

# **High Frequency Quoting, Trading and the Efficiency of Prices**

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# What is “High Frequency Quoting/Trading”?

## How fast is fast?

Size	9:30 10:00	10:00 10:30	10:30 11:00	11:00 11:30	11:30 12:00	12:00 12:30	12:30 1:00	1:00 1:30	1:30 2:00	2:00 2:30	2:30 3:00	3:00 3:30	3:30 4:00
<i>Panel A: Average number of trades per second</i>													
Small	0.05	0.05	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.05	0.10
2	0.15	0.14	0.12	0.11	0.10	0.09	0.08	0.08	0.01	0.10	0.11	0.14	0.28
3	0.33	0.32	0.27	0.24	0.21	0.18	0.17	0.18	0.19	0.22	0.24	0.31	0.60
4	0.65	0.62	0.50	0.44	0.38	0.34	0.32	0.32	0.34	0.40	0.44	0.56	1.06
Large	2.05	1.77	1.41	1.22	1.05	0.92	0.85	0.86	0.90	1.05	1.14	1.42	2.62
SPY	39.28	32.54	24.05	20.43	17.52	14.79	13.36	13.99	14.62	17.92	18.88	22.35	39.01
IWM	13.45	10.88	7.67	6.42	5.43	4.62	4.28	4.40	4.61	5.67	6.07	7.24	13.12
<i>Panel B: Average number of quote updates per second</i>													
Small	1.42	0.98	0.79	0.69	0.62	0.56	0.52	0.52	0.52	0.59	0.61	0.70	1.09
2	3.57	2.85	2.33	2.04	1.79	1.60	1.48	1.49	1.55	1.78	1.82	2.13	3.27
3	6.49	5.82	4.82	4.21	3.64	3.23	3.00	3.04	3.17	3.72	3.81	4.51	6.85
4	10.81	10.79	9.08	7.92	6.70	5.84	5.42	5.49	5.72	6.70	6.99	8.28	12.42
Large	25.52	26.02	21.80	18.80	15.93	13.76	12.69	12.87	13.27	15.45	16.18	19.00	27.55
SPY	376.40	315.86	249.11	211.02	181.34	152.05	135.89	136.48	138.14	158.88	165.07	188.99	288.95
IWM	252.90	219.86	172.82	141.70	120.81	101.24	91.12	91.42	93.30	107.87	113.11	127.48	186.53

Sample: All stocks with Price>\$1 and market cap>\$100m at beginning of month 2009-2011

Quote Update: Any change in price or size of BBO at all public exchanges

# Why do we care?

- Potentially adverse consequences
  - Increase in adverse selection, wasteful arms race (see, e.g., Biais, Foucault and Moinas (2012), Budish, Cramton and Shim (2013), Han, Khapko and Kyle (2014))
- Or not
  - Frequent quoting is just a standard way to mitigate risk (Baruch and Glosten (2013))
- Or sometimes
  - Lower latency generates higher liquidity provision, but not always (Ait-Sahalia and Saglam (2013)).
- Bigger Picture
  - Liquidity today is (mostly) endogenous
    - Minimal affirmative obligations and no negative obligations
  - Equilibrium asset pricing can and should account for willingness of intermediaries to participate in market
  - Welfare
    - Affirmative obligations in a true DMM system can improve welfare (Bessembinder, Hao and Lemmon (2011))
    - Stiglitz (2014): Not so fast, there is no guarantee that speed increases welfare and in fact can reduce welfare. “Intermediate Variables”

# What do we know?

- Identify HFT (e.g. the Nasdaq), and examine consequences
  - Brogaard, Hendershott & Riordan (2013), Hirschey (2013), Tong (2013), etc.
  - Evidence is mixed
- Papers that identify changes in market structure that facilitate HF activity
  - Hendershott, Jones and Menkveld (2011)
    - Introduction of autoquote on NYSE in 2003, evolution from 2001 to 2005
  - Menkveld (2012)
    - HFT entry in 32 Dutch stocks on Chi-X and Euronext, Jan 2007-June 2008
  - Riordan and Storkenmaier (2012)
    - Introduction of Xetra 8.0 on Deutsche Borse, 98 stocks, March-May 2007
- Execution risk: Hasbrouck (2013)

# What do we do and why is it new?

1. Large sample data: tradeoff generalizability and identification
  - Full cross-section of U.S. equities
  - 2009-2011
  - Millisecond data
2. Resiliency/fragility and “Stress test”
  - Liquidity sweeps that remove large amount of liquidity across market venues
3. The introduction of Arrowhead on the Tokyo Stock Exchange
  - Drops latency in the 2<sup>nd</sup> largest market in the world from 1-2 seconds to 2 milliseconds

## Measuring HF Activity: “Quote” Updates

“Quote” Updates:

# of changes in BBO or size in **all** lit venues in an interval

- Venue choice is endogenous.
- One venue can be at NBBO, even though top of book at multiple venues can be at the same price.
- Does not include Level II of book, or dark pools.
- Changes occur due to
  - Submissions, cancellations and expirations
  - Trades
- Underestimates magnitude of true changes but no obvious bias for our tests

# Dependent Variables

$$VR(q) \equiv \frac{Var[r_t(q)]}{qVar[r_t]} = 1 + 2 \sum_{k=1}^{q-1} \left(1 - \frac{k}{q}\right) \rho(k)$$

If trading at short horizon is “noisy”,  $VR < 1$

If trading at short horizon has trend,  $VR > 1$

All returns are based on quote midpoint to avoid bid-ask bounce

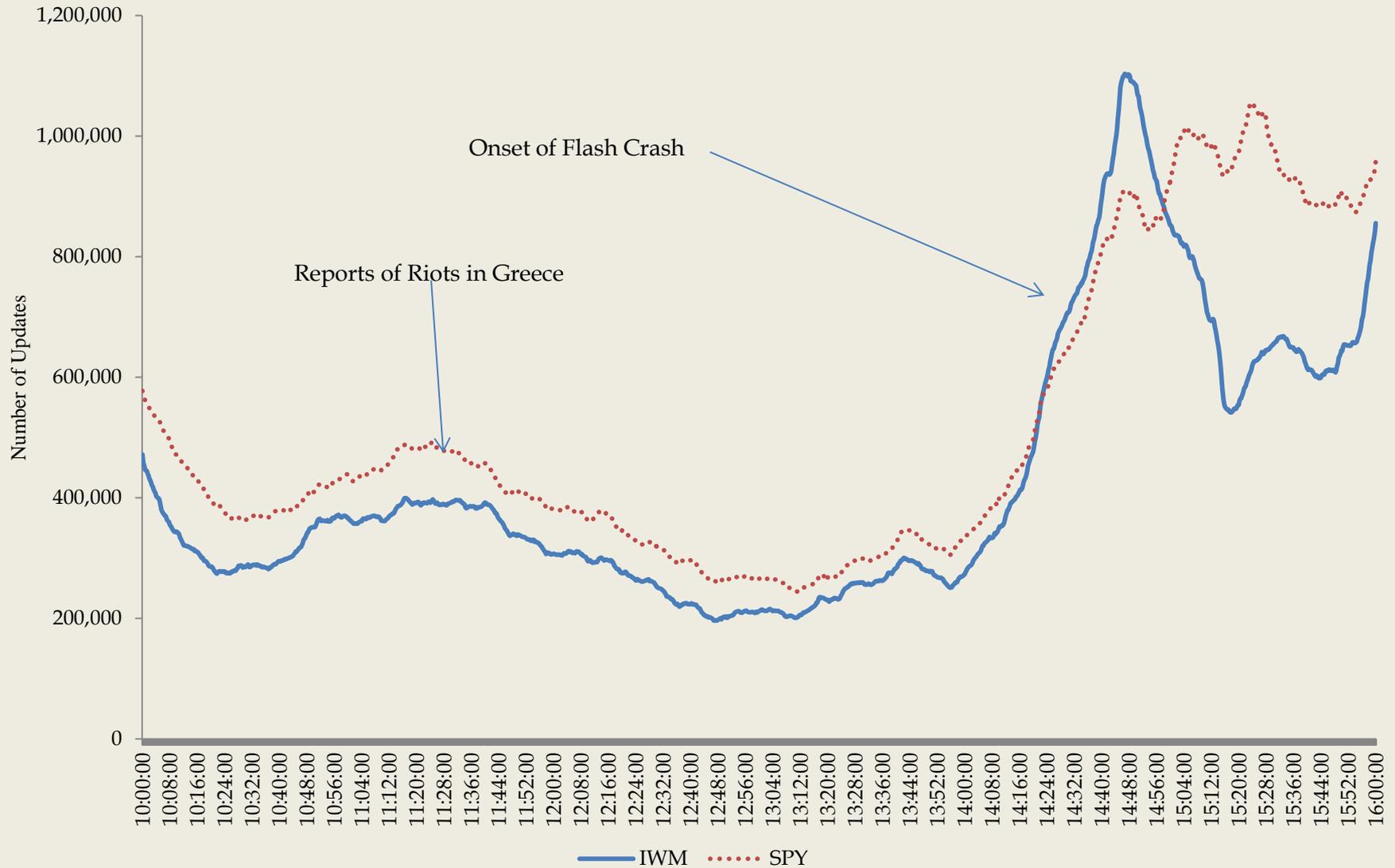
$$es_{jt} = q_{jt} (p_{jt} - m_{jt}) / m_{jt}$$

$$rs_{jt} = q_{jt} (p_{jt} - m_{jt+\tau}) / m_{jt}$$

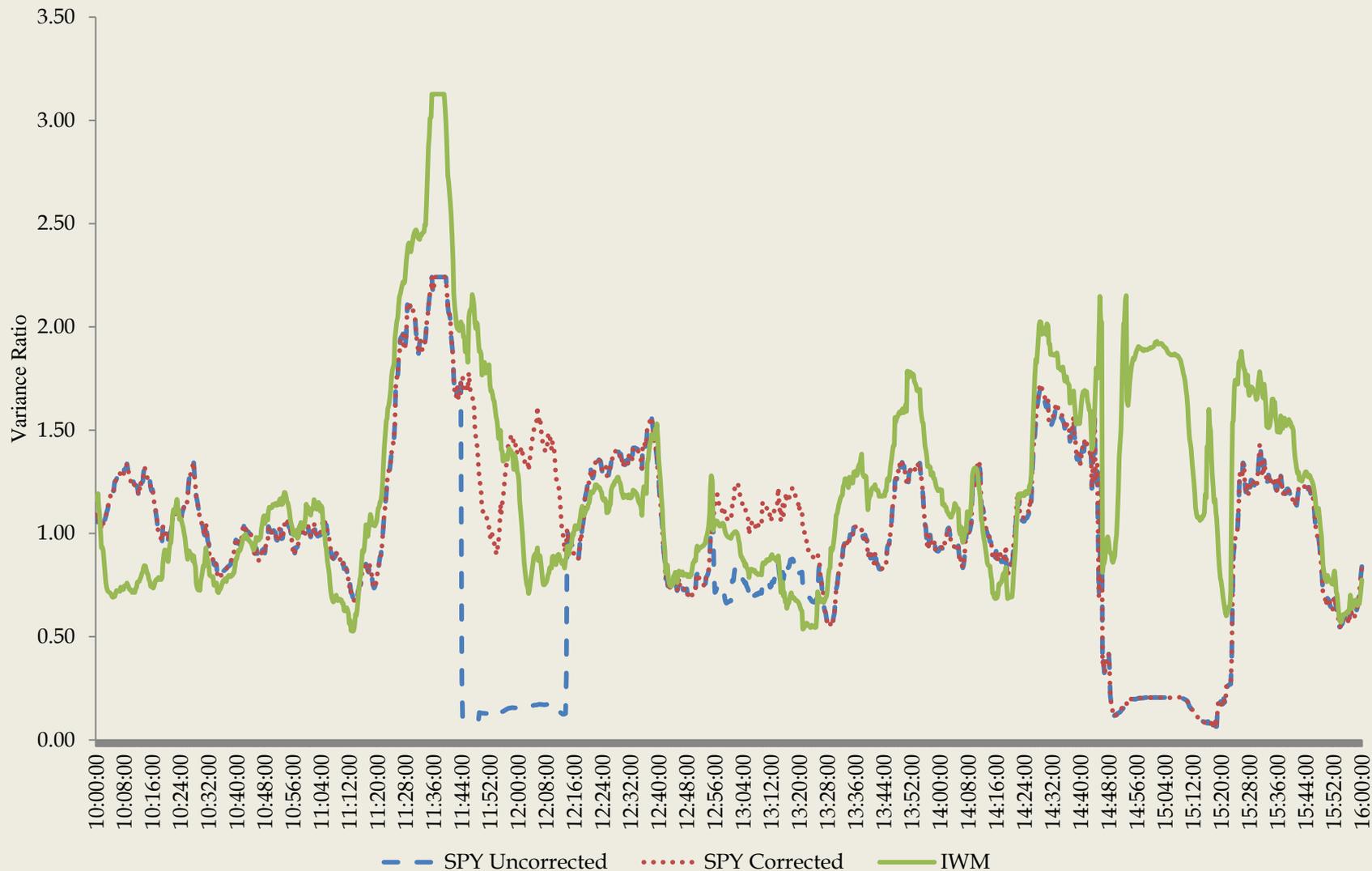
$$pi_{jt} = q_{jt} (m_{jt+\tau} - m_{jt}) / m_{jt}$$

Where  $\tau = 1, \dots, 20$  seconds

# Illustration of the HF variable during Flash Crash: Half-hour sums of updates, rolling forward in 15 seconds



# Are Variance Ratios Affected by Flash Crash: Variance Ratios rolling forward in 15 second intervals



# Data and Sampling

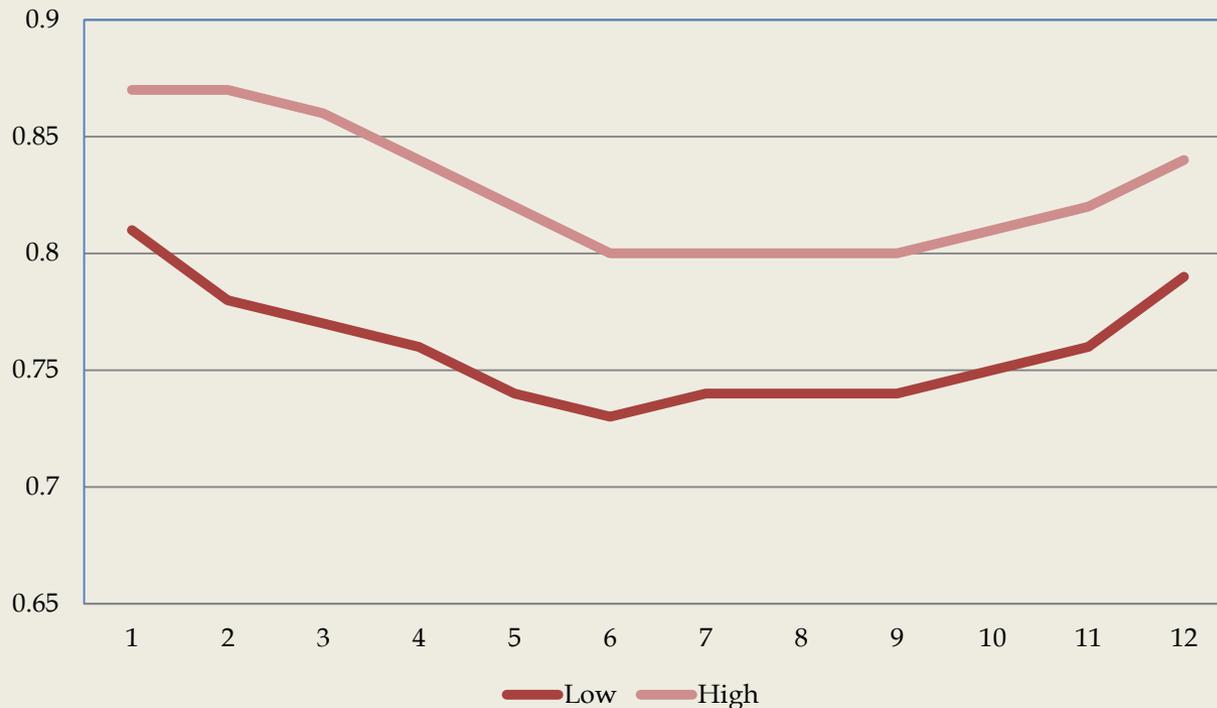
- 2009-2011
  - Second Resolution TAQ for 2009
  - Millisecond Resolution TAQ 2010-2011
- Full Cross-Section of Common Stocks (CRSP Share Codes 10,11)
- NYSE size quintiles, not including stocks < \$1 in price and <\$100m in market cap
- TSE data
  - 300 largest market cap stocks on 1<sup>st</sup> Section of TSE
  - July 2009 to March 2011
  - Full message stream as updates to orderbook

# Base Tests

- Triple sorts
  - Sort firms into size quintiles
  - For each size quintile, sort into trade quintiles
  - Within each size/trade quintile, sort firms into Low and High update groups in the prior half hour
- Dependent Variables
  - Variance Ratios
    - Compute average of  $|VR-1|$  for each stock, average in Low and High update groups
    - Report time series average of difference between High and Low
  - Effective Spreads
    - Similar process

# Simple Average Variance Ratios in Low and High Update Groups

## Small Firms



Sample: All stocks with Price > \$1 at beginning of month 2009-2011

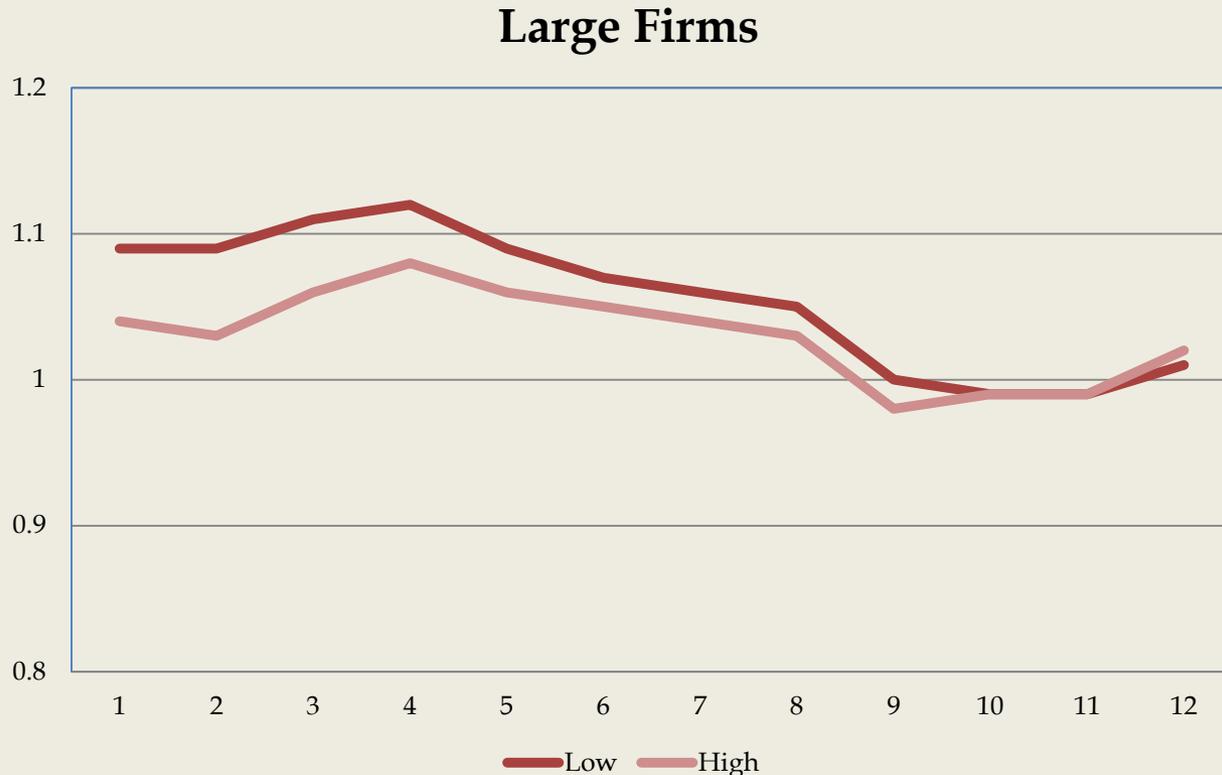
Quote Update: Any change in price or size of BBO at all public exchanges

Low and High Groups based on updates in the prior half hour

X-axis shows half hour intervals, from 10:00 am to 4:00 pm

Y-axis shows average variance ratios

# Simple Average Variance Ratios in Low and High Update Groups



Sample: All stocks with Price > \$1 at beginning of month 2009-2011

Quote Update: Any change in price or size of BBO at all public exchanges

Low and High Groups based on updates in the prior half hour

X-axis shows half hour intervals, from 10:00 am to 4:00 pm

Y-axis shows average variance ratios

# Average *Differences* in |VR-1| Between Low and High Update Groups

15 second, 5 minute intervals

	Quintiles Formed on Number of Trades				
	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5
Small	-0.033 (0.002)	-0.028 (0.001)	-0.021 (0.001)	-0.017 (0.001)	-0.018 (0.001)
2	-0.018 (0.001)	-0.012 (0.001)	-0.019 (0.001)	-0.020 (0.001)	-0.026 (0.001)
3	-0.017 (0.001)	-0.020 (0.001)	-0.022 (0.001)	-0.030 (0.001)	-0.035 (0.001)
4	-0.022 (0.001)	-0.028 (0.001)	-0.033 (0.001)	-0.037 (0.001)	-0.034 (0.001)
Large	-0.027 (0.001)	-0.031 (0.001)	-0.032 (0.001)	-0.031 (0.001)	-0.034 (0.001)

100 millisecond, 1-2 second intervals

	<i>Differences in Average Variance Ratios (Size Quintile 5 only)</i>				
100ms, 1sec.	0.0004 (0.0004)	-0.0014 (0.0004)	-0.0014 (0.0003)	0.0023 (0.0004)	0.0047 (0.0006)
100ms, 2sec.	0.0011 (0.0005)	-0.0048 (0.0005)	-0.0049 (0.0005)	-0.0005 (0.0004)	0.0004 (0.0004)

Sample: All stocks with Price>\$1 and market cap>\$100m at beginning of month 2009-2011

Quote Update: Any change in price or size of BBO at all public exchanges

Low and High Groups based on updates in the prior half hour

Standard Errors in parentheses

# Average *Differences* in Effective Spreads between Low and High Update Groups in Basis Points

	Quintiles Formed on Number of Trades				
	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5
Small	-6.10 (5.81)	-0.70 (0.25)	-3.68 (0.19)	-4.23 (0.07)	-1.58 (0.08)
2	-1.27 (0.18)	-0.96 (0.04)	-0.77 (0.04)	-0.66 (0.05)	-0.62 (0.07)
3	-2.00 (0.05)	-0.12 (0.04)	0.06 (0.04)	-0.31 (0.05)	-0.58 (0.06)
4	-1.27 (0.05)	0.15 (0.04)	-0.22 (0.04)	-0.91 (0.05)	-1.20 (0.06)
Large	-0.61 (0.04)	-0.28 (0.03)	-0.46 (0.04)	-1.13 (0.04)	-1.12 (0.05)

Sample: All stocks with Price > \$1 and market cap > \$100m at beginning of month 2009-2011

Quote Update: Any change in price or size of BBO at all public exchanges

Low and High Groups based on updates in the prior half hour

Standard Errors in parentheses

# Where are the Differences in Effective Spreads Coming From?

Size Quintile	Trade Quintile	Eff. Spreads	Realized Spreads				Price Impact			
			t+1	t+5	t+10	t+20	t+1	t+5	t+10	t+20
Small	1	-36.71	-14.0	-14.6	-14.2	-13.8	-22.7	-22.2	-22.5	-22.9
	2	-11.45	-4.9	-5.5	-5.4	-5.3	-6.5	-5.9	-6.0	-6.2
	3	-7.18	-5.3	-5.4	-5.2	-5.0	-1.9	-1.8	-2.0	-2.2
	4	-7.45	-5.5	-5.3	-5.1	-4.8	-1.9	-2.2	-2.4	-2.6
	5	-4.67	-3.7	-3.7	-3.6	-3.4	-1.0	-1.0	-1.1	-1.3
2	1	-4.26	-2.4	-2.7	-2.6	-2.5	-1.8	-1.6	-1.6	-1.8
	2	-0.99	-0.9	-0.9	-0.9	-0.9	-0.1	0.0	-0.1	-0.1
	3	-1.11	-0.8	-0.8	-0.8	-0.8	-0.3	-0.3	-0.3	-0.4
	4	-0.97	-0.9	-0.9	-0.9	-0.8	0.0	-0.1	-0.1	-0.1
	5	-0.71	-0.5	-0.8	-0.7	-0.7	-0.2	0.0	0.0	-0.1
3	1	-2.68	-1.6	-1.6	-1.6	-1.5	-1.0	-1.1	-1.1	-1.2
	2	-0.40	-0.5	-0.5	-0.5	-0.5	0.1	0.1	0.1	0.1
	3	-0.43	-0.4	-0.4	-0.4	-0.4	0.0	0.0	0.0	0.0
	4	-0.28	-0.3	-0.4	-0.4	-0.4	0.0	0.1	0.1	0.1
	5	-0.41	-0.4	-0.6	-0.5	-0.5	0.0	0.2	0.1	0.0
4	1	-0.71	-0.6	-0.5	-0.5	-0.4	-0.1	-0.2	-0.2	-0.3
	2	-0.08	0.0	-0.1	-0.1	-0.1	-0.1	0.0	0.0	0.0
	3	0.03	0.0	-0.1	-0.1	-0.1	0.1	0.2	0.2	0.2
	4	-0.09	-0.1	-0.2	-0.2	-0.2	0.0	0.2	0.1	0.1
	5	-0.34	-0.3	-0.5	-0.4	-0.4	0.0	0.1	0.1	0.1
Large	1	-0.06	-0.1	-0.1	-0.1	-0.1	0.0	0.1	0.1	0.0
	2	0.06	0.1	-0.1	-0.1	-0.1	0.0	0.1	0.1	0.1
	3	-0.06	0.0	-0.1	-0.1	-0.1	0.0	0.1	0.1	0.0
	4	-0.20	-0.2	-0.2	-0.2	-0.1	0.0	0.0	0.0	-0.1
	5	-0.15	-0.1	-0.1	0.0	0.0	0.0	-0.1	-0.1	-0.1

# Is the Market Resilient? Rapid Liquidity Sweeps

## Definition

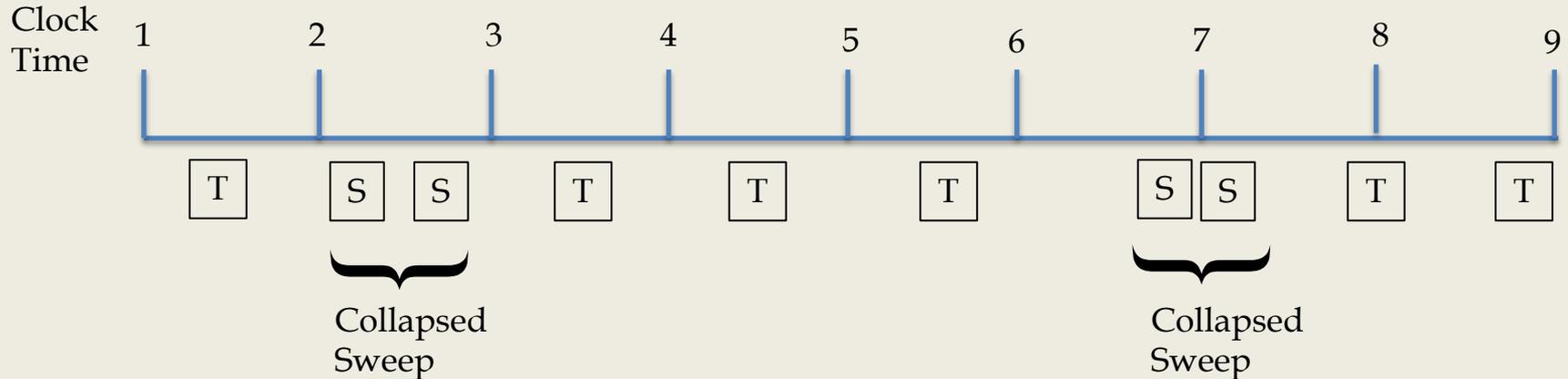
- Multiple trades in the same stock in the same millisecond printed in multiple reporting venues
  - Not mechanical printing of trades
  - Not necessarily simultaneous because of latency differences between venues and CQS...but close.
  - Sweeping liquidity off top of order books

## Basic Statistics (2010-2011)

- 764 million shocks
- \$17.6 trillion compared to market volume of \$ 70 trillion
- This is not inconsequential

# Collapsing Sweeps

Median time between trades in same half hour over prior month = 1 second



- Collapsed Sweeps
  - 746 million individual sweeps → 404 million collapsed sweeps
  - Quintiles 1-4: 6 trades per collapsed sweep
  - Quintile 5: 8 trades per collapsed sweep
  - 50% of trades in collapsed sweeps are ISOs
- Focus on Large Sweeps
  - Only look at collapsed sweeps greater than 10,000 shares
  - Median time between sweeps: Small (748 seconds), Large (68 seconds)

# Large Liquidity Sweeps

<i>Time difference in seconds between successive collapsed liquidity sweeps greater than 10,000 shares</i>							
	% Unique	10 <sup>th</sup> Perc.	25 <sup>th</sup> Perc.	Median	Mean	75 <sup>th</sup> Perc.	90 <sup>th</sup> Perc.
<i>Collapsed Buyer-Initiated Sweeps</i>							
Small	30.80	32.32	147.00	748.17	2456.94	2913.31	7498.26
2	18.47	18.52	87.42	432.55	1695.96	1689.12	4868.18
3	11.06	11.67	53.69	271.23	1171.53	1034.32	3074.75
4	8.68	8.21	36.49	173.30	886.61	653.04	2100.75
Large	3.64	3.62	15.20	68.17	454.26	259.13	874.68
<i>Collapsed Seller-Initiated Sweeps</i>							
Small	31.06	34.30	161.83	811.03	2569.59	3125.52	7854.48
2	18.71	18.77	90.37	454.65	1753.06	1774.13	5063.75
3	11.19	11.77	55.33	278.62	1183.89	1055.01	3134.42
4	8.73	8.29	37.06	175.91	892.54	663.33	2117.95
Large	3.64	3.55	15.04	67.67	453.29	258.93	1903.30

# How Resilient is the Market?

## Paired Variance Ratios Before and After Large Liquidity Drawdowns

<i>/VR-1/ Before and After Liquidity Sweeps Greater than 10,000 shares</i>				
	Pre-Sweep	Post-Sweep	$\Delta VR-1 $	t-statistic
<i>Buyer-Initiated</i>				
Small	0.3133	0.3038	-0.0095	-2.88
2	0.3046	0.2948	-0.0097	-5.33
3	0.2991	0.2919	-0.0072	-5.11
4	0.3013	0.2946	-0.0066	-6.37
Large	0.2696	0.2648	-0.0047	-14.90
<i>Seller-Initiated</i>				
Small	0.3114	0.3085	-0.0028	-0.85
2	0.3034	0.2930	-0.0103	-5.86
3	0.2953	0.2899	-0.0054	-3.84
4	0.2950	0.2919	-0.0030	-2.99
Large	0.2681	0.2642	-0.0039	-12.38

# How Resilient is the Market?

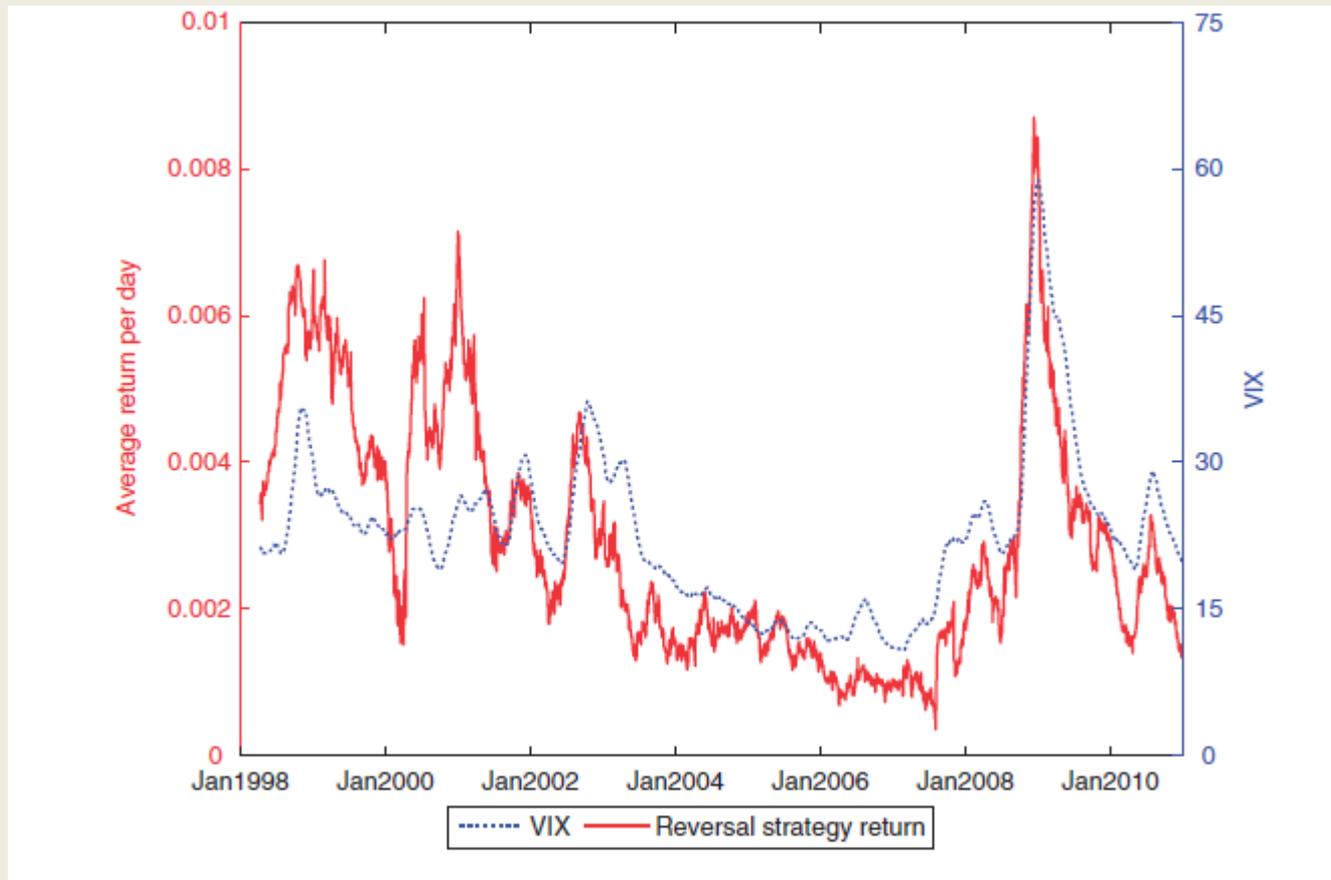
## Paired Effective Spreads Before and After Large Liquidity Drawdowns

<i>Average Effective Half-Spreads Around Liquidity Sweep Greater than 10,000 shares</i>					
	Pre-Sweep	Intra- Sweep	Post- Sweep	$\Delta$ Effec. Spread	t-statistic
<i>Buyer-Initiated</i>					
Small	20.10	121.59	17.80	-2.29	-3.41
2	10.16	65.30	9.30	-0.80	-8.05
3	7.61	49.73	6.93	-0.68	-8.21
4	6.08	34.26	5.24	-0.83	-7.38
Large	3.04	17.18	2.68	-0.36	-9.68
<i>Seller-Initiated</i>					
Small	19.59	115.22	17.77	-1.85	-3.48
2	10.35	65.73	9.41	-0.93	-7.74
3	7.77	48.08	6.98	-0.71	-5.84
4	6.29	33.61	5.27	-1.02	-5.13
Large	3.08	17.37	2.70	-0.38	-14.18

# What Factors Drive Changes in Supply Curves or Liquidity Provision?

- Risk
- Return
- And how is the risk/return managed?

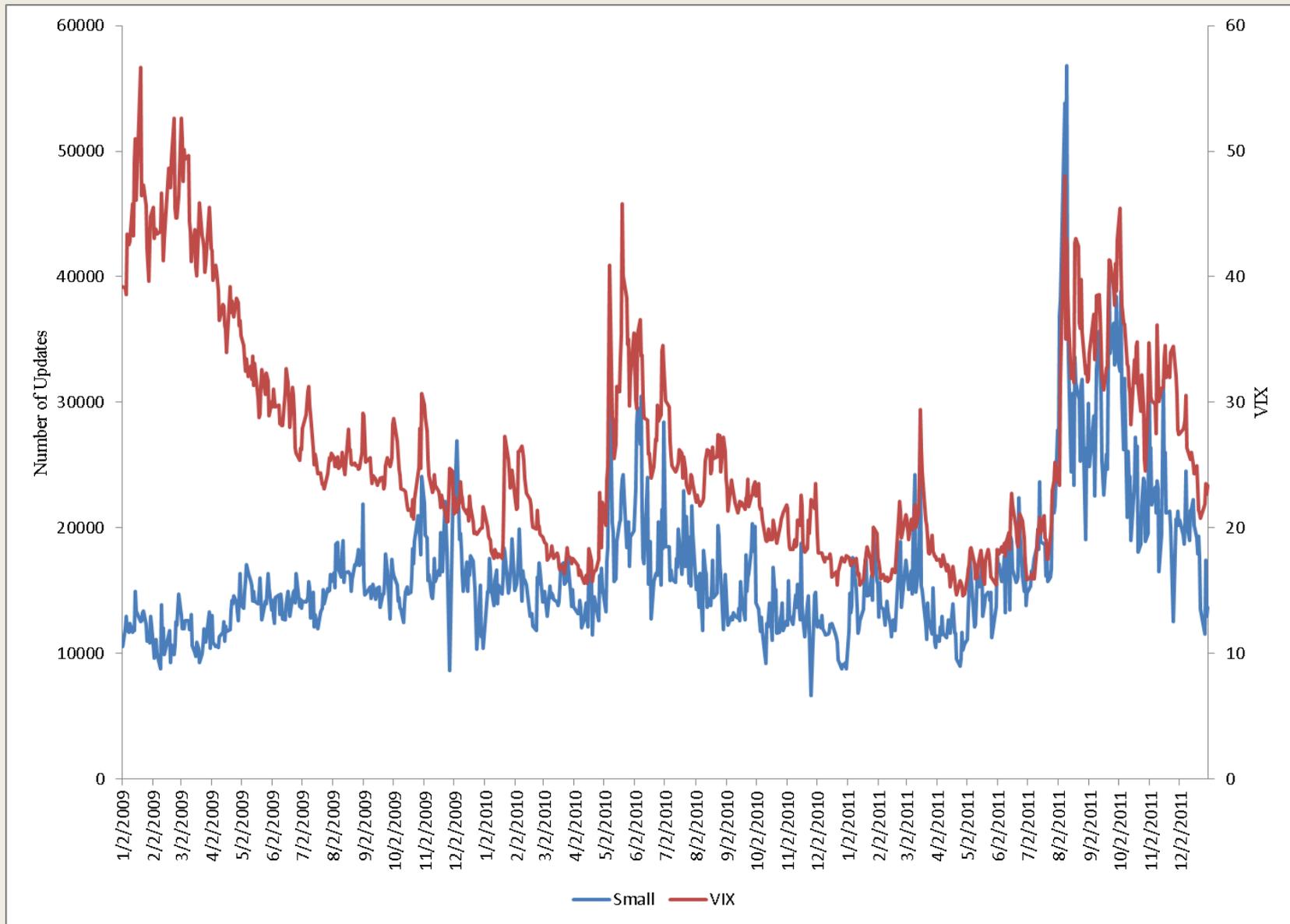
# The Returns to Liquidity Provision



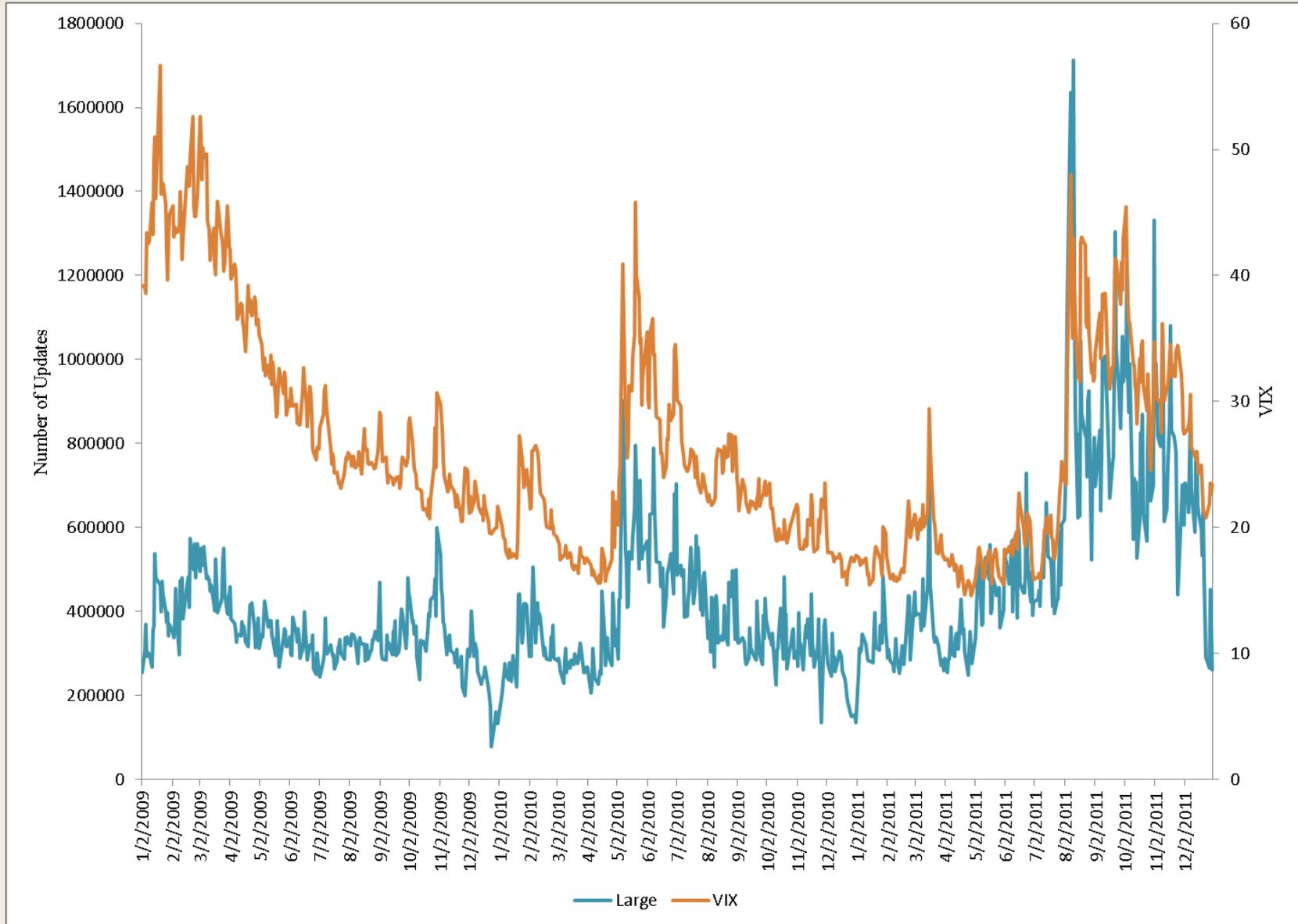
Source: Nagel (2012)

Reversal strategy return is three month moving average of long-short return reversal strategy based on prior 5-day returns

# Time Variation in Changes in Supply Curves: Small Cap



# Time Variation in Changes in Supply Curves: Large Cap



# What is the time-series relation between updates and VIX?

## Bivariate Vector Autoregressions

	Small		Size Quintile 2		Size Quintile 3		Size Quintile 4		Large	
	$\Delta\text{Upd}_t$	$\Delta\text{VIX}_t$								
$\Delta\text{Upd}_{t-1}$	-0.500 (12.67)	0.001 (0.07)	-0.493 (12.19)	0.008 (0.48)	-0.488 (11.93)	0.010 (0.61)	-0.487 (11.81)	0.006 (0.42)	-0.474 (11.43)	0.008 (0.54)
$\Delta\text{Upd}_{t-2}$	-0.264 (6.11)	0.017 (0.86)	-0.306 (6.94)	0.012 (0.63)	-0.302 (6.81)	0.016 (0.90)	-0.313 (6.96)	0.010 (0.58)	-0.312 (6.93)	0.009 (0.56)
$\Delta\text{Upd}_{t-3}$	-0.208 (4.80)	0.015 (0.74)	-0.250 (5.66)	-0.011 (0.06)	-0.258 (5.81)	0.001 (0.09)	-0.239 (5.32)	-0.004 (0.25)	-0.235 (5.21)	0.001 (0.08)
$\Delta\text{Upd}_{t-4}$	-0.026 (0.67)	0.031 (1.65)	-0.073 (1.82)	0.023 (1.33)	0.075 (1.85)	0.031 (1.82)	-0.071 (1.74)	0.024 (1.50)	-0.079 (1.90)	0.028 (1.74)
$\Delta\text{VIX}_{t-1}$	0.427 (5.18)	-0.102 (2.59)	0.503 (5.40)	-0.108 (2.67)	0.531 (5.45)	-0.110 (2.69)	0.581 (5.59)	-0.106 (2.59)	0.571 (5.49)	-0.110 (2.65)
$\Delta\text{VIX}_{t-2}$	0.107 (1.27)	-0.075 (1.86)	0.166 (1.73)	-0.073 (1.76)	0.209 (2.09)	-0.080 (1.91)	0.239 (2.23)	-0.073 (1.72)	0.212 (1.98)	-0.072 (1.71)
$\Delta\text{VIX}_{t-3}$	0.029 (0.35)	-0.111 (2.78)	0.144 (1.52)	-0.098 (2.37)	0.201 (2.02)	-0.101 (2.43)	0.196 (1.84)	-0.094 (2.23)	0.183 (1.72)	-0.101 (2.38)
$\Delta\text{VIX}_{t-4}$	-0.028 (0.34)	-0.054 (1.37)	0.027 (0.29)	-0.051 (1.26)	0.066 (0.67)	-0.061 (1.50)	0.065 (0.63)	-0.056 (1.37)	0.078 (0.75)	-0.062 (1.51)

- Liquidity suppliers react quickly to changes in VIX
  - Effects of changes in VIX die out quickly (past one day)
- No significant effect of changes in updates on changes in VIX

# Average *Differences* in |VR-1| Between Low and High Update Groups: Update Groups Formed from *Prior Day*

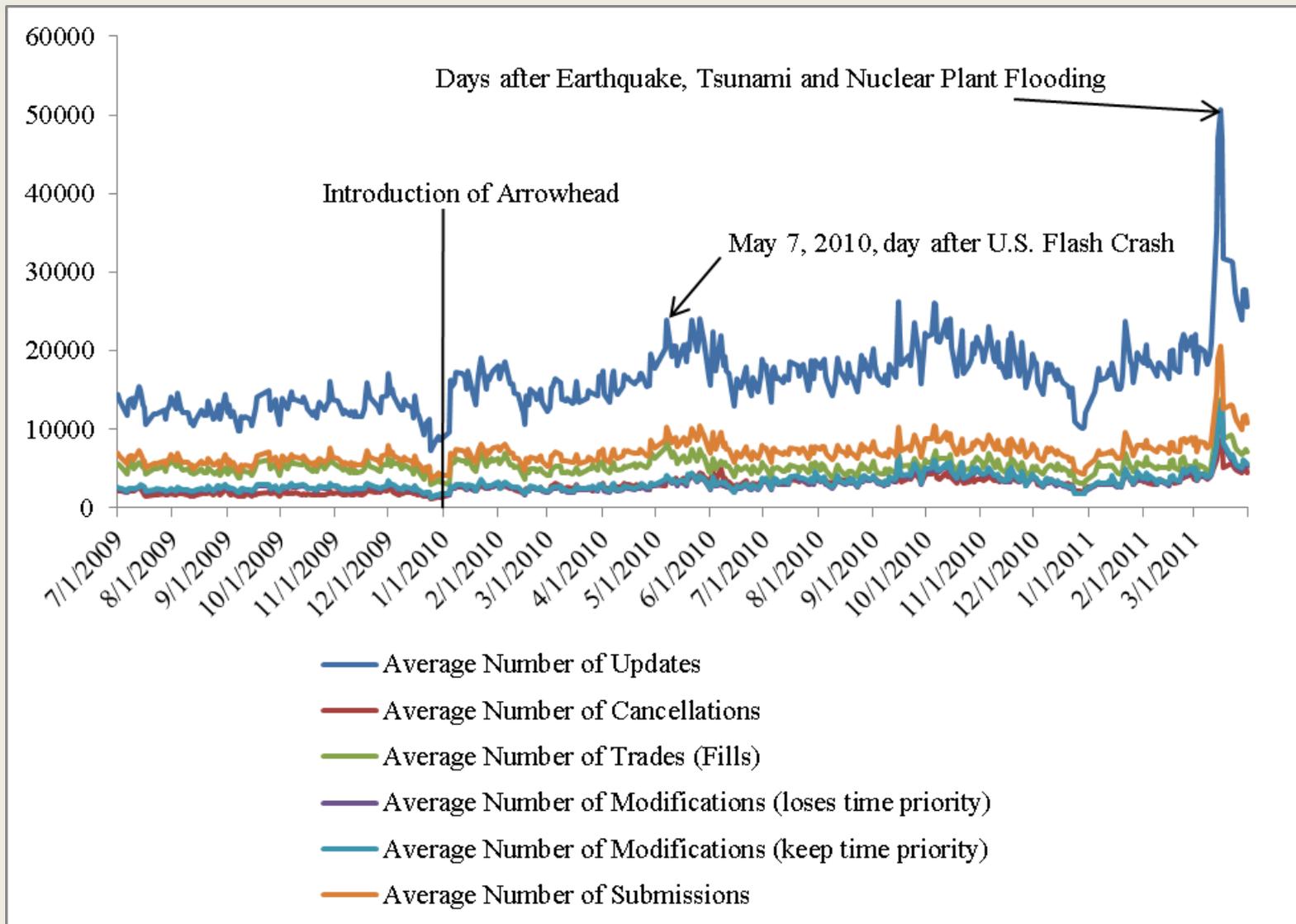
15 second, 5 minute intervals

	Quintiles Formed on Number of Trades in Prior Half Hour				
	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5
Small	-0.077 (0.001)	-0.049 (0.001)	-0.031 (0.001)	-0.015 (0.001)	-0.013 (0.001)
2	-0.025 (0.001)	-0.009 (0.001)	-0.009 (0.001)	-0.010 (0.001)	-0.021 (0.001)
3	-0.013 (0.001)	-0.010 (0.001)	-0.013 (0.001)	-0.023 (0.001)	-0.030 (0.001)
4	-0.015 (0.001)	-0.016 (0.001)	-0.026 (0.001)	-0.029 (0.001)	-0.027 (0.001)
Large	-0.019 (0.001)	-0.024 (0.001)	-0.027 (0.001)	-0.024 (0.001)	-0.029 (0.001)

# TSE's Introduction of Arrowhead (Jan 4, 2010)

- New infrastructure
  - Time from order submission to posting/execution dropped from 1-2 seconds to 2 millisecond
  - Co-location of servers
- Changes in trading protocols
  - Data time stamps from minutes to milliseconds
  - Change in tick size for some securities (based on price grid)
  - “Sequential Trade Quote”: alerting system where a single order that could move prices beyond a band triggers the alert
  - “Special Quote Renewal”:
    - Special price quote dissemination designed to attract contra order flow
    - Price limits that act as trigger raised (to allow prices to move more freely)
    - Allowable range of next price (“renewal price interval”) also raised
    - Changes based on price grid

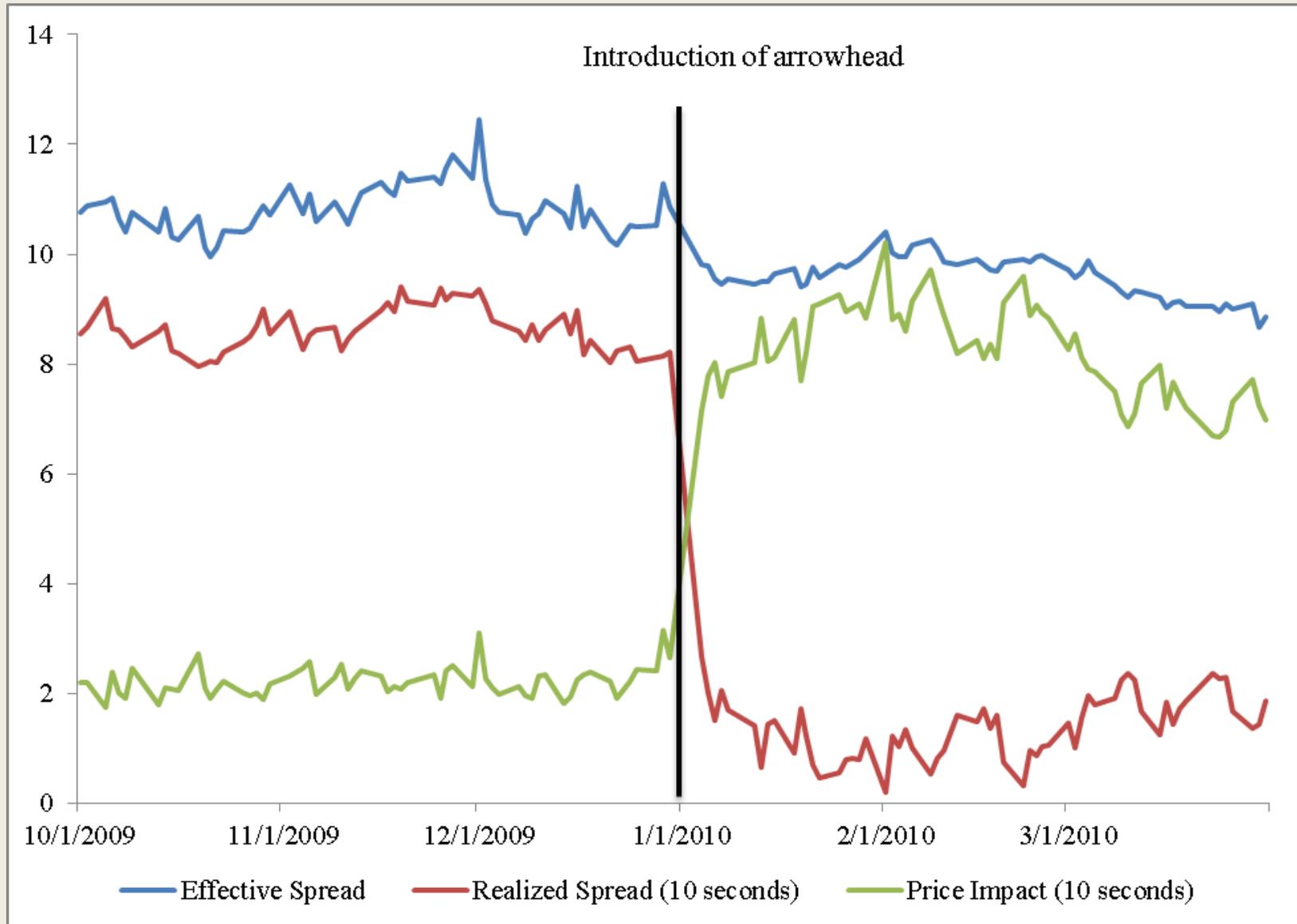
# Update Activity Before and After Arrowhead



# Changes in Variance Ratios and Spreads around Arrowhead Introduction

	$ VR-1 _{pre} -  VR-1 _{post}$	$\Delta$ Effective Spread	$\Delta$ Realized Spread	$\Delta$ Price Impact
9:00 - 9:30	-0.016 (1.80)	-1.16 (11.12)	-8.89 (45.93)	7.73 (39.32)
9:30 - 10:00	-0.037 (3.18)	-1.00 (8.87)	-7.81 (39.20)	6.80 (35.13)
10:00 - 10:30	-0.020 (1.97)	-1.01 (7.95)	-6.90 (40.36)	5.92 (37.58)
10:30 - 11:00	-0.015 (1.02)	-0.90 (7.52)	-6.40 (36.35)	5.50 (36.52)
12:30 - 1:00	-0.019 (1.85)	-2.69 (22.68)	-6.88 (42.16)	4.19 (22.92)
1:00 - 1:30	-0.025 (2.25)	-0.90 (7.38)	-6.18 (37.26)	5.29 (36.04)
1:30 - 2:00	-0.019 (1.13)	-0.89 (7.25)	-5.94 (38.86)	5.04 (34.29)
2:00 - 2:30	-0.027 (1.97)	-0.88 (7.18)	-5.95 (39.41)	5.06 (37.32)
2:30 - 3:00	-0.026 (1.54)	-1.00 (7.56)	-5.07 (37.06)	4.14 (39.33)

# Spreads Before and After Arrowhead



# Conclusion

- What can we conclude?
  - High-frequency activity is associated with improvements in market quality in U.S. markets
  - Market appears to be resilient in face of large liquidity drawdowns
  - Arrowhead introduction in Japanese equity market
    - Associated with increases in updates, improvements in measures of market quality
- Care in interpretation
  - Externalities
  - Welfare
  - Unintended consequences of some proposed changes