FINANSTILSYNET

M E M O

Danish Financial Supervisory Authority

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Assessment of the tick size rules in MiFID II

In January 2018, pan-European rules were introduced for the minimum size of price changes in trading venues (tick sizes) for shares and equity-like instruments.

The objective was, among other things, to halt trading venues' incentive to reduce tick sizes in order to gain turnover from each other. Moreover, tick sizes should be set at a level where they would contribute to well-functioning markets, the reason being that the level of tick sizes affects the behaviour of the investors, including market makers and firms using HFT (high-frequency trading), see box 1.

This memorandum assesses the tick size rules in respect of their impact on transaction costs on the Danish stock market for trades below DKK 500,000. The assessment has been done due to the review of MiFID II (Markets in Financial Instruments Directive II).

Based on the memorandum, it is the assessment of the Danish FSA that

- the harmonisation of tick sizes in the EU has prevented the level of tick sizes to be used as a competition parameter;
- the change to the new MiFiD II tick size regime has had no or only minor impact on the transaction costs in Danish shares in general, at least for trades below DKK 500,000 which is the focus of the analysis;
- there are indications of an increase in tick sizes giving higher transactions costs and lower tick sizes giving lower transactions costs. This applies especially to large cap shares and indicates that tick size may advantageously be lowered for the more liquid Danish shares.

Box 1. Tick size and possible consequences for the market

A tick size is the minimum movement of various order prices for purchase and sale, respectively. It is thus also the minimum price difference at any time between the order prices following each other. If, for instance, a share has a tick size of DKK 1, this means that the order prices may be e.g. DKK 100 or 101, but nothing in between. The tick size of a share therefore also decides the minimum price difference between purchase and sales orders and therefore the minimum bid-ask spread of the share.

On the one hand, a higher tick size indicates that it will be more expensive for investors to trade as the difference between bid and offer prices will increase. This may lower the demand for the share and thus reduce the liquidity and the price. Moreover, it will be more expensive to set a price a little better than the best bid (one tick better), which may restrain the supply of liquidity like it may hamper competition between investors, including market makers, in case there is more than one.

On the other hand, a low tick size reduces the incentive to act as market maker, as the lowest possible bid-ask spread is reduced and the market maker therefore will earn less profit from buying and then selling a share.

A low tick size also implies that it is less expensive for other investors to place orders at marginally better prices than the market maker who will consequently lose business. This could mean that the market maker will cease to provide liquidity in the form of bids and offers placed on the trading venue. This may impair the price formation, as the market maker collects and assesses available information to determine at which price he will trade a share.

The tick sizes must also be considered in relation to HFT. Analyses show that the HFT activity increases in case of a tick size reduction, cf. Breckenfelder (2019) and Grimstvedt (2017). One explanation may be that lower tick sizes provide more arbitrage opportunities, which is especially advantageous for HFT traders as they may very quickly utilise differences in prices, also across markets. Moreover, HFT traders can react very quickly to new information and consequently benefit from other players in the market being slower at updating their orders. Low tick sizes are therefore an advantage for HFT traders, as there is only a small price interval where a certain price is optimal. Therefore, the investors must update their orders frequently as the HFT traders will otherwise utilise the other investors' obsolete prices. This may have the negative derived effect on the market that the other investors become more cautious in their orders, thus reducing the liquidity of the best prices.

1. The rules for tick size

MiFID II states the minimum tick sizes allowed for all shares and a number of equity-like instruments at which trading venues in the EU may allow orders to

be placed. Trades on the trading venue may, however, be made at the mid-point between two ticks if they are made below a reference price or are sufficiently large. The tick size rules to a wide extent also apply to so-called systemic internalisers, i.e. investment firms trading in an organised way against its proprietary capital outside a trading venue. OTC trading is not comprised by the rules.

The level of the minimum tick sizes allowed are stated in a table in the Commission Delegated Regulation (EU) 2017/588. It is permitted to apply higher tick sizes. The table shows that the tick size of a share depends on the price and liquidity of the share. Higher price entails higher tick size, which ensures that tick size relative to the price is fairly stable. Higher liquidity (defined as the average daily trading volume in the share calculated by ESMA once a year) results in lower tick size in order not to unnecessarily limit the minimum bid-ask spread for liquid instruments.

The tick size table is calibrated by ESMA on a pan-European data set of more than 4,000 shares. It is here attempted to set tick sizes so that they support well-functioning markets. There are, however, significant differences between the stock markets of the various countries which increases the risk that the pan-European tick size rules are not optimal for some countries or markets.

2. Harmonisation of tick sizes

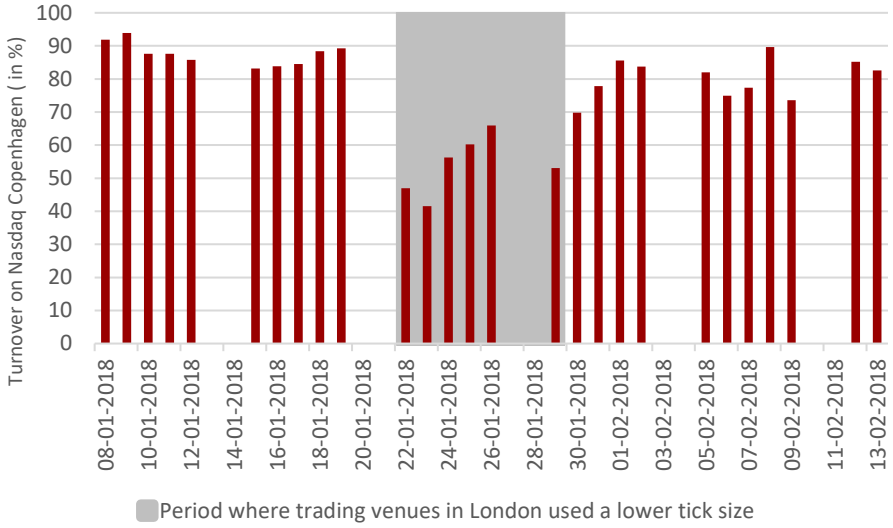
The experience after the break of the exchange monopoly in 2007 was that trading venues reduced their tick sizes several times in order to attract a larger share of the turnover. The reason for this is that the best prices are often found on the trading venue with the lowest tick size, just as it also gets less costly to offer a price which is a little better (one tick better). In order to avoid this situation, the trading venues entered into an industry agreement on minimum tick sizes. However, this agreement was broken several times.

On this background, the EU countries chose to lay down pan-European lower limits for tick sizes in MiFID II. The purpose was to prevent trading venues from competing for business by reducing tick sizes, as disproportionately low tick sizes may damage the market quality, cf. box 1.

The fact that differences in tick sizes across trading venues may have a great impact on where business takes place was clear in January 2018 in connection with trading in the AMBU share. A few days this share was erroneously traded at lower tick size on certain trading venues in London than on Nasdaq Copenhagen. The share of transactions in Copenhagen immediately fell from 84 to 54 per cent, cf. chart 1. Smart order routing increased the speed at which the volume was moved to London[1].

[1] Smart order routing is a mechanism which automatically re-directs orders to one or more other trading venues in order to get the best possible execution.

Chart 1. Impact of non-harmonised tick sizes on the distribution of transactions



Note: Share of turnover on Nasdaq Copenhagen compared to turnover on all trading venues. OTC and SI transactions are omitted from the calculation.

Source: Fidessa.

3. Impact on liquidity of changes in tick sizes

This section analyses the impact on the liquidity of shares due to the changes in tick sizes implemented in MiFID II. This is important for well-functioning markets as liquid shares are characterised by the investors being able to get in and out of their positions quickly and at low costs. In this way, the capital may flow more smoothly, and it increases the demand for shares which improves the financing opportunities of the enterprises.

The analyses only consider shares traded on Nasdaq Copenhagen, which is the only trading venue in Denmark. The analyses are based on the shares coming under a new tick size regime on 3 January 2018 as a consequence of MiFID II. This implied a shift from the tick size regime applied by Nasdaq Copenhagen before MiFID II. As a consequence of the new tick size rules, some shares got a lower tick size, other shares a higher, and some shares experienced no change.

The optimal tick size may differ from one share to another, depending, among other things, on the liquidity of the share. Consequently, the shares in the analyses are divided according to market cap, as most large cap shares are liquid as opposed to small and mid cap shares. This indicates that it is more important to have a market maker in the small and mid cap shares in order to ensure liquidity. This may indicate that tick sizes for these shares should be higher in order to increase the spread between bid and offer prices, which increases the income of the market maker.

Box 2. Regressions of liquidity measures

The analysis uses three models to investigate the extent to which changes in tick sizes may explain changes in a number of liquidity measures for the Danish stock market. The liquidity measures applied are the best bid-ask spread and round trip cost (RTC, see section 3.2 for an explanation) of DKK 25,000, 100,000, 250,000 and 500,000. The models are estimated on small and mid cap shares and large cap shares, respectively, in order to take into account that the impact of tick size may vary depending on the underlying liquidity of the share.

Model 1: Decrease, no change or increase in tick size

Model 1 investigates whether there is an effect of tick size changes on the specific liquidity measure at the transition to MiFID II when controlling for other variables. The model is:

$$\Delta S_i = \beta_0 + \beta_1 \Delta turnover_i + \beta_2 \Delta volatility_i + \beta_3 tick\ size\ change_i$$

Δ indicates the percentage change from the average in a certain period before MiFID II came into force until a certain period after. The periods considered are from December 2017 until January 2018 (i.e. the month immediately prior to and after MiFID II came into force) and from September-October 2017 until April-May 2018, respectively. The last tries to adjust for the fact that there was some uncertainty among market players in respect of the new rules in MiFID II around MiFID II came into force.

$tick\ size\ change_i$ is a categorical variable indicating either: i) reduced tick size, ii) unchanged tick size or iii) increased tick size. This means that the level of the tick size change is not included, only the sign. The estimates for *tick size change* has $tick\ size_{unchanged}$ as reference and should therefore be interpreted as the difference to the shares with unchanged tick size. If, for example, the estimate of $tick\ size_{increased}$ is not significantly different from 0, there will statistically be no effect of a tick size increase on the specific liquidity measure.

Model 2: Relative tick size in periods with different volatility

Model 2 investigates whether the level of tick size has an impact on the liquidity measures chosen in a month with low volatility (January 2018) compared to a month with high volatility (December 2018). The model is:

$$\Delta S_i = \beta_0 + \beta_1 \Delta turnover_i + \beta_2 \Delta volatility_i + \beta_3 relative\ tick\ size_i$$

In order to compare tick size level across shares, irrespective of the price of the share, $relative\ tick\ size_i$, is used, i.e. the relationship between the level of the tick size and the price of the share. The model applies average values for December 2018, but the results are not affected when instead using average values for January 2018.

Model 3: Tick size changes due to shift to new price band

Model 3 investigates to which degree tick size changes due to price changes can explain changes in the liquidity measures. More precisely, this model gives a new observation every time a share price crosses a price band in the MiFID II tick size table so that the share gets a new tick size. As this method gives a relatively high number of observations, this analysis is divided on all three segments. The observation consists of relative changes in the bid-ask spread, RTC and control variables calculated as the difference between the level five days before and five days after the tick size change. The five days have been chosen to balance between there being enough time for the changes in RTC only with very little probability being random, and sufficiently short time for other factors than tick size not to change. The model is:

$$\Delta S_{i,t} = \beta_0 + \beta_1 \Delta turnover_{i,t} + \beta_2 \Delta volatility_{i,t} + \beta_3 \, tick\ size\ change_{i,t}$$

$tick\ size\ change_{i}$ is a categorical variable as in model 1 and may therefore have the categories *reduced*, *unchanged* and *increased*. If, for example, the price of a share increases so that a price band in the tick size table is crossed from the bottom, the share will have a higher tick size, and the variable takes the value *increased*.

For comparison reasons, a set of observations without change in tick size is formed. These observations act as a reference set and describe the variation on the days when there is no tick size change. These observations are formed through random selection of a number of combinations of {ISIN, date} where there is no tick size change.

Designations common for all models:

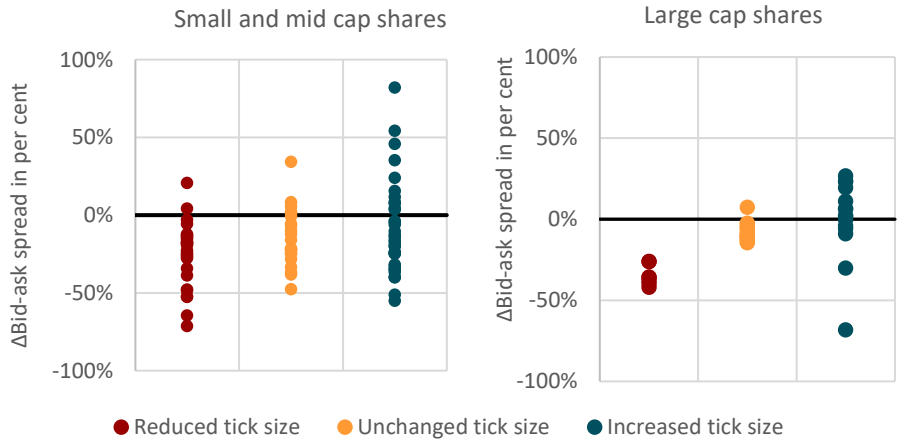
- *i* indicates a specific share.
- Δ indicates a percentage change.
- S_i is the dependent variable which, depending on the regression, is either the relative bid-ask spread or RTC for DKK 25,000, 100,000, 250,000 or 500,000. For example, ΔS_i may indicate the percentage change of the average from the first period to the average of the second period for RTC250,000 for share *i*.
- *Volatility* is the average of the daily volatility of the share calculated as the difference between the highest and the lowest market price observed for the share divided by the average price of the share on the same day.
- *Turnover* is the turnover in DKK on Nasdaq Copenhagen.

3.1 The relative bid-ask spread

There are several ways of measuring liquidity. One is the relative bid-ask spread, i.e. the spread between the best bid and offer prices available on the market compared to the share price. The relative bid-ask spread describes the spread costs (as a part of the share price) when buying one share and then selling it.

For liquid shares tick size is often curbed to the difference between the best bid and offer price on the market, i.e. when there is only one tick size between the two. If tick size changes, it will often mechanically affect the bid-ask spread. This is the case for a large number of the Danish large cap shares, as the relative bid-ask spread from December 2017 to January 2018 decreased for all shares with reduced tick size, whereas the shares with an increased tick size comprised a majority with higher spread, cf. chart 2, right.

Chart 2. Effect of changed tick size on the relative bid-ask spread



Note: The change in the bid-ask spread for each share is calculated as the percentage change from the average for December 2017 to the average for January 2018.
Source: Nasdaq Copenhagen.

Large cap shares are typically naturally liquid, and therefore they do not require a market maker to the same extent as small and mid cap shares. Chart 2 may therefore indicate that it will be advantageous to lower the tick size for these shares as they will then have a lower bid-ask spread. However, it should be pointed out that the volumes of the best bid and offer prices must be expected to decrease the lower the tick size. This is due to the fact that lower tick size means that there are more prices on which to place orders resulting in a decrease in the volume at each price level. The French financial regulatory agency has noted a similar trade-off between the bid-ask spread and the volume of available best prices for French shares, cf. AMF (2018).

For retail customers typically trading small volumes of shares, a reduction of the bid-ask spread must be expected to reduce their transaction costs. However, the measure does not indicate anything about the transaction costs for investors trading larger volumes than available at best price.

3.2 Round trip costs

For investors trading larger volumes of shares, it is more relevant to consider the liquidity measure round trip costs (RTC). This indicates the time weighted

average of the cost of first buying and then selling for a certain amount at the same time. As opposed to the bid-ask spread, the liquidity measure takes into consideration the market depth. Specifically, the measure considers that the volumes must be distributed on several prices at a lower tick size, i.e. the volumes at each price level will decrease, including the volumes on the best bid and ask.

The cost arises from crossing the bid-ask spread. If the order book is thin, a large order will be executed on price levels further and further away from the best price, and RTC will therefore be higher, cf. box 3 showing an example of how RTC is calculated.

In this memorandum, RTC for DKK 25,000, 100,000, 250,000 and 500,000 is applied. RTC for e.g. 250,000 is in the following designated RTC250,000.

Box 3. Calculation of round trip costs (RTC)

As an example, RTC250,000 is calculated at a certain time when the order book for a share looks as in the table below. RTC250,000 for the entire day is calculated as a time weighted average of such calculations.

Bid			Ask		
Price	Volume	Volume in DKK	Price	Volume	Volume in DKK
158.2	506	80,049	158.4	350	55,440
158.0	1,961	309,838	158.6	528	83,741
157.8	2,549	402,232	158.8	1,858	295,050
157.6	494	77,854	159.0	1,563	248,517
157.4	1,000	157,400	159.2	7,227	1,150,538

RTC250,000 is the difference between the volume weighted average bid price and the volume weighted average offer price, relative to the average of the two.

The volume weighted average bid price is obtained by bying the volume available on the best offer price. If there is not sufficient volume for a bid price of DKK 250,000, volume available on the next best offer price will also be purchased and so on, until a total purchase price of DKK 250,000 is reached.

In the order book in the above table, the volume weighted average offer price is (350·158.4+528·158.6+699·158.8)/(350+528+699) = 158.555 DKK, and the volume weighted average offer price is (506·158.2+1076·158)/(506+1076) = 158.064 DKK.

RTC250,000 at the time is then (158.555-158.064)/((158.555+158.064)/2) = 0.3105%.

3.2.1 Impact on RTC250,000 of tick size change in MiFID II

There is a tendency to a decrease in RTC250,000 for most shares from the month before MiFID II came into force until the month after, cf. chart 3. This is shown by the fact that most of the points lie below the 45 degree line in the chart for small and mid cap shares, and that the points lie either on or below the 45 degree line in the chart for large cap shares.

All large cap shares with a lower tick size have experienced a decrease in RTC250,000[2]. This should be seen in the context that especially for these shares the tick size sets the lower limit for best bid-ask spread and that these shares have a relatively large number of orders at a least DKK 250,000 on the best bid and offer. This reflects the fact that large cap shares are typically liquid and that the shares with lower tick sizes under the MiFID II regime are the most liquid shares.

For small and mid cap shares it is seen that shares with reduced tick size in general have had a larger decrease in RTC250,000 than shares with unchanged tick size, which again have had a somewhat bigger decrase than shares with increased tick size.

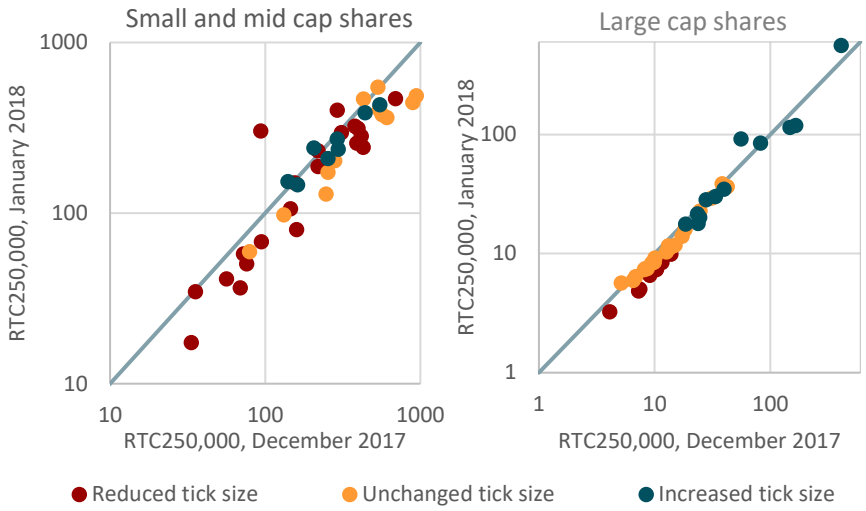
Qualitatively, the same picture is seen as described above and shown in chart 3 for best bid-ask spread and for RTC for DKK 25,000, 100,000, 250,000 and 500,000.

The observations from chart 3 are supported by a simple regression using share specific control variables, cf. box 2 (model 1). The regression coefficients show that the impact on transaction costs (measured at best bid-ask spread and RTC) of a tick size change in general is insignificant, however, with the exception of large cap shares, cf. table B1 in appendix 1.

Consequently there is no sign that a tick size increase improves the liquidity the way that the market maker theory prescribes, cf. box 1. However, the model does not take into consideration that market makers typically are obliged to provide two-way prices for a long, prearranged period. This may imply that the impact of the tick size changes are not observed until a market maker agreement expires or a new is signed as the market maker cannot react to the changed tick sizes until this point in time.

[2] Large cap shares with reduced tick size from December 2017 to January 2018 are Mærsk B, Carlsberg B, Chr. Hansen, Genmab, Nets, Novo Nordisk B and Pandora.

Chart 3. RTC250,000 for individual shares before and after MiFID II



Note: Please note that a logarithmic scale is used. Shares below the 45 degree line have seen a decrease in RTC250,000 from December 2017 (before MiFID II) to January 2018 (after MiFID II).

Source: Nasdaq Copenhagen.

A similar regression, but where the changes are calculated for the period September-October 2017 until April-May 2018, shows similar results, namely that RTC for large cap shares with a reduced tick size have decreased, cf. table B2 in appendix 1. The change of period is a robustness check in order to take into consideration that in the months up to and after the transition to MiFID II there was some uncertainty among the market participants in respect of the new rules.

This regression also shows that changes in the liquidity measures for the large cap shares are especially driven by other factors than tick size changes. An increase in share specific volatility therefore has negative impact, and increased turnover is seen to reduce RTC.

3.2.2 Impact of tick size in periods with high volatility

The transition to MiFID II took place at a time when the market volatility was very low. This may be important for model 1 finding that the changes in tick size for some shares have no or limited impact.

The tick sizes may be more important in periods with high volatility as the price movements are then quicker and more frequent. An investor, including a market maker, may therefore more easily risk that his order prices in the market will be stale which is utilised by other investors who trade at these prices. This is supported by research showing that HFT companies utilise their speed to quickly trade on orders lying in the market, whereby arbitrage strategies are more profitable in volatile periods. They also to a higher degree

apply aggressive trading strategies rather than market maker strategies in times of high volatility, cf. Goldstein (2018).

On this background, it is investigated whether best bid-ask spread and RTC are affected differently by change of tick size depending on whether the volatility is high or low. Higher volatility will, other things being equal, result in higher RTC. The investigations comprise two analyses:

- An analysis as to whether changes in RTC from January 2018 (low volatility) until December 2018 (high volatility) depend on the tick size level of the shares, cf. box 2 (model 2)[3].
- An analysis of tick size changes which exploits that a share gets a new tick size in case of change of a price band, cf. section 1. The analysis takes place on the period from 3 January 2018, when MiFID II came into force, until end November 2019, cf. box 2 (model 3). In this way, it is possible to consider the effect of tick size changes over a long period with varying volatility.

Neither analyses show any sign that it will give lower best bid-ask spread or RTC that a share has a high tick size, or that the tick size increases. Therefore, the analyses do not indicate that a higher tick size improves the liquidity, e.g. by protecting the market maker in periods with high volatility.

3.2.2.1 Impact of tick size level in case of increased volatility

There is a tendency to an increase in RTC250,000 for most shares from January 2018 to December 2018, cf. chart 4. The increase in RTC is a natural consequence of increased volatility.

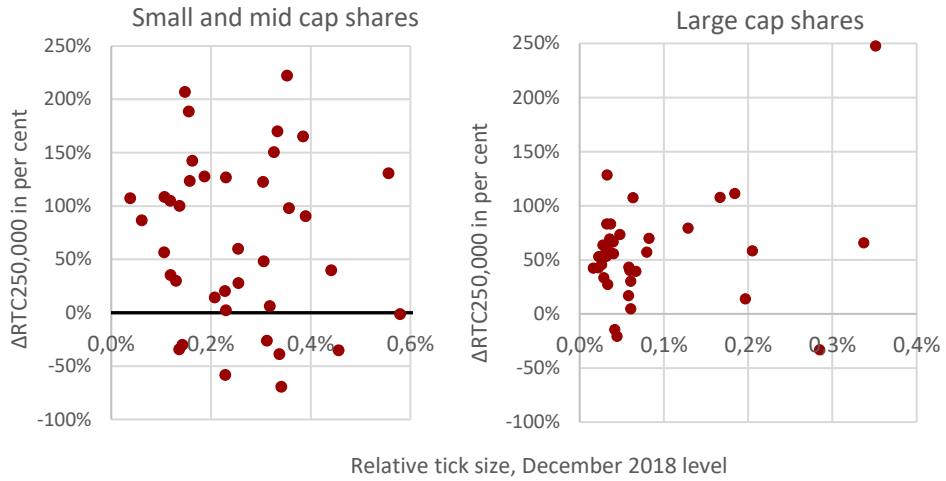
For none of the market cap segments there is any sign that changes in RTC250,000 from a low to a high volatility period depend on the relative tick size. Therefore, there is no indication that a higher relative tick size reduces the impact on RTC at high volatility.

A simple regression, with control variables for share specific conditions, cf. model 2 in box 2, supports that the tick size level seems to have no impact on the increase in RTC250,000 in a period with high volatility.

It appears from the regression that, in case of an increase in volatility, the coefficient for the relative tick size for all segments is insignificant in respect of affecting the increase in the bid-ask spread and RTC at all levels from DKK 25,000 to 500,000 (however, with the exception of the bid-ask spread for small and mid cap shares), cf. table B3 in appendix 1.

[3] The volatility measure V2X stating the implicit volatility based on option prices of selected European shares increased from 12.2 in January 2018 to 20.8 in December 2018.

Chart 4. Change in RTC250,000 and level of relative tick size



Note: "ΔRTC250,000 in per cent" indicates the percentage change in RTC250,000 from January 2018 until December 2018 compared to RTC in January 2018. "Relative tick size" is the tick size compared to the share price, here calculated as the average for December 2018. Changes in RTC250,000 over 250 per cent are omitted (two observations).

Source: Nasdaq Copenhagen.

3.2.2.2 Impact of current changes to the tick size level

An alternative method for investigating whether tick size changes are of importance for the bid-ask spread and RTC in case of varying volatility is to exploit that the tick size changes for a share at the moment when the share price crosses certain price band thresholds, cf. section 1. For instance, tick size changes from 0.1 to 0.2 if a share with an average of 700 transactions per day changes from a price of 199 to 200. The method provides observations over a long period (from January 2018 to November 2019) with varying volatility which is used in a regression, cf. model 3 in box 2.

The regression shows that for large cap shares, tick size reductions have reduced transaction costs, whereas tick size increases, on the other hand, have increased transaction costs, cf. table B4 in appendix 1. This applies especially to the bid-ask spread and small levels of RTC. For the small and mid cap shares, the tick size changes have in general had no or only limited impact on the bid-ask spread and RTC.

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Appendix 1

Table B1. Results for model 1: Decrease, no change or increase in tick size and impact on liquidity measures. Change from December 2017 to January 2018

Segment	Dependent variables	ΔBid-ask spread	ΔRTC25,000	ΔRTC100,000	ΔRTC250,000	ΔRTC500,000
Large Cap	Intercept	-0.07*[0.04]	-0.07*[0.04]	-0.08**[0.04]	-0.10***[0.03]	-0.09*[0.05]
	Tick size increased	0.09[0.06]	0.08[0.06]	0.04[0.06]	0.01[0.04]	0.09[0.07]
	Tick size reduced	-0.27***[0.07]	-0.26***[0.07]	-0.19***[0.07]	-0.17***[0.05]	-0.14[0.09]
	Tick size unchanged	.	.	.	.	.
	Δturnover	-0.06[0.06]	-0.07[0.06]	-0.10*[0.06]	-0.10**[0.04]	-0.22***[0.07]
	Δvolatility	0.04[0.12]	0.06[0.11]	0.15[0.11]	0.09[0.08]	0.42***[0.14]
	Observations	38	38	38	38	38
	R^2	0.42	0.41	0.30	0.37	0.39
Small and Mid Cap	Intercept	-0.12**[0.05]	-0.15***[0.06]	-0.21***[0.054]	-0.23***[0.05]	-0.32***[0.07]
	Tick size increased	0.06[0.07]	0.04[0.07]	0.11[0.07]	0.23***[0.07]	0.43***[0.09]
	Tick size reduced	-0.12[0.07]	-0.09[0.07]	-0.03[0.07]	-0.01[0.07]	0.09[0.08]
	Tick size unchanged	.	.	.	.	.
	Δturnover	-0.07**[0.03]	-0.07**[0.03]	-0.07*[0.04]	-0.06[0.04]	0.03[0.04]
	Δvolatility	0.04[0.05]	0.09*[0.05]	0.19**[0.09]	0.22**[0.09]	-0.03[0.11]
	Observations	82	79	71	55	31
	R^2	0.13	0.12	0.15	0.34	0.48

Note: The changes are calculated as the difference from the average in December 2017 to the average in January 2018. It includes only shares with at least five days with a coverage of at least 5 per cent for each month. When calculating the monthly average for a share, days with daily turnover exceeding the monthly average by a factor 10 have been omitted. The significance levels 10 per cent, 5 per cent and 1 per cent are stated with *, ** and ***, respectively.

Table B2: Results for model 1: Decrease, no change or increase in tick size and impact on liquidity measures. Change from September-October 2017 to April-May 2018

Segment	Dependent variables	ΔBid-ask spread	ΔRTC25,000	ΔRTC100,000	ΔRTC250,000	ΔRTC500,000
Large Cap	Intercept	0.22[0.20]	0.16[0.19]	0.11[0.15]	0.06[0.15]	0.01[0.25]
	Tick size increased	0.02[0.20]	0.05[0.19]	0.04[0.15]	0.09[0.15]	0.194[0.25]
	Tick size reduced	-0.57***[0.21]	-0.52**[0.19]	-0.39**[0.15]	-0.27*[0.16]	-0.16[0.25]
	Tick size unchanged	.	.	.	.	.
	Δturnover	-0.13**[0.05]	-0.14***[0.05]	-0.17***[0.04]	-0.24***[0.04]	-0.31***[0.06]
	Δvolatility	0.21*[0.12]	0.21*[0.11]	0.22**[0.09]	0.29***[0.09]	0.488***[0.15]
	Observations	37	37	37	37	37
	R^2	0.69	0.71	0.71	0.68	0.53
Small and Mid Cap	Intercept	0.21**[0.10]	0.21**[0.10]	0.15[0.14]	-0.08[0.14]	-0.08[0.16]
	Tick size increased	-0.00[0.12]	-0.05[0.11]	0.21[0.17]	0.35**[0.16]	0.23[0.20]
	Tick size reduced	-0.16[0.12]	-0.15[0.13]	0.05[0.18]	0.39**[0.16]	0.330[0.19]
	Tick size unchanged	.	.	.	.	.
	Δturnover	-0.02[0.02]	-0.03*[0.02]	-0.05*[0.03]	-0.05**[0.02]	-0.09***[0.03]
	Δvolatility	0.00[0.01]	-0.00[0.01]	0.00[0.09]	0.09[0.09]	0.66***[0.24]
	Observations	73	73	69	54	35
	R^2	0.07	0.08	0.07	0.18	0.36

Note: The changes are calculated as the difference from the average in the period September-October 2017 to the average in April-May 2018. It includes only shares with at least five days with a coverage of at least 5 per cent for each of the two periods. When calculating the monthly average for a share, days with daily turnover exceeding the monthly average by a factor 10 have been omitted. The significance levels 10 per cent, 5 per cent and 1 per cent are stated with *, ** and ***, respectively.

Tabel B3: Results for model 2: Relative tick size in periods with different volatility and impact on liquidity measures

Segment	Dependent variables	ΔBid-ask spread	ΔRTC25,000	ΔRTC100,000	ΔRTC250,000	ΔRTC500,000
Large cap	Intercept	0.17**[0.07]	0.152**[0.073]	0.205**[0.083]	0.303***[0.1]	0.345***[0.107]
	Relative tick size December 2018	-0.01[0.01]	-0.000[0.005]	0.002[0.006]	-0.011[0.007]	-0.002[0.009]
	Δturnover	-0.13[0.14]	-0.128[0.149]	-0.257[0.169]	-0.562**[0.205]	-0.624***[0.221]
	Δvolatility	0.11[0.09]	0.121[0.094]	0.179[0.106]	0.383***[0.129]	0.448***[0.144]
	Observations	32	32	32	32	31
	R^2	0.07	0.07	0.16	0.29	0.35
Small and mid cap	Intercept	0.55***[0.12]	0.47***[0.13]	0.25[0.26]	0.51**[0.21]	0.43[0.39]
	Relative tick size December 2018	-0.01***[0.00]	-0.00[0.00]	0.01[0.01]	-0.01[0.01]	0.02[0.02]
	Δturnover	-0.29***[0.10]	-0.31***[0.11]	-0.32[0.24]	-0.38**[0.17]	-0.51[0.30]
	Δvolatility	0.32***[0.06]	0.38***[0.06]	0.51***[0.12]	0.86***[0.10]	0.61***[0.16]
	Observations	59	59	52	35	23
	R^2	0.45	0.43	0.28	0.72	0.46

Note: The changes are calculated as the difference from the average in January 2018 to the average in December 2018. December 2018 was a volatile month compared to January 2018. It includes only shares with at least five days with a coverage of at least 5 per cent for each month. When calculating the monthly average for a share, days with daily turnover exceeding the monthly average by a factor 10 have been omitted. Shares with a change in turnover of more than a factor 3 have been omitted. The significance levels 10 per cent, 5 per cent and 1 per cent are stated with *, ** and ***, respectively.

Table B4: Results for model 3: Tick size changes due to change to new price band and impact on liquidity measures

Seg-ment	Dependent variables	ΔBid-ask spread	ΔRTC25.000	ΔRTC100.000	ΔRTC250.000	ΔRTC500.000
Large Cap	Intercept	0.00[0.0]	-0.01[0.02]	-0.01[0.01]	0.01[0.01]	0.01[0.02]
	Tick size reduced	-0.27***[0.02]	-0.23***[0.03]	-0.17***[0.02]	-0.14***[0.02]	-0.13***[0.03]
	Tick size un-changed	.	.	.	.	.
	Tick size increased	0.22***[0.03]	0.22***[0.03]	0.18***[0.03]	0.11***[0.02]	0.09***[0.03]
	Δturnover	-0.03*[0.02]	-0.05**[0.02]	-0.05**[0.02]	-0.05***[0.02]	-0.04*[0.02]
	Δvolatility	0.07***[0.02]	0.08***[0.02]	0.09***[0.02]	0.08***[0.02]	0.10***[0.02]
	Observations	197	197	197	197	194
	R^2	0.59	0.54	0.44	0.34	0.27
Mid Cap	Intercept	-0.04[0.04]	-0.03[0.04]	-0.03[0.04]	-0.03[0.04]	-0.04[0.04]
	Tick size reduced	-0.10*[0.05]	-0.07[0.05]	-0.05[0.06]	0.005[0.053]	0.01[0.06]
	Tick size un-changed	.	.	.	.	.
	Tick size increased	0.08[0.06]	0.03[0.06]	-0.04[0.06]	-0.10*[0.06]	-0.10[0.06]
	Δturnover	-0.08***[0.03]	-0.09***[0..3]	-0.10***[0.03]	-0.09***[0.03]	-0.10***[0.03]
	Δvolatility	0.15**[0.06]	0.18***[0.06]	0.18***[0.06]	0.15**[0.07]	0.21***[0.07]
	Observations	116	114	114	107	98
	R^2	0.13	0.2	0.12	0.13	0.14
Small Cap	Intercept	-0.08***[0.03]	-0.10***[0.04]	-0.08**[0.04]	-0.03[0.06]	-0.01[0.06]
	Tick size reduced	-0.01[0.05]	-0.02[0.07]	0.01[0.07]	0.01[0.11]	-0.02[0.12]
	Tick size un-changed	.	.	.	.	.
	Tick size increased	0.01[0.06]	0.00[0.08]	-0.11[0.08]	-0.27**[0.11]	-0.27**[0.11]
	Δturnover	-0.09***[0.02]	-0.05**[0.02]	-0.08***[0.02]	-0.01[0.03]	-0.08**[0.04]
	Δvolatility	0.38***[0.03]	0.17***[0.04]	0.22***[0.04]	0.09*[0.05]	0.25**[0.10]
	Observations	185	167	150	88	43
	R^2	0.50	0.10	0.17	0.11	0.32

Note: The changes are calculated as the difference between the level five days before and five days after the tick size change. For the level both before and after the tick size change, five consecutive days are found with unchanged tick size which is as close as possible to the tick size change. The five consecutive days should, however, at the most lie 15 trading days from the tick size change. Moreover, each day must have a coverage of minimum 12.5 per cent. The observations with unchanged tick size have been chosen through random extraction. The significance levels 10 per cent, 5 per cent and 1 per cent are stated with *, ** and ***, respectively.