Algorithmic Trading

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Topics

1. Market Macrostructure
2. **Market Microstructure**
3. Algorithmic Trading Fundamentals
4. Algorithmic Execution
5. Algorithmic Market-Making
6. Algorithmic Investment
7. The Future of Algorithmic Trading

2. Market Microstructure

I. What is market microstructure?

- Characteristics that define how a market is organised in order to facilitate trading, taking into account different trade-offs like:
  - immediacy to trade
  - minimise the cost of trading
  - fair price determination
- Such architecture of markets is typically analysed looking at the following dimensions:
  - Trading mechanisms: how in practice investors interact with each other to trade (buy or sell) instruments
  - Trading frequency: how often can a financial instrument be traded
  - Order types: how investors communicate their intention of trading
  - Trading protocols: what are the technical rules of the market
  - Transparency: which information can be given to investors to ensure they can trade fairly

Trading mechanisms

1. **Quote-driven:** investors must transact with a specialised dealer (aka market maker), who keeps an inventory of instruments and quotes indicatives prices at which they will buy and sell a given quantity
   - Investors cannot transact with each other
   - For executable quotes there is a negotiation process

2. **Order-driven**: investors participate equally, placing orders on an order book that are then matched using a consistent set of rules
   - There is no negotiation process

3. **Hybrid**:
   - Quote-driven markets with dealers quoting executable prices for different quantities
   - Order-driven market with dealers that must contractually provide continuous two-way passive orders

Trading frequency

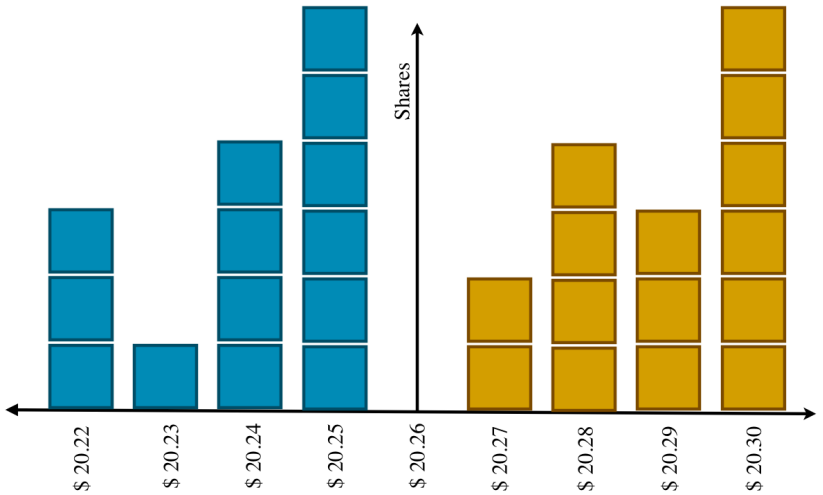
1. **Continuous trading**
   - Trading happens continuously within a window of time
   - Order-driven markets use a continuous double auction, structured in a limit order book
   - Quote-driven markets have dealers constantly updating bid and offer prices, which can be indicative (purely quote-driven markets) or firm (hybrid markets)
2. **Continuous trading with call**
   - Continuous trading with scheduled call auctions, typically in volatile periods (open, close, high volatility)
3. **Scheduled call auctions**
   - Orders aggregate without crossing until a scheduled auction at a specific time
4. **Request-driven trading**:
   - Trading happens at a discretionary time by request of the client

A classification of markets

	Order-driven	Quote-driven	Hybrid: order-driven with market makers	Hybrid: quote-driven executable
Continuous	Instinet (dark pool)	Liquidnet (dark pool)	CME	MTS, Currenex
Continuous with call	Tokyo SE		Euronext, LSE, Eurex, BME, NYSE	EBS Direct, NASDAQ, BrokerTec
Scheduled call	ITG POSIT (dark pool)			
Request		Bloomberg, Tradeweb, MarketAxess		

II. Order-driven markets

- Mostly based in continuous double auctions structured in a central limit order book (CLOB)
- CLOBs display at any time all the live orders
  - Aggregated anonymously by price and volume, ordered by price
  - Separated in buy orders (“bids”) and sell orders (“asks” or “offers”)



Example of CLOB

https://www.binance.com/en/trade/BTC_USDT

Important concepts

- Best bid/ask: highest sell / lowest buy price
- Best opposite: best ask for a buy order and best bid for a sell
- Market depth: number of bid/ask levels
- Mid-price: normally average between best bid and best ask
- Spread: difference between best ask and best bid
- Volume imbalance:

$$Volume\ imbalance_k\% = \frac{Buy\ volume_k - Sell\ volume_k}{Buy\ volume_k + Sell\ volume_k}$$

- Depth imbalance:

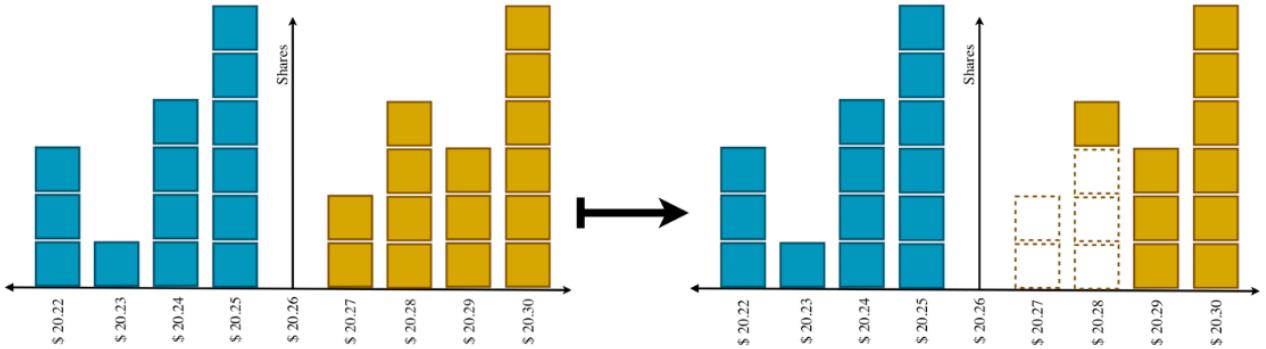
$$DI_t = \frac{\sum_{i=1}^{n} VolBid_{i,t} - \sum_{i=1}^{n} VolAsk_{i,t}}{\sum_{i=1}^{n} VolBid_{i,t} + \sum_{i=1}^{n} VolAsk_{i,t}}$$

- Type of order book data:
  - Level I: shows only best bid and ask
  - Level II: shows all available bids and asks aggregated, or up to a certain market depth (e.g. 5 levels)
  - Level III: shows all the individual orders with id's, times, prices and sizes, which are used to build the order book

Types of orders in order-driven markets:

1) Market orders

- Instruction to buy or sell a given quantity at the best possible price
- Focus on completing the order with no specific price limit
- They have the risk of executing at worse prices than best bid / ask if there is not enough volume (liquidity)
- They have always an immediate cost with respect to best bid / ask: crossing the spread



Example

Order book

Buys				Sells			
Id	Time	Size	Price	Price	Size	Time	Id
B1	8:25:00	1,000	100	101	1,000	8:25:00	S1
B2	8:20:20	1,500	99	102	800	8:20:25	S2
B3	8:24:00	900	98	102	1,200	8:24:09	S3

Market order to buy 2000 titles: it hits limit orders at “sells” side

Buys		Sells			
Size	Price	Price	Size	Time	Id
1,000	100	101	1,000	8:25:00	S1
800	99	102	1,500	8:20:25	S2
1,500	98	104	2,000	8:19:09	S3
		106	3,000	8:15:00	S4

(a) before

	Sells			
	Price	Size	Time	Id
.	~~101~~	~~1,000~~	~~8:25:00~~	~~S1~~
.	~~102~~	~~1,000~~	~~8:20:25~~	~~S2~~
.	102	**500**	8:20:25	S2
.	104	2,000	8:19:09	S3
.	106	3,000	8:15:00	S4

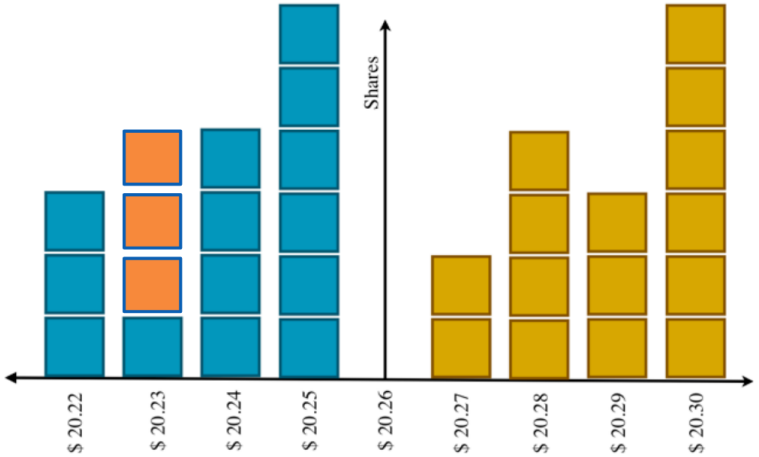
(b) after

Final price is the average price weighted by size executed at each price level.
In the example: price = (1000 * 101 + 1000 * 102) / 2000 = 101.5

Source: Johnson, B. (2010)

2) Limit orders

- Instruction to buy or sell a given quantity at a specified price or better
- Limit orders will try to fill as much as the order as they can, if there is an opposite order in the LOB (aggressive limit order) . Otherwise the order will be placed in the LOB until it is executed, cancelled or expires (passive limit order)
- They have the risk of non being executed
- Priority for execution: it depends on the rules of the LOB
  - Generally they have price priority
  - When there are orders with the same price:
    - Priority rule: time priority
    - Pro-rata rule: proportional execution to size



Example

Passive limit order for 1000 titles at price 100

Buys				Sells	
Id	Time	Size	Price	Price	Size
B1	8:25:00	500	100	101	1,000
B2	8:20:25	1,500	99	102	800
B3	8:24:09	2,000	98	102	1,500

(a) before

Buys				
Id	Time	Size	Price	
B1	8:25:00	500	100	.
B4	8:28:00	1,000	100	.
B2	8:20:25	1,500	99	.
B3	8:24:09	2,000	98	.

(b) after

Aggressive limit order for 2000 titles at price 101

Buys				Sells			
Id	Time	Size	Price	Price	Size	Time	Id
B1	8:25:01	1,000	100	101	1,000	8:25:00	S1
B2	8:20:02	800	99	102	1,500	8:20:25	S2
B3	8:24:09	1,500	98	104	2,000	8:19:09	S3

(a) before

Buys				Sells			
Id	Time	Size	Price	Price	Size	Time	Id
B4	8:28:00	1,000	101	~~101~~	~~1,000~~	~~8:25:00~~	~~S1~~
B1	8:25:01	1,000	100	102	1,500	8:20:25	S2
B2	8:20:02	800	99	104	2,000	8:19:09	S3
B3	8:24:09	1,500	98				

(b) after

Source: Johnson, B. (2010)

3) Other types of orders (not exhaustive)

- Market-to-limit: market order with implicit price limit at the best opposite
- Immediate-or-cancel: any portion of the order that cannot be executed against existing orders will be cancelled
- Fill-or-kill: the order either executes immediately in full or not at all
- All-or-none: the order must be executed in full or not at all, but it doesn't have to be executed immediately
- Stop (limit) order: order to buy as market (limit) order when the price rises to a certain level, or to sell as market (limit) order when the price falls to a certain level
- Hidden orders: non-visible limit orders, usually with lowest priority at the price
- Iceberg orders: hidden order that shows a fraction of it as visible, refilling it when the fraction gets executed. The fraction is a parameter of the order. The displayed part as normal priority and the hidden one only price priority.

Typical trading protocols in order-driven markets

- Order priority: rules to select which existing orders are executed first. As seen, typically price priority, and then time or size (pro-rata) priority
- Minimum trade quantities (lot sizes): example 1 unit, 1000 units, …
- Minimum price increments (tick sizes): some markets change them depending on the price level
- Opening/closing procedures: how the market opens/close and what is considered the official opening/closing price. Many markets open/close with call auctions
- Trading halts and circuit breakers: continuous trading stops for regulatory reasons, large price moves, etc. They allow markets to absorb new information. Normally followed by special call auctions

Trading fees

- Most venues only charge orders that are executed: no fee is paid for inserting and cancelling orders
- Upon execution, the price depends on the type of order, the type of instrument and the volume traded
- Regarding the fee structure according to the type of orders, the main ones are:
  - **Regular**: subsidize liquidity providers, which get a rebate in fees when passive limit orders are executed. Most typical scheme in Europe and USA
  - **Inverted**: subsidize liquidity takers, which get a rebate in fees when aggresive limit or market orders are executed. It exists in some USA Exchanges like BATS BYX and NASDAQ OMX BX

Order-book data ("Tick data")

The highest-frequency data is a collection of sequential "ticks," arrivals of the latest quote, trade, price, and volume information. Tick data usually has the following properties:

- A timestamp
- A financial security identification code
- An indicator of what information it carries:
  - Bid price
  - Ask price
  - Available bid volume
  - Available ask volume
  - Last trade price
  - Last trade size
  - Option-specific data, such as implied volatility
- The market value information, such as the actual numerical value of the price, available volume, or size

Source: Alridge, I. (2010)

Channel ID	Order ID	Price	Amount	Sequence ID	Bitfinex Timestamp
[128595	[45470461298	9768.170458	-0.010512]]	252	1589985309306150000
[128595	[45469341169	9769.6	-0.12046283]]	253	1589985309306180000
[128595	[45470459669	9771.1	-0.8]]	254	1589985309306200000
[128595	[45470413613	0	1]]	255	1589985309306920000
[128595	[45469341170	9761.7	0.12046283]]	256	1589985309306960000
[128595	[45470461284	9768.1	-0.02848238]]	257	1589985309306960000
[128595	[45470459669	9770.1	-0.8]]	258	1589985309307010000
[128595	[45470202897	9763.9	0.0036]]	259	1589985309307050000
[128595	[45470007028	9762.7	0.37129728]]	260	1589985309307160000

Tick Data (Source: Bitfinex)

Bid orders - Sunday, September 1, 2019 12:00:18.607 AM - Bitfinex BTC/USD

date	type	price	amount
1567296018607	b	9 620,10	0,0584
1567296018607	b	9 620,00	0,5000
1567296018607	b	9 618,80	0,0293
1567296018607	b	9 618,70	1,0000
1567296018607	b	9 616,80	0,1989
1567296018607	b	9 616,70	2,0000
1567296018607	b	9 616,30	0,0208
1567296018607	b	9 614,00	0,7788
1567296018607	b	9 613,90	0,2000
1567296018607	b	9 613,80	0,0101
1567296018607	b	9 613,40	0,6808
1567296018607	b	9 613,20	0,2000
1567296018607	b	9 613,10	0,3000
1567296018607	b	9 613,00	0,6000
1567296018607	b	9 612,90	0,0004
1567296018607	b	9 612,60	0,3730
1567296018607	b	9 611,70	0,2909
1567296018607	b	9 610,60	0,1333
1567296018607	b	9 609,50	1,1566
1567296018607	b	9 609,10	0,0543
1567296018607	b	9 608,60	1,9047
1567296018607	b	9 608,10	0,2262
1567296018607	b	9 608,00	3,7302

Ask orders - Sunday, September 1, 2019 12:00:18.607 AM - Bitfinex BTC/USD

date	type	price	amount
1567296018607	a	10 260,00	0,0350
1567296018607	a	10 261,00	0,1349
1567296018607	a	10 262,00	0,0315
1567296018607	a	10 263,00	0,0400
1567296018607	a	10 264,00	0,0300
1567296018607	a	10 265,00	0,0339
1567296018607	a	10 266,00	0,0700
1567296018607	a	10 267,00	0,0732
1567296018607	a	10 268,00	0,0300
1567296018607	a	10 269,00	0,1300
1567296018607	a	10 270,00	0,7629
1567296018607	a	10 271,00	0,0300
1567296018607	a	10 272,00	0,0305
1567296018607	a	10 273,00	0,0500
1567296018607	a	10 274,00	0,0300
1567296018607	a	10 275,00	0,0360
1567296018607	a	10 276,00	0,1811
1567296018607	a	10 277,00	0,0490
1567296018607	a	10 278,00	0,0300
1567296018607	a	10 279,00	0,1554
1567296018607	a	10 280,00	0,0830
1567296018607	a	10 281,00	0,0305
1567296018607	a	10 282,00	0,0300

Market Depth Data (Source: Bitfinex)

Financial security identification codes

- TICKER SYMBOL: unique identifier to represent a particular security listed on an exchange or traded publicly. All listed securities have a unique ticker symbol. Example: IBM, MSFT,…

- ISIN: “International Securities Identification Number”. Based on ISO standards. It identifies uniquely the security irrespective of currency and exchange (unlike TICKER). Therefore it usually requires another identifier like MIC to identify the exchange. Used widely in bonds, equities, warrants, commercial paper and most listed derivatives. Example: LT0000610040

- CUSIP: “Committee on Uniform Securities Identification Procedures”. Identifies issuer and type instrument. Mostly used in US stock and bonds. It has nine characters, the first six for issuer, the next two for type of issue, and the last a control digit. Example: 008000AA7

- SEDOL: “Stock Exchange Daily Official List”. Identifier used for all securities trading on the London Stock Exchange or other exchanges in the U.K. Typically used for securities not traded in US. It doesn’t depends on the exchange, for what it needs the MIC. Example: B0WNLY7

- RIC: “Reuters Instrument Code”. Code used by Reuters to identify financial instruments and indices. It has two parts separated by “.”: first for the instrument and second (optional) for the exchange. Example: MSFT.OQ

Example: Bolsas y Mercados Españoles

Bolsas y Mercados Españoles — Spain (EMEA) 

Market Information	
Venue Identifier	MIC: XMAD
Time Zone	GMT+1
Instrument Code	Bloomberg: SM ISIN: ES Reuters: MC
Investor ID	Not Required
Trading Hours	Open: Monday - Friday: 09:00 - 17:30 hrs[1]
Opening Auction Details	08:30 - 09:00 hrs
Closing Auction Details	17:30 - 17:35 hrs
Currency	Euro (EUR)

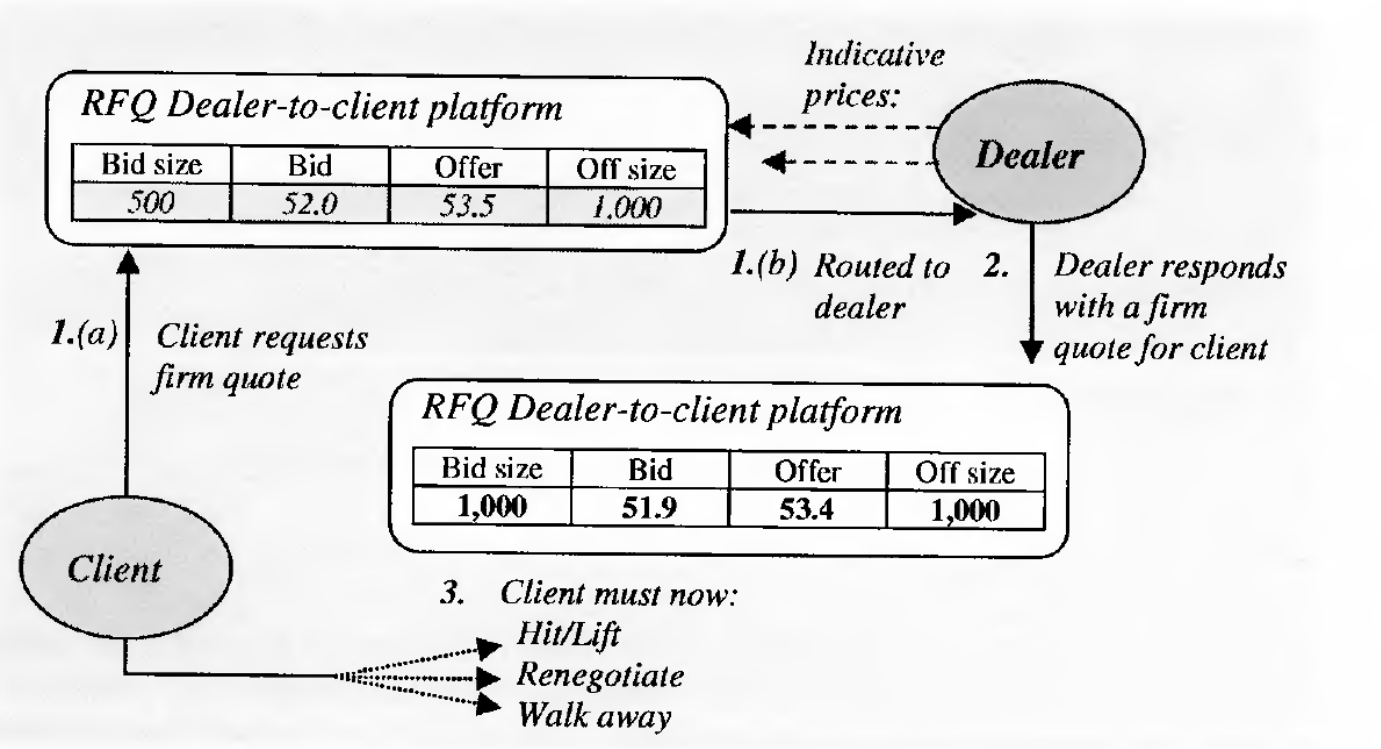
Basic Information	The cash equity market in Spain is a common platform open to market members of Bolsa de Madrid and the 3 other Exchanges in Spain (Barcelona, Bilbao and Valencia), and come under the common holding company: BME (Bolsas y Mercados Españoles). Trading on all segments within BME's Equity Unit is based on single electronic order book per security that matches parameters based on price/time priority. Besides Equities, market segments are: ETFs, Warrants & Certificates, Latibex (Eurodenominated MTF for Latin American Stocks) & MAB (MTF for Alternatives)
Order Types Supported	Market Order Limit Order Market-to-Limit Order Iceberg Order Minimum Volume Conditions are also supported Validity: Immediate or Cancel Fill or Kill
Stock Tick Size	Stock tick size is determined in accordance with MiFID II rules. See Annex to RTS 11 for the tick size table, here http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2017.087.01.0411.01.ENG&toc=OJ:L:2017:087:TOC
Trading Units	Minimum tradable quantity is 1 security in all segments
Block Trading	Available
Odd-Lot Trading	Not applicable

III. Quote-driven markets

- Can be based directly on quotes given over the phone, email or chat, or using an electronic platform where dealers give **indicative** quotes for certain sizes
- They are usually more suitable for more illiquid instruments, where there wouldn't be enough interests to build an order book
- There are two types of electronic platforms:
  - Single-dealer: only one-dealer quotes prices
  - Multi-dealer: several dealers quote prices and compete
- In order to get an executable quote, there are two main protocols
  - Request for Quote (RfQ)
  - Request for Stream (RfS)
- RfQ and RfS protocols are typical in Fixed Income, FX and some OTC derivatives

Request for Quote (RfQ)

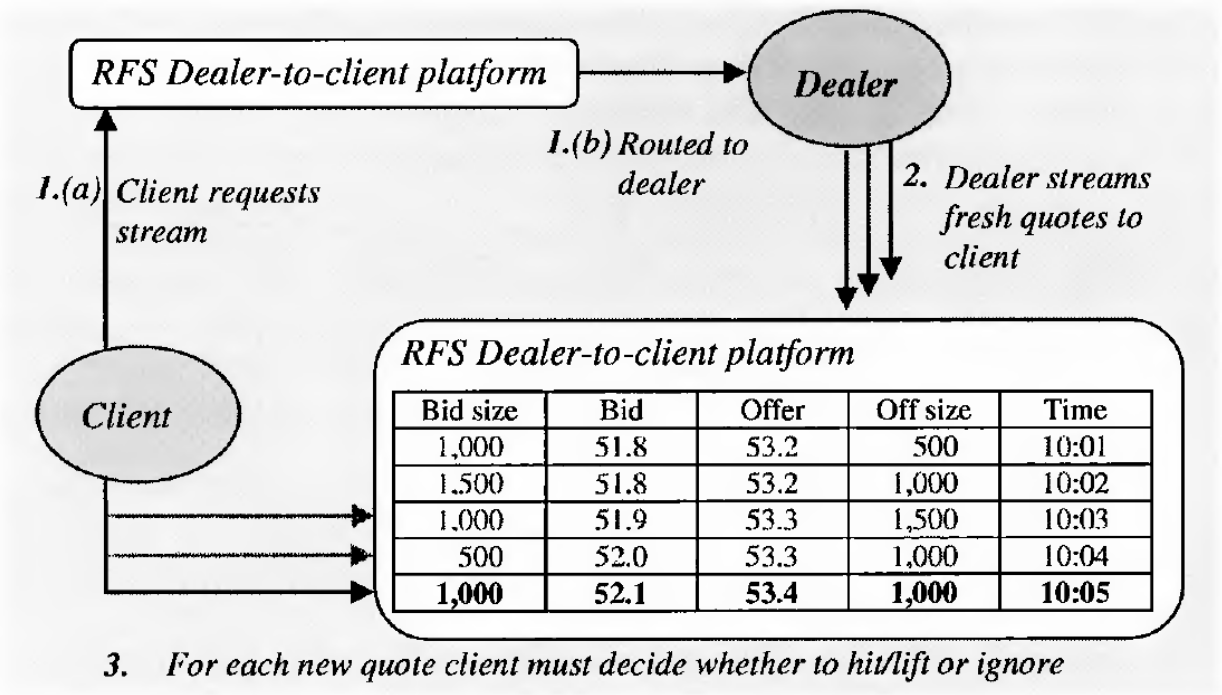
- The client sends a request for executable price to a single dealer or several ones
- The dealer(s) send the quotes after as much as a max time set in the platform
- The client can then hit/lift the quote, renegotiate or walk away
- The dealer who wins the trade, usually gets information of the second best quote ("cover price"). The second best knows it was second, but doesn't know the closing price. Dealers don't know with whom are they competing.



Source: Johnson, B. (2010)

Request for Stream (RfS)

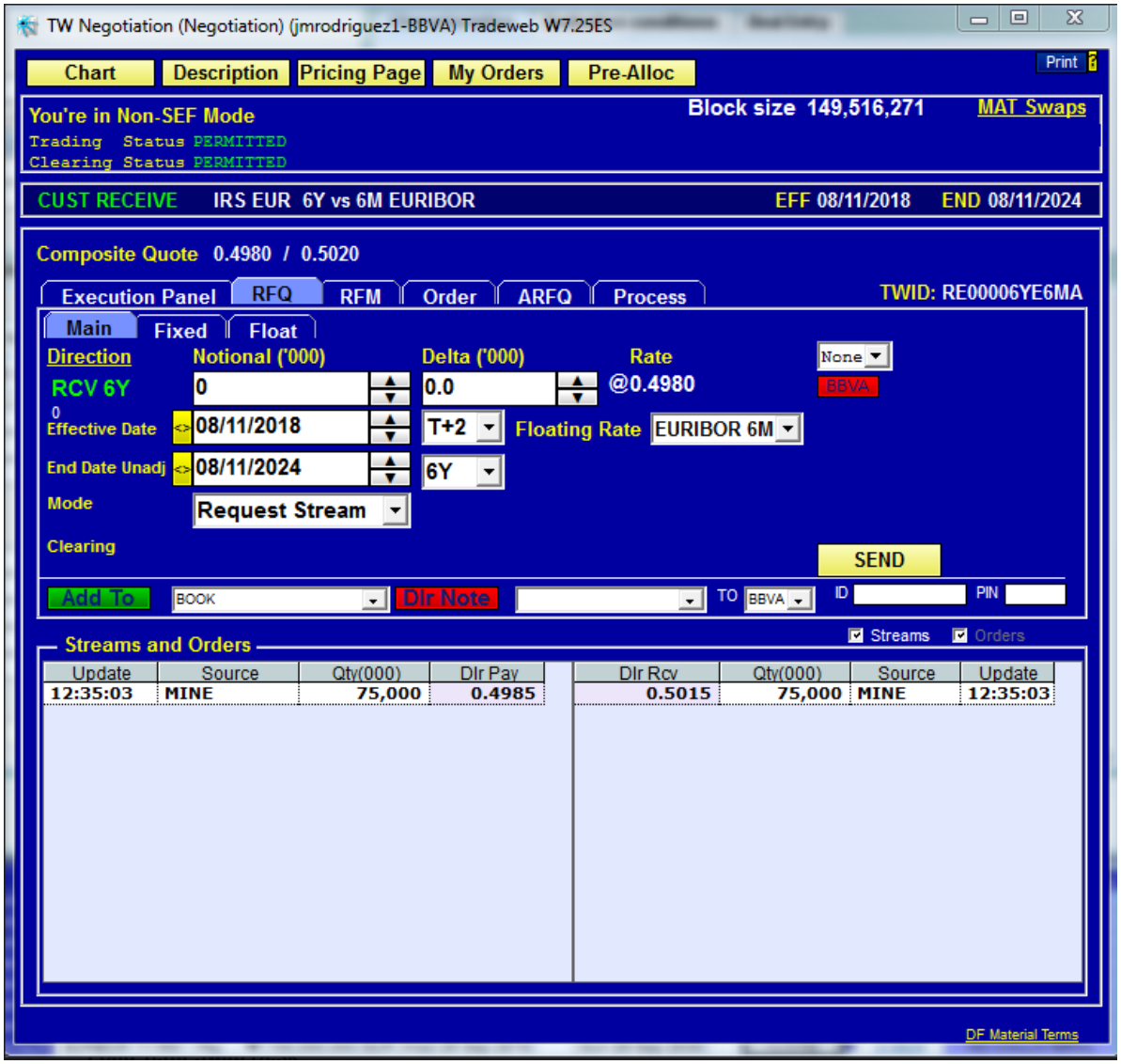
- Similar to the RfQ, but the client can subscribe to a stream of prices from the dealer(s), in order to wait for possible price improvements



Bid size	Bid	Offer	Off size	Time
1,000	51.8	53.2	500	10:01
1,500	51.8	53.2	1,000	10:02
1,000	51.9	53.3	1,500	10:03
500	52.0	53.3	1,000	10:04
1,000	**52.1**	**53.4**	**1,000**	**10:05**

Source: Johnson, B. (2010)

Example: Tradeweb RfQ

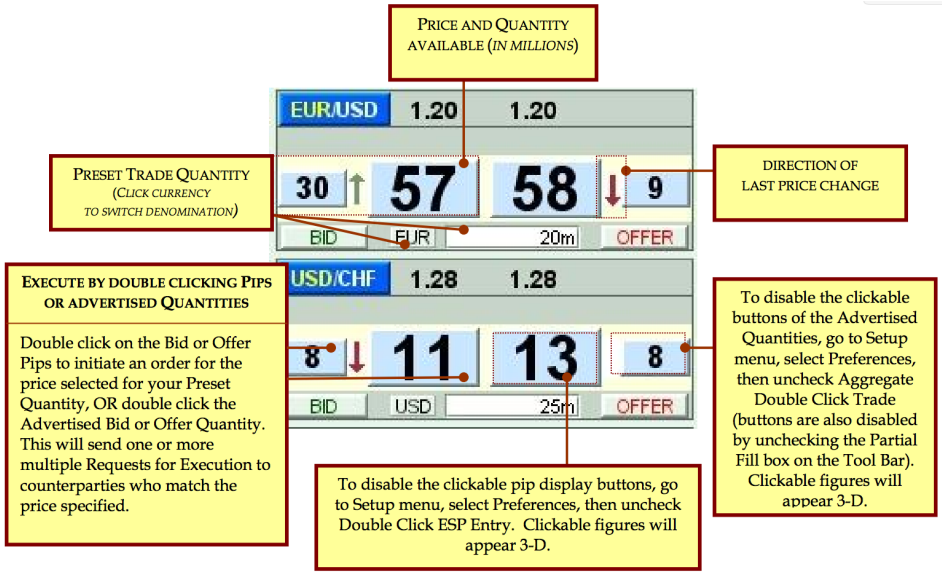


RfQ data

id	datetime	product_id	market	client	price	side	volume	cover_price	axe	status
BBG_FITDNA:E308B234B23C0052	2022-08-26 11:44:52	ES00000121S7	BBGX	BQ1+H+dlw6YqFz6yFYcgGg==	126.516	sell	0.158000000	0.000000	N	TradedAway
TWB_18/03/2021_EUGV_5044_OUTRIGHT	2021-03-18 12:15:54	IT0005425233	TW EuRates	sK0L83hjWz29LcLHzIWQfg==	100.086	buy	0.050000000	0.000000	N	CustRejectedQuote
BBG_FITDNA:E2CEBB0CE5FC0007	2022-07-13 12:31:08	IT0005217390	BBGX	Q2t7N1ZObEdF+qtk1jO2jg==	81.3117	buy	1.000000000	0.000000	N	Expired
BBG_FITDNA:E0DF1EC1E0340011	2021-07-02 14:12:17	ES00000123X3	BBG EuRates	tLBe2HBbi2Sf2e468tLdhg==	111.4907	sell	5.000000000	0.000000	N	Expired
BBG_FITDNA:E138A5B4E0340008	2021-09-08 11:59:48	XS2207976783	BBG EuCredit	lGAyC3jpeUVNSaLwFVjHeA==	106.85	sell	0.250000000	107.060000	N	CustAcceptedQuote
BBG_FITDNA:E2CD3CDCE0340020	2022-07-12 09:20:29	IT0005494239	BBGX	f1KV1Gc+Sv5c/5vnXO+V+Q==	94.131	sell	0.100000000	0.000000	N	TradedAway
TWB_15/06/2022_EUGV_611_OUTRIGHT	2022-06-15 10:09:05	ES0000012B70	TW EuRates	0lYrRaAEaTRgJrFkFz2skQ==	105.024	buy	0.150000000	104.855000	N	CustAcceptedQuote
BBG_FITDNA:DEF36DD4C0680058	2020-06-24 15:14:28	ES0000012F84	BBG EuRates	VvTDMCVK0EcSbwep0J6mAg==	100.85	sell	1.500000000	0.000000	N	CustRejectedQuote
TWB_17/02/2021_EUGV_3879_OUTRIGHT	2021-02-17 11:00:54	IT0005363111	TW EuRates	sK0L83hjWz29LcLHzIWQfg==	156.269	buy	0.200000000	0.000000	N	TradedAway
BBG_FITDNA:E18B9145E1B4003C	2021-11-10 09:30:46	ES0L02205067	BBG EuRates	EffRzBQM5lW4afnBfRJmBQ==	-1000000	sell	18.000000000	0.000000	N	Expired

IV. Hybrid markets :
Quote-driven with executable prices

- Dealer quotes become similar to limit orders
- When a platform aggregates several executable quotes, like EBS Direct for FX, it looks similar to an order book
- Example: FX Spot in Currenex



https://www.renesource.com/attachments/en/CURRENEX_Summary.pdf

Order-driven with official liquidity providers

- There are arrangements with liquidity providers (market makers) to help price formation, increase liquidity and reduce volatility
- Example: “specialists” or “Designated Market Makers” in NYSE

New York Stock Exchange (NYSE) — USA (AMERICAS)

Market Information	
Venue Identifier	MIC: XNYS
Time Zone	GMT-5
Instrument Code	Bloomberg UN Reuters .N
Investor ID	No ID Requirements
Trading Hours	Open: Monday to Friday Continuous Trading: 09:30 to 16:00 hrs Program Trades crossing session (Electronic Filing Program EFP): 16:00 - 18:30 hrs
Opening Auction Details	Submission of MOO/LOO: 07:30 to 09:30 (NYSE)
Closing Auction Details	Submission of MOC/LOC: Before 15:45 Closing Offset (CO) orders may be entered anytime before 4:00 pm.
Currency	US Dollar (USD)

Basic Information	The parent company of NYSE (MIC: XNYS) is NYSE Euronext. NYSE trades more than one- third of the world’s cash equity volume using all-electronic, block, anonymous, and hybrid trading models. Equity products are Common stock, preferred stock, ADRs, warrants, rights. The cornerstone of the NYSE market model is the Designated Market Maker (DMM). Formerly known as “Specialists”, DMMs have obligations for maintaining fair and orderly markets for their assigned securities. They operate both manually and electronically to facilitate price discovery during market openings, closings and during periods of substantial trading imbalances or instability with a “high touch” approach.
Order Types Supported	With Price-Time Priority[1] Immediate or Cancel (IOC) Market Order Limit Order Auction Orders (MOO/LOO ; MOC/ LOC & Closing Offset) Reserve Orders (limit orders with minimum displayed amount & non- displayed amount which replenishes the displayed amount after each execution) Stop Order Good Till Cancel Order Agency Cross Undisplayed Price
Stock Tick Size	**Price** / **Tick Size** 0 - 1 / 0.0001 1 and above / 0.0100

V. Transparency

- *Amount of market information that is available before and after a trade has occurred*
- **Pre-trade transparency**: quotes, prices and sizes of existing orders, …
- **Post-trade transparency**: trade execution details
- From less to more transparent markets: OTC, single-dealer, multi-dealer, lit order-book
- **Quote-driven markets**:
  - Pre-trade transparency: only show the dealer's quotes, more transparency when multiple dealers are available. Dealer and investor know who are dealing with.
  - Post-trade transparency: trades are not usually made public, dealers don't know which dealer won the trade in multi-dealer platforms.
- **Order-driven markets**:
  - Pre-trade transparency: Lit order books show a lot of pre-trade information, although normally orders are aggregated and anonymous, and many permit hidden orders. Opaque order books (dark pools) don't show this information, although sometimes the crossing price will be that of a lit venue.
  - Post-trade transparency: Lit order books give anonymised information of closed trades. Dark pools don't usually
- **MiFID** regulation has been tackling transparency in European markets:
  - MiFID I: mandated reporting for OTC Equities
  - MiFID II: extends it to other asset clases