusion
Exchanges keep speeding up...

<table>
<thead>
<tr>
<th>Date</th>
<th>Exchange</th>
<th>ΔLatency</th>
<th>New Latency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q4 2008</td>
<td>NYSE EuroNext</td>
<td>10x</td>
<td>150μs</td>
</tr>
<tr>
<td>Q1 2009</td>
<td>NYSE Amex</td>
<td>21x</td>
<td>5ms</td>
</tr>
<tr>
<td>Q1 2010</td>
<td>NASDAQ OMX Nordic</td>
<td>10x</td>
<td>250μs</td>
</tr>
<tr>
<td>Q1 2010</td>
<td>Tokyo Stock Exchange</td>
<td>200x</td>
<td>5ms</td>
</tr>
</tbody>
</table>

Source: Pagnotta and Philippon (2013)
...to the benefit of high-frequency traders? Investors?

1. Brogaard, Hendershott, and Riordan (2014) find that high-frequency traders are equally active on both sides, takers and makers of price quotes.
...to the benefit of high-frequency traders? Investors?

1. Brogaard, Hendershott, and Riordan (2014) find that high-frequency traders are equally active on both sides, takers and makers of price quotes.

2. Baron, Brogaard, and Kirilenko (2012) and Hagstromer and Norden (2013) find HFTs specialize and their types are persistent through time.
1. *Evidence:*  
HFTs adverse select and get adverse selected.  
(Hendershott and Riordan, 2011; Baron, Brogaard, and Kirilenko, 2012; Brogaard, Hendershott, and Riordan, 2014).
1. **Evidence:**
   HFTs adverse select and get adverse selected.
   (Hendershott and Riordan, 2011; Baron, Brogaard, and Kirilenko, 2012; Brogaard, Hendershott, and Riordan, 2014).

2. **Theory:**
   HFTs fast/informed speculators...
   (Foucault, Hombert, and Roşu, 2013; Biais, Foucault, and Moinas, 2013)
1. *Evidence:* 
HFTs adverse select and get adverse selected. 
(Hendershott and Riordan, 2011; Baron, Brogaard, and Kirilenko, 2012; Brogaard, Hendershott, and Riordan, 2014).

2. *Theory:* 
HFTs fast/informed speculators... 
(Foucault, Hombert, and Roșu, 2013; Biais, Foucault, and Moinas, 2013) 
...or endogenously become market maker... 
(Jovanovic and Menkveld, 2011)
1. **Evidence:**
   HFTs adverse select and get adverse selected.
   (Hendershott and Riordan, 2011; Baron, Brogaard, and Kirilenko, 2012; Brogaard, Hendershott, and Riordan, 2014).

2. **Theory:**
   HFTs fast/informed speculators...
   (Foucault, Hombert, and Roşu, 2013; Biais, Foucault, and Moinas, 2013)
   ...or endogenously become market maker...
   (Jovanovic and Menkveld, 2011)
   ...or are on both sides.
   (Budish, Cramton, and Shim, 2013)
Adverse selection cost HFM

February 1, 2010: NASDAQ system upgrade testing period
February 8, 2010: NASDAQ system upgrade
Our attempt on exchange speed and market quality

Liquidity traders

Exchange

High-frequency market makers (HFM)
Our attempt on exchange speed and market quality

Liquidity traders

Exchange

High-frequency bandits (HFBs)

High-frequency market makers (HFMs)
Takeaways

1. Lower exchange latency can reduce market quality. High-frequency market makers (HFM) meet high-frequency bandits/speculators (HFBs) more often. Spread is increased due to higher adverse selection.

2. Lower exchange latency allows an “incumbent” HFM to earn rents through economies of scale from quote monitoring.

3. A NASDAQ-OMX speed change analysis confirms model predictions: HFMs raise their spreads due to higher larger adverse selection cost. Calibration reasonably successful.
Takeaways

1. Lower exchange latency can reduce market quality. High-frequency market makers (HFM) meet high-frequency bandits/speculators (HFB) more often. Spread is increased due to higher adverse selection.

2. Lower exchange latency allows an “incumbent” HFM to earn rents through economies of scale from quote monitoring.
Takeaways

1. Lower exchange latency can reduce market quality. High-frequency market makers (HFM)s meet high-frequency bandits/speculators (HFBs) more often. Spread is increased due to higher adverse selection.

2. Lower exchange latency allows an “incumbent” HFM to earn rents through economies of scale from quote monitoring.

3. A NASDAQ-OMX speed change analysis confirms model predictions: HFM)s raise their spreads due to higher larger adverse selection cost. Calibration reasonably successful.
Outline

Motivation

Model

Evidence

Conclusion
Primitives

Risk-neutral agents

1. Informed and fast: Market makers (HFM) and bandits (HFBs). Monitoring cost per unit of time for HFM: \( c \).
Primitives

*Risk-neutral agents*

1. Informed and fast: Market makers (HFM$s$) and bandits (HFB$s$). Monitoring cost per unit of time for HFM: $c$.
2. Uninformed and slow: Liquidity traders (LT).
Primitives

Risk-neutral agents

1. Informed and fast: Market makers (HFM) and bandits (HFB). Monitoring cost per unit of time for HFM: $c$.
2. Uninformed and slow: Liquidity traders (LT).

Exchange

1. Limit order book can only store the lowest ask and highest bid.
Primitives

Risk-neutral agents
1. Informed and fast: Market makers (HFM) and bandits (HFBs). Monitoring cost per unit of time for HFM: $c$.
2. Uninformed and slow: Liquidity traders (LT).

Exchange
1. Limit order book can only store the lowest ask and highest bid.
2. Latency: HFTs visit exchange periodically, period length is $\delta$. 
Primitives

Risk-neutral agents

1. Informed and fast: Market makers (HFM) and bandits (HFB). Monitoring cost per unit of time for HFM: $c$.

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

Exchange

1. Limit order book can only store the lowest ask and highest bid.

2. Latency: HFTs visit exchange periodically, period length is $\delta$.

Asset

1. Common value $v_t$: Each period news arrives with probability $\alpha \delta$, value jumps by $\sigma$, up or down with equal probability.
Primitives

**Risk-neutral agents**
1. Informed and fast: Market makers (HFM$s$) and bandits (HFB$s$). Monitoring cost per unit of time for HFM: $c$.
2. Uninformed and slow: Liquidity traders (LT).

**Exchange**
1. Limit order book can only store the lowest ask and highest bid.
2. **Latency**: HFT$s$ visit exchange periodically, period length is $\delta$.

**Asset**
1. Common value $v_t$: Each period news arrives with probability $\alpha\delta$, value jumps by $\sigma$, up or down with equal probability.
2. Each period an LT arrives with probability $\mu\delta$. His trade motivation is a private value larger than $\sigma$ or smaller than $-\sigma$, both equally likely.
Timing

At each time point $k\delta$, HFTs revisit the market.

HFMs and HFBs are on the market

News arrival
Probability: $\alpha\delta$
$v' = v \pm \sigma$

LT arrival
Probability: $\mu\delta$

$t_0 = 0$
$t_1 = \delta$
$t_2 = 2\delta$
$t_k = k\delta$
$t_{k+1} = (k + 1)\delta$

Order resolution stage. HFBs consider consuming the price quote. HFMs reconsider outstanding price quotes.

Monitoring stage. HFMs decide whether or not to pay monitoring cost $c$.

Order submission stage. HFMs submit new price quotes. HFMs with quotes outstanding go first.
Timing

At each time point $k\delta$, HFTs revisit the market.

1. **Order resolution stage.** HFBs consider consuming the price quote. HFMs reconsider outstanding price quotes.
Timing

At each time point $k\delta$, HFTs revisit the market.

HFMs and HFBs are on the market

News arrival
Probability: $\alpha \delta$

$\nu' = \nu \pm \sigma$

1. **Order resolution stage**. HFBs consider consuming the price quote. HFMs reconsider outstanding price quotes.

2. **Monitoring stage**. HFMs decide whether or not to pay monitoring cost $c$. 
Timing

At each time point $k\delta$, HFTs revisit the market.

1. **Order resolution stage.** HFBs consider consuming the price quote. HFMs reconsider outstanding price quotes.

2. **Monitoring stage.** HFMs decide whether or not to pay monitoring cost $c$.

3. **Order submission stage.** HFMs submit new price quotes. HFMs with quotes outstanding go first.
Solution strategy

1. The dynamic game is a sequence of static stage games that depend on the state of the order book.
Solution strategy

1. The dynamic game is a sequence of static stage games that depend on the state of the order book.
2. Equilibrium price quote by HFM\(s\) nailed by competitive threat.
HFM profit

No news event ($s$ is half-spread, referred to as spread throughout):

\[
\begin{align*}
\text{No news} & \quad \text{LT} \\
(1 - \alpha \delta) & \quad \mu \delta \quad s +
\end{align*}
\]
HFM profit

No news event ($s$ is half-spread, referred to as spread throughout):

\[
\begin{aligned}
\text{No news} & \quad \text{LT} \\
(1 - \alpha \delta) \mu \delta s & \quad + \\
\end{aligned}
\]

News event and asset value is monitored:

\[
\begin{aligned}
\text{News} & \quad \left[ \text{LT on news side} \quad \text{LT on no-news side} \quad \text{No LT and HFB executes} \right] \\
\alpha \delta & \quad \left[ \frac{1}{2} \mu \delta (s - \sigma) \quad \frac{1}{2} \mu \delta (s + \sigma) \quad \left(1 - \frac{\mu \delta}{2}\right) \frac{1}{2} (s - \sigma) \right] - c \delta.
\end{aligned}
\]
HFM profit

No news event (s is half-spread, referred to as spread throughout):

\[
\text{No news profit} + \left(1 - \alpha \delta \right) \mu \delta \ s \ + \\
\text{News event and asset value is monitored:}
\]

\[
\alpha \delta \left[ \text{LT on news side} + \frac{1}{2} \mu \delta (s - \sigma) + \frac{1}{2} \mu \delta (s + \sigma) + \left(1 - \frac{\mu \delta}{2}\right) \frac{1}{2} (s - \sigma) \right] - c \delta. \\
\text{Or, news event and asset value is not monitored:}
\]

\[
\alpha \delta \left[ \text{LT on news side} + \frac{1}{2} \mu \delta (s - \sigma) + \frac{1}{2} \mu \delta (s + \sigma) + \left(1 - \frac{\mu \delta}{2}\right) (s - \sigma) \right].
\]
## Equilibrium conditional spread

<table>
<thead>
<tr>
<th>Monitored?</th>
<th>Order type</th>
<th>Conditional spread</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>All</td>
<td>$s_{U2} = \frac{\alpha \sigma (2-\mu \delta)}{2\mu + \alpha (2-\mu \delta)}$</td>
</tr>
<tr>
<td>Yes</td>
<td>Two-sided (bid and ask)</td>
<td>$s_{I2} = \frac{\alpha \sigma (2-\mu \delta) + 4c}{4\mu + \alpha (2-\mu \delta)}$</td>
</tr>
<tr>
<td>Yes</td>
<td>One-sided (bid or ask)</td>
<td>$s_{I1} = \frac{\alpha \sigma (2-\mu \delta) + 8c}{4\mu + \alpha (2-\mu \delta)}$</td>
</tr>
</tbody>
</table>

1. Economies of scope from monitoring two quotes (amortization benefit): $s_{I2} < s_{I1}$.  


Equilibrium conditional spread

<table>
<thead>
<tr>
<th>Monitored?</th>
<th>Order type</th>
<th>Conditional spread</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>All</td>
<td>$s_{U2} = \frac{\alpha \sigma (2 - \mu \delta)}{2 \mu + \alpha (2 - \mu \delta)}$</td>
</tr>
<tr>
<td>Yes</td>
<td>Two-sided (bid and ask)</td>
<td>$s_{I2} = \frac{\alpha \sigma (2 - \mu \delta) + 4c}{4 \mu + \alpha (2 - \mu \delta)}$</td>
</tr>
<tr>
<td>Yes</td>
<td>One-sided (bid or ask)</td>
<td>$s_{I1} = \frac{\alpha \sigma (2 - \mu \delta) + 8c}{4 \mu + \alpha (2 - \mu \delta)}$</td>
</tr>
</tbody>
</table>

1. Economies of scope from monitoring two quotes (amortization benefit): $s_{I2} < s_{I1}$.
2. Monitoring strategy: select lowest spread from $s_{Ii}$ and $s_{U2}$. 
Equilibrium conditional spread

<table>
<thead>
<tr>
<th>Monitored?</th>
<th>Order type</th>
<th>Conditional spread</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>All</td>
<td>( S_{U2} = \frac{\alpha \sigma (2-\mu \delta)}{2\mu + \alpha (2-\mu \delta)} )</td>
</tr>
<tr>
<td>Yes</td>
<td>Two-sided (bid and ask)</td>
<td>( S_{l2} = \frac{\alpha \sigma (2-\mu \delta) + 4c}{4\mu + \alpha (2-\mu \delta)} )</td>
</tr>
<tr>
<td>Yes</td>
<td>One-sided (bid or ask)</td>
<td>( S_{l1} = \frac{\alpha \sigma (2-\mu \delta) + 8c}{4\mu + \alpha (2-\mu \delta)} )</td>
</tr>
</tbody>
</table>

1. Economies of scope from monitoring two quotes (amortization benefit): \( S_{l2} < S_{l1} \).
2. Monitoring strategy: select lowest spread from \( S_{l_i} \) and \( S_{U2} \).
3. Comparative statics: \( s \uparrow \alpha, s \uparrow \sigma, s \downarrow \delta, s \downarrow \mu \).
Stage game equilibrium

Proposition 1

The equilibrium strategy in the stage game is as follows:

1. The incumbent HFM cancels all limit orders if there was news event in the previous period.

2. The incumbent HFM does not cancel any of his outstanding limit orders if there was no news in the previous period.

3. An HFM posts a sell price quote at $v_t + s_2^*$ and a buy price quote at $v_t - s_2^*$ when the order book is empty. He monitors only if $s_2^* = s_{I2}$.

4. The HFM posts a sell price quote of $v_t + s_1^*$ if the order book is empty on the sell side. He posts a buy price quote of $v_t - s_1^*$ if the book is empty on the buy side. He monitors only if $s_1^* = s_{I1}$.

5. HFBs submit a market order to trade on news in case there is news.
Low monitoring cost: $s_{I2} < s_U$, $s_{I1} \leq s_U$
Low monitoring cost: $s_{l2} < s_U$, $s_{l1} \leq s_U$

- 
  - Dashed line: Two-sided price quotes, monitoring HFM
  - Purple line: One-sided price quote, monitoring HFM
  - Green line: Non-monitoring HFM

HFM always monitors two-sided price quotes.

- HFM does not monitor a one-sided price quote.
High monitoring cost: $s_{I2} \lesssim s_U$, $s_{I1} > s_U$
High monitoring cost: \( s_{I2} \leq s_U, s_{I1} > s_U \)
Full solution recursive model

Conditional spread: \( s_2^* = \min \{ s_{I2}, s_U \} \) and \( s_1^* = \min \{ s_{I1}, s_U \} \).

Two spreads possible on either side imply four states of the book:

\((Ask_t - v_t, v_t - Bid_t) \in \left\{ (s_2^*, s_2^*), (s_2^*, s_1^*), (s_1^*, s_2^*), (s_1^*, s_1^*) \right\} .\)
Full solution recursive model

*Conditional spread*: \( s_2^* = \min \{ s_{I2}, s_U \} \) and \( s_1^* = \min \{ s_{I1}, s_U \} \).

Two spreads possible on either side imply four states of the book:

\((Ask_t - v_t, v_t - Bid_t) \in \{ (s_2^*, s_2^*), (s_2^*, s_1^*), (s_1^*, s_2^*), (s_1^*, s_1^*) \}\).

Transition matrix \( P \) is:

\[
\begin{pmatrix}
1 - (1 - \alpha \delta) \mu \delta & (1 - \alpha \delta) \frac{1}{2} \mu \delta & (1 - \alpha \delta) \frac{1}{2} \mu \delta & 0 \\
\alpha \delta & (1 - \alpha \delta) (1 - \frac{1}{2} \mu \delta) & 0 & (1 - \alpha \delta) \frac{1}{2} \mu \delta \\
\alpha \delta & 0 & (1 - \alpha \delta) (1 - \frac{1}{2} \mu \delta) & (1 - \alpha \delta) \frac{1}{2} \mu \delta \\
\alpha \delta & 0 & 0 & 1 - \alpha \delta
\end{pmatrix}
\]
Steady state spread

1. Let \( s^* = \left( s_2^*, \frac{s_1^*+s_2^*}{2}, \frac{s_1^*+s_2^*}{2}, s_1^* \right) \) is the vector of conditional spreads.
Steady state spread

1. Let \( s^* = \left( s_2^*, \frac{s_1^* + s_2^*}{2}, \frac{s_1^* + s_2^*}{2}, s_1^* \right) \) is the vector of conditional spreads.

2. Let \( \lambda \) be the left eigenvector of \( P \) corresponding to the unit eigenvalue and set the sum of its elements equal to one:

\[
\lambda \propto \left( \frac{\alpha(2\alpha + \mu - \alpha \mu \delta)}{\mu^2(1-\alpha \delta)^2}, \frac{\alpha}{\mu(1-\alpha \delta)}, \frac{\alpha}{\mu(1-\alpha \delta)}, 1 \right).
\]
Steady state spread

1. Let \( s^* = \left( s_2^*, \frac{s_1^*+s_2^*}{2}, \frac{s_1^*+s_2^*}{2}, s_1^* \right) \) is the vector of conditional spreads.

2. Let \( \lambda \) be the left eigenvector of \( P \) corresponding to the unit eigenvalue and set the sum of its elements equal to one:

\[
\lambda \propto \left( \frac{\alpha(2\alpha+\mu-\alpha\mu\delta)}{\mu^2(1-\alpha\delta)^2}, \frac{\alpha}{\mu(1-\alpha\delta)}, \frac{\alpha}{\mu(1-\alpha\delta)}, 1 \right).
\]

3. The steady state average spread therefore equals:

\[ s = \lambda \cdot s^*. \]
Steady state spread

1. Let $s^* = \left( s_2^*, \frac{s_1^* + s_2^*}{2}, \frac{s_1^* + s_2^*}{2}, s_1^* \right)$ is the vector of conditional spreads.

2. Let $\lambda$ be the left eigenvector of $P$ corresponding to the unit eigenvalue and set the sum of its elements equal to one:

$$\lambda \propto \left( \frac{\alpha(2\alpha + \mu - \alpha \mu \delta)}{\mu^2(1-\alpha \delta)^2}, \frac{\alpha}{\mu(1-\alpha \delta)}, \frac{\alpha}{\mu(1-\alpha \delta)}, 1 \right).$$

3. The steady state average spread therefore equals:

$$s = \lambda \cdot s^*.$$

4. The effect of latency on $s$ can be decomposed as:

$$\frac{\partial s}{\partial \delta} = \lambda \cdot \frac{\partial}{\partial \delta} s^* + \underbrace{\frac{\partial \lambda}{\partial \delta}} \cdot s^*.$$

Conditional spread effect  Spread distribution effect
Steady state spread properties

Proposition 2
The steady state equilibrium spread $s$
1. increases in exchange speed (i.e., it decreases in $\delta$).
2. increases in the frequency of news arrival ($\alpha$).
3. increases in the size of news ($\sigma$).
Steady state spread properties

Proposition 2
The steady state equilibrium spread $s$
1. increases in exchange speed (i.e., it decreases in $\delta$).
2. increases in the frequency of news arrival ($\alpha$).
3. increases in the size of news ($\sigma$).

Proposition 3
If HFMs monitor quotes the spread increases as the exchange speed increases both through a static and a dynamic channel. A higher exchange speed both increases the adverse selection cost (conditional spread) and the probability of rents for HFMs as the state distribution shifts. If monitoring is never optimal, the exchange latency does not affect the steady state distribution. The static effect is the only one in that case.
Latency effect on the steady state spread

Steady state probabilities fixed at those for slowest exchange

Latency effect on conditional spreads

Faster markets

Slower markets

Steady state bid–ask spread vs. Exchange latency (δ)
Latency effect on the steady state spread

- Steady state probabilities
- Steady state probabilities fixed at those for slowest exchange

Latency effect on spread distribution
Latency effect on conditional spreads

Steady state bid–ask spread

Exchange latency ($\delta$)

Slower markets
Faster markets
Latency effect on quote flickering

1. *Definition quote flickering*: The expected number of spread changes in one unit of time.
Latency effect on quote flickering

1. *Definition quote flickering*: The expected number of spread changes in one unit of time.

2. Probabilities of spread changes in a single period of length $\delta$:

   $$Pr[\text{Spread change}] = \lambda(\nu - \text{diag}(P)),$$
Latency effect on quote flickering

1. *Definition quote flickering*: The expected number of spread changes in one unit of time.
2. Probabilities of spread changes in a single period of length $\delta$:

$$Pr[Spread \ change] = \lambda(\nu - \text{diag}(P)),$$

3. The amount of quote flickering therefore is:

$$\frac{Pr[Spread \ change]}{\delta}$$
Proposition 4
Quote flickering increases in exchange speed (i.e., decreases in $\delta$).
Latency effect on quote flickering

- Faster markets
- Slower markets

Quote flickering vs Exchange latency ($\delta$)
Outline

Motivation

Model

Evidence

Conclusion
Data


3. *Identification:* On Feb 8, 2010, NASDAQ OMX implemented a technology upgrade (INET) that reduced latency tenfold and allowed for colocation.

4. *HFT Identification:* Followed Kirilenko, Kyle, Samadi, and Tuzun (2011) criteria, i.e.,
   4.1 Number of traded contracts "large"
   4.2 End-of-day positions "small," and
   4.3 Net positions cross zero "often" throughout the day.

Data

1. **Source**: Thomson-Reuters tick history trade and quote data for Swedish, Danish, and Finnish stocks. Data includes trader IDs.
2. **Sample**: Nordic 40 stocks from Nov 8, 2009 through May 8, 2010.
3. **Identification**: On Feb 8, 2010, NASDAQ OMX implemented a technology upgrade (INET) that reduced latency tenfold and allowed for colocation.
4. Followed Kirilenko, Kyle, Samadi, and Tuzun (2011) criteria, i.e.,
   4.1 Number of traded contracts “large”
   4.2 End-of-day positions “small,” and
   4.3 Net positions cross zero “often” throughout the day.
Data

1. **Source**: Thomson-Reuters tick history trade and quote data for Swedish, Danish, and Finnish stocks. Data includes trader IDs.

2. **Sample**: Nordic 40 stocks from Nov 8, 2009 through May 8, 2010.

3. **Identification**: On Feb 8, 2010, NASDAQ OMX implemented a technology upgrade (INET) that reduced latency tenfold and allowed for colocation.

4. **HFT Identification**: Followed Kirilenko, Kyle, Samadi, and Tuzun (2011) criteria, i.e.,
   - 4.1 Number of traded contracts “large”
   - 4.2 End-of-day positions “small,” and
   - 4.3 Net positions cross zero “often” throughout the day.
Data

1. **Source**: Thomson-Reuters tick history trade and quote data for Swedish, Danish, and Finnish stocks. Data includes trader IDs.

2. **Sample**: Nordic 40 stocks from Nov 8, 2009 through May 8, 2010.

3. **Identification**: On Feb 8, 2010, NASDAQ OMX implemented a technology upgrade (INET) that reduced latency tenfold and allowed for colocation.

4. **HFT Identification**: Followed Kirilenko, Kyle, Samadi, and Tuzun (2011) criteria, i.e.,
   4.1 Number of traded contracts “large”
   4.2 End-of-day positions “small,” and
   4.3 Net positions cross zero “often” throughout the day.

Adverse selection cost HFMs

February 1, 2010: NASDAQ system upgrade testing period
February 8, 2010: NASDAQ system upgrade
Effective spread HFMs

February 1, 2010: NASDAQ system upgrade testing period
February 8, 2010: NASDAQ system upgrade

Effective spread (basis points)
Panel data FE model with event and trader type dummies:

\[ AS_{ijt} = \left( \beta_0 + \beta_1 d_{HFM}^j \right) + d_{\text{INET}} t \left( \beta_2 + \beta_3 d_{HFM} \right) + \theta_i + Controls_{it} + \epsilon_{ijt} \]

*Controls*: volatility, stock turnover, inverse price, log market cap.
## Results

<table>
<thead>
<tr>
<th>Controls</th>
<th>Effective spread</th>
<th></th>
<th>Adverse selection</th>
<th></th>
<th>Realized spread</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>$d_{HFM}d_{INET}$</td>
<td>1.04*** 4.87</td>
<td>1.06*** 4.46</td>
<td>0.68** 2.20</td>
<td>0.68** 2.22</td>
<td>0.37 1.22</td>
<td>0.38 1.21</td>
</tr>
<tr>
<td>$d_{INET}$</td>
<td>0.41** 2.26</td>
<td>0.08 0.35</td>
<td>1.43*** 12.06</td>
<td>1.21*** 9.42</td>
<td>−1.02*** −7.14</td>
<td>−1.12*** −6.14</td>
</tr>
<tr>
<td>$d_{HFM}$</td>
<td>0.15 0.94</td>
<td>2.03*** 7.69</td>
<td>−1.88*** −7.48</td>
<td>−1.89*** −7.49</td>
<td>2.04*** 7.93</td>
<td>2.03*** 7.69</td>
</tr>
</tbody>
</table>

#Observations: 151,075
### Calibration

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-event latency ($\delta$)</td>
<td>50 milliseconds</td>
</tr>
<tr>
<td>Post-event latency ($\delta$)</td>
<td>0.25 milliseconds</td>
</tr>
<tr>
<td>News rate ($\alpha$)</td>
<td>5 events per second</td>
</tr>
<tr>
<td>Size of news ($\sigma$)</td>
<td>10 basis points</td>
</tr>
<tr>
<td>Monitoring cost ($c$)</td>
<td>0.1 basis points per second</td>
</tr>
<tr>
<td>LT arrival rate ($\mu$)</td>
<td>5 arrivals per second (sample median)</td>
</tr>
</tbody>
</table>
Trade clustering

Cumulative distribution function of intertrade duration

Intertrade duration frequency

Time (seconds)
1. Calibration yields a 35% increase in adverse selection cost.
Calibration

1. Calibration yields a 35% increase in adverse selection cost.
2. This change is most sensitive to pre-event latency.
Calibration

1. Calibration yields a 35% increase in adverse selection cost.
2. This change is most sensitive to pre-event latency.
3. Pre-event latency has to be increased to 145 milliseconds to match the observed 540% adverse selection cost increase.
Calibration

1. Calibration yields a 35% increase in adverse selection cost.
2. This change is most sensitive to pre-event latency.
3. Pre-event latency has to be increased to 145 milliseconds to match the observed 540% adverse selection cost increase.
4. The news size ($\sigma$) and intensity ($\alpha$) affect the level of adverse selection cost, not so much the relative change.
Outline

Motivation

Model

Evidence

Conclusion
Conclusion

1. Lower exchange latency can reduce market quality. High-frequency market makers (HFM)s meet high-frequency bandits/speculators (HFBs) more often. Spread is increased due to higher adverse selection.
Conclusion

1. Lower exchange latency can reduce market quality. High-frequency market makers (HFM) meet high-frequency bandits/speculators (HFB) more often. Spread is increased due to higher adverse selection.

2. Lower exchange latency allows an “incumbent” HFM to earn rents through economies of scale from quote monitoring.
Conclusion

1. Lower exchange latency can reduce market quality. High-frequency market makers (HFM s) meet high-frequency bandits/speculators (HFBs) more often. Spread is increased due to higher adverse selection.

2. Lower exchange latency allows an “incumbent” HFM to earn rents through economies of scale from quote monitoring.

3. A NASDAQ-OMX speed change analysis confirms model predictions: HFMs raise their spreads due to higher larger adverse selection cost. Calibration reasonably successful.


