

Order Book Liquidity on Primary Markets post MiFID II

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Summary

This study assesses the impact of the new financial regulation (MiFID II) on the liquidity of stocks on a selection of major primary, European lit markets. An analysis of the limit order book (LOB) liquidity is presented, including a review of bid-ask spreads, near-touch volumes, and the LOB liquidity distributions across different tick levels. The shallow and deep costs of executing orders of different sizes by crossing the spread and sweeping the book are also evaluated. Detailed outcomes are presented for the STOXX 600, STOXX 50, FTSE 100, DAX 30, and CAC 40 as a function of the tick size changes that became effective as part of MiFID II and are compared between Q4 2017 and January 2018.

Across the above European indices, as well as a number of sector-specific indices, for stocks with *decreased* tick sizes spreads narrowed (e.g. STOXX 600: -27%), liquidity at touch decreased (STOXX 600: -57%), the order book volume distribution shifted towards the bid and ask tick levels, while simultaneously broadening. As a consequence, deep and shallow costs of crossing the spread and potentially traversing through multiple levels of the LOB declined marginally. The inverse trend – but often more pronounced regarding spread widening and trading costs – is observed for *increased* ticks. Stocks with unaltered tick schedules have seen no consistent effects on spreads or their LOB-volume distribution on the primary, lit venues, although often experiencing a small decline in near touch liquidity.

To obtain meaningful, high-level results, index-weighted aggregates of the above liquidity metrics are also computed. Despite the fact that overall outcomes generally point towards slightly higher costs of trading (e.g. an increase of over $+6\%$ for the STOXX 600), on an index basis, aggregate results are predominantly governed by the ratio and weights of the underlying constituents with reduced, unchanged, and enlarged ticks. Consequently, the impact on the trading costs of algorithmic strategies is mostly dictated by universe selection as well the passive- or aggressiveness of the adopted trading style.

1 Introduction

The advent of MiFID II on 3 January 2018, marked the most significant overhaul of European financial regulations in the past decade. With significant market micro-structure changes afoot, participants are eager to understand the early effects of the new regulation on equity trading. Delayed implementation of the dark volume caps, however, means that it is still early to understand the full impact of MiFID II on the liquidity landscape and to draw statistically significant conclusions. Nonetheless, some trends have already become apparent and outline the trajectory of some of the main liquidity parameters that drive trading behaviour and execution costs.

One of the major questions to address is, how the change of the tick schedules for many European stocks has affected volumes, volatilities, spreads, and the shape of the limit order book (LOB) itself on major European markets? Whilst the shift of liquidity away from primary markets towards dark pools and the role of periodic auctions and systematic internalisers (SIs) are not discussed in this paper, they certainly warrant a separate, thorough investigation themselves – in particular in view of the further anticipated effects of the outstanding regulatory changes.

Due to the vast information that has already become available by inspecting LOB data (even over a few weeks, only), this study mainly focuses on the trends observed for quoted spreads, shallow and deep liquidity, as well as the key parameters describing the order book volume and price distributions in general.

The analysis is carried out for a selection of major European indices, viz. the STOXX 600, STOXX 50, FTSE 100, DAX 30, CAC 40, as well as a number of sector indices, and concentrates mostly on the results obtained for the primary, lit markets. Index level changes are evaluated by comparing the outcomes for the last quarter of 2017 with the ones in January 2018. The potential impact of the observed changes on passive and aggressive trading algorithms and associated trading costs are also discussed. In contrast to market impact costs [1], trading cost in this study refer to the relative slippage of the execution price of a security versus its mid price achieved by crossing the spread and sweeping parts of the LOB to liquidate the full order.

The paper is structured as follows: Sec. 2 introduces the main liquidity metrics that define quantities related to spreads, volumes, and LOB volume distributions as well as the adopted methodology to aggregate and average those parameters. Sec. 3 presents the observed results for the above liquidity

metrics prior to and after MiFID II, grouped by tick size changes. Particular focus is set on near-touch liquidity, the shape of the order book, and the shallow and deep costs of instantaneously executing smaller and larger orders, respectively. Lastly, Sec. 4 summarises the observations and highlights the potential effect of the regulatory changes on different trading styles.

2 Limit Order Book Liquidity Metrics and Methodology

When interacting with primary lit markets, many trading algorithms are capable of making decisions based on the visible, quoted volume at multiple levels of the LOB. The top-level bid-ask spread, the quoted liquidity at touch (first level of the book), the overall volume imbalance, and the liquidity at levels deeper inside the book are often key parameters to determine an adequate order size and price level and whether to cross the spread or not.

To this purpose, it is useful to understand and characterise the shape of the LOB since different observed shapes will have an influence on decision making and the resulting trading costs. A snapshot of the order book for Vodafone on the LSE (VOD.L) on the first day after MiFID II is displayed in Fig. 1.

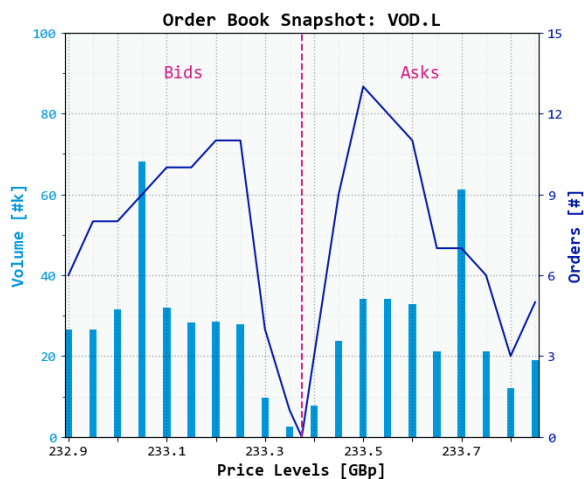


Figure 1: Snapshot of the limit order book state of Vodafone (VOD.L) at 09:00 am on 3 Jan, 2018. The available volume in thousands of shares (■, left) and the number of outstanding orders (—, right) are displayed for each of the first ten bid and ask price levels. The mid price is marked by a vertical line (---).

The snapshot shows the available volume (■) and the number of standing orders (—) at each of the

first ten bid and ask price levels for the stock. It already becomes apparent that most of the quoted liquidity is not available at the touch, but beyond price levels 3 and 4 of the book. The same applies to the number of orders at each level. At the same time, average order sizes in the middle of the book seem to be smaller which follows by considering the ratio of the available volume to the number of orders at a price level. It will be interesting to see if these are common phenomena across different stocks and how they depend on the tick size and spread.

2.1 Definition of Liquidity Metrics

To unambiguously describe the state of the order book and its dynamics, the following definitions are employed throughout this study.

Prices: for a single point of time, t_i , the quoted ask and bid prices at the different levels, j , of the order book ($j \in [1, 10]$) are denoted by α_{ij} and β_{ij} , respectively. For brevity, the top-level ($j = 1$) ask and bid prices are written as $a_i \equiv \alpha_{i1}$ and $b_i \equiv \beta_{i1}$. The tick size expressed in basis points or a given currency is denoted by γ .

Volumes: likewise, at time t_i , the ask and bid volumes (measured in shares) at the different price levels, j , are denoted by $v_{ij}^{(a)}$ and $v_{ij}^{(b)}$. The average bid-ask volume is defined as¹: $\bar{v}_{ij} = \frac{1}{2} [v_{ij}^{(a)} + v_{ij}^{(b)}]$.

The total visible volumes in the order book on the ask and bid sides up to highest visible tick level ($j_{\max} = 10$) are: $\nu_i^{(a,b)} = \sum_{j=1}^{j_{\max}} v_{ij}^{(a,b)}$ with their average being $\bar{\nu}_i = \frac{1}{2} [\nu_i^{(a)} + \nu_i^{(b)}]$.

Orders: the outstanding number of ask and bid orders at the different price levels, j , are given by $n_{ij}^{(a)}$ and $n_{ij}^{(b)}$.

State Persistency: a given order book state observed between times t_i and $t_{i'}$ is said to persist for a time period, $\Delta t_i = t_{i'} - t_i$, if during this time period none of the ask or bid prices, volumes, or number of orders changed.

2.2 Liquidity at Touch

For small order sizes relative to the average daily volume (ADV) and low trading urgencies, it is usually sufficient to interact with the liquidity that is

¹The superscripts (a) and (b) are usually omitted from an expression (e.g. n_{ij} or v_{ij}), when it applies to both the ask and bid parts of the analysis.

available immediately adjacent to either side of the mid. When comparing the evolution of spreads and liquidity over the course of time and across different stocks, there are many ways to aggregate intra-day and to average across multi-day periods. In this analysis, averages are computed using the following methodology.

2.2.1 Average Liquidity by Price Level

The average volume (in shares) for a price level, j , is computed as the time-weighted mean of all the quoted ask and bid volumes on a given day between the continuous trading hours:

$$v_j = \frac{\sum_i \bar{v}_{ij} \Delta t_i}{\sum_i \Delta t_i}, \quad (1)$$

where each order book state persisted for a time Δt_i and $i \in [1, N]$ for N different order book states in a given day.

If the total, daily traded volume (including the open and close auctions) is defined as V , then the average volume *ratio*, ϑ_j , for each price level is given by²:

$$\vartheta_j = v_j / V. \quad (2)$$

Multi-day averages are then computed by taking the *mean* of the daily volume ratios over the desired time horizon.

2.2.2 Average Top-Level Spreads

The top of book bid-ask spread at time, t_i , is given by:

$$s_i = \frac{a_i - b_i}{\frac{1}{2}(a_i + b_i)}. \quad (3)$$

In a similar vein to the volume, the average spread, s , on a given day is then computed as the time- and volume-weighted mean of all the quoted spreads, s_i .

$$s = \frac{\sum_i s_i \bar{v}_{i1} \Delta t_i}{\sum_i \bar{v}_{i1} \Delta t_i}, \quad (4)$$

where the applied volume weight, \bar{v}_{i1} , is that of the average top of book ($j = 1$) bid-ask liquidity, only. As with volumes, spreads are then averaged across multiple days by taking the mean of the daily values.

²The advantage of using a dimensionless volume ratio, like ϑ , instead of an absolute touch value (e.g. in EUR) is that it becomes more comparable historically and across a universe since it is not affected by exchange rate fluctuations, corporate actions which might asymmetrically affect price and volume, and special days, such as half days, etc.

2.3 Low-Level Volume Distribution

The state of the LOB is highly dynamic due to the continuous arrival and crossing of limit, market, and more complex orders as well as the cancellation of existing ones. Therefore, the price levels, outstanding orders, and volumes will undergo constant revision. Hence, it is desirable to find a relatively stable and representable distribution of the volume across the book for a given stock. This distribution may then be fitted and compared for time periods prior to and post MiFID II to see if any visible changes of the shallow and deep liquidity have occurred. A good model will allow a comparison across stocks of different industries and capitalisations to highlight main differences and how they might be related to trading behaviour and affect costs.

Despite its dynamic nature, the LOB has key features that re-occur for different stocks and that can be discerned by creating a normalised view (see Fig 2). This view is created by converting the absolute

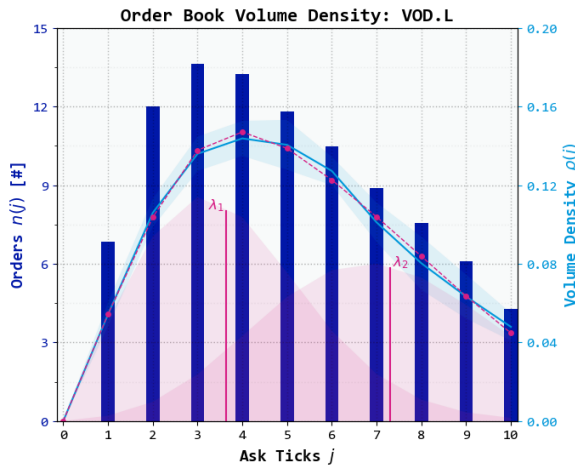


Figure 2: Normalised view of the ask side of the order book for Vodafone (VOD.L) aggregated over January 2018. The average number of orders, $n_j^{(a)}$ (■, left), and the volume density, $\rho_j^{(a)}$ (—, right), are shown as a function of the price level, j , (in ticks from the near touch). The one STD confidence bands for the averaged daily volume densities across the month are also illustrated (■). A fit for $\rho_j^{(a)}$ is given by superposing two Poisson distributions with parameters λ_1 and λ_2 (■) on top of each other (---).

ask price levels (e.g. in GBP) into tick space and aligning the corresponding quote volumes and outstanding number of orders with their relative positions from the touch³.

³For example, for a stock with a tick size of $\gamma = 1$ USD and quoted ask (price, volume)-pairs of (100 USD, 50k),

2.3.1 Volume Density

In addition to the tick alignment, at each point of time, t_i , the quoted bid and ask volumes are also normalised by the total volume visible across the first ten tick levels, i.e. $\nu_i^{(a)}$ and $\nu_i^{(b)}$, to create a volume density, $\rho_{ij} = v_{ij}/\nu_i$, for both the ask and bid sides of the LOB as a function of the tick level, j . The volume densities are aggregated across a given day by computing a time- and volume-weighted average for each of the observed order book states:

$$\rho(j) \equiv \rho_j = \frac{\sum_i \rho_{ij} \nu_i \Delta t_i}{\sum_i \nu_i \Delta t_i}. \quad (5)$$

The bid and ask distributions, $\rho_j^{(a)}$ and $\rho_j^{(b)}$, may then simply be averaged across days to get a representative view over a longer time horizon. By definition, the volume density sums to unity across all visible tick levels and may be interpreted as a probability density function. The ask volume density (—) depicted in the graph was created by averaging over January 2018 and the shaded area (■) highlights the one standard deviation (STD) confidence bands.

The cumulative volume density, $\varrho(j)$, follows from the density, $\rho(j)$, by summing over the different tick levels: $\varrho(j) = \sum_{j'=1}^j \rho(j')$.

2.3.2 Shallow and Deep Costs

Shifts in the bid-ask spread and order book liquidity distribution of a stock, can be assessed by evaluating and comparing the costs of crossing the spread and removing one or multiple levels of the order book. How many levels of the LOB are traversed in a single sweep is entirely determined by the size of the order and the volume distribution in the book. For meaningful comparisons it is useful to fix the order size relative to the daily volume or to choose a fixed notional. One may then evaluate the shallow costs of liquidating a relatively small order versus the deep costs of a larger-sized one.

In general, for the liquidation of an arbitrary overall quantity, Q , in this study the cost, C , defined as the relative price difference (e.g. in basis points) to be paid in excess of the mid price is given by:

$$C_{\text{bps}} = \frac{s_{\text{bps}}}{2} + \gamma_{\text{bps}} \sum_{j=1}^J (j-1) \frac{q_j}{Q}, \quad (6)$$

where the individual q_j correspond to the quantities executed at each price level, j , and $Q = \sum_j q_j$. The integer, J , corresponds to the nearest tick level for which sufficient cumulative volume is available to

(101 USD, 60k), (103 USD, 70k), in tick space this would correspond to (1, 50k), (2, 60k), and (4, 70k).

complete the order, namely $Q \leq \nu \sum_{j=1}^J \rho(j)$. If insufficient liquidity is visible in the top levels of the book (i.e. $J > j_{\max}$), the corresponding costs can only be coarsely approximated with the help of a fitted liquidity distribution.

2.3.3 Liquidity Distribution Fit

Generating a parametrised fit for the order book volume distribution has the benefit that many types of analysis become mathematically more tractable. For instance, the estimation of the residual, non-visible order book liquidity may be achieved by integrating over the tails of the distribution. Likewise, different types of market impact, based on the interaction with multiple levels of the LOB, may be evaluated analytically.

Superposition of Poisson Distributions

From a variety of conceivable one- or two-parameter distributions (e.g. log-normal, Poisson, and Γ), a combination of two independent Poisson distributions was found to yield the best fit results (highest R^2 -values). This is illustrated in Fig. 2, where a fit for the volume density (---) was computed by overlaying two Poisson distributions with different parameters, λ_1 and λ_2 , on top of each other (■) and employing least squares minimisation.

Poisson distributions are commonly used in the context of arrival times to estimate the probability of a certain number of events occurring in a fixed period of time [3]. In this study, a single Poisson distribution essentially estimates the probability of the arrival of an order at a given price level measured in units of ticks from the near-touch price.

A combination of such distributions would correspond to a process where multiple agents, each with their own anticipation of fair-value price levels, interact with each other. Hence, for two superposed Poisson distributions, the fit parameters, λ_1 and λ_2 , could be interpreted as the two major price levels (in tick space) towards which different types of market participants (e.g. high-frequency traders, market makers, private investors, etc.) deem short- and medium-term prices to gravitate, respectively.

Normalisation, Mean, and Variance

A single, normalised Poisson probability distribution has the functional form: $\Pr(X = j) = \frac{\lambda^j}{j!} e^{-\lambda}$, where X is a random variable with discrete realisations, $j \in \{0, 1, \dots, \infty\}$, and the distribution parameter, λ , represents both the mean, $\mathbb{E}[X]$, as well as the variance, $\mathbb{V}[X]$, of the process, namely: $\lambda = \mathbb{E}[X] = \mathbb{V}[X]$.

For the order book volume density, $\rho(j)$, the normalisation occurs for the tick levels between $j = 1$ and $j_{\max} = 10$, only. Therefore, the re-normalised superposition of two equally-weighted Poisson distributions between those tick levels may be expressed as:

$$\hat{\rho}(j) = \tilde{\rho} \left[\frac{\lambda_1^j}{j!} e^{-\lambda_1} + \frac{\lambda_2^j}{j!} e^{-\lambda_2} \right], \quad (7)$$

where the normalisation constant, $\tilde{\rho}$, is given by

$$\frac{1}{\tilde{\rho}} = \sum_{j=1}^{j_{\max}} \left[\frac{\lambda_1^j}{j!} e^{-\lambda_1} + \frac{\lambda_2^j}{j!} e^{-\lambda_2} \right]. \quad (8)$$

For later reference, a normalisation over all tick levels, $j \in [1, \infty]$, would result in a slightly different normalisation constant, $\tilde{\rho}_{\infty}$:

$$\begin{aligned} \frac{1}{\tilde{\rho}_{\infty}} &= \sum_{j=1}^{\infty} \left[\frac{\lambda_1^j}{j!} e^{-\lambda_1} + \frac{\lambda_2^j}{j!} e^{-\lambda_2} \right] \\ &= 2 - e^{-\lambda_1} - e^{-\lambda_2} \end{aligned} \quad (9)$$

The mean and variance of this distribution are identical again and for Eqn. (7) simply become:

$$\Lambda \equiv \mathbb{E}[X] = \mathbb{V}[X] = \tilde{\rho} (\lambda_1 + \lambda_2). \quad (10)$$

There will be separate fitted mean or variance values, $\Lambda^{(a)}$ and $\Lambda^{(b)}$, for the ask and bid sides of the order book, respectively, which can be combined into a single average: $\bar{\Lambda} \equiv \frac{1}{2} [\Lambda^{(a)} + \Lambda^{(b)}]$.

Residual Volume Ratio

The above Poisson superposition with the two different normalisation constants, $\tilde{\rho}$ and $\tilde{\rho}_{\infty}$, can be used to estimate the residual liquidity, $\nu_{\infty} - \nu$, for all tick levels $j > j_{\max} = 10$, in terms of the visible liquidity, ν , for tick levels $1 \leq j \leq j_{\max}$, by employing the relation: $\nu_{\infty} \tilde{\rho}_{\infty} = \nu \tilde{\rho}$. The residual liquidity ratio, r_{ν} , then becomes

$$r_{\nu} \equiv \frac{\nu_{\infty} - \nu}{\nu} = \left(\frac{\tilde{\rho}}{\tilde{\rho}_{\infty}} - 1 \right), \quad (11)$$

and may be estimated directly from the fit.

Quality of Fit

Lastly, the goodness of the fit can be measured using adjusted or unadjusted R^2 -values according to their standard definitions⁴ [4] and results are displayed in Sec. 3.

With all relevant quantities and liquidity metrics defined, the next section highlights how they have been affected by the regulatory changes.

⁴The unadjusted R^2 -value for a variable, y , with a fit \hat{y} is given by: $R^2 = 1 - \text{SSE}/\text{SST}$, where $\text{SSE} = \sum_i (y_i - \hat{y}_i)^2$ represents the sum of the squared errors or deviations and $\text{SST} = \sum_i (y_i - \bar{y})^2$ is the sum of the squared total for all the observed data points, (x_i, y_i) .

3 Lit Liquidity Results

In the following, the impact of MiFID II on the shallow and deep liquidity of some of the primary lit markets is analysed. This does not include how liquidity has potentially shifted from primary markets to dark pools or SIs, but more how spreads, liquidity at touch, and the general distribution of volume in the LOBs have been affected⁵.

For brevity, detailed results are presented mostly for the FTSE 100, DAX 30, and STOXX 50. However, many of the outcomes have also been observed for most other indices in EMEA. Unless otherwise indicated, changes in data are generally evaluated by comparing results in the last quarter (1 Oct to 31 Dec) of 2017 with the first month (2 to 31 Jan) of 2018.⁶

One aspect of MiFID II was the change of tick schedules for many stocks at the beginning of January. In the light of this, much of the analysis is broken out into the effects that increased or decreased tick sizes had on the observed metrics.

3.1 Effects on Spreads

A main driver of trading costs and indicator of stock liquidity is the daily bid-ask spread, s , computed as outlined in Eqn. (4). Averaging the daily values over the Q4 2017 (s') and January 2018 (s'') periods allows a direct comparison of the effect of MiFID II and the associated tick schedule change. The results are shown in Tab. 1.

For the 40 stocks in the FTSE 100 for which tick sizes were reduced, also spreads declined strongly by $\Delta s = (s'' - s')/s' \approx -33\%$. Similarly, for increased tick sizes, spreads rose significantly by $\Delta s \approx +12\%$. The same trend can be observed for the DAX 30, STOXX 50, and all of the more than 20 European indices in a variety of sectors, industries, and countries that are included in this study.

On the other hand, there is a mixed picture for stocks with unchanged tick sizes. Both the DAX 30 and STOXX 50 do not exhibit any material changes in spreads and the CAC 40 saw a slight rise by just over +2%. In contrast to that, spreads for the 50 FTSE 100 stocks that were not affected by the change in tick schedules, the spread still reduced by almost -15%.

It should also be noted that the spread changes are by far smaller than the associated changes in tick

⁵Initial findings suggest, however, that there has been no major change in the volume distribution between lit and dark venues, whereas periodic auctions have had a significant up-tick in trading activity [2].

⁶A quantity, q , computed for the 2017 period is denoted by a prime (e.g. q'), while one for 2018 is marked by a double prime (q'').

Index	Tick	No	s' [bps]	s'' [bps]	Δs [%]
FTSE	↓	40	8.03	5.37	-33.1
FTSE	↔	52	5.53	4.72	-14.7
FTSE	↑	5	7.36	8.24	12.0
FTSE	*	97	6.53	5.08	-22.2
DAX	↓	6	3.82	2.72	-28.7
DAX	↔	10	3.28	3.29	0.3
DAX	↑	13	3.50	4.72	35.6
DAX	*	29	3.52	3.83	8.9
STOXX	↓	8	3.86	2.75	-28.8
STOXX	↔	32	3.49	3.42	-1.9
STOXX	↑	10	3.57	4.62	29.5
STOXX	*	50	3.55	3.52	-0.7

Table 1: Average daily spreads for Q4 2017 (s') compared with January 2018 (s'') and their percentage changes, $\Delta s = (s'' - s')/s'$, for the FTSE 100, DAX 30, and STOXX 50. Spreads are grouped by the tick size changes effective since MiFID II (decreased: ↓, unchanged: ↔, increased: ↑). The index-weighted average is also shown (*).

size (when expressed relative to the stock price). For example, 40 of the FTSE 100 stocks had an average tick size reduction by over -55%, whereas the associated drop in spread was only around -33%. Nonetheless, the effect of MiFID II on spreads is clearly visible and in most cases driven by a change in the tick schedules.

Weighted aggregate values for the resulting spreads for the overall index (*) are also displayed in Tab. 1. For example for the FTSE 100 a drop by -22% resulted in January 2018 when compared with Q4 2017.

3.2 Effects on Shallow Liquidity

If other liquidity metrics were unchanged, an overall reduction in spreads would hint at improved market efficiency and reduced trading costs, while an increase in spreads would point in the reverse direction. Therefore, the next step is to inspect the liquidity at near touch, to see if any visible effects have emerged that might support the above trends. To this end, Tab. 2 shows the daily near-touch (tick level: $j = 1$) liquidity ratios, ϑ_1 , averaged over Q4 2017 (ϑ_1') and January 2018 (ϑ_1'') and their relative change ($\Delta\vartheta_1$). The definition of ϑ_j for arbitrary tick levels, j , is given in Eqns. (1) and (2).

The results in Tab. 2 indicate that a reduction in tick size led to a strong decrease in near-touch ($j = 1$, only) liquidity, while an increase in tick size yielded the opposite outcome. This effect is confounded by inspection of the data for other European indices, where near-touch liquidity ratios for reduced tick sizes have declined by -40% or more

Index	Tick	No	ϑ'_1 [%]	ϑ''_1 [%]	$\Delta\vartheta_1$ [%]
FTSE	↓	40	0.360	0.151	-58.0
FTSE	↔	52	0.180	0.143	-20.9
FTSE	↑	5	0.231	0.311	34.4
FTSE	*	97	0.257	0.153	-40.4
DAX	↓	6	0.108	0.042	-60.8
DAX	↔	10	0.097	0.082	-16.0
DAX	↑	13	0.084	0.122	45.6
DAX	*	29	0.094	0.091	-3.2
STOXX	↓	8	0.123	0.047	-61.7
STOXX	↔	32	0.134	0.113	-15.9
STOXX	↑	10	0.123	0.158	28.6
STOXX	*	50	0.127	0.107	-15.3

Table 2: Average bid-ask touch volumes (tick level: $j = 1$) as a fraction of the daily traded volume for Q4 2017 (ϑ'_1) compared with January 2018 (ϑ''_1) and the changes, $\Delta\vartheta_1 = (\vartheta''_1 - \vartheta'_1)/\vartheta'_1$, for the FTSE 100, DAX 30, and STOXX 50. Like above, volume ratios are grouped by tick size changes (decreased: ↓, unchanged: ↔, increased: ↑) and an index-weighted average is included (*).

and risen by +25% or more in the case of increased tick schedules. For example, the STOXX 600 saw a tremendous increase from on average $\vartheta'_1 = 0.37\%$ to $\vartheta''_1 = 0.76\%$ (corresponding to a relative change $\Delta\vartheta_1 = +105\%$) for its more than 175 stocks that experienced a tick size elevation.

While, in the light of the spread reductions or inflations in line with the tick sizes, these trends might seem intuitive, for many indices near-touch liquidity ratios still dropped even for identical tick schedules. For instance, the 52 stocks of the FTSE 100 for which ticks remained unaltered still experienced a reduction in the near-touch liquidity ratio by over -20%. Similar results occurred for the DAX 30 and STOXX 50 (see Tab. 2).

Completely in line with the trends for near-touch liquidity, the number of posted orders at the touch has increased for stocks with larger tick sizes and touch liquidity in 2018, whereas it reduced for ones with similar or smaller tick sizes. The respective change ratios are roughly in proportion, suggesting that there was no material effect on the absolute, average quote sizes (although this was not explicitly verified in this study)⁷.

Since first results indicate that the overall split of lit to dark liquidity in January has mostly been un-

⁷Generally, on a note of caution, for some sector-specific indices with a small number of constituents and potentially heavy index weights for individual names, touch liquidity numbers can sometimes be skewed by pending corporate actions (e.g. Buwog: BWOA.VI in the real estate sector). For longer aggregation periods and indices with roughly equally weighted constituents, this becomes less of a problem.

affected compared with previous months, the question is: where might the near-touch liquidity have gone to or come from for the different tick size scenarios outlined above? Has it simply migrated further up or down in the order book and if so, how large is the shift?

3.3 Effects on Deep Liquidity

3.3.1 Unchanged Tick Size

To illustrate how a change in tick sizes might affect the availability of shallow liquidity in the order book and the underlying low-level volume distribution, consider a highly liquid stock with an unchanged tick schedule first (Fig. 3).

The graph shows the (cumulative) volume density as a function of the bid ($j < 0$) and ask ($j > 0$) tick levels for Vodafone (VOD.L) for the pre- and post-MiFID II periods⁸. The double Poisson distribution, $\hat{\rho}(j)$, that fits the volume density, $\rho(j)$, is also plotted and visually indicates a very good match ($R^2 \approx 0.98$).

Inspecting the volume densities and the key metrics displayed in the figure inset, it becomes apparent that most quantities have not changed significantly for this stock: the absolute tick size, γ (in GBP), the average daily volume, spread, and overall visible book volume across all ten levels stayed roughly constant.

Minor changes have occurred for the volume ratios at the touch level, ϑ_1 , and deepest visible level, ϑ_{10} , both of which have diminished slightly. At the same time, the Poisson mean and variance post MiFID II ($\bar{\Lambda}''$) has decreased compared to its previous value ($\bar{\Lambda}'$). Consequently, the volume distribution has shifted marginally towards the touch while narrowing at the same time.

As a result, an almost negligible rise or drop can be seen for the shallow and deep costs, C_{50} and C_{100} , for liquidating positions of 0.50% and 1.00% of daily volume, respectively, by crossing the spread and sweeping the book.

3.3.2 Decreased Tick Size

In contrast, an example for a tick size reduction under MiFID II is displayed in Fig. 4. The graph shows the order book volume densities for the German stock of Bayer (BAYGn.DE). It becomes apparent that the tick size reduction from 0.05 EUR to 0.02 EUR had a strong effect on the volume distribution inside the book. The fairly narrow distribution with volume maxima around the third tick

⁸Negative values of j are only used for plotting purposes, while absolute values, $|j|$, are used when evaluating the mathematical expressions for any of the above metrics.

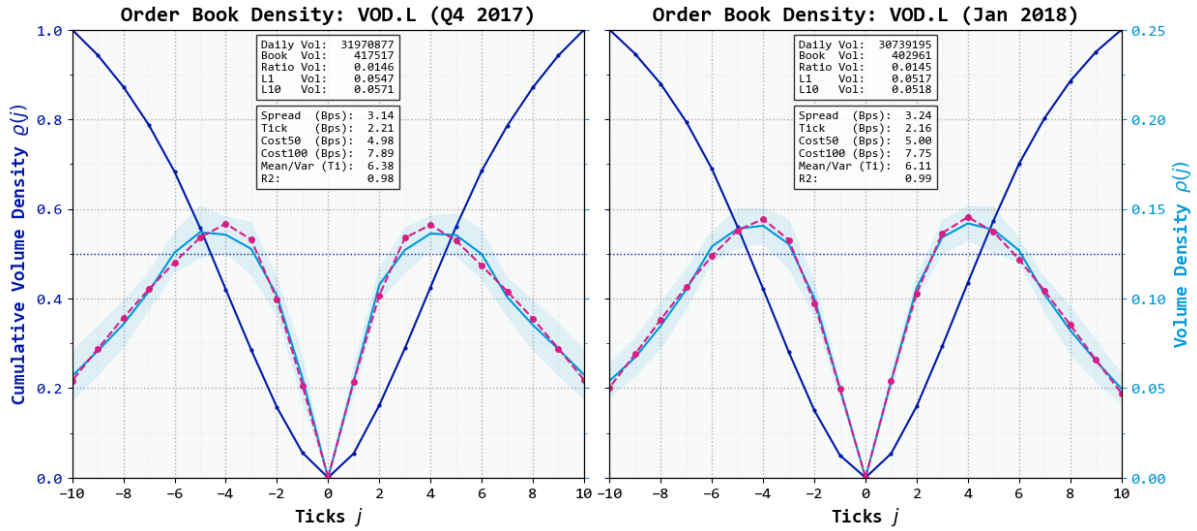


Figure 3: Cumulative density, $q(j)$ (—, left axis), and density, $\rho(j)$ (—, right axis), of the ask and bid volumes in the order book of Vodafone (VOD.L) plotted as a function of the normalised tick distance, j , from touch. Tick size is *unchanged*. A double Poisson fit, $\hat{\rho}(j)$, for the volume density is also shown (---) together with its one STD confidence bands for the aggregation periods pre- and post-MiFID II (■). The inset shows some of the main stock characteristics which are mostly unchanged for the two time periods.

level ($|j| = 3$) has shifted further down into the book to levels four and five. This becomes clear when looking at the near touch volume ratio that drastically reduced, while the deep liquidity (e.g. $|j| = 10$) has significantly increased. The mean and variance of the fitted distributions confirm this, as $\bar{\Lambda}' < \bar{\Lambda}''$, which implies a widening of the distribution and shift towards higher tick levels post-MiFID II.

Simultaneously, the overall liquidity visible within the first ten tick levels has more than halved, in line with the tick reduction. The spread on the other hand has not reduced as drastically. The overall effect on the trading costs is indicated by the rising shallow and deep costs which also stand in contrast to the reduced spread.

3.3.3 Increased Tick Size

An almost completely reverse picture can be observed for the increased tick size experienced by Tesco (TSCO.L) displayed in Fig. 5. The relatively wide volume distribution prior to the regulatory changes has considerably narrowed ($\bar{\Lambda}' > \bar{\Lambda}''$) due to the larger tick size. As expected by this change, both total visible liquidity and spread have increased, albeit not in proportion to the magnitude of the tick change.

At the same time, near touch liquidity is only slightly abated, while visible volume deep inside the book has strongly reduced. Shallow and deep trad-

ing costs, C_{50} and C_{100} , have both been affected by this shift of liquidity and both rose notably.

3.3.4 Order Book Volume Shifts on the Primary Lit Markets

The three cases above are all good illustrations of the general effects that a change in tick size can have on the liquidity distribution in the LOB. Against this backdrop, it is interesting to see how big the impact for stocks with varying tick schedules has been and if securities with unchanged tick sizes have seen any non-anticipated or re-occurring changes on an index or aggregate basis.

Tab. 3 shows the percentage change, $\Delta\bar{\Lambda}$, of the mean and variance of the bid-ask volume densities (averaged over the ask and bid sides). For decreasing tick sizes the fitted parameter, $\bar{\Lambda}$, has consistently increased, indicating a shift of the volume density deeper into the order book and a spreading out of liquidity across multiple levels. The strongest change can be seen for the FTSE 100 at +32.1%, while the DAX 30 and STOXX 50 have seen smaller increments. For increasing tick sizes, the reverse trend manifests itself with liquidity narrowing and migrating towards the touch of the LOB. For stocks with identical tick schedules, changes in $\bar{\Lambda}$ are fairly marginal and not uni-directional.

Very similar results can be observed when looking across other European indices: medium to large increases (decreases) in the mean of the distribu-

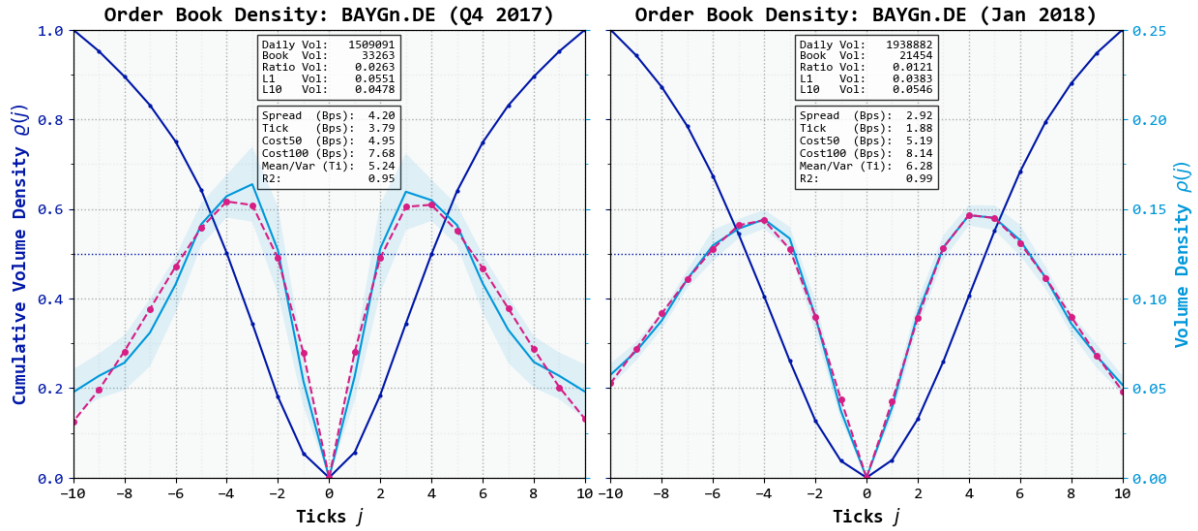


Figure 4: Cumulative density, $\varrho(j)$ (—, left axis), and density, $\rho(j)$ (—, right axis), of the ask and bid volumes in the order book of Bayer (BAYGn.DE) as a function of the normalised tick distance, j , from touch. Tick size has *decreased*. The Poisson fit for the volume density is also shown (---) alongside with the one STD confidence bands for the two aggregation periods (■). The inset shows some of the main stock characteristics which have changed notably since MiFID II.

tion, $\hat{\rho}(j)$, for tick sizes that have become smaller (larger).

Alongside with the shift of the liquidity depending on the change of the tick size, the fraction of residual liquidity is also affected. The ratio r_ν of volume that is currently invisible (as it resides beyond the first ten levels of the order book), has seen a major up-tick for shrinking tick sizes and strong reduction for risen tick sizes. On the other hand, no clear trends are discernible for unaltered tick schedules, indicating – in keeping with the stability of $\bar{\Lambda}$ – that the bulk of their volume has not shifted inside the order book or materially spread out.

3.4 Shallow and Deep Trading Costs

The question of how the shift of liquidity might have affected the cost of trading by crossing the spread and interacting with the shallow and deep liquidity of the order book is addressed in Tab. 4. The table details those costs [see Eqn. (6)] broken out by index and in dependence on whether tick sizes have changed or not. Looking at the shallow cost, $C_s = C_{50}$, of trading 0.5% of ADV first, those costs have declined across the board, however to the smallest extent for the STOXX 50. At the opposite end of the spectrum, stocks with a tick size increment saw an increase of the shallow costs by +23% for the STOXX 50 and by still significant amounts for the other indices. For constant tick sizes, C_s has increased for the DAX 30, STOXX 50, and CAC 40

while it has marginally decreased for the FTSE 100. Looking across other European or sector-specific indices, the trend of decreasing shallow costs for stocks with a diminished tick size is fairly common. Contrasting this with the average values of C_s for stocks with increased ticks, the opposite outcome can be observed with almost no exceptions.

Interestingly, the magnitude of the cost increase for rising tick sizes is significantly higher than the cost savings that go hand in hand with the tick size reduction. It also appears that the FTSE 100 is one of few indices for which costs have gone down slightly for stocks with no tick size change. Almost all other indices saw a small to moderate rise in shallow costs instead.

Turning to the deep costs, C_d , shown in the three rightmost columns of Tab. 4, a similar picture paints itself as for the shallow costs above: reduced tick sizes generally lead to reduced values of C_d (exception here is the STOXX 50 with a small up-tick), while unchanged and increased tick sizes tend to cause a rise in the deep costs. Again, the data for European indices confirms those tendencies.

Visually complementing the data in the above table, Fig. 6 shows the change in the shallow and deep costs pre- and post-MiFID II for multiple order sizes and for the constituents of the STOXX 600 which saw a decrease ($\sim 25\%$ of index) or increase ($\sim 30\%$ of index) in tick size.

For very small order sizes (0.05% of ADV), the costs pretty much equate to half the spread only, whereas

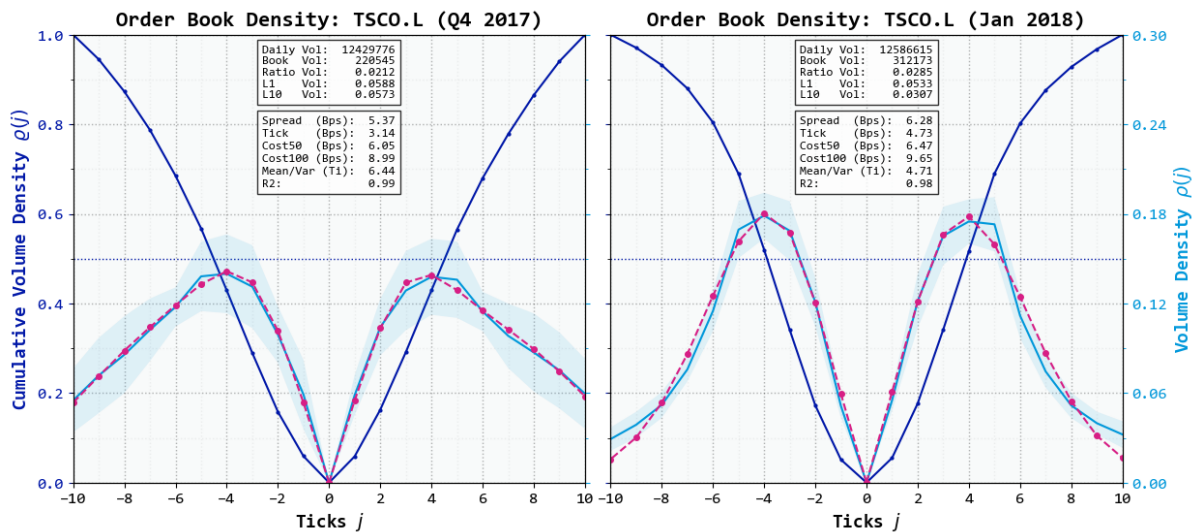


Figure 5: Order book (cumulative) volume densities, $\varrho(j)$ (—, left axis) and $\rho(j)$ (—, right axis), for Tesco (TSCO.L) as a function of the normalised ticks, j . Tick size has *increased*. Poisson fit for the volume density (—•) as well as the one STD confidence bands for the two aggregation periods (■) are shown. Many of the stock properties have changed considerably since MiFID II (see inset).

for larger sizes the distribution of volume in the order book comes into play. The changes in shallow costs (distance between --- and — lines) for tick increases compared with tick decreases are similar in magnitude but reversed. The changes are purely driven by the change in spreads associated with adapted tick schedules.

In contrast, for larger orders sizes, while the difference in deep costs between the pre- and post-MiFID II periods stay roughly the same for increased tick sizes, the gap narrows significantly for reduced tick sizes the larger the order becomes. Since the shallow and deep cost differences for stocks with unaltered tick schedules (not shown) are generally fairly small, the dysbalance in deep costs between constituents with raised and reduced ticks will dominate the aggregate results on an index basis: for the STOXX 600 the index weighted average of the deep costs, C_d , has risen by over +5%.

That index-level results are heavily dominated by the number of stocks that have seen a change in tick size and the direction of the change is demonstrated by the results for the CAC 40. None of the constituents saw a downward revision of their tick sizes, whereas 15 of the 40 members were affected by a tick size increase. Due to generally reduced liquidity at touch and marginally higher spreads for stocks with unaltered tick sizes, shallow and deep costs have both risen. Simultaneously, for the stocks with raised tick sizes, spreads have materially increased and outweigh the addition of

touch liquidity in this case. Therefore, shallow and deep costs for those stocks have also risen since MiFID II. Thus, on an index aggregate level, both shallow and deep costs, C_{50} and C_{100} , respectively, have experienced a major increase of between 12-14% for the CAC 40.

This concludes the analysis of how some of the meaningful liquidity indicators for primary lit markets (i.e. spreads, touch volume, liquidity distribution, and shallow vs. deep trading costs) have changed since MiFID II. A summary of the results and how the changes might affect algorithmic trading is given below.

4 Conclusions

4.1 Summary

The most suitable way to analyse changes in the liquidity patterns after the new regulations seems to be by grouping stocks into categories of reduced, unaltered, and increased *tick sizes*.

- **Spreads.** There is a noticeable decrease (increase) of bid-ask spreads for stocks with reduced (elevated) tick sizes post MiFID II. For example FTSE 100 spreads have fallen by over -33% for its 40 stocks with diminished tick sizes. Trends for securities with unaltered tick schedules are much less clear and vary by sector, country, etc.

Index	Tick	$\bar{\Lambda}'$	$\bar{\Lambda}''$	$\Delta\bar{\Lambda}[\%]$	$r'_\nu[\%]$	$r''_\nu[\%]$	$\Delta r_\nu[\%]$
FTSE	↓	5.28	6.97	32.1	4.6	13.1	184.2
FTSE	↔	7.23	7.11	-1.7	14.9	13.9	-6.7
FTSE	↑	8.74	6.22	-28.8	24.3	9.2	-62.0
FTSE	*	6.47	6.95	7.3	11.0	13.0	17.8
DAX	↓	7.33	7.88	7.5	16.4	18.4	12.6
DAX	↔	6.91	7.00	1.3	12.9	13.2	2.7
DAX	↑	7.77	6.07	-21.9	17.3	7.3	-58.1
DAX	*	7.29	6.74	-7.6	15.1	11.5	-23.8
STOXX	↓	7.11	7.75	8.9	15.3	18.2	19.3
STOXX	↔	6.44	6.66	3.4	11.3	12.4	9.8
STOXX	↑	6.62	5.12	-22.6	12.7	3.7	-71.2
STOXX	*	6.65	6.57	-1.2	12.6	11.8	-6.2

Table 3: Average characteristics of the mean and variance of the order book volume distribution for Q4 2017 ($\bar{\Lambda}'$) compared with January 2018 ($\bar{\Lambda}''$) and the associated relative change, $\Delta\bar{\Lambda}$, for the FTSE 100, DAX 30, and STOXX 50. Similar data for the residual volume ratio, r_ν , of the volume residing in tick levels beyond $j_{\max} = 10$ is also given. Results are grouped by tick size changes (decreased: ↓, unchanged: ↔, increased: ↑) and an index-weighted average is available (*).

- **Touch Liquidity.** Reduced volumes at the bid and ask levels are observed as well as smaller overall, visible order book liquidity for reduced tick sizes, and the opposite for enlarged ticks (e.g. +34% uptick in near touch volume ratios for FTSE 100). For stocks without a tick schedule revision, there is still a slight drain on near-touch and overall visible liquidity. The number of orders at touch has changed roughly in line with volume leading to mostly unchanged quote sizes.
- **Volume Distribution.** A shift of the volume peak to deeper price levels and a widening of the volume distribution across multiple levels for reduced tick sizes is perceivable (for instance, the mean of distribution moved by +32% away from the touch for the FTSE 100). The reverse happens for increased tick sizes, causing narrower peaks located closer to the bid-ask price levels. For unchanged ticks, the outcome depends on the analysis universe, but mostly no major change can be observed.
- **Shallow and Deep Costs.** The impact on trading costs by sweeping parts of the book are complex as they are governed by a dynamic superposition of the spread and volume effects. *Shallow costs* are mostly driven by the increase or decrease of the spreads as long as the submission size is suitably low for the order to interact with the volume at touch only. For

Index	Tick	C'_s	C''_s	$\Delta C_s[\%]$	C'_d	C''_d	$\Delta C_d[\%]$
FTSE	↓	5.7	5.3	-8.6	8.3	7.5	-9.6
FTSE	↔	5.3	5.2	-1.1	7.5	7.6	1.7
FTSE	↑	5.8	5.9	2.5	8.2	8.9	9.2
FTSE	*	5.4	5.2	-3.7	7.8	7.6	-2.7
DAX	↓	5.4	5.2	-3.8	8.2	7.1	-13.3
DAX	↔	4.3	4.8	13.1	6.3	7.7	21.6
DAX	↑	4.2	5.1	21.2	6.0	7.1	18.0
DAX	*	4.5	5.1	11.6	6.6	7.3	10.0
STOXX	↓	5.1	5.1	-1.1	8.0	8.6	7.8
STOXX	↔	4.3	4.7	8.9	6.3	6.9	9.6
STOXX	↑	3.9	4.8	23.0	5.9	7.0	18.3
STOXX	*	4.4	4.8	9.3	6.6	7.2	8.7
CAC	↔	4.6	5.0	9.7	6.3	6.9	9.3
CAC	↑	3.8	4.6	21.3	5.7	6.6	15.3
CAC	*	4.3	4.8	13.9	6.0	6.7	12.0

Table 4: The shallow and deep costs, $C_s = C_{50}$ and $C_d = C_{100}$, of crossing 0.5% and 1.0% of ADV. Costs are shown in basis points for Q4 2017 (C') and January 2018 (C'') for the FTSE 100, DAX 30, STOXX 50, and CAC 40. Tick groups are like in other tables (decreased: ↓, unchanged: ↔, increased: ↑, index-weighted average: *).

the *deep costs*, the underlying volume distribution plays a major role and the spread and volume effects can counteract each other depending on order size. Lower tick sizes commonly imply lower shallow and deep costs, whereas stocks with enlarged ticks experience the opposite outcome. For unchanged ticks, the reduced volume at touch often dominates the outcome, resulting in larger costs for most indices, the FTSE 100 being an exception with reasonably stable costs.

- **Index Level.** The average outcome is dictated by the index composition in terms of stocks that have or have not been affected by a tick schedule revision (e.g. on aggregate, the STOXX 600 roughly saw a +6% increase in shallow and deep costs dominated by the 30% of stocks with enlarged tick sizes). Generally, looking purely at index-level results is much less informative than grouping by tick-change categories.

4.2 Impact on Trading Strategies

For many trading algorithms, key decisions are based on observed spreads and liquidity on the primary market. Changes in strategy performance before and after MiFID II will be governed by the type of strategy, its benchmark, and whether it hinges on passive posting or aggressive taking.

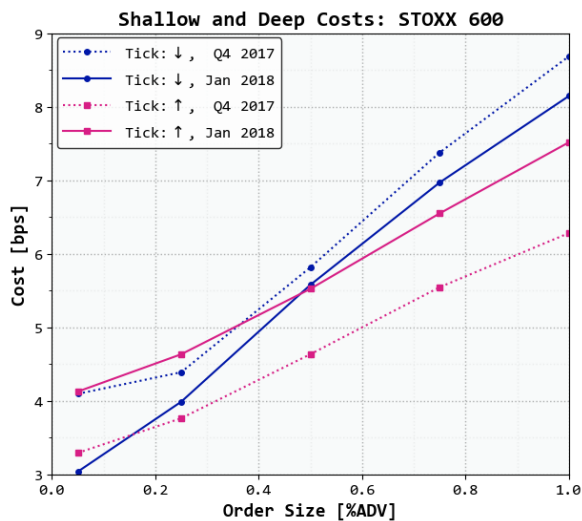


Figure 6: The shallow and deep costs of crossing the spread and sweeping the book for various order sizes as a percentage of daily volume for the STOXX 600. Aggregate results are evaluated for stocks with increased and decreased tick sizes and compared for the pre- and post-MiFID II periods.

4.2.1 Passive Posting

For passive strategies (e.g. low participation rate, full-day VWAP-algorithms), performance gains arise from saving the spread (or half the spread for mid-point trades in dark). Therefore, if the arrival frequency and size of marketable orders has not drastically changed since MiFID II, those types of strategies should benefit from wider spreads.

Nevertheless, this is only true if queue sizes are not heavily inflated such that fill rates plunge. If the likelihood of a near-touch cross reduces and the strategy works on a minimum participation rate basis, it will periodically have to cross the spread itself and incur an additional cost (plus potential taker fees). Therefore, the ratio between the spread increase and near touch liquidity improvement is a key metric.

For stocks with tick size increments, this ratio is mostly below one, suggesting that queue sizes have increased disproportionately to spreads. Thus, unless a strategy can afford to stay ultra passive for long periods of time and avoid crossing the spread, this suggests that additional costs might be incurred. The trade-off ultimately depends on the size of the spread and the frequency at which the strategy embarks on spread crossing.

The opposite is true for decreased spreads which

imply that algorithmic performance of passive strategies would decline unless reduced queue sizes mean that the spread can be saved sufficiently often. The ratio of the spread reduction to near-touch liquidity depletion is yet again below unity for stocks with decreased tick sizes. Nevertheless, the overall result, yet again, depends on the configuration of the strategy in terms of spread crossing preferences and the actual spread of the traded instrument.

4.2.2 Aggressive Taking

For aggressive strategies (e.g. a high-urgency IS-algorithm), the magnitude of the spread and the liquidity at tick levels away from the touch are both crucial. Therefore, a spread increase although seemingly detrimental might result in a much larger amount of liquidity being available towards the near the touch, allowing significant cost savings even for larger orders since fewer levels of the LOB have to be traversed. A strategy evaluation and a potential re-parametrisation can be based on the shallow and deep cost results presented above. Filling at mid point or far touch in dark is obviously also an important consideration which might be affected by the advent of SIS and the introduction of dark caps.

In conclusion, most of the analysis presented in this study focusses on spreads, near-touch volumes, the liquidity distribution across the order book, and the effect of these metrics on shallow and deep trading costs. The results, grouped by tick size changes, pre- and post-MiFID II, should be highly relevant to help assess how trading costs might be affected depending on strategy type and the markets that are traded on.

References

- [1] Almgren, R. and Chriss, N. (2001). *Optimal Execution of Portfolio Transactions*. Journal of Risk **3**.
- [2] Cboe Global Markets (2018). *European Equities Market Share*. <https://markets.cboe.com/europe/equities/>
- [3] Ross, S. (2010). *Introduction to Probability Models*, Elsevier.
- [4] Draper, N. R. (1998). *Applied Regression Analysis*, Wiley.

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