Mathematical Market Microstructure – An Optimization Approach

Lecture I – An introduction to market design and microstructure features within a global context

FINM 37601 – Fall, 2023

By Hongsong Chou, Ph.D.

AGENDA

- An outline of this course

- An introduction to trading venues and trading practices
  - Asset prices and their practical pricing
  - Global exchanges and trading venues
  - Quote-driven markets vs. order-driven markets
  - Market participants and their trading practices

- Market microstructure characteristics of global markets
  - Price process
  - Risk
  - Liquidity
  - Structure-specific features

- A practical introduction to algorithmic trading
  - Definitions of algorithmic trading
  - Industrial overview of algorithmic trading practices

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WHAT IS THIS COURSE ABOUT?

- This course provides a balanced view on theoretical framework for solving optimal execution strategy design problems and practical aspects of implementing such strategies in liquid product trading;

- The following topics will be covered in this course:
  - Market design and practical aspects of algorithmic trading;
  - Quadratic optimization framework for optimal execution strategy design;
  - Market microstructure theory esp. on information/inventory-based optimal quoting processes;
  - Stochastic control approach to optimal execution strategy design and optimal market making;
  - A review of latest developments in market microstructure research and applications of machine learning techniques in trading research and strategy decision.

GRADING OF THIS COURSE

- There will be NO final exam;
- There will be three assignments distributed throughout the lectures, which will contribute 20%, 40% and 40% to the final score, respectively;
- Assignments are important extentions to the lectures; some assignments are themselves reading requirements in addition to data analyses and/or derivations;
- Timeline for assignments:
  - Assignment 1: distributed on Nov. 3; due on Nov. 11;
  - Assignment 2: distributed on Nov. 10; due on Nov. 18;
  - Assignment 3: distributed on Nov. 17; due on Dec. 1;
- Office hours: 4pm - 5pm on Nov. 10/17 and Dec. 1 in Rm. 301, Stevanovich Center; individual zoom Q&A sessions can be available upon request;
- To contact me via email: chou1@uchicago.edu;
- Our TAs are Mr. Mohammad Moravvej (moravvej@uchicago.edu) and Philip Lee (philiplee@uchicago.edu).

SCHEDULE OF THIS COURSE

- Lecture I (6pm – 9pm, Oct. 27 Chicago time): An introduction to market design and algorithmic trading within a global context;

- Lecture II (6pm – 9pm, Nov. 3 Chicago time): Practical aspects of trading algorithm optimization and an overview of market microstructure theory;

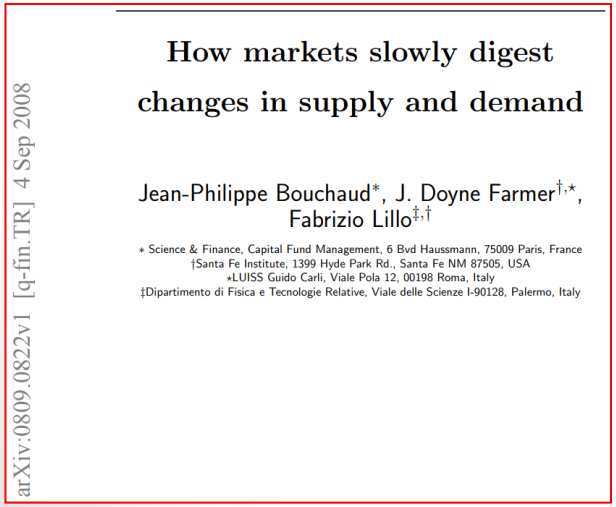
- Lecture III (6pm – 9pm, Nov. 10 Chicago time): On the optimal design of execution algorithms;

- Lecture IV (6pm – 9pm, Nov. 17 Chicago time): Stochastic programming and its applications to trading algorithms and market making (part I);

  (*No class on Thanksgiving week*)

- Lecture V (6pm – 9pm, Dec. 1 Chicago time): Stochastic programming and its applications to trading algorithms and market making (part II), and a discussion on recent developments in market microstructure research and applications of machine learning techniques in trading research and strategy decision.

SUGGESTED (NOT REQUIRED) READINGS



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- Market microstructure characteristics and variables of global markets
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ASSET PRICES - A FEW EXAMPLES (I)

Source: Google Finance

ASSET PRICES - A FEW EXAMPLES (II)

Source: Google Finance

ASSET PRICES - A FEW EXAMPLES (III)

Source: Google Finance

ASSET PRICES - A FEW EXAMPLES (IV)

Source: CNBC.com, MarketWatch.com

HOW TO PRICE AN ASSET?

- Asset pricing example:

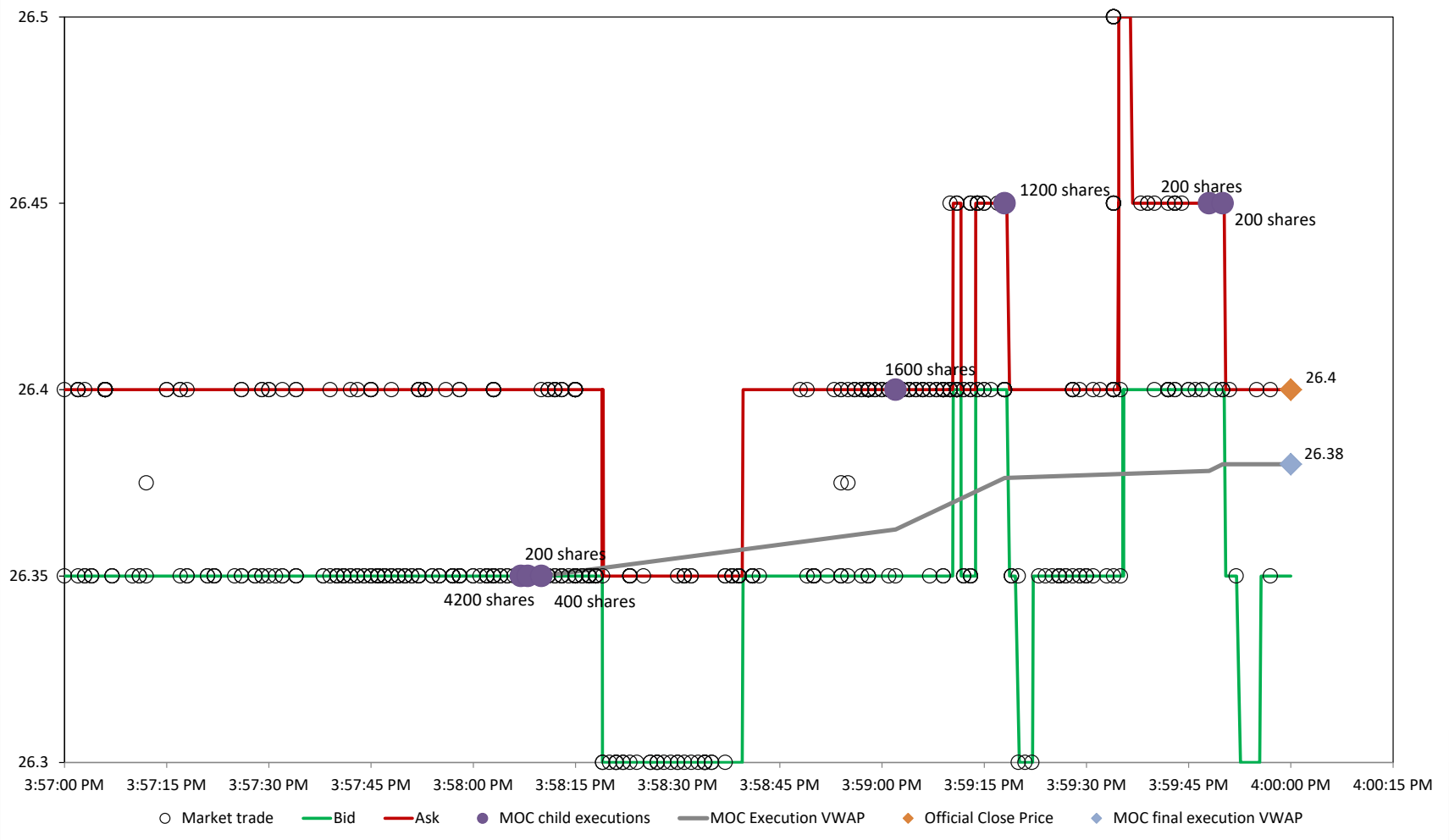
$$C_0 = \exp(-rT)E_Q[(S_T - K)_+] = S_0\Phi(d_1) - K\exp(-rT)\Phi(d_2)$$

$$d_1 = \frac{log(S_0/K) + (r + \sigma^2/2)T}{\sigma\sqrt{T}}$$

$$d_2 = \frac{log(S_0/K) + (r - \sigma^2/2)T}{\sigma\sqrt{T}} = d_1 - \sigma\sqrt{T}.$$

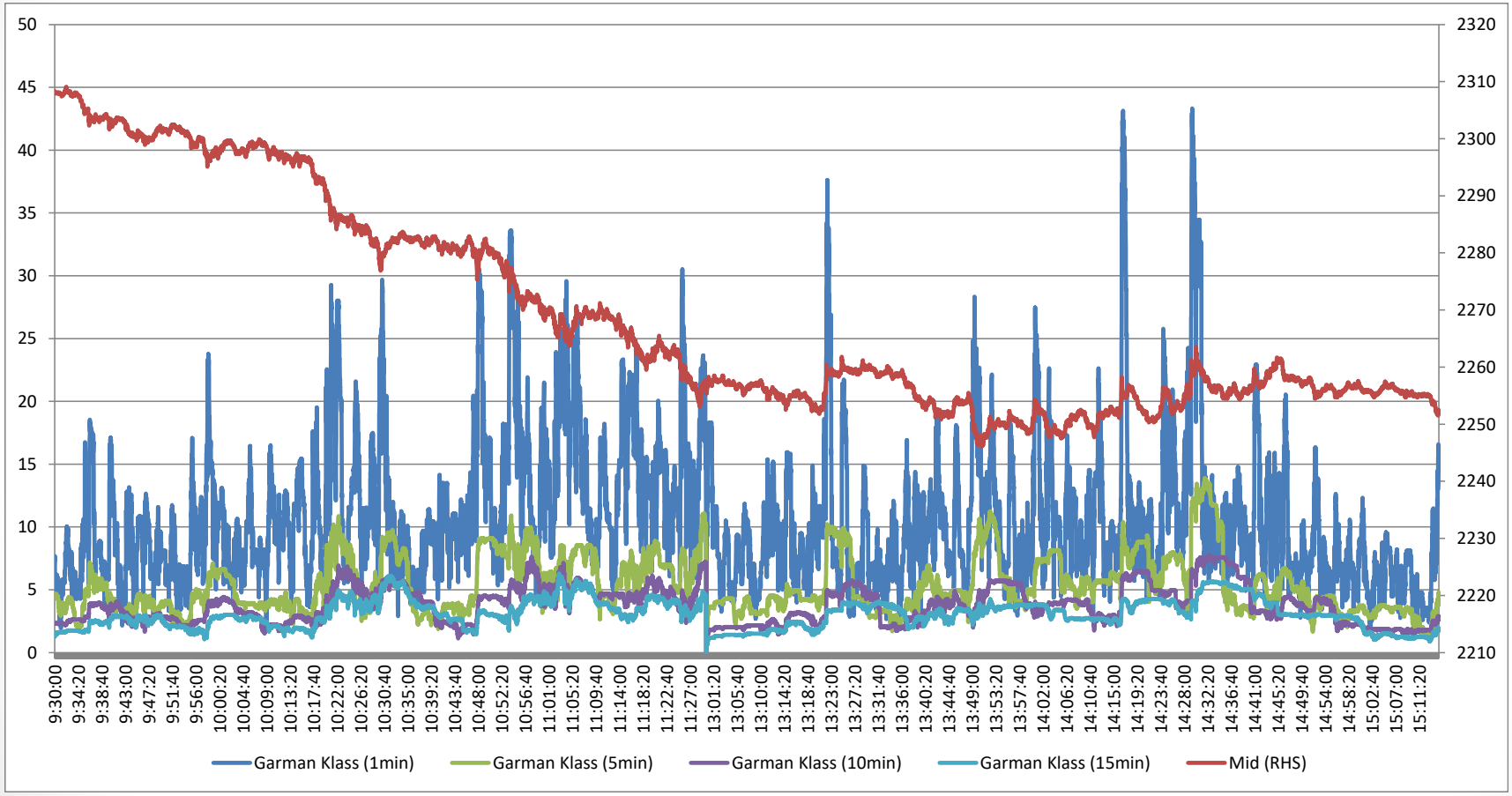
- How S_0 is determined, then?

ASSET PRICING AT HIGH-FREQUENCIES



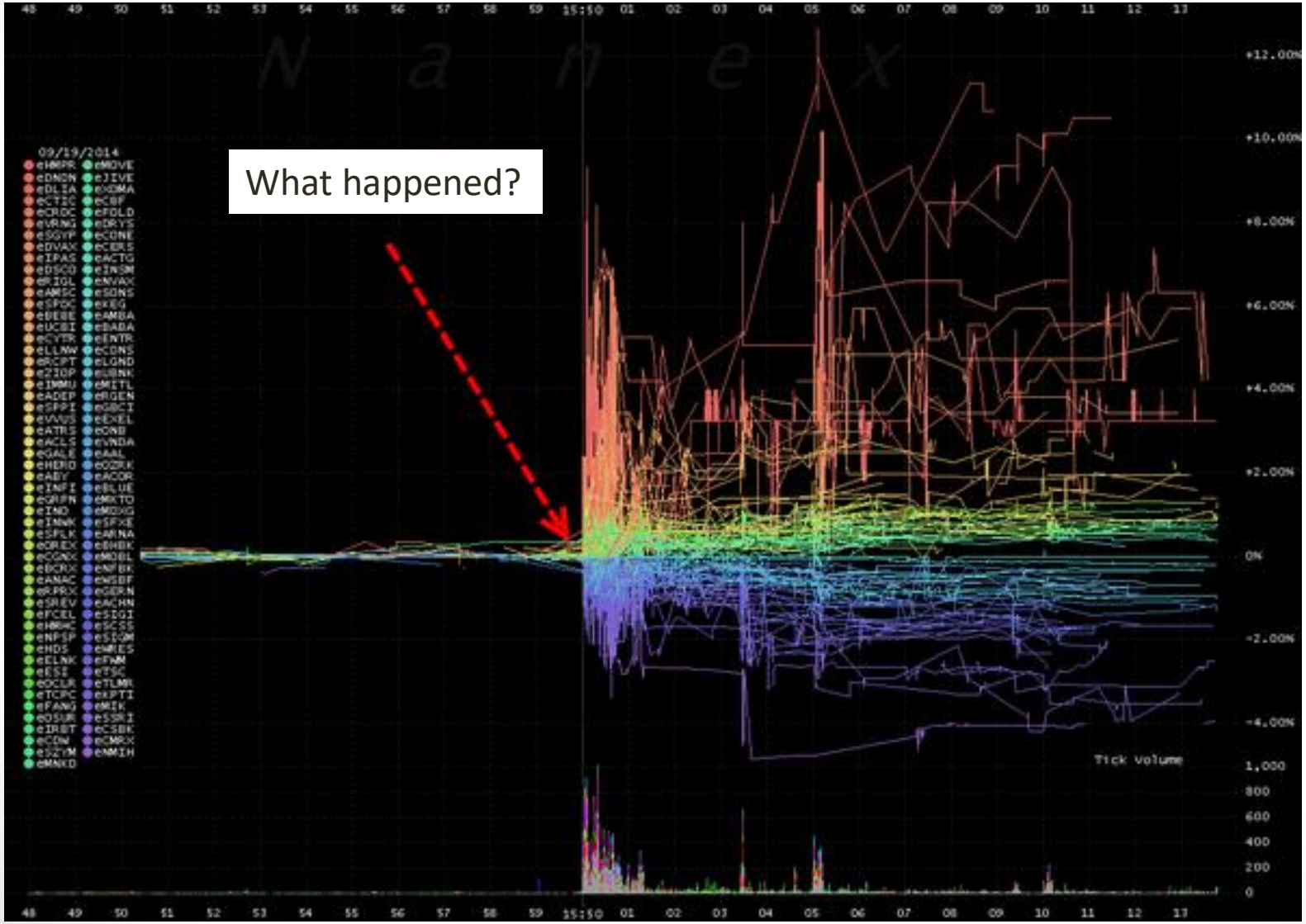
Source: Charles River Advisors Limited; ticker is 1299.HK (AIA Group).

INTRADAY VOLATILITIES (I)



Source: Charles River Advisors Limited

INTRADAY VOLATILITIES (II)



BASIC FUNCTIONALITIES OF EXCHANGES

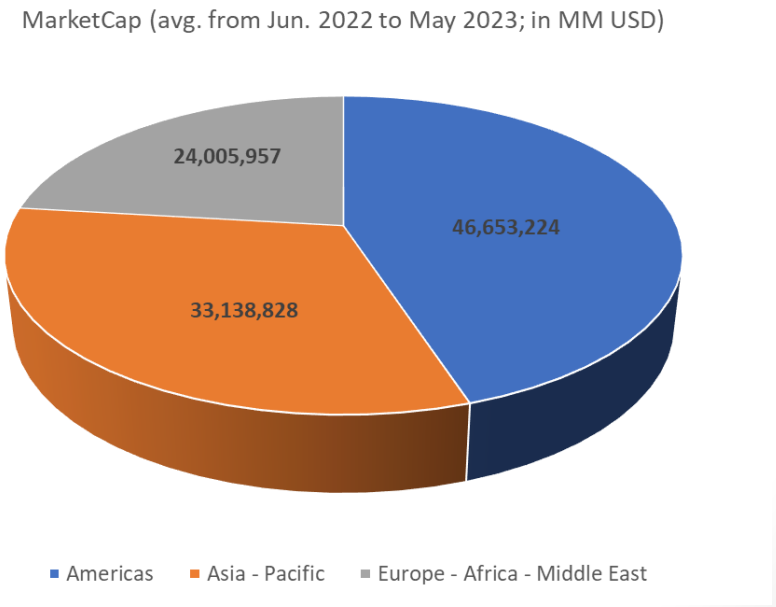
- Facilitation of placement and trade of securities between participants:
  - Placement and trade: primary and secondary market concepts; trading mechanisms include order- and quote-driven markets, etc.;
  - Securities: liquid "cash" instruments (stocks, ETFs), derivatives (index futures, index/stock options, warrants, etc.), commodities and FX products, liquid bonds, and so on;
  - Participants: retail and institutional investors, (agency) brokers, (principal) dealers, market makers, corporates, municipal and government agencies, etc.;
- A key task for exchange is to discover prices of "basic" or "fundamental" values of securities, upon which many "capital allocation processes" depend and many financial products derive their prices from.

BASIC REQUIREMENTS FOR EXCHANGES

- Accessibility of capital allocation – primary market;
- Effectiveness in terms of price discovery – secondary market, both speed and stability;
- Transparency and efficiency in information dissemination to all or groups of market participants;
- Regulations of industry associations and market participants;
- Social welfare, such as investor and company educations.

SOME BASIC STATISTICS ON WORLD EXCHANGES (I)

- Total market capitalization of global exchanges as of May of 2023 is **104 trillion** USD according to the World Federation of Exchanges; as a comparison, the world GPD as of May 2023 was **106 trillion USD**, according to the IMF; the U.S. GPD in 2019 was **27 trillion** USD, followed by China's **19 trillion** USD and Japan's **4.4 trillion** USD and Germany's **4.3 trillion** USD.



SOME BASIC STATISTICS ON WORLD EXCHANGES (II)

- Equity market capitalization ranked globally (top 30; avg. from Jun. 2022 to May 2023; USD MM):

Ranking	Exchange	avg Market Cap
1	NYSE	24,065,338
2	Nasdaq - US	17,953,386
3	Shanghai Stock Exchange	6,993,701
4	Euronext	6,118,817
5	Japan Exchange Group	5,380,425
6	Shenzhen Stock Exchange	4,920,758
7	Hong Kong Exchanges and Clearing	4,564,434
8	National Stock Exchange of India	3,307,971
9	LSE Group London Stock Exchange	3,119,628
10	TMX Group	2,881,664
11	Saudi Exchange (Tadawul)	2,849,175
12	Nasdaq Nordic and Baltics	1,848,314
13	SIX Swiss Exchange	1,845,394
14	Deutsche Boerse AG	1,840,803
15	Korea Exchange	1,731,582
16	ASX Australian Securities Exchange	1,683,553
17	Taiwan Stock Exchange	1,559,626
18	Tehran Stock Exchange	1,318,309
19	Johannesburg Stock Exchange	1,127,010
20	B3 - Brasil Bolsa Balcão	797,328
21	Abu Dhabi Securities Exchange	674,050
22	BME Spanish Exchanges	658,629
23	Singapore Exchange	618,611
24	Indonesia Stock Exchange	607,259
25	Moscow Exchange	563,472
26	The Stock Exchange of Thailand	559,713
27	Bolsa Mexicana de Valores	467,477
28	Bursa Malaysia	369,240
29	Tel-Aviv Stock Exchange	279,803
30	Borsa Istanbul	269,392

Source: The World Federation of Exchanges; ECC Info Mgmt Ltd.

SOME BASIC STATISTICS ON WORLD EXCHANGES (III)

- Value of share trading EOB ranked globally (average and annualized from Jun. 2022 to May 2023; USD MM):

Ranking	Exch	Turnover (annualized)
1	NYSE	25,493,622
2	Nasdaq - US	22,780,485
3	Shenzhen Stock Exchange	19,218,523
4	Cboe Global Markets	15,070,162
5	Shanghai Stock Exchange	14,209,817
6	Japan Exchange Group	5,275,564
7	Korea Exchange	2,813,975
8	Hong Kong Exchanges and Clearing	2,498,767
9	Euronext	2,340,435
10	Cboe Europe	2,248,095
11	TMX Group	2,058,995
12	Taiwan Stock Exchange	1,661,034
13	National Stock Exchange of India	1,477,931
14	B3 - Brasil Bolsa Balcão	1,168,091
15	Deutsche Boerse AG	1,069,824
16	MIAX Exchange Group	1,052,429
17	Borsa Istanbul	1,046,629
18	LSE Group London Stock Exchange	1,008,966
19	ASX Australian Securities Exchange	964,227
20	Nasdaq Nordic and Baltics	757,411
21	SIX Swiss Exchange	717,652
22	Taipei Exchange	485,378
23	The Stock Exchange of Thailand	413,083
24	Saudi Exchange (Tadawul)	329,523
25	BME Spanish Exchanges	304,626
26	Johannesburg Stock Exchange	277,914
27	Singapore Exchange	202,423
28	Tehran Stock Exchange	192,713
29	Indonesia Stock Exchange	163,445
30	Moscow Exchange	156,911

Source: The World Federation of Exchanges; ECC Info Mgmt Ltd.

SOME BASIC STATISTICS ON WORLD EXCHANGES (IV)

- Annual turnover-to-market cap ratio:

Ranking	Exchange	avg Market Cap	Turnover (annualized)	TO/MC
1	Shenzhen Stock Exchange	4,920,758	19,218,523	3.91
2	Borsa Istanbul	269,392	1,046,629	3.89
3	Shanghai Stock Exchange	6,993,701	14,209,817	2.03
4	Korea Exchange	1,731,582	2,813,975	1.63
5	B3 - Brasil Bolsa Balcão	797,328	1,168,091	1.47
6	Nasdaq - US	17,953,386	22,780,485	1.27
7	Taiwan Stock Exchange	1,559,626	1,661,034	1.07
8	NYSE	24,065,338	25,493,622	1.06
9	Japan Exchange Group	5,380,425	5,275,564	0.98
10	The Stock Exchange of Thailand	559,713	413,083	0.74
11	TMX Group	2,881,664	2,058,995	0.71
12	Deutsche Boerse AG	1,840,803	1,069,824	0.58
13	ASX Australian Securities Exchange	1,683,553	964,227	0.57
14	Hong Kong Exchanges and Clearing	4,564,434	2,498,767	0.55
15	BME Spanish Exchanges	658,629	304,626	0.46
16	National Stock Exchange of India	3,307,971	1,477,931	0.45
17	Nasdaq Nordic and Baltics	1,848,314	757,411	0.41
18	SIX Swiss Exchange	1,845,394	717,652	0.39
19	Euronext	6,118,817	2,340,435	0.38
20	Tel-Aviv Stock Exchange	279,803	102,809	0.37
21	Singapore Exchange	618,611	202,423	0.33
22	LSE Group London Stock Exchange	3,119,628	1,008,966	0.32
23	Moscow Exchange	563,472	156,911	0.28
24	Bursa Malaysia	369,240	101,228	0.27
25	Indonesia Stock Exchange	607,259	163,445	0.27
26	Johannesburg Stock Exchange	1,127,010	277,914	0.25
27	Bolsa Mexicana de Valores	467,477	98,722	0.21
28	Abu Dhabi Securities Exchange	674,050	103,254	0.15
29	Tehran Stock Exchange	1,318,309	192,713	0.15
30	Saudi Exchange (Tadawul)	2,849,175	329,523	0.12

World avg: 1.08

Source: The World Federation of Exchanges; ECC Info Mgmt Ltd.

ALTERNATIVE TRADING VENUES

- Alternative trading services (ATSs) are places where security transactions can be done in parallel to exchanges, but they have the following unique characteristics:
  - For many ATSs, they derive prices from a “primary” exchange;
  - Many ATSs need to report trades to a centralized regulation body, but such reports are often delayed;
  - Many ATSs do not publish “market data”, thus are often called “dark pools”; there also are aggregators of dark pools;
  - ATSs often have unique trading mechanisms (such as periodic batch auctions) and specially designed order types (such as hidden orders);
  - On a global scale, ATSs are taking trading volumes away from traditional exchanges, which is leading to more and more liquidity fragmentation.

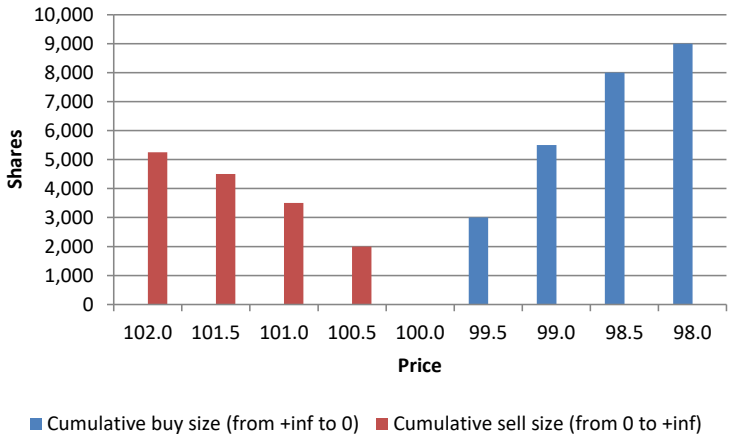
EXAMPLES OF ALTERNATIVE TRADING VENUES

- ECNs (Electronic Crossing Networks)
  - POSIT of ITG: batch auctions at randomly selected time points throughout the day; market data not available (i.e., dark); about 13 times crosses per trading day; mostly used by institutions to trade large blocks;
  - Instinet's "pre-open VWAP" crossing engines: mostly for institutions' large whole-day VWAP orders; price is determined *posterior* after market close when the whole-day VWAP is determined; residuals from "pre-open VWAP" crosses can be re-crossed;
- Broker dark pools:
  - SigmaX of Goldman Sachs, CrossFinder of Credit Suisse, NX of Nomura, etc.;
  - Most use continuous double auction trading mechanism with traders taking/providing liquidity;
  - Most of the trades (about 90%+) are done at the "mid-quote" of the NBBO (National Best Bid and Offer) derived from lit pools;
  - Tabb Group estimate that the volume traded in dark pools in the U.S. is about 10-15% of total transactions in 2018.

BASIC TRADING MECHANISMS (I)

- First principle of trading: Buy low, sell high;
- Second principle of trading: Trading is a zero-sum game;
- Supply-and-demand: no crosses

Cumulative buy size (from +inf to 0)	Buy size	Price	Sell size	Cumulative sell size (from 0 to +inf)
0		102.50	500	5750
0		102.00	750	5250
0		101.50	1000	4500
0		101.00	1500	3500
0		100.50	2000	2000
0		100.00		0
3000	3000	99.50		0
5500	2500	99.00		0
8000	2500	98.50		0
9000	1000	98.00		0
9500	500	97.50		0



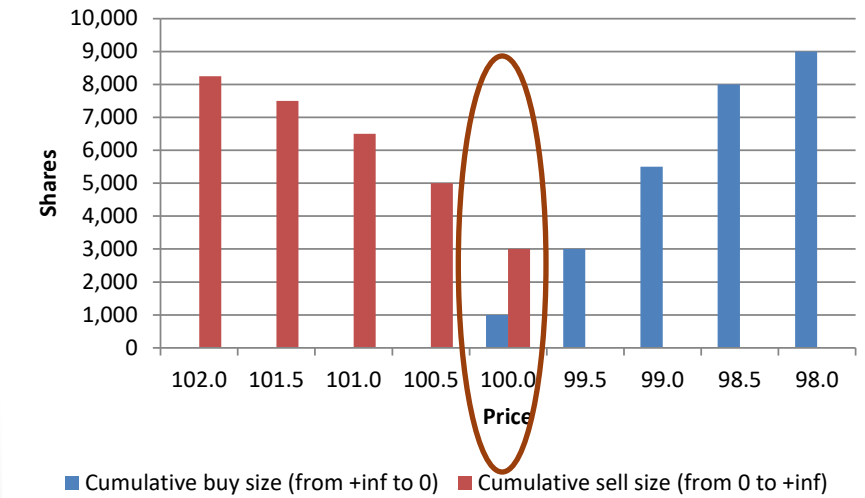
Key concepts:

- Supply;
- Demand;
- Tick;
- Bid-ask Spread;
- NBBO;
- Order book;
- Etc.

BASIC TRADING MECHANISMS (II)

- Supply-and-demand: cross emerges

Cumulative buy size (from +inf to 0)	Buy size	Price	Sell size	Cumulative sell size (from 0 to +inf)
0		102.50	500	8750
0		102.00	750	8250
0		101.50	1000	7500
0		101.00	1500	6500
0		100.50	2000	5000
1000	1000	100.00	3000	3000
3000	2000	99.50		0
5500	2500	99.00		0
8000	2500	98.50		0
9000	1000	98.00		0
9500	500	97.50		0



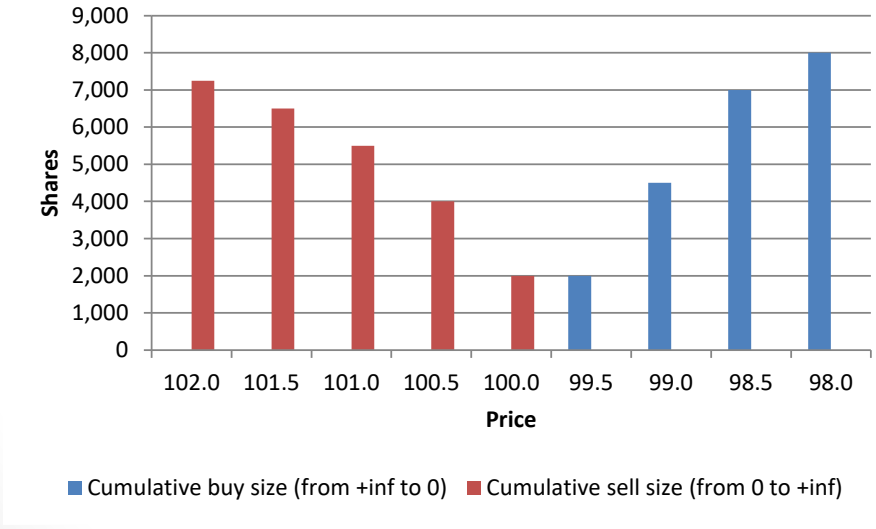
Key concepts:

- Order cancellation;
- Order submission;
- "Jump the queue";
- Price-time priority or Pro Rata crossing;
- Crosses done when supply and demand curve "cross";
- Transaction reporting;
- Liquidity taking vs. liquidity provision;
- Order book dynamics;
- Etc.

BASIC TRADING MECHANISMS (III)

- Supply-and-demand: after cross is done

Cumulative buy size (from +inf to 0)	Buy size	Price	Sell size	Cumulative sell size (from 0 to +inf)
0		102.50	500	7750
0		102.00	750	7250
0		101.50	1000	6500
0		101.00	1500	5500
0		100.50	2000	4000
0		100.00	**2000**	2000
2000	2000	99.50		0
4500	2500	99.00		0
7000	2500	98.50		0
8000	1000	98.00		0
8500	500	97.50		0



Key concepts:

- Spread improvement;
- Transaction cost in terms of bid-ask spread.

BASIC TRADING MECHANISMS (IV)

- Order-driven market vs. quote-driven market:
  - **Order-driven market** maintains an order book and crosses supply-demand according to a pre-defined trading rules; almost all stock exchanges in the world are order-driven markets; investors still need to employ "brokers" to trade into the an order-driven market, but this is more due to exchange membership requirements nowadays than other factors and is being further expanded by the adoption of electronic trading practices;
  - **Quote-driven market** employs "dealers" to facilitate price discovery; many (if not all) OTC markets for illiquid instrument trading are quote-driven markets where investors have to deal with one or several "dealers"; dealers are obliged to quote prices for investors; there also exist inter-dealer markets which are also quote-driven;
  - From trading mechanism point of view, the two markets can overlap; an order-driven market often employ "market makers" to quote prices continuously; these "market makers" are essentially "dealers".

BASIC TRADING MECHANISMS (V)

- Other price discovery mechanisms and facilitation rules that are worth mentioning:
  - Open and close auctions;
    - For the determination of "official" open and close prices of securities;
    - Most markets use "batch double call auction" to cross supply-demand at open and close;
    - Other markets use specially designed mechanism (such as Hong Kong's median-of-5-snapshots in last minute);
    - Market cannot be opened unless an open auction is conducted;
    - If close auction cannot be done due to whatever reasons, exchange often specifies a close price based on pre-defined trading rules;
  - Trading breaks (lunch breaks for many Asian markets);
  - Trading halts (trading-related or company-related);
  - Up and down limits (to avoid excessive volatility; but its effectiveness is often questioned by both academics and practitioners);
  - Circuit breakers (a hot topic now in the U.S. related to HFT).

MARKET PARTICIPANTS

- Retail vs. Institutions;
- Retail vs. Wholesale;
- Brokers and their clients;
  - IPOs;
  - Secondary market trading;
  - Third market trading (not commonly mentioned anymore as it is so common now);
- Dealers who quote for other people and manage inventory risks;
- Specialists who are a special kind of dealers but are “exchange floor-based”;
- Market makers (a special kind of dealers);
- Corporates that find risk solutions from the financial markets;
- Clearing companies and custodians;
- Others: Regulators, vendors, etc.

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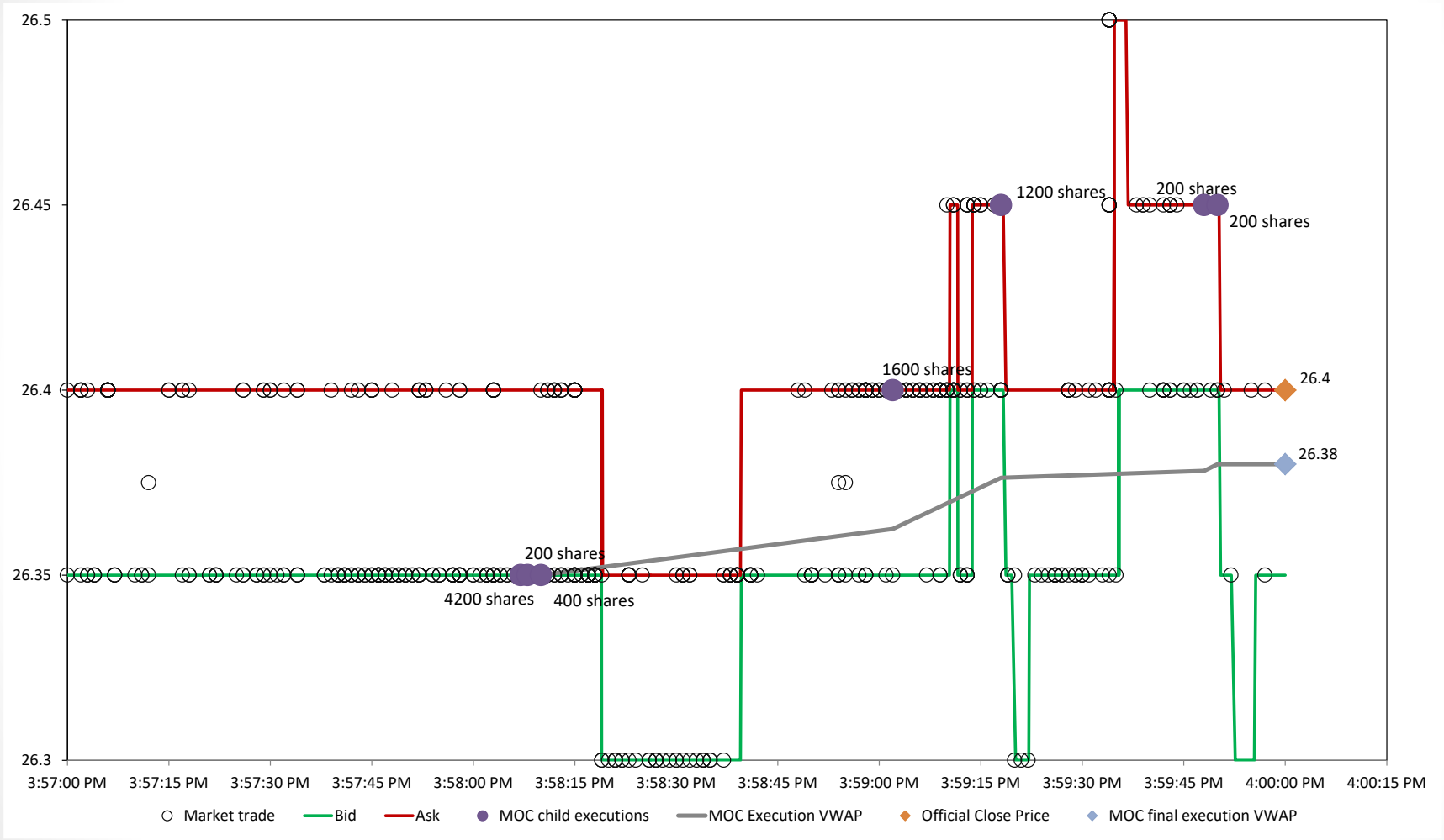
TRACKING A TRADE IN THE MARKET



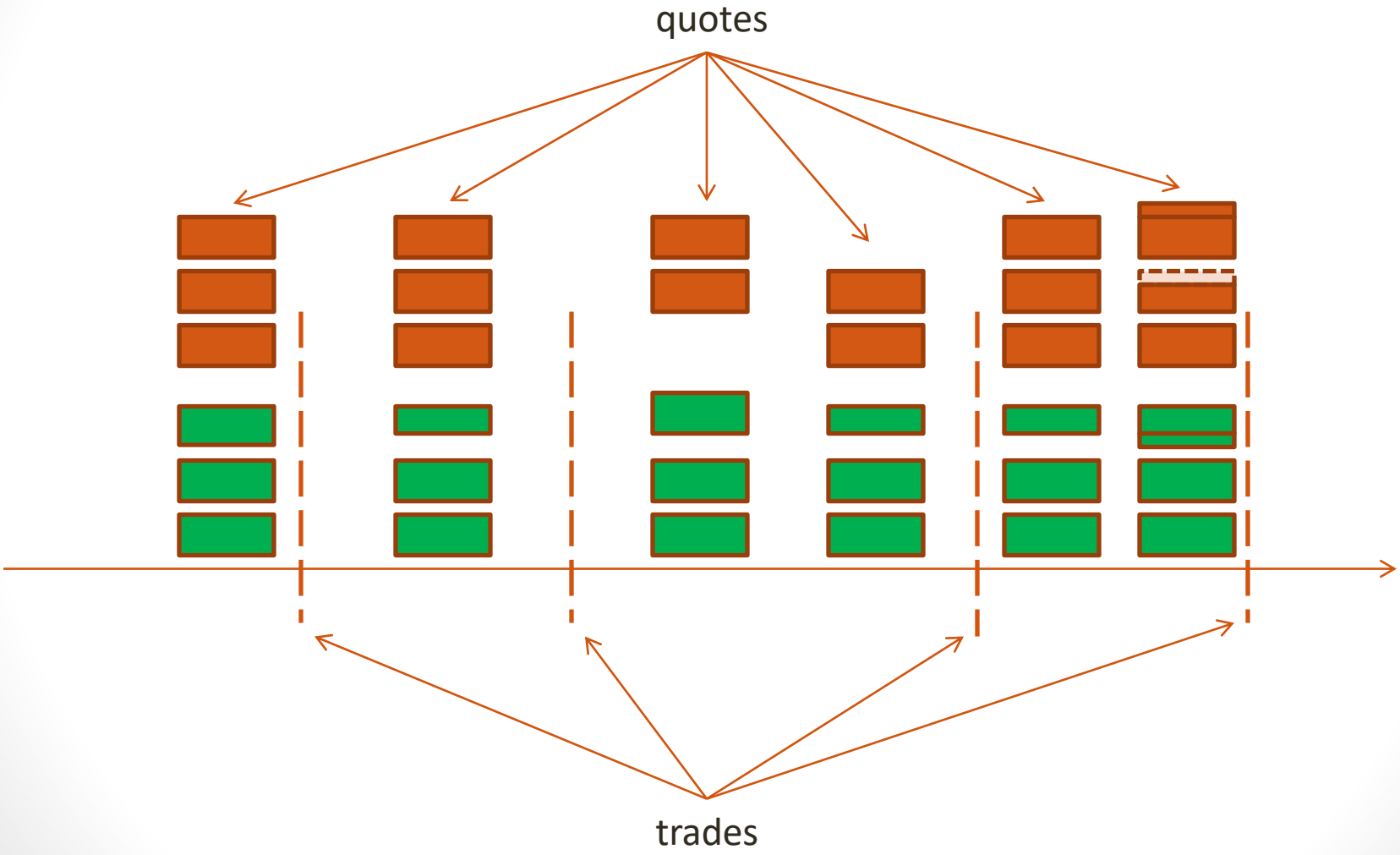
Source: Charles River Advisors Limited; ticker is 1299.HK (AIA Group).

DISCUSSION ON HIGH-FREQUENCY MARKET DATA (I)

- Market data are temporal sequences of order and execution events that happen on a market;
- Orders are the desire of a trader who wants to buy or sell a certain asset; executions are the results from market transactions;
- Each order has (at least) the following fields to be specified: ticker, side, size, type, price, time in force;
- Each execution has (at least) the following fields to be specified: ticker, size, price, time;
- Different markets publish different contents at different time frequency; some publish all events stamped by time, often up to micro-seconds; others publish snapshots at a much lower time frequency;
- Market data are often decomposed into two time series, trades and quotes, which can be combined together as one type of data – quotes – as long as trades are considered as market orders.

DISCUSSION ON HIGH-FREQUENCY MARKET DATA (II)

- Market event timeline:



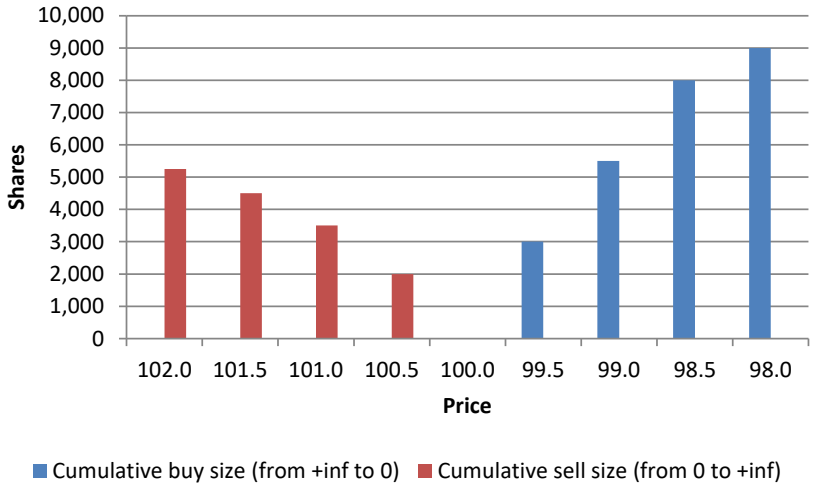
MARKET ORDERS VS. LIMIT ORDERS (I)

- Limit orders are the records that a market participant sends to an exchange, indicating the desire to transact a trade at certain price level;
- The “certain price level” is often called limit price;
- A market order is the record that a market participant sends to an exchange, indicating the desire to transact a trade at whatever price level that has the other side orders;
- A market order is essentially a limit order with an infinite (positive or negative) limit price;
- However, a limit order can become “marketable” if the limit price allows the limit order to be crossed on the other side of the order book immediately.

MARKET ORDERS VS. LIMIT ORDERS (II)

- Limit orders, market orders and marketable limit orders:

Cumulative buy size (from +inf to 0)	Buy size	Price	Sell size	Cumulative sell size (from 0 to +inf)
0		102.50	500	5750
0		102.00	750	5250
0		101.50	1000	4500
0		101.00	1500	3500
0		100.50	2000	2000
0		100.00		0
3000	3000	99.50		0
5500	2500	99.00		0
8000	2500	98.50		0
9000	1000	98.00		0
9500	500	97.50		0



MARKET DATA EXAMPLES - TRADES

C1 | id_trade

	A	B	C	D	E	F	G	H
1		date	id_trade	time	sign	BS	price	ntrade
2	1	20130805	0	92507100	NA	B	3.92	1000
3	2	20130805	1	92507100	NA	B	3.92	400
4	3	20130805	2	92507100	NA	B	3.92	100
5	4	20130805	3	92507100	NA	B	3.92	8800
6	5	20130805	4	92507100	NA	B	3.92	1200
7	6	20130805	5	92507100	NA	B	3.92	1500
8	7	20130805	6	92507100	NA	B	3.92	627
9	8	20130805	7	92507100	NA	B	3.92	1567
10	9	20130805	8	92507100	NA	B	3.92	1000
11	10	20130805	9	92507100	NA	B	3.92	100
12	11	20130805	10	92507100	NA	B	3.92	806
13	12	20130805	11	92507100	NA	B	3.92	1194
14	13	20130805	12	92507100	NA	B	3.92	100
15	14	20130805	13	92507100	NA	B	3.92	9006

trade_SH_601398_20130805

Descriptions of relevant fields in the trade data files:

- date: date of the trading day;
- time: time of the current snapshot taken;
- BS: sign of the trade. B: buy; S: sell; you can directly use this data to determine sign of each trade;
- price: price of the trade;
- ntrade: size of the trade.

MARKET DATA EXAMPLES - QUOTES

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1		date	time	price	volume	turnover	ntrade	BS	acc_volume	acc_turnover	AskPrice1	AskPrice2	AskPrice3	AskPrice4	AskPrice5	AskPrice6	AskPrice7	AskPrice8	AskPrice9	AskPrice10	AskVolume1
47	46	20130221	93007	4.21	442338	1862390	343	S	1346693	5671059	4.22	4.23	4.24	4.25	4.26	4.27	4.28	4.29	4.3	4.31	127700
48	47	20130221	93011	4.21	222100	935062	379	S	1568793	6606121	4.22	4.23	4.24	4.25	4.26	4.27	4.28	4.29	4.3	4.31	125600
49	48	20130221	93013	4.21	18400	77464	380	S	1587193	6683585	4.22	4.23	4.24	4.25	4.26	4.27	4.28	4.29	4.3	4.31	125600
50	49	20130221	93017	4.21	35000	147350	385	S	1622193	6830935	4.22	4.23	4.24	4.25	4.26	4.27	4.28	4.29	4.3	4.31	125600
51	50	20130221	93019	4.2	71340	300109	399	S	1693533	7131044	4.22	4.23	4.24	4.25	4.26	4.27	4.28	4.29	4.3	4.31	125600
52	51	20130221	93023	4.2	177140	744048	425	S	1870673	7875092	4.21	4.22	4.23	4.24	4.25	4.26	4.27	4.28	4.29	4.3	33200
53	52	20130221	93025	4.2	6900	28980	426	S	1877573	7904072	4.21	4.22	4.23	4.24	4.25	4.26	4.27	4.28	4.29	4.3	40100
54	53	20130221	93029	4.2	28143	118206	430	S	1905716	8022278	4.21	4.22	4.23	4.24	4.25	4.26	4.27	4.28	4.29	4.3	39600
55	54	20130221	93031	4.2	23179	97352	434	S	1928895	8119630	4.21	4.22	4.23	4.24	4.25	4.26	4.27	4.28	4.29	4.3	39600
56	55	20130221	93035	4.2	21850	91775	439	S	1950745	8211405	4.21	4.22	4.23	4.24	4.25	4.26	4.27	4.28	4.29	4.3	39100
57	56	20130221	93037	4.2	6900	28980	440	S	1957645	8240385	4.21	4.22	4.23	4.24	4.25	4.26	4.27	4.28	4.29	4.3	39100
58	57	20130221	93041	4.21	38800	163276	445	B	1996445	8403661	4.21	4.22	4.23	4.24	4.25	4.26	4.27	4.28	4.29	4.3	7500
59	58	20130221	93043	4.21	7500	31575	447	B	2003945	8435236	4.22	4.23	4.24	4.25	4.26	4.27	4.28	4.29	4.3	4.31	159600
60	59	20130221	93047	4.21	49540	208545	453	S	2053585	8643781	4.21	4.22	4.23	4.24	4.25	4.26	4.27	4.28	4.29	4.3	3800
61	60	20130221	93049	4.2	400	1680	454	S	2053985	8645461	4.21	4.22	4.23	4.24	4.25	4.26	4.27	4.28	4.29	4.3	5300
62	61	20130221	93053	4.2	41600	174725	458	S	2095585	8820186	4.21	4.22	4.23	4.24	4.25	4.26	4.27	4.28	4.29	4.3	18743
63	62	20130221	93057	4.2	0	0	458		2095585	8820186	4.21	4.22	4.23	4.24	4.25	4.26	4.27	4.28	4.29	4.3	18743
64	63	20130221	93059	4.2	1000	4200	459	S	2096585	8824386	4.21	4.22	4.23	4.24	4.25	4.26	4.27	4.28	4.29	4.3	20943
65	64	20130221	93103	4.2	0	0	459		2096585	8824386	4.21	4.22	4.23	4.24	4.25	4.26	4.27	4.28	4.29	4.3	21043
66	65	20130221	93105	4.2	5250	22050	460	S	2101835	8846436	4.21	4.22	4.23	4.24	4.25	4.26	4.27	4.28	4.29	4.3	21043
67	66	20130221	93109	4.2	13000	54600	462	S	2114835	8901036	4.21	4.22	4.23	4.24	4.25	4.26	4.27	4.28	4.29	4.3	21043
68	67	20130221	93111	4.2	0	0	462		2114835	8901036	4.21	4.22	4.23	4.24	4.25	4.26	4.27	4.28	4.29	4.3	21043
69	68	20130221	93115	4.21	5200	21892	467	B	2120035	8922928	4.21	4.22	4.23	4.24	4.25	4.26	4.27	4.28	4.29	4.3	15943
70	69	20130221	93117	4.21	15943	67120	471	B	2135978	8990048	4.22	4.23	4.24	4.25	4.26	4.27	4.28	4.29	4.3	4.31	139600

quote_SH_601398_20130221

Descriptions of relevant fields in the quote data files:

- date: date of the trading day;
- time: time of the current snapshot taken;
- price: the price of the last trade within a snapshot;
- volume: summation of the sizes for each trade from the immediate previous snapshot to the current snapshot;
- turnover: summation of trade size*trade price for each trade within a snapshot; note that turnover divided by volume gives the VWAP of trades from previous snapshot to the current one;
- ntrade: the size of the last trade within a snapshot;
- BS: sign of the last trade within a snapshot;
- acc_volume: accumulated trading volume since market open;
- acc_turnover: accumulated total turnover since market open;
- AskPrice1-10: the latest ask prices from the previous snapshot to the current one;
- AskVolume1-10: the latest ask volume at the specific ask price from previous snapshot to the current one. For example, AskVolume1 is the ask volume at AskPrice1;
- BidPirce1-10: the latest bid prices from previous snapshot to the current one;
- BidVolume1-10: the latest bid volume at the specific bid price from previous snapshot to the current one.

KEY MICROSTRUCTURE VARIABLES TO OBSERVE

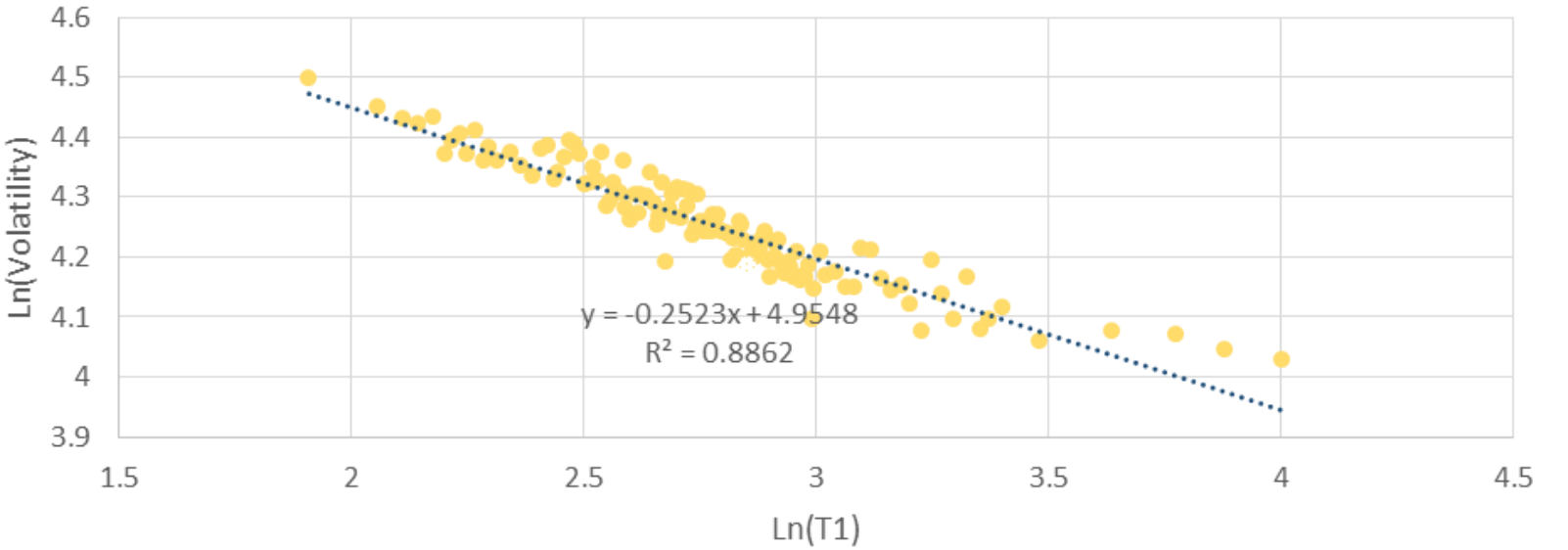
- **Price-related**: Quotes at different levels, trade price, VWAP, MA, mid-quote and weighted mid-quote, etc.;
- **Volume-related**: trade size, MA of trade volume, quote sizes, queue size and queue turnover time, inserted/filled/cancelled volumes of limit orders, etc.;
- **Trading-related**: the arrival rates of limit orders and market orders (or, the inter-trade durations), order book dynamics variables such as book pressure, centroids of bid/offer sides in terms of moving average prices, etc.;
- **Event-related**: company- and government-related news, cross-market correlations, etc.;
- **Cross-sectional**: sector and major index (and their futures) movements, related instruments such as options to stocks, etc.

BID-ASK BOUNCE AND TRADE PRICE PROCESS

- Let a be the ask, b the bid, p the trade price; then $s = b - a$ is the bid-ask (full) spread; by definition, $b < a$;
- Assume that the trade price following a Bernoulli process with a probability of ρ on the ask and 1-ρ on the bid; further assume that the bid and ask remain constant;
- Then the average trade price is $E[p] = \rho a + (1-\rho)b = b + \rho(a-b)$; for a Buy order, $(1-\rho)(a-b)$ is also called "spread captured"; for a Sell order, $\rho(a-b)$;
- The variance of the trade price is $E[p^2 - E[p]^2] = \rho(1-\rho)(a-b)^2$; or, the standard deviation of the trade price is $\sqrt{\rho(1-\rho)}|a-b|$;
- When ρ = ½, we have the standard deviation of the trade price to be $½|a-b|$, which is half of the bid-ask spread;
- But how could this be related to the "volatility" of the stock?
- If we assume a "time scale" during which the price process moves from a random bid-ask bounce into a random walk process, then such time scale can be roughly estimated as $T \sim \left[\sqrt{\rho(1-\rho)}\,|a-b|/\sigma\right]^{1/\gamma}$, where σ is the stock volatility calculated from an assumption of price process for the mid-quote, and γ is 0.5 for an arithmetic Brownian process.

SOME EMPIRICAL RESULT

- About 2400 stocks that are traded on Shanghai and Shen Zhen stock exchanges;
- Data were collected between Jan. 2014 and Aug. 2015.



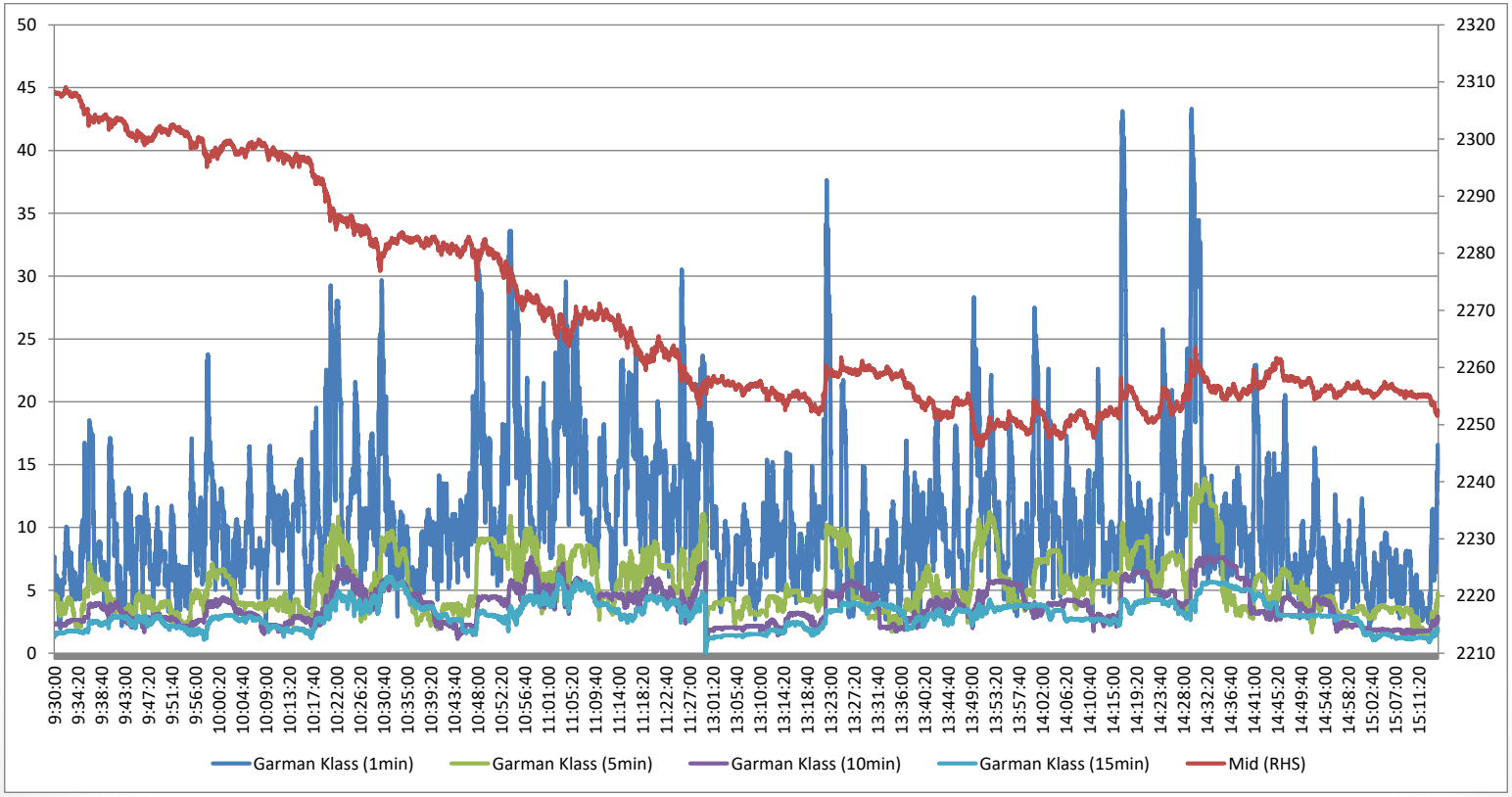
Source: Market Efficiency project by Y. Wang et al., Fall 2016

RELATIONSHIP BETWEEN SPREAD AND VOLATILITY

- If we re-write the "time scale" formula as $\sigma \sim \sqrt{\rho(1-\rho)} Spd / T^{\gamma}$, it gives the relationship between the volatility of the stock and the bid-ask spread of the stock; both variables are key parameters of the "liquidity" of the stock;
- If we re-write this formula (again!) as $Spd \sim \sigma T^{\gamma} / \left[\sqrt{\rho(1-\rho)}\right]$, it gives a (simplified) quoting formula for market making to manage their trading risk; of course, a sophisticated market maker usually has a more complicated formula than this, but the essence is the same in terms of risk management; it indicates that the "intrinsic" volatility of the stock, key characteristic trading time scales as well as order flow statistics will affect the quoted bid-ask spread of the stock; what is missing from this formula is the potential drift of the stock if there is one;
- The drift should be extracted from the analysis of the mid-quote price, $(a+b)/2$; therefore, at market microstructure level, the trade price process is a combination of a bid-ask bounce process and a mid-quote price process, the latter one of which can be modeled quite extensively even with potential jumps.

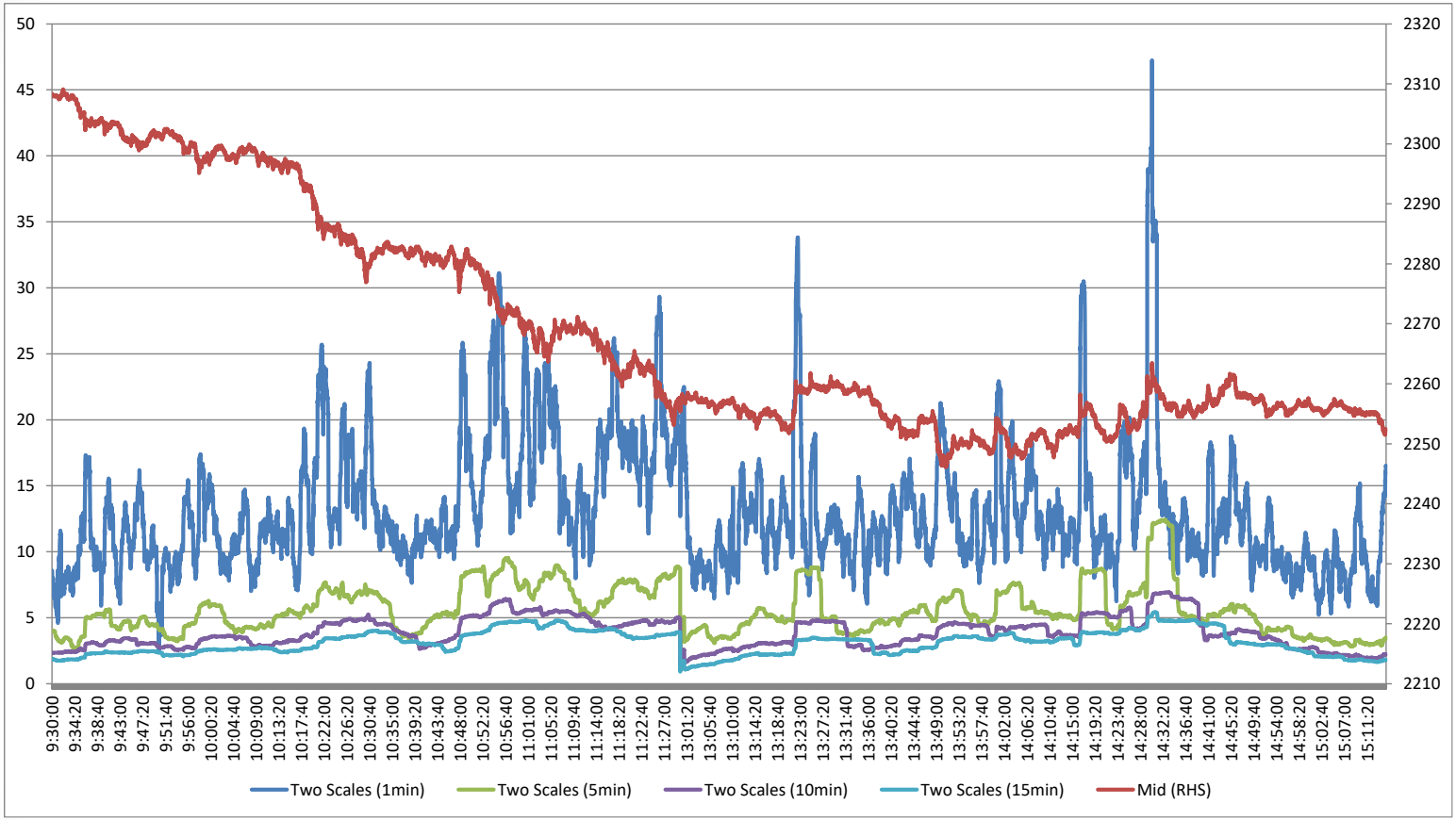
CALCULATING INTRADAY VOLATILITY (I)

- As affected by market microstructure noise, correct and efficient intraday volatility calculation is a key task of any algorithmic and high-frequency traders;
- Below are a few examples using different intraday volatility estimators with various parameters (underlying security: CSI300 index future, on Oct. 26, 2012):



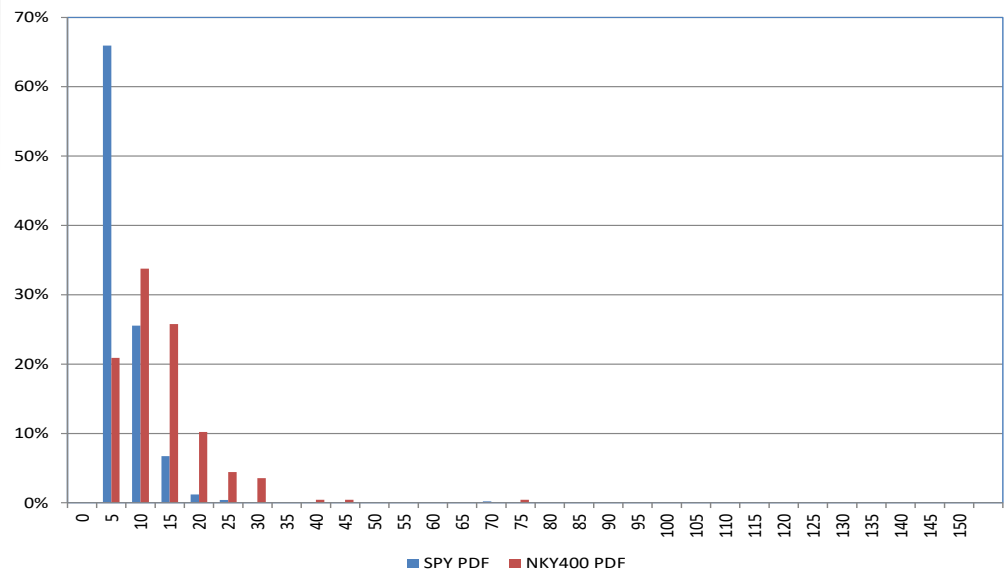
Source: Charles River Advisors Limited

CALCULATING INTRADAY VOLATILITY (II)



Source: Charles River Advisors Limited

STRUCTURE-SPECIFIC LIQUIDITY CHARACTERISTICS (I)



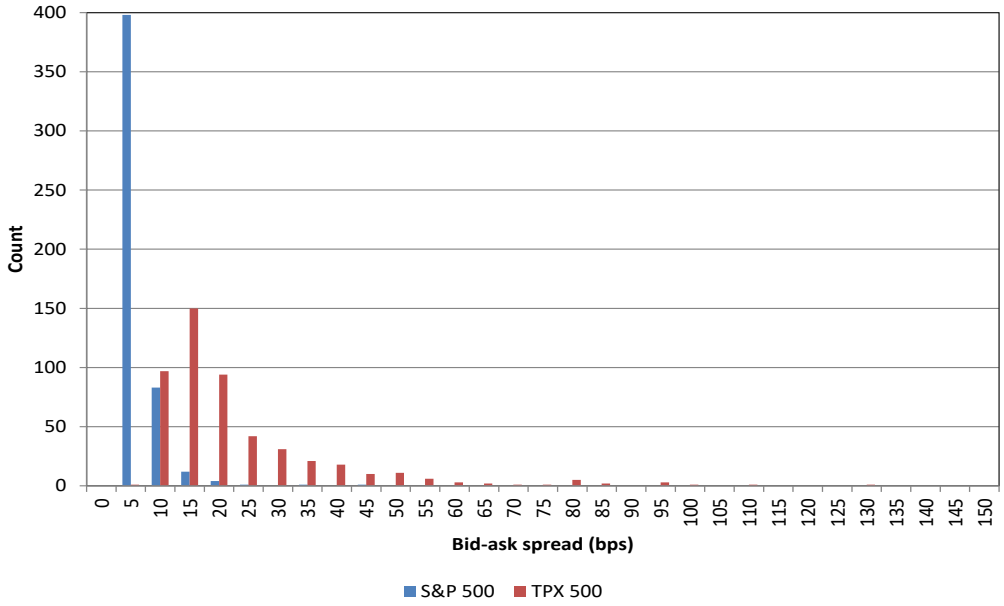
A key factor in such different bid-ask spread distribution is how different exchanges determine tick size.

Tokyo Stock Exchange tick size schedule:

	Stock price per share	Tick size
	¥ 1,000 or less:	¥ 0.1
Above	¥ 1,000 ~ ¥ 5,000:	¥ 0.5
〃	¥ 5,000 ~ ¥ 10,000:	¥ 1
〃	¥ 10,000 ~ ¥ 50,000:	¥ 5
〃	¥ 50,000 ~ ¥ 100,000:	¥ 10
〃	¥ 300,000 ~ ¥ 500,000:	¥ 50
〃	¥ 500,000 ~ ¥ 1,000,000:	¥ 100
〃	¥ 1,000,000 ~ ¥ 5,000,000:	¥ 500
〃	¥ 5,000,000 ~ ¥ 10,000,000:	¥ 1,000
〃	¥ 10,000,000 ~ ¥ 50,000,000:	¥ 5,000
〃	¥ 50,000,000:	¥ 10,000

Source: Tokyo Stock Exchange, for TOPIX100 stocks only.

STRUCTURE-SPECIFIC LIQUIDITY CHARACTERISTICS (I)



A key factor in such different bid-ask spread distribution is how different exchanges determine tick size.

Before July, 2014!

Tokyo Stock Exchange tick size schedule:

	Stock price per share	Tick size
	¥ 3,000 or less:	¥ 1
Above	¥ 3,000 ~ ¥ 5,000:	¥ 5
〃	¥ 5,000 ~ ¥ 30,000:	¥ 10
〃	¥ 30,000 ~ ¥ 50,000:	¥ 50
〃	¥ 50,000 ~ ¥ 300,000:	¥ 100
〃	¥ 300,000 ~ ¥ 500,000:	¥ 500
〃	¥ 500,000 ~ ¥ 3,000,000:	¥ 1,000
〃	¥ 3,000,000 ~ ¥ 5,000,000:	¥ 5,000
〃	¥ 5,000,000 ~ ¥ 30,000,000:	¥ 10,000
〃	¥ 30,000,000 ~ ¥ 50,000,000:	¥ 50,000
〃	¥ 50,000,000:	¥ 100,000

Source: Tokyo Stock Exchange

STRUCTURE-SPECIFIC LIQUIDITY CHARACTERISTICS (II)

- Lunch breaks can lead to concentration of trading volume and elevated volatility level near PM open;
- For markets that set daily limit prices for stocks, liquidity can dry up quickly as trade price gradually moves toward the limit where significant order imbalance can build up; exact daily limit values are decided by exchanges (in % terms or values) and can be changed from time to time; for any trading systems, this is a risk aspect that has to be controlled and implemented;
- Different markets have different trading rules when trading is under stress, such as the **Keihai** situation for Japan, which can significantly slow down continuous trading process and even completely stop it; depending on the direction of liquidity provision, different market participants will react differently when such situation arises;

AGENDA

- An outline of this course

- An introduction to trading venues and trading practices
  - Asset prices and their practical pricing
  - Global exchanges and trading venues
  - Quote-driven markets vs. order-driven markets
  - Market participants and their trading practices

- Market microstructure characteristics of global markets
  - Price process
  - Risk
  - Liquidity
  - Structure-specific features

- A practical introduction to algorithmic trading
  - Definitions of algorithmic trading
  - Industrial overview of algorithmic trading practices

DEFINING ALGORITHMIC TRADING (I)

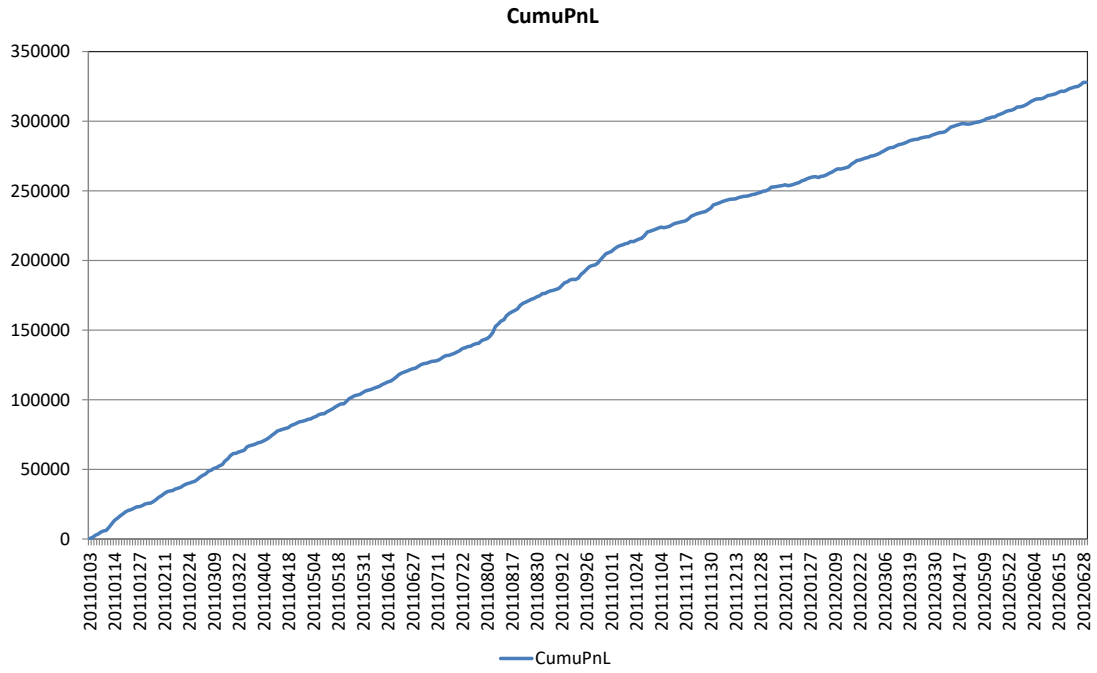
- On the “Buy-side”, many people define algorithmic trading strategies as a group of quantitative investment strategies; the widely discussed high-frequency trading strategies nowadays can be regarded as a special sub-group of algorithmic trading strategies, albeit many HFT strategies are algorithmic trading strategies at certain extremes in terms of telecommunication speed and computational intensity;
- In the broker community, algorithmic trading strategies are often considered synonymous to execution strategies with two main goals: straight-through operation (a.k.a. automation of procedural operations), and economy of scale (a.k.a. lower unit cost in terms of trading, both explicit and implicit costs);
- My view is that any successful trading algorithm has to be a combination of both: excellent investment strategy ideas and effective/efficient implementation of latest technologies.

DEFINING ALGORITHMIC TRADING (II)

- Broadly speaking, when the main goal of algorithmic trading strategies is to maximize risk-adjusted return of the trading process, they are essentially a form of high-frequency trading strategies; on the other hand, if the main goal is to minimize trading cost, they are more of the nature of execution algorithms; in this seminar, we will loosely define the latter as “algorithmic trading (AT)” while the former as “HFT”;
- Undoubtedly, AT and HFT always share the same technology and quantitative infrastructure; the exact set-up of such infrastructures can be different depending on the economics of trading operations; so far, HFT has been leading AT in terms of climbing technology curve, while AT often provides market microstructure insights in terms of HFT strategy design.

DEFINING ALGORITHMIC TRADING (III)

- The trend in the industry is that algorithmic trading and HFT are converging onto one platform; below is an example of using the "market making module" in AT platform and turning it into a HFT strategy with no significant re-modeling and re-coding:



Source: Charles River Advisors Limited; stock is 0005.HK.

EARLY PHASES OF AT DEVELOPMENT

- The rapid growth of index funds and passive investment strategies in the 1970s and 1980s led to significant investment money going to index-based funds, which drove the development of portfolio-based trading aiming at tracking error minimization and more regular and frequent index-based rebalancing of portfolios; it also led to the adoption of quantitative ways of stock selection, portfolio optimization and risk management;
- In the 1990s and early 2000s, ETFs and other low-cost investment vehicles started to be embraced by both institutional and retail investors; at the same time, asset under management by hedge funds exploded; all of such developments in the asset management industry led to frequent transition trades that got the broker/dealer community to start introducing program trading desks that are powered by automated trading processes and systems;
- Algorithmic trading strategies started to grow out of such program trading desks with more systematic ways to conduct portfolio trading and, eventually, single stock trading.

SECOND PHASE OF AT DEVELOPMENT (I)

- A key reason why algorithmic trading has taken liquid market trading by storm in the past decade in developed market (and currently in developing markets) is due to regulatory changes; the first example is the decimalization of tick sizes in the U.S. in 2000;

SECOND PHASE OF AT DEVELOPMENT (II)

- RegNMS (Regulation National Market System) in the U.S.:
  - Introduced by SEC in 2005 and established as regulations in 2007;
  - Main goal was to promote a national market system with more transparency in pricing (trade through rule and sub-penny pricing), market access and market data dissemination;
  - Essentially removed monopoly by major exchanges and introduced venue competition;
  - New trading technologies such as “smart order routers” and HFT strategies such as “venue or latency arbitrage” are direct results of the regulatory changes enacted in RegNMS;
  - There have been arguments that RegNMS led to lower transaction cost on per trade basis for investors but also liquidity fragmentation and elevated complexity of trading systems in the U.S.; the technology “arms-race” of recent years has also been argued to be a direct result of venue competition that left individual investors “out in the slow and cold”.

SECOND PHASE OF AT DEVELOPMENT (III)

- MiFID (Markets in Financial Instruments Directive) in EU:
  - Officially published in 2006 and went effective in 2007 in EU;
  - Goal is to increase the level of competition between service providers and consumer protection;
  - Introduced a comprehensive definition of “best execution”, which combines price, speed, service content, service quality, etc. under one umbrella;
  - Provided official definitions of key service components, such as: pre-trade transparency, post-trade transparency, client categorization, client order handling, and systematic internalization service provider (or, systematic internalizer);
  - The effect of MiFID has been debated in recent years, with trading volume coming down significantly since the introduction of MiFID.

SECOND PHASE OF AT DEVELOPMENT (IV)

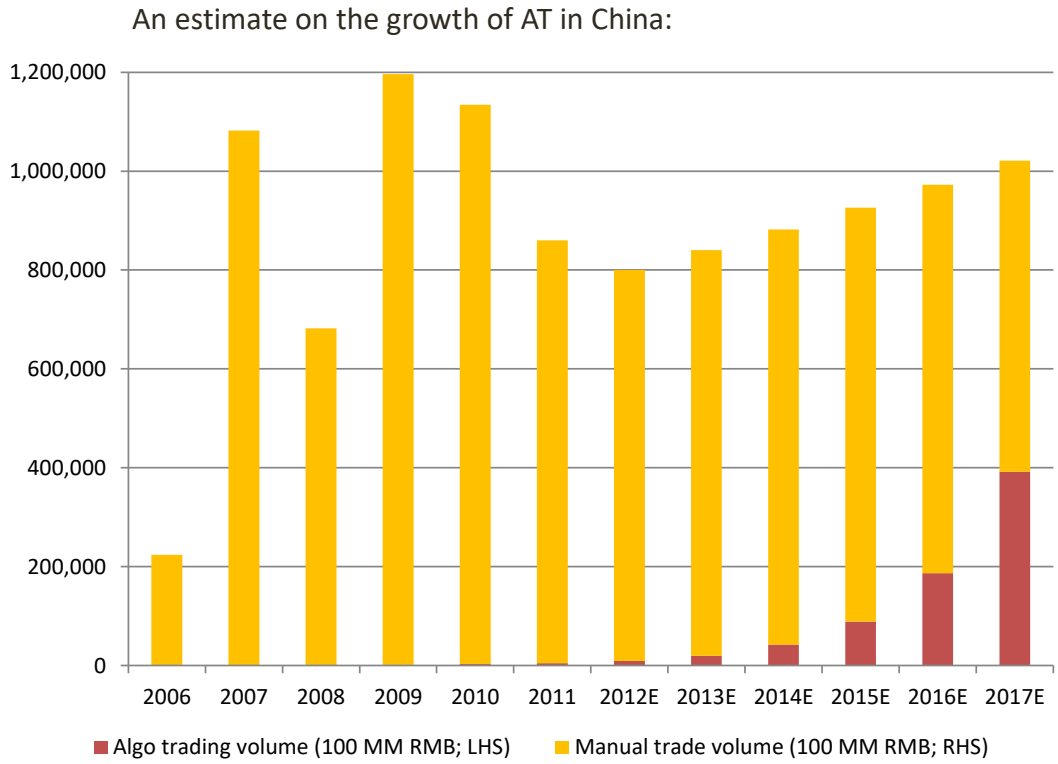
- Alternative Trading Systems in Japan
  - Trading volume in Japan has been mostly concentrated on TSE;
  - Alternative Trading Systems (such as broker dark pools, electronic crossing engines, etc.) have been gradually introduced in Japan since early 2000s;
  - Many ATSs (esp. broker dark pools) still need to report their trades to ToSNeT before matches done in the pools are "officially" transacted;
  - In 2010, Chi-X Japan obtained PTS (Proprietary Trading System) license to become a new exchange and started to introduce "fractional tick size" pricing for Japanese stocks; in Jan. 2012, Chi-X Japan started to provide "liquidity credit", which is essentially a rebate for liquidity providers;
- Regulatory changes in other countries:
  - CentrePoint in Australia;
  - "Dark pools" in Hong Kong;
  - "Off Exchange Trading" in China;
  - Etc.

THE ADOPTION AND REGULATION OF AT/HFT

- HFT volume is at historical high in terms of trading volume:
  - UK：about 30%；
  - U.S.：about 60%；
  - Japan：about 15%；
- Government agencies and self-regulatory bodies throughout the world are contemplating how to regulate HFT as a disruptive new force of trading and asset management:
  - New requirements are being considered: notification of algorithms, circuit breakers, minimum tick sizes, obligations for market makers, minimum resting times of orders, minimum order-to-execution ratios, maker-taker pricing (or, rebate mechanisms), centralized limit order book, requirements for internalization engines, call auctions vs. continuous double auctions, new order priority rules, etc.

THERE IS STILL GROWTH IN AT/HFT

- Even though AT/HFT are facing regulatory scrutiny nowadays, they continue to grow in trading volume and usage, especially in developing markets:



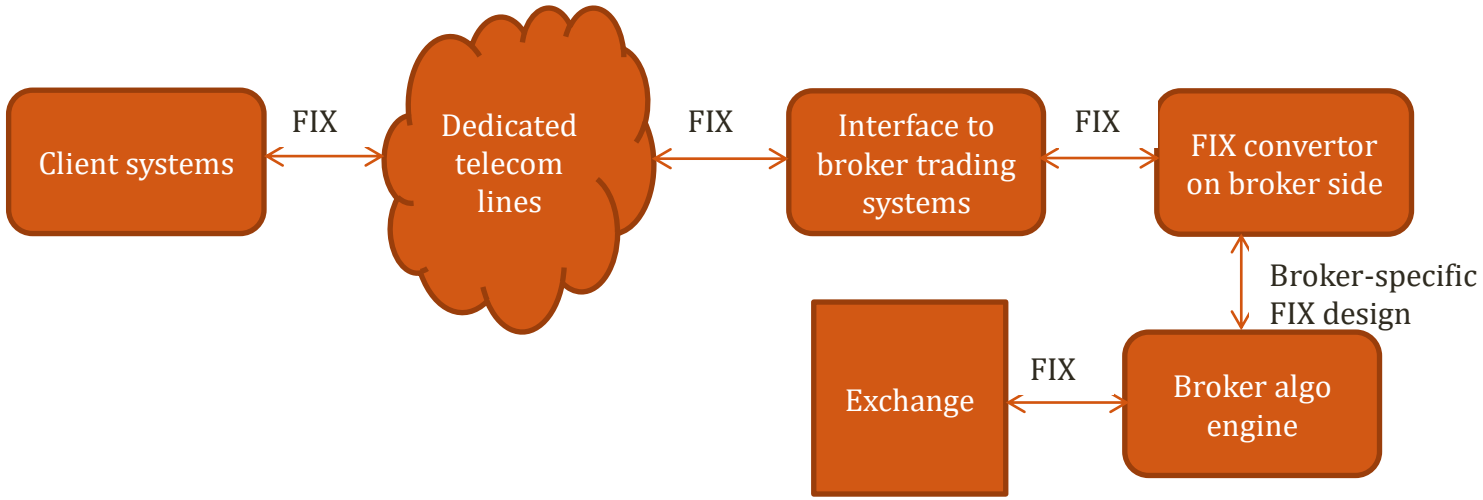
Source: Charles River Advisors Limited

THE ENABLING EFFECTS OF TECHNOLOGIES

- The development of algorithmic trading as a trading practice has been enabled by the development of financial technologies; several specific areas of technology development have also been encouraged by the rapid adoption of algorithmic trading, such as:
  - Communication via internet technology: one obvious example is the establishment of FIX (Financial Information eXchange) as the standard protocol for message communications;
  - Bid data: trading data (especially tick data that are time-stamped) have exploded in volume; on top of this, processed- and analyzed-data can be multi-fold more;
  - Low-latency communication technologies at both the software level and hardware level also significantly contributed.

STANDARDIZATION OF TRADING COMMUNICATIONS (I)

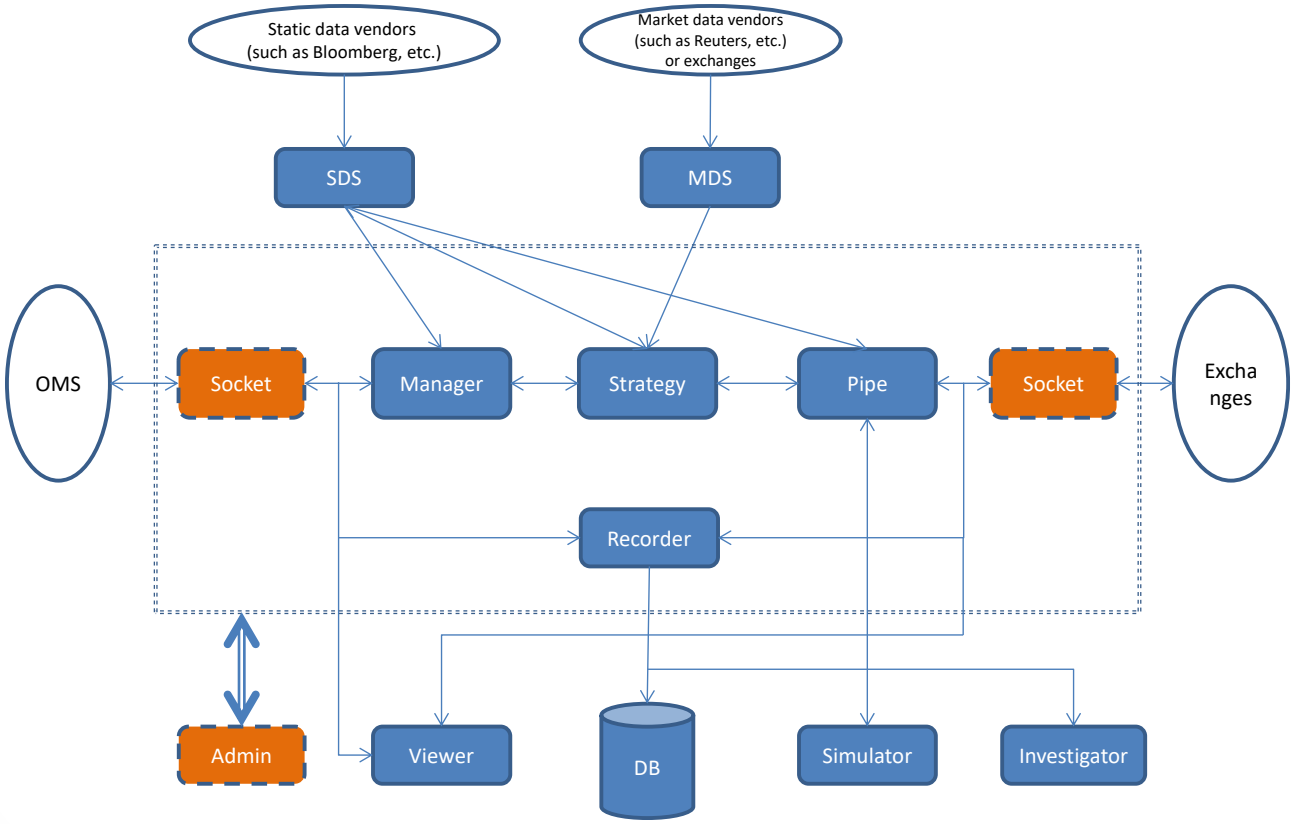
- FIX (Financial Information eXchange) standardized both the content and the best practices of electronic trading.



Source: Charles River Advisors Limited

STANDARDIZATION OF TRADING COMMUNICATIONS (II)

- Below is a simplified example of an algorithmic trading platform that utilizes FIX to communicate between any pair of components:

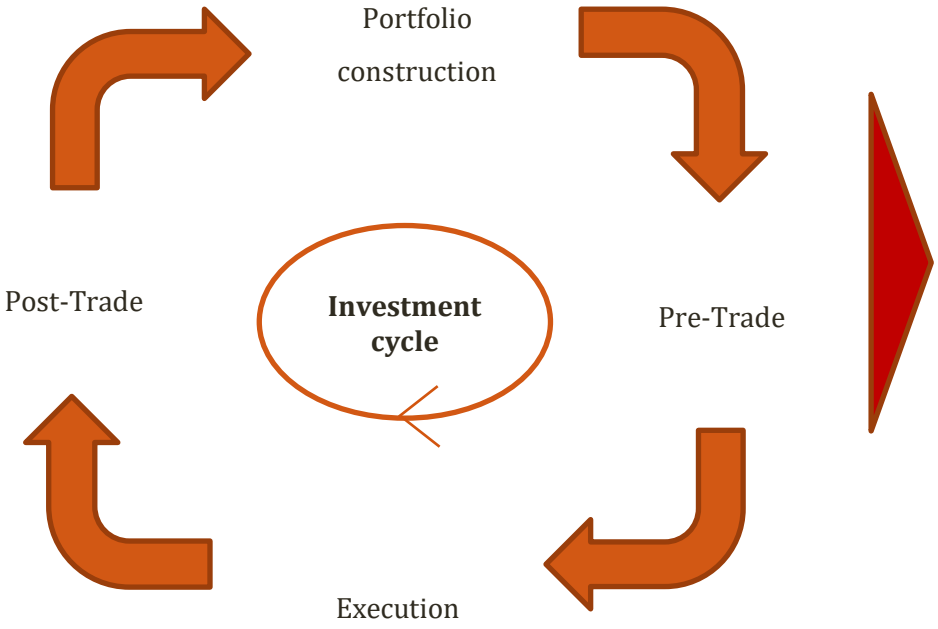


Source: Charles River Advisors Limited

THE "ARMS-RACE" FOR SPEED

- Market data latency numbers：
  a. NYSE/NASDAQ： nano- to micro-second level;
  b. Tokyo: ~1 ms;
  c. Hong Kong: 3-5 ms;
  d. China: a few micro- to a few seconds;
  e. London: sub-micro-second level;
- Basic requirements for HFT：
  a. Maximum latency of market data should be at micro-second level;
  b. Exchange gateway latency should be as small as possible;
  c. Co-location is a must;
  d. Technologies such as FPGA start to spread globally.

AT ON THE "BUY-SIDE"



More and more asset management firms are taking algorithmic trading strategies as part of their investment cycle, especially focusing on alpha-enhancement and cost-reduction.

THAT'S ALL FOR THIS LECTURE.

THANK YOU!