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Foundations · market mechanics from the ground up

Liquidity: depth, price impact and when the resting orders disappear

Chapter 3 of 10

Liquidity is the amount that can be traded without moving the price. This chapter works through how a large order runs through the order book, explains the square-root rule of thumb for price impact, shows when market makers withdraw their orders, how opening and closing auctions form a price and what VWAP and TWAP mean as a yardstick of execution.

Field	Value
Series	Futures, options and who makes the price
Scope	Chapter 3 of 10
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In one sentence: Liquidity is not a fixed stock but an offer by market makers that they withdraw as soon as quoting prices becomes dangerous for them, and that is why it is smallest exactly when many need it.

What this chapter is: an explanation with worked examples. The order book is the made-up example from chapter 2. The square-root rule is an empirical value from the literature, not a law. The numbers on spreads, auctions and VWAP come from our own measurements and are marked as such. **Not a trading recommendation.**

Chapter 2 showed how an order is executed in the order book. This one is about what that costs and what those costs depend on.

1. What liquidity is: three measures

A market is called liquid when a lot can be traded without moving the price. This can be measured by three things:

- **Spread:** the distance between bid and ask. It is the price of a small trade.
- **Depth:** the quantity resting at the best price levels. It determines what a large trade costs.
- **Recovery:** how quickly the book is refilled after a large order.

Volume is not one of them. Volume counts how much was traded. Liquidity describes how much could be traded. On a day of panic volume is high and liquidity is poor.

2. A large order runs through the book

The order book from chapter 2, sell side:

Price	Resting contracts	Cumulative
7,000.25	120	120
7,000.50	180	300
7,000.75	260	560
7,001.00	310	870

The bid is at 7,000.00, so the midpoint between bid and ask is 7,000.125. A fund buys 500 contracts with a market order:

- 120 contracts at 7,000.25
- 180 contracts at 7,000.50
- 200 contracts at 7,000.75

$$\text{Average price} = \frac{120 \times 7{,}000.25 + 180 \times 7{,}000.50 + 200 \times 7{,}000.75}{500} = 7{,}000.54$$

Measured against the midpoint the fund has paid 0.415 points too much on average. One point is worth 50 USD:

$$0.415 \times 50 \text{ USD} \times 500 = 10{,}375 \text{ USD}$$

These costs are called **slippage**. They have two parts. Half the spread (0.125 points) would have been paid by a single contract as well. The rest (0.29 points) arises because the order was larger than the best price level.

An order that empties several price levels at once in this way is called a **sweep**. After the trade the ask is at 7,000.75, two levels higher than before. This shift is the **price impact** (market impact) of the order.

What happens next decides the true cost. If market makers refill the emptied levels immediately, the move was temporary. If they do not, because they suspect information behind the order, the price stays up. Then the market has learned from the order.

3. The square-root rule of thumb

Large investors therefore split their orders into many small pieces and spread them over hours. How strongly the price reacts in total then depends on the size of the whole order relative to daily turnover. There is a rule of thumb for this that has been measured similarly in many markets:

$$\text{Price impact} \approx Y \cdot \sigma_{\text{day}} \cdot \sqrt{\frac{Q}{V}}$$

Here σ_{day} is the usual daily fluctuation, Q the size of the order, V the daily turnover and Y a factor of the order of one.

This is an empirical value, not a derivation. The rule summarises measurements on orders of large investors. Depending on the study the exponent lies between about 0.4 and 0.7, and the factor Y differs from market to market.

Worked example. The index is at 7,000 and fluctuates by 1 % on a usual day, that is by 70 points. With $Y = 1$:

Order as a share of daily turnover	Price impact	In points
0.25 %	0.05 %	3.5
1 %	0.10 %	7.0
4 %	0.20 %	14.0
16 %	0.40 %	28.0

The message is in the root: an order four times as large moves the price only twice as far. The first contracts are the most expensive. Conversely this means: even a small order moves the price noticeably, and more than a glance at the visible depth would suggest.

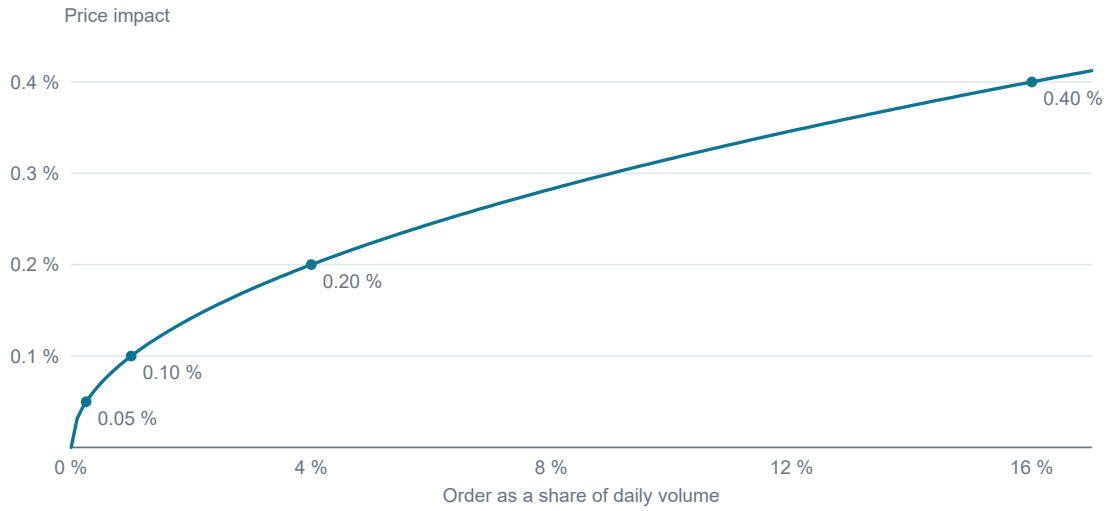


Fig. 1: Price impact by the square-root rule of thumb for a daily fluctuation of 1 % and Y = 1. The dots are the four rows of the table.

4. When liquidity disappears

The spread from chapter 2 was $s = 2\,\pi\,J$: share of the informed times the size of their advantage. From this it follows directly when a market maker widens his quotes or takes them out of the book altogether.

Before and after scheduled news. At 14:30 German time the US labour market data are released. In the second after that almost every order is "informed", because it already knows the number, and the jump J is large. Whoever quotes prices now loses. Market makers withdraw their orders beforehand.

This can be measured. On tick data for gold (April 2023 to December 2024, 452 trading days, morning and midday in New York) we looked for all moments in which the spread jumped to at least three times its usual value:

	Usual spread	Spread in the event	Back to normal after (median)	In 90 % of cases after
Outside scheduled releases	0.13 USD	0.45 USD	1 second	13 seconds
Around data releases	0.16 USD	0.65 USD	12 seconds	39 seconds

Outside scheduled releases such a jump occurred 2.5 times a day on average. A market order at that moment costs three to four times as much. No direction could be derived from it: whoever followed the move after such a jump or traded against it was at zero before costs (−0.07 basis points, t −0.26) and negative after costs (to the study).

At the edges of trading hours. At night and between sessions fewer market makers quote prices. The spread is wider, the depth smaller. The same order then moves the price further.

In fast moves. When a sweep empties several levels, the remaining market makers do not know whether there is information behind it. As a precaution they pull their orders. Depth falls exactly when further orders arrive. This is how medium-sized moves sometimes become large ones: the price falls through a thin book.

5. Auctions: one price for all

Twice a day trading on stock exchanges works differently: at the open and at the close. Instead of executing orders continuously, the exchange collects them for a few minutes and then computes a single price at which all matching orders are executed at once.

The rule: the price that applies is the one at which the largest quantity can be traded.

Worked example. For four possible prices it is known how much would be bought and sold in total:

Price	Willing to buy at this price or higher	Willing to sell at this price or lower	Tradable
6,999	900	200	200
7,000	700	500	500
7,001	400	800	400
7,002	150	1,000	150

Tradable is the smaller of the two quantities in each case. It is largest at 7,000, so 7,000 is the auction price. 500 units are traded, a surplus of 200 buy orders remains unexecuted. This surplus is called the **imbalance**. Some exchanges publish it shortly before the auction.

Why auctions matter:

- **The closing auction sets the closing price.** The value of every fund is computed from it. Index funds, which have to replicate an index exactly, therefore prefer to trade in the closing auction. On an ordinary day more liquidity is concentrated there than in any other minute.
- **The opening auction processes the night.** All orders that have accumulated since the previous evening meet in one price.
- **Settlement prices form in auctions.** The DAX future is settled on expiry day at the price of the midday auction at 13:00, the large US index futures at the opening prices of the shares (chapter 4).

We have measured that forced trading arrives there. On the days on which large indices change their composition, the price range in the auction window was 1.2 to 1.7 times as wide as on comparison days in all eight index markets examined (to the study). From the published imbalance before the closing auction, by contrast, nothing could be earned (to the study).

6. VWAP and TWAP: the yardstick of execution

A fund that buys 500 contracts spread over the day wants to know afterwards whether it was executed well. For that it needs a reference price. Two are common.

VWAP (volume weighted average price) is the average price of all trades of the day, weighted by their size:

$$\mathrm{VWAP} = \frac{\sum_i p_i \cdot v_i}{\sum_i v_i}$$

TWAP (time weighted average price) is the average of prices over time, without weighting by size.

Worked example. Three trades: 100 contracts at 7,000, 300 at 7,004 and 100 at 7,010.

$$\mathrm{VWAP} = \frac{100 \times 7{,}000 + 300 \times 7{,}004 + 100 \times 7{,}010}{500} = 7{,}004.4$$

The plain average of the three prices would be 7,004.67. The VWAP lies closer to 7,004 because the largest quantity was traded there.

The VWAP is a **yardstick**: whoever bought below the VWAP bought better than the average of the market. Many execution programmes are designed to come as close to it as possible. They therefore trade more when the market trades a lot, above all at the open and the close.

From this it is often concluded that the VWAP is a line from which the price bounces. We tested that, on the TWAP, because no true exchange volume is available for index CFDs. In the Nasdaq 100, S&P 500 and DAX (2015 to 2026, 17,858 touches of the TWAP of the running session) the line was broken in about half the cases on the first, second and third touch (52 %, 49 %, 50 %). A random market with the same fluctuation but no direction gave the same values (54 %, 49 %, 52 %, to the study). Rules with VWAP bands and VWAP bounces earned nothing after costs (to the study). The VWAP measures how well someone executed. As a price level it is of no use.

Common misconception

> **Common misconception:** "High volume means high liquidity." Volume is what was traded. Liquidity is what would be tradable at the current price. In a sell-off volume rises because many have to sell at once, while the spread widens and depth falls. The most expensive minutes of a year are those with record turnover.

What you should understand now

- Liquidity has three sides: spread, depth and the speed at which the book is refilled. Volume is none of them.
- An order larger than the best price level pays more than half the spread. The difference to the midpoint is called slippage, the lasting shift price impact.
- By the square-root rule of thumb an order four times as large moves the price about twice as far. That is an empirical value.
- Market makers withdraw their orders when the share of informed orders or the size of the jumps rises: around news, at the edges of trading hours and in fast moves.
- An auction forms a single price for all, where the largest quantity is tradable. VWAP and TWAP are reference prices for the quality of an execution.

Limits of this account

- **Rule of thumb.** The square-root rule holds on average over many orders of large investors. For a single order the impact can be a multiple or zero. For very small and very large orders it fits less well.
- **Own measurements.** The numbers on the spread come from gold ticks of a single broker, not from the order book of an exchange, and cover 21 months. We have not measured this for index futures. The TWAP evaluation uses index CFDs on minute data.
- **Auction rule.** Real exchanges have additional rules for the case that several prices give the same quantity, and safeguards against extreme auction prices.
- **Not covered:** liquidity off the exchange, that is, the trading of large blocks between banks and funds that never appears in the order book.

Continue with chapter 4: what exactly a future is, who uses it for what and why its price is tied to the index.

An explanation of market mechanics with worked examples. Not investment advice and not a trading recommendation. Trading futures and options involves the risk of loss up to and beyond the capital employed.