
CINEMA
Now Playing
Systemic Microstructure Risks of
High Frequency Trading


I'VE GOT A STOCK HERE THAT COULD REALLY EXCEL
REALLY EXCEL?
EXCEL?
SELL?
SELL?
SELL
SE
SELL!
SELL!
SELL!
SELL!
ELL!
SELL!
THIS IS MADNESS! I CAN'T TAKE ANYMORE
GOOD BYE!
GOOD BYE?
BYE?
Buy?
BUY!
Buy!
BUY!!!
Buy
Buy!
I'VE GOT A STOCK HERE..

CMU
CENTRAL MICHIGAN UNIVERSITY
College of Business Administration

Systemic Microstructure Risks of High Speed Trading

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Implementing Arrowhead: A Natural Experiment

Event:

- January 4, 2010 – Tokyo Stock Exchange (TSE) launches enhanced trading platform: “Arrowhead”
- 1500x Increase in System Speed vs. Prior System
  - Order processing latency reduced to 3 milliseconds
  - No more delayed trading (Lehmann and Modest, 1994; Ahn, Hamao and Ho, 2002; Uno and Shibata, 2012)

Outcome:

- HFT increased from 0% of total TSE trade volume to 36% within 24 months

How does low latency effect Market Quality?

Institutional Details

- Total listed market cap over $3 trillion
  - largest stock exchange headquartered outside the US
  - NYSE Euronext /TSE agreement: linked network access
- Electronic automated trading system
  - two trading sessions: 0900–1100 and 1230–1500
  - Purely order-driven market.
  - No “Upstairs Market” => no hidden orders
  - Varying tick sizes and minimum trading
- Not Fragmented (TSE has 91% of total volume)
  - Ideal non-fragmented set-up to study pure effects
- Chan, Hamao & Lakonishok, 1991; Bremer, Hiraki, & Sweeney, 1997; Ahn, Hamao, & Ho, 2002

Low Latency Trading and Market Quality

- Does Arrowhead increase or decrease cost of immediacy?
  - (Foucault, Röell, and Sandas, 2003) Vs. (Rosu, 2009; Boehmer, Saar and Yu, 2005)
  - R1: Arrowhead decreases COI
- Does Arrowhead increase or reduce volatility?
  - (Hendershott, Jones, and Menkveld, 2011; Hendershott and Moulton, 2011) Vs. (Brogaard, 2010; Hasbrouck and Saar, 2012)
  - R2: Arrowhead decreases volatility

HFT and Microstructure Risk

- Systemic risks
  - CoVaR (Adrian & Brunnermeier, 2011); CoVaQ
- Shock Propagation risks
  - Autocorrelation:
  - Parlour (1998) Vs. Biais, Hillion, and Spatt (1995)
  - Cross correlation:
  - Barker (2006) Vs. Chordia, Roll, & Subhramanyam (2000)
- Quote stuffing risks: Quotes-to-trades Ratio
  - runs in process (Hasbrouck and Saar, 2013), Message traffic (Hendershott, Jones, and Menkveld, 2011)

Low Latency and Evolution of LOB

- **Does low latency effect the future evolution of the LOB?**
  - ✓ **Price Placement**
  - ✓ **COI's effect on market quality measures**

- **Rosu's (2009) theory of Attrition:**
  - **Does lower COI in faster markets attract Fleeting orders?**

Best Quotes

Stock 1				Stock 2			
Bid Vol	Bid	Ask Vol	Ask	Bid Vol	Bid	Ask Vol	Ask
200	**20**	**200**	**21**	**200**	**20**	**200**	**21**
100	18	100	24	900	19	900	22
100	15	100	26	900	18	900	23
200	12	200	29	800	17	800	24
1200	10	1200	31	600	16	600	25
Avg. Daily Volume:		1,000,000				1,000,000	

Both stocks are equally liquid?

Traditional Liquidity Measures:

1. Bid-Ask Spread
2. Depth
3. Volume

Complete Limit Order Book

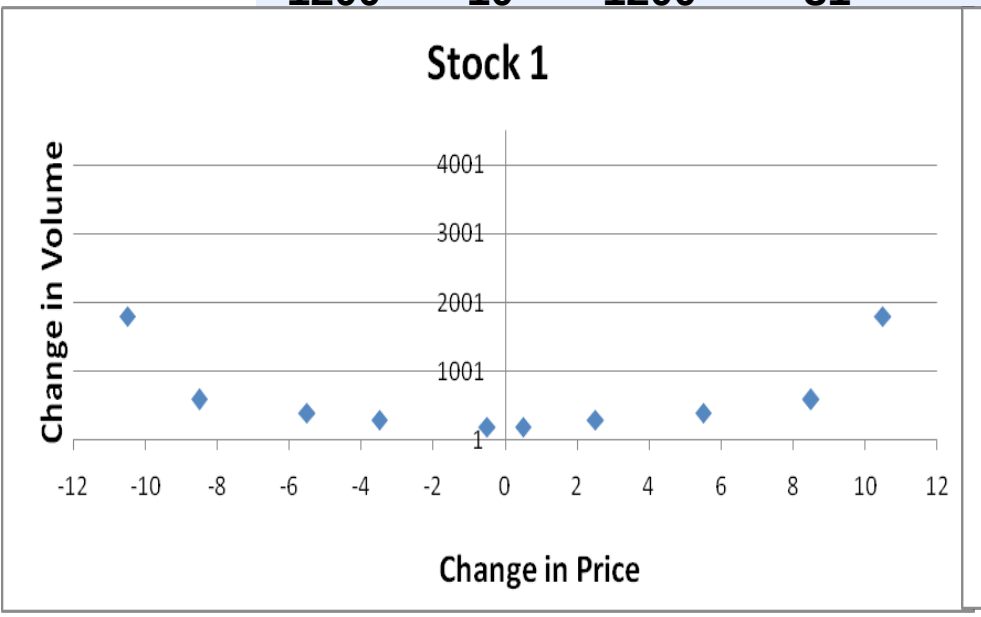
Stock 1

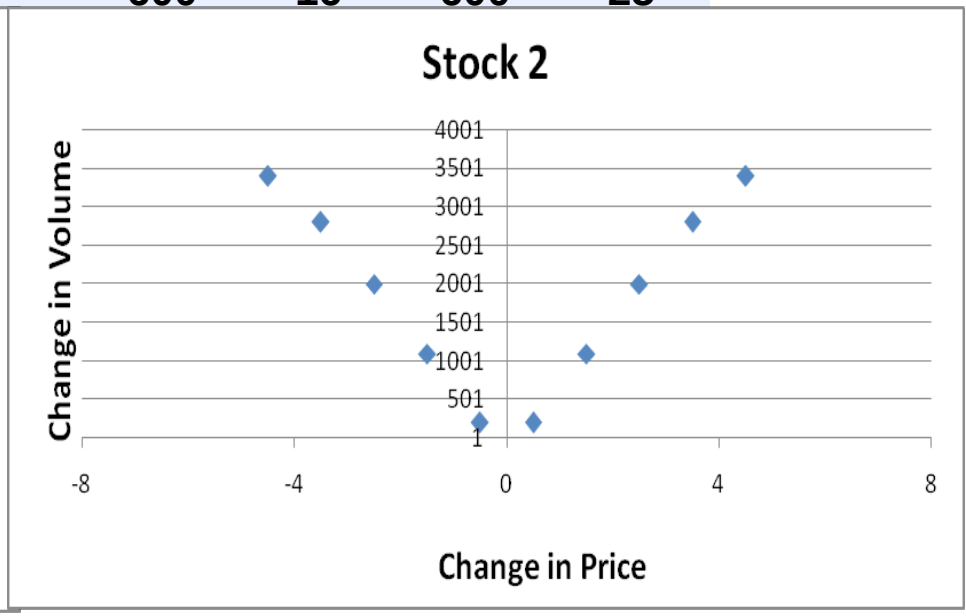
Bid Vol	Bid	Ask Vol	Ask
200	20	200	21
100	18	100	24
100	15	100	26
200	12	200	29
1200	10	1200	31

Stock 2

Bid Vol	Bid	Ask Vol	Ask
200	20	200	21
900	19	900	22
900	18	900	23
800	17	800	24
600	16	600	25

To Buy 0.1% of average daily volume =1000 shares:





Liquidity Measures

- ✓ Limit Order Book Slope: (Naes & Skjeltorp, 2006)

$$DE_{i,t} = \frac{1}{N_B}\left\{\frac{v_1^B}{\left|p_1^B / p_0 - 1\right|} + \sum_{\tau=1}^{N_B-1}\frac{v_{\tau+1}^B / v_\tau^B - 1}{\left|p_{\tau+1}^B / p_\tau^B - 1\right|}\right\}$$

- ✓ LOB Cost of Immediacy (Benston, Irvine, and Kandel,2002)

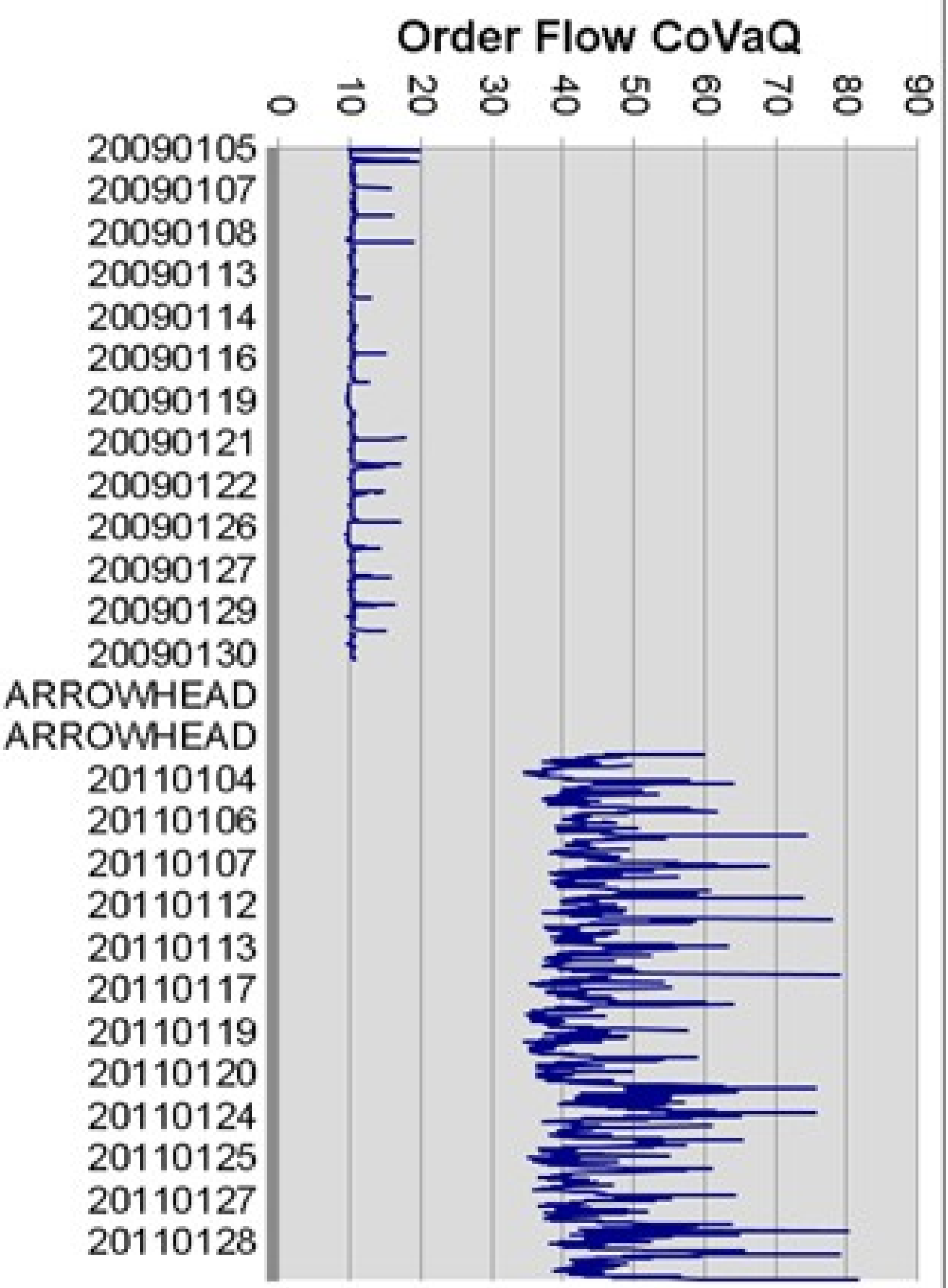
$$Cost-to-Trade_i = \frac{\sum_{k=1}^{K} I_k^{Buy}\left(Midquote - P_k^{Buy}\right) + \sum_{k=1}^{K} I_k^{Sell}\left(P_k^{Sell} - Midquote\right)}{T \times Midquote}$$

- ✓ Traditional Measures: Proportionate Spreads, Depth, Number of Trades, Average Trade Size.
- ✓ Advanced measures: Quotes-to-trade ratio (Hasbrouck and Saar, 2012; Hendershott, Jones, and Menkveld, 2011)

DATA

- 150 TSE first section firms before & after Arrowhead
  - June 2008 pre-crisis, January 2009, and January 2011.
  - 50 large-, 50 mid-, and 50 small-cap TOPIX firms
  - Source: Nikkei Digital Media Inc.'s Nikkei Economic Electronic Database Systems (NEEDS)
- Limit Order Book Data: info. on each order and trade, date and time, stock code, order/trade price, order/trade volume, 5 best bid and ask quotes and sizes (Sample).
- Intraday analysis: Data aggregated at 1 minute frequency.

	(1)	(2)	(3)	(4)	(5)
	Pre-Crisis	Arrowhead			
		Pre	Post	(3) – (2)	(3) – (1)
Trading Risk Measures					
AUTOCORR	0.03	0.02	0.11	0.09**	0.08**
CROSSCORR	0.02	-0.03	0.04	0.07**	0.02
QSR	2.74	2.89	6.69	3.80**	0.95**
ΔCOVAR	-0.10	-0.07	0.10	0.17**	0.22**
ΔCOVAQ	9.57	10.3	44.2	33.9**	34.6**
Market Quality Measures					
COI (basis pts)	51.2	59.5	28.4	-31.1**	-22.9**
SLOPE	19.6	20.4	20.7	0.29**	1.12*
SPREAD (%)	0.22	0.23	0.16	-0.07*	-0.06*
DEPTH (‘000)	32.8	44.9	258	213**	225**
VOLUME	95.0	93.7	109.9	16.1**	14.9**
NTRDS	4.08	7.34	11.2	3.81**	7.07**
SIZE	4,185	3,800	3,132	-668**	-1,05**
TRADESPEED	0.07	0.08	0.12	0.04**	0.05**


Order Flow CoVaQ
0
10
20
30
40
50
60
70
80
90
20090105
20090107
20090108
20090113
20090114
20090116
20090119
20090121
20090122
20090126
20090127
20090129
20090130
ARROWHEAD
ARROWHEAD
20110104
20110106
20110107
20110112
20110113
20110117
20110119
20110120
20110124
20110125
20110127
20110128

Panel A. Impact of Arrowhead on *COI*					
Variables	All firms	%t (%sign)	Large cap	Mid cap	Small cap
ARROWHEAD	-3.55*	98 (95)	-4.53*	-2.89*	-1.92*
LOG PRICE	-2.44*	95 (89)	-2.86*	-2.29*	-2.35*
LOG NTRDS	1.84*	80 (71)	3.83*	2.06*	0.91*
VOLATILITY	4.30*	100 (99)	4.64*	4.23*	3.89*
LOG VOL	-2.04*	84 (74)	-5.07*	-1.54*	-1.96*
MKTRET	-0.14	46 (60)	-0.21	-0.18	-0.01
HIGHSPEED	-0.21	75 (53)	-1.06*	-0.12	0.78*
LOWSPEED	1.17	42 (74)	2.07*	1.17	-0.33
ADJ R^2	0.148		0.114	0.121	0.174
Panel B. Impact of Arrowhead on *SLOPE*					
ARROWHEAD	2.31*	93 (97)	3.39*	2.22*	1.84*
LOG PRICE	2.31*	89 (93)	3.07*	2.34*	1.71*
LOG NTRDS	-0.41	40 (68)	-0.58	-0.44	-0.16
VOLATILITY	-2.93*	100 (99)	-5.38*	-3.92*	-2.32*
LOG VOL	2.14*	76 (86)	4.04*	1.82*	0.44
MKTRET	0.08	13 (51)	0.12	0.06	0.07
HIGHSPEED	-0.01	55 (52)	0.27	0.18	-0.47
LOWSPEED	-0.19	18 (64)	-0.44*	-0.32	0.22
ADJ R^2	0.139		0.167	0.126	0.112

Cross-correlation

- ✓ Lower cross correlation during highly liquid markets (Baker and Wurgler, 2006).
- ✓ Higher Cross correlation (Chordia, Roll, and Subrahmanyam, 2000; Hasbrouck and Seppi, 2001)

H1:Low Latency increases Cross-correlation due to increase in program trading

LOB COI Predicts future Cross Correlation

$$CROSSCORR_{i,t+1} = \alpha_i + \beta_{1i} COI_{i,t} + \beta_{2i} SLOPE_{i,t} + \beta_{3i} NTRDS_{i,t} + \beta_{4i} ATS_{i,t} + \beta_{5i} SPREAD_{i,t} + \beta_{6i} DEPTH_{i,t} + \beta_{7i} TRADING\ SPEED_{i,t} + \beta_{8i} VOLATILITY_{i,t} + \beta_{9i} RETURN_{i,t} + \beta_{10i} ARROWHEAD_{i,t} + \beta_{11i} MKTRET_{i,t} + \beta_{12i} ARROWHEAD_{i,t} * COI_{i,t} + \beta_{13i} ARROWHEAD_{i,t} * SLOPE_{it} + \mu_{i,t+1}$$

Variables	(β)	%t (%sign)
ARROWHEAD	0.91*	64 (79)
COI	0.41*	72 (65)
SLOPE	-0.22*	50 (62)
ARROW*COI	0.38	18 (71)
ARROW*SLOPE	-0.14	28 (66)

ARROWHEAD increased Cross correlation

The higher the COI, the higher is the Cross correlation

LOB COI Predicts the future Quotes-to-trade ratio

$$QUOTES\text{-}TO\text{-}TRADE\ RATIO_{i,t+1} = \alpha_i + \beta_{1i}\, COI_{i,t} + \beta_{2i}\, SLOPE_{i,t} + \beta_{3i}\, MONDAY_{t+1} + \beta_{4i}\, NTRDS_{i,t} + \beta_{5i}\, ATS_{i,t} + \beta_{6i}\, SPREAD_{i,t} + \beta_{7i}\, DEPTH_{i,t} + \beta_{8i} VOLATILITY_{i,t} + \beta_{9i} MKTRET_{i,t} + \beta_{10i} ARROWHEAD_{i,t} + \beta_{11i} ARROWHEAD_{i,t} * COI_{i,t} + \beta_{12i} ARROWHEAD_{i,t} * SLOPE_{it} + \mu_{i,t+1}$$

Variables	(β)	%t (%sign)
ARROWHEAD	2.59*	88 (97)
COI	-1.31*	64 (72)
SLOPE	2.03*	79 (92)
ARROW*COI	-1.54*	81 (88)
ARROW*SLOPE	2.33*	83 (96)

ARROWHEAD increased Quote-to-trade ratio; strengthens COI =>Quotes-to-trade ratio relation.

Higher COI => Lower Quotes-to-trade ratio

$$VAX_{i,t} = \alpha_i + \beta_i S_{t-1}$$

$$VAX_{MKT,t} = \alpha_{MKT} + \beta_{MKT} S_{t-1}$$

$$COVAX_{i,t} = \alpha_{MKT|i} + \beta_{MKT|i} S_{t-1} + \gamma_{MKT|i} VAX_{i,t}$$

$$\Delta COVAX_{i,t} = COVAX_{i,t} - VAR_{MKT,t}$$

where $\Delta COVAX_{i,t}$ denotes the difference between the *VAX* of the stock market conditional on the illiquidity risk of a particular stock *i*, $COVAX_i$, and the unconditional *VAX* of the stock market, i.e., $VaR_{MKT,t}$. Hence, $\Delta CoVaX_{i,t}$ serves as a measure of how much a stock adds to overall systemic risk.

LOB COI Predicts the future CoVaQ

$$X_{i,t+1} = \alpha_i + \beta_{0i} ARROWHEAD_{i,t} + \beta_{1i} COI_{i,t} + \beta_{2i} SLOPE_{i,t} + \beta_{3i} NTRDS_{i,t} + \beta_{4i} ATS_{i,t} + \beta_{5i} SPREAD_{i,t} + \beta_{6i} DEPTH_{i,t} + \beta_{7i} VOLATILITY_{i,t} + \beta_{8i} RETURN_{i,t} + \beta_{9i} HIGHSPEED_{i,t} + \beta_{10i} LOWSPEED_{i,t} + \beta_{11i} ARROWHEAD_{i,t} * COI_{i,t} + \beta_{12i} ARROWHEAD_{i,t} * SLOPE_{it} + \mu_{i,t+1}$$

Variables	(β)	%t (%sign)
ARROWHEAD	1.21*	77(88)
COI	1.08*	85(81)
SLOPE	-0.36	48(71)
ARROW*COI	1.96*	82(88)
ARROW*SLOPE	-1.18*	66(78)

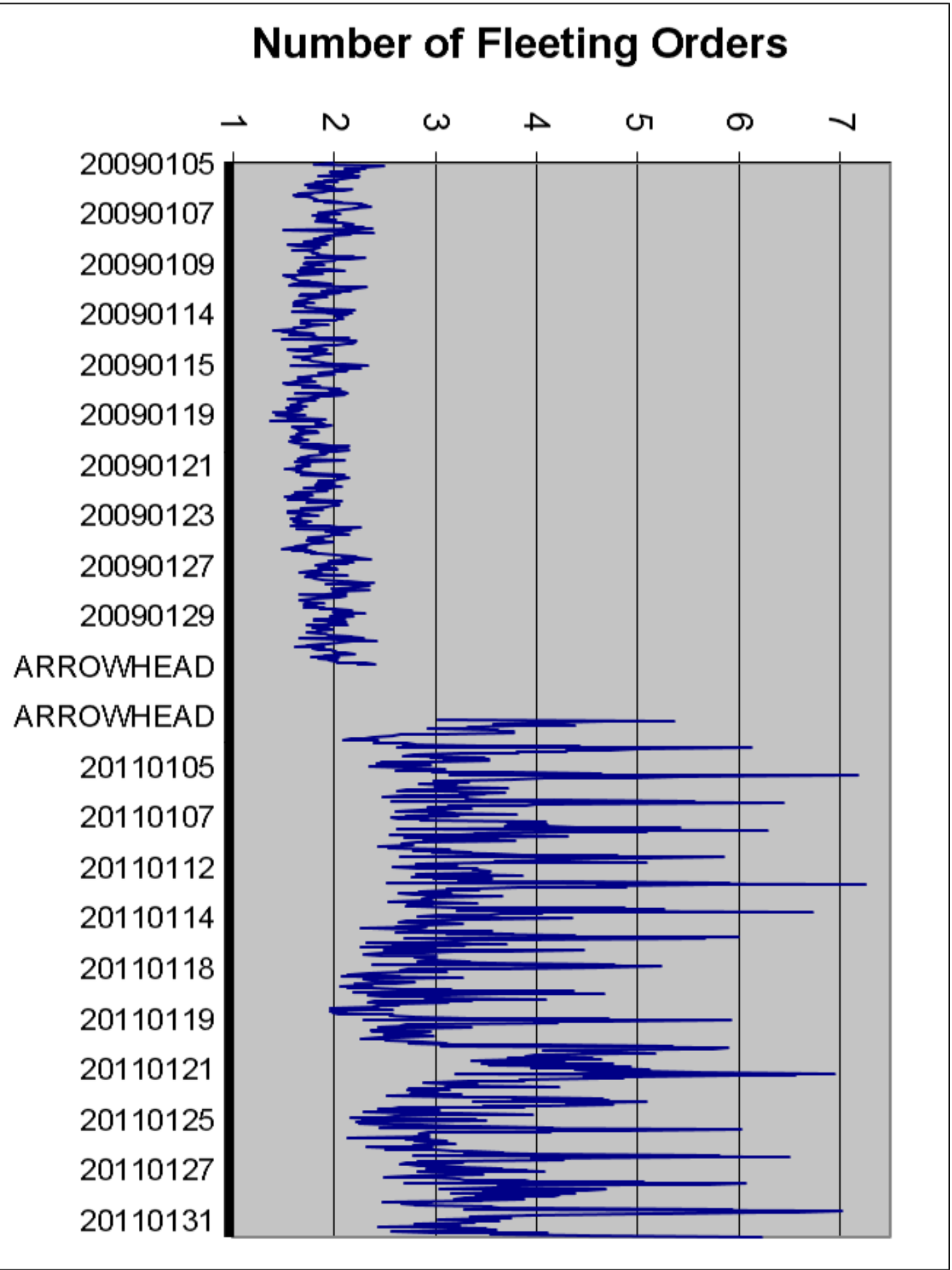
ARROWHEAD increased CoVaQ

Fleeting orders

- Rosu (2009): when the LOB is full, traders play a “game of attrition”

H1: Low Latency facilitates fleeting orders.

Bid Vol	Bid	Ask Vol	Ask
200	20	200	21
900	19	900	22
900	18	900	23
800	17	800	24
600	16	600	25


Number of Fleeting Orders
1
2
3
4
5
6
7
20090105
20090107
20090109
20090114
20090115
20090119
20090121
20090123
20090127
20090129
ARROWHEAD
ARROWHEAD
20110105
20110107
20110112
20110114
20110118
20110119
20110121
20110125
20110127
20110131

LOB COI Predicts the fleeting orders

$$FLEET_{i,t+1} = \alpha_i + \beta_{1i} COI_{i,t} + \beta_{2i} SLOPE_{i,t} + \beta_{3i} NTRDS_{i,t} + \beta_{4i} ATS_{i,t} + \beta_{5i} SPREAD_{i,t} + \beta_{6i} DEPTH_{i,t} + \beta_{7i} TRADING\ SPEED_{i,t} + \beta_{8i} VOLATILITY_{i,t} + \beta_{9i} RETURN_{i,t} + \beta_{10i} ARROWHEAD_{i,t} + \beta_{11i} MKTRET_{i,t} + \beta_{12i} ARROWHEAD_{i,t} * COI_{i,t} + \beta_{13i} ARROWHEAD_{i,t} * SLOPE_{it} + \mu_{i,t+1}$$

Variables	(β)	%t (%sign)
ARROWHEAD	1.74*	89(91)
COI	-1.19*	68(79)
SLOPE	1.85*	93(85)
ARROW*COI	-0.62*	53(69)
ARROW*SLOPE	0.89*	79(80)

Higher COI discourages fleeting orders

ARROWHEAD increased the frequency of fleeting orders; strengthened COI => fleeting orders relation.

	Full Sample (TSE difference-Osaka difference)	Large Cap	Medium Cap	Small Cap
Variable	Coefficient (Std Err)	Coefficient (Std Err)	Coefficient (Std Err)	Coefficient (Std Err)
AUTO CORR	0.56** (0.12)	1.23** (0.15)	0.61** (0.11)	0.21 (0.24)
CROSS CORR	0.29* (0.11)	0.47** (0.12)	0.28* (0.09)	0.19† (0.10)
QSR	0.68** (0.16)	0.87** (0.14)	0.54* (0.19)	0.57* (0.19)
ΔCOVAR	0.76** (0.18)	1.23** (0.15)	0.61** (0.11)	0.21 (0.24)
ΔCOVAQ	1.43** (0.34)	2.21** (0.54)	1.28** (0.32)	0.95* (0.31)
COI (basis pts)	-0.21* (0.10)	-0.50** (0.11)	-0.29* (0.12)	-0.06 (0.08)
SLOPE	0.11 (0.08)	0.18* (0.09)	0.10 (0.09)	0.04 (0.06)

Panel A. Effect of Arrowhead on tail risk, as defined by trading minutes when the market return is in the 5th percentile or less

	(1)	(2)	(3)
Variables	Pre Arrowhead	Post Arrowhead	(1) – (2)
AUTOCORR	-0.01	0.16	0.17**
CROSSCORR	0.04	0.10	0.06**
QSR	2.00	8.18	6.18**
ΔCOVAR (basis pts)	0.05	0.24	0.19**
ΔCOVAQ	16.32	74.21	57.89**

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Variables	AUTO CORR	%t (%sign)	CROSS CORR	%t (%sign)	QTR	%t (%sign)	COVAR	%t (%sign)	COVAQ	%t (%sign)
ARROWHEAD	0.76*	69(74)	0.99*	72(85)	2.11*	88(96)	0.63*	77(86)	1.03*	72(85)
TAILMIN	0.63*	55(60)	0.91*	79(92)	1.84*	85(99)	0.82*	81(90)	0.91*	66(85)
ARROWHEAD *TAILMIN	1.03*	84(96)	1.12*	82(84)	2.26 *	94(99)	0.93*	85(92)	1.01*	78(90)
COI	-0.56*	72(70)	0.51*	79(80)	-0.81*	62(78)	0.52*	70(86)	0.87*	68(92)
SLOPE	0.38	43(75)	-0.41*	58(75)	1.84*	79(91)	-0.35*	54(70)	-0.32	42(67)
NTRDS	0.81*	77(90)	-0.12	15(67)	-0.41	37(60)	0.64*	75(90)	0.63*	65(84)
ATS	-0.23	40(68)	-0.29	50(54)	-0.49	25(67)	0.17	49(70)	-0.47*	53(70)
SPREAD	-0.07	39(89)	0.08	30(65)	-0.62	48(69)	0.05	42(87)	0.45*	61(72)
DEPTH	0.14	37(82)	-0.19	35(52)	0.23	39(84)	-0.11	39(73)	-0.64*	76(91)
RETURN	0.09	5(66)	0.01	1(50)	0.01	2 (67)	0.74*	82(99)	0.11	19(76)
HIGHSPEED	0.72*	61(67)	0.09	25(90)	0.93*	69(80)	-0.39	47(78)	0.65*	69(65)
LOWSPEED	-0.20	8(80)	-0.11	3(67)	-0.10	7 (75)	-0.17	22(78)	-0.18	25(63)
ADJ R^2	0.049		0.113		0.204		0.161		0.062	

Robustness Tests

- Alternate sample selection:
  - MTU of 1,000
  - Drop special quotes
- Time dummies for intraday seasonality
- Analyses based on 5 minutes, 10 minutes and 30 minutes snapshot of LOB

Conclusions

- Low-latency affects market quality:
  - Reduced COI and volatility; Increased #of trades
  - Increased Quotes-to-trade ratio, autocorrelation & cross correlation, CoVaR and CoVaQ

- Arrowhead increased the probability of systemic crash, especially during tail events.