Does Tick Size Matter?
- Evidence from the Stockholm Stock Exchange

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Abstract

On September 25th, 2006, OMX changed the minimum price increment, i.e. tick size, on a number of stocks traded at the Stockholm Stock Exchange (SSE). Previous research has shown that different market participants have different views on what constitutes an optimal tick size. We investigate what impact this particular tick size reduction has on parameters affecting market quality; i.e. the components of liquidity supply and intraday volatility. Consistent with previous studies, we find that for high volume stocks a reduced minimum tick size results in an improvement in market quality. For low volume stocks, the effects are not as strong as for the high volume stocks. The overall impact on the Stockholm Stock Exchange following this tick size reduction is positive, thus this tick size reduction should increase its competitiveness level from an international point of view.

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1. INTRODUCTION

Over the last couple of years, stock exchanges around the world have adapted to a smaller minimum price increment, i.e. tick size, in order to increase trading volume and reduce transaction costs. But what actually constitutes an optimal tick size, and why does it really matter? Or expressed in another way, why is the tick size not just set to the minimum possible value expressed with two decimals, i.e. 0,01 SEK?

In theory, the effect of the minimum tick-size upon liquidity supply is twofold. If the tick size is too large, the bid-ask spread, i.e. the difference between the best bid price and ask price in the order book, could become unnecessary large, imposing a redundant cost to investors. On the contrary, if the tick size is too small, it may as well decrease the depth in the order book since people will be reluctant to display their orders, as there will become easier to front-run orders in the order book. Hence, a too small tick size may reduce the profitability of supplying liquidity.

Thus, research concerning an optimal tick size level in the equity market has been a frequently discussed topic in academic literature over the last decade. The main focus of the discussion has been related to the different views regarding what truly constitutes a reasonable tick size among market participants. Despite the large volume of research in this field, there is still no uniform settlement.

1.1 PURPOSE

At September 25th, 2006, OMX changed the tick size in a number of stocks traded at the Stockholm Stock Exchange (SSE). The origin of this was due to the criticism about the forced bid-ask spread, i.e. the difference between the bid and the ask price, being too large in several instruments. The purpose of this thesis is thus to study how this tick size reduction has affected the SSE and the parameters underlying market quality, i.e. liquidity supply and volatility.

1.2 CONTRIBUTION

Our study contributes to the existing literature in several ways. To begin with, this is the first known public study after Niemeyer and Sandås (1994) that have investigated the impact of tick size upon the Stockholm Stock Exchange. In addition to Niemeyer and Sandås, we provide an empirical study of an actual tick size change.

Second, most of the previous studies have been on North American exchanges, which use a market design based on market makers (dealers and specialists) with uniform pricing systems. This study, in contrast, focuses on an electronic limit order book market, where stocks with lower trade prices are priced in smaller fractions than stocks with higher trade prices. Thus, this study adds understanding to how tick size affects limit order book market.

Third, this is an empirical study of a rare event comprising tremendous data. This has required a great deal of work in the development of parameter estimates through application programming. As it is the most extensive public study so far, the construction of this device will be of great assistance for further studies (see section 7.1 *Tools and Devices*).

Finally, the contribution of our work will mainly affect the decision makers who have the power to change as well as shape the trading rules of the market microstructure. The academic framework jointly with the empirical results of this thesis will bring clarity and understanding upon the impact of a tick size change, and thus influence how regulators should modify the level of minimum tick sizes in order to enhance market quality, and accordingly develop the functionality of the capital market.

1.3 OUTLINE OF THESIS

We begin with a short description of the current market design supervised by OMX and discuss the recent tick size change, in section 2. In section 3 we explain the different components of market quality, and in section 4 we summarize the previous research and findings. In section 5 we form our hypothesis, and in section 6 and 7 respectively, we provide our sample selection, parameter formations, data filtering and working methodology. In section 8 we present the empirical results and a discussion of those. Finally, in section 9 we provide a robustness check of our results and we conclude our findings in section 10.

2. MARKET DESIGN

OMX operates the largest security exchange in Northern Europe and provides technology solutions for financial and energy markets worldwide. Through their exchanges in Copenhagen, Stockholm, Helsinki, Riga, Tallinn and Vilnius, OMX offers access to about 80 percent of the Nordic and Baltic security markets (OMX annual report, 2006).

The Stockholm Stock Exchange (SSE), and its trading system SAXESS, comprises a total of 276 companies as of 31/12 2006, which aggregates to 4 275 billion SEK in market cap. Almost 70 000 stock trades are closed each day with a total turnover of about 22 billion SEK on average every day, which is approximately 5 521 billion SEK on a yearly basis as of the end of 2006 (OMX *Yearly Statistics for 2006*).

SAXESS trades continuously from 09:00 to 17:30[1], except at the opening and closing calls at the start and the end of the market opening hours. Matching orders are automatically executed according to price-then-time priority. Orders may be adjusted or withdrawn and both market and limit orders may be entered (*OMX website*).

2.1 TICK SIZE STRUCTURE

In general, the OMX exchanges have different tick size regulations for different markets in order to enhance market efficiency. As various approaches of the tick size tables have different benefits, OMX have chosen to apply dissimilar regulations among the Nordic countries dependent upon currency, trading volumes and country specific rules (*New tick size for OMX exchanges*, 2006).

The structure applied for the Stockholm Stock Exchange is to base the tick size on the share price by creating bands to equalize the tick size costs (see Table 1 for an example). The benefit of this approach is mainly that the tick size could be lowered for high turnover stocks, where the tick size is a binding constraint due to lower bid-ask spread. The recent change of minimum tick size attributes to this particular structure.

[1] The exact start and end time varies between stocks with a few minutes disparity

2.2 TICK SIZE CHANGE

In an effort to improve liquidity, OMX changed the tick size in a number of stocks. Table 1 illustrates the old as well as the new tick size structure which is applied on all stocks at Stockholm Stock Exchange. Two changes have been made as of September 25th 2006.

1. The most pronounced one is that the previous fourth price interval (50-99,75 SEK) has been widened to 50-149,75 SEK, which means that the tick size have been reduced from 0,50 SEK to 0,25 SEK for stocks with trade prices between 100-149,75 SEK.

2. Furthermore, for the *most liquid stocks* at SAXESS, which includes Ericsson (A and B shares), Nordea, and Nokia SDB, a separate tick size structure has been introduced. As have been pointed out in Table 1, this group of most liquid stocks will have a separate tick size table with smaller minimum tick sizes than the rest of the shares.

Table 1 Tick size table before and after the change

New Tick Size Table				Previous Tick Size Table		
Row	**Interval (SEK)**	**All Other Stocks**	**Most Liquid Stocks**	**Row**	**Interval (SEK)**	**All Stocks**
1	0.00 - 4.99	0.01	***0.01***	**1**	0.00 - 4.99	0.01
2	5.00 - 14.95 (14.99)	0.05	***0.01***	**2**	5.00 - 14.95	0.05
3	15.00 - 49.90 (49.95)	0.10	***0.05***	**3**	15.00 - 49.90	0.10
4	50.00 - 149.75 (149.90)	***0.25***	***0.10***	**4**	50.00 - 99.75	0.25
5	150.00 - 499.50 (499.75)	0.50	***0.25***	**5**	100.00 - 499.50	0.50
6	500.00 - 4999.00 (4999.50)	1.00	***0.50***	**6**	500.00 - 4999.00	1.00
7	5000.00 -	5.00	***1.00***	**7**	5000.00 -	5.00

Table 1 presents the tick size table before and after the reduction. Changes are accentuated in italic.

To illustrate the first change, and exemplify how to interpret Table 1 we can look at the Electrolux B share, which was traded at around 120 SEK as of September 25th 2006. Previous to the tick size reduction, this particular share was traded at prices with minimum tick size of 0,50 SEK (e.g. 120,50 SEK, 121 SEK, 121,50 SEK and so forth). After the tick size change, the new minimum tick size for the Electrolux B share is 0,25 SEK (e.g. 120,25 SEK, 120,50 SEK, 120,75 SEK and so forth).

To illustrate the latter change, we can look at the Nokia share. Before the change, the share price of Nokia was slightly below 150 SEK. With the old tick size table, this would imply a minimum tick size of 0,50 SEK. After the tick size reduction, the new minimum tick size for the Nokia share is 0,10 SEK. However, if the Nokia share price increase above 150 SEK, it will once again have a new tick size of 0,25 SEK instead.

3. QUALITY OF THE CAPITAL MARKET

Capital markets have the important role to allocate capital efficiently among market participants. The trading rules and systems used by a capital market, i.e. its *market microstructure*, are central as it determines what people can know and act (Harris, 2003). To facilitate an efficient capital market, *liquidity supply* and *volatility* becomes the most vital factors in order to enhance *market quality*. The influence of the recent tick size change upon these two components of market quality constitutes the foundation of this thesis.

3.1 COMPONENTS OF LIQUIDITY

As liquidity is strongly dependent upon the chosen level of minimum tick sizes, an optimal balance between a too large and too small minimum tick size will have a significant impact upon the components of liquidity supply, and consequently the overall market quality.

Liquidity in a market refers to the ability to trade quickly at prices that are reasonable in the light of the underlying demand or supply conditions. Hence, a liquid market is characterized by a place where buyers and sellers can find each other and are able to buy and sell large volumes quickly without affecting the share price (Schwartz, 1993).

In research article concerning liquidity supply academics usually divide the liquidity components into a couple of dimensions where the following are the most pronounced: *width, breadth, depth, immediacy,* and *resiliency*. As various literature and investment banks tend to define these parameters differently, we have throughout this thesis applied the definition and approaches manifested in the renowned literature: R*eshaping the Equity Market* by Robert A. Schwartz.

- *Width* is defined by the bid-ask spread. The spread originates from impatient traders who are willing to right away buy at the best available ask price and sell at the best available bid price. The price they pay in order to trade immediately is simply the bid-ask spread.

- *Breadth* on the contrary is defined as the volume at the best bid and ask price. Thus a market is broad if the best buy and sell orders exist in substantial volume. The breadth

dimension is closely related to the width dimension, as a narrower quoted bid-ask spread, could adversely affect liquidity provision on the top order book level.

- *Depth* measures how much of a given volume that is available at each price level. A market is deep if orders exist at an array of prices in close neighborhood above and below the price at which shares are currently traded at.

- *Immediacy* measures the time it takes to trade an order of a given size, hence in a liquid market, orders are executed rather quickly.

- *Resiliency* is a measure of the time it takes for the market to restore a temporary imbalance in the share price caused by uninformed traders, or larger investors requesting significant amount of shares.

In this study we will concentrate on the first three dimensions; width (measured as bid-ask spread), breadth and depth. The forth dimension, immediacy, is indirectly concealed in the breadth and depth dimensions, as the time it takes to trade an order of a given size mainly depends on the volume available for trade.

As of today, the last dimension, resiliency, is still not well defined. What constitutes a temporary or permanent imbalance in the share price caused by a particular event is still not fully agreed upon among researchers. As a measure of resiliency requires extensive research period to fully observe the tangible impact of an imbalance in the share price, it is generally very difficult to compute this dimension, and thus it has been limited in this study.

3.1.1 LIQUIDITY MEASURE

Beside the difficulties to measure resiliency, previous research have faced difficulties in measuring the impact of other dimensions as well. One in particular which has faced a lot of inconsistent results throughout previous researches, due to new regulations or event happenings, is the market depth dimension.

Previous research has revealed various measures underlying the depth dimension due to different views regarding its impact upon liquidity supply (see section 4 for details). One of these is obliquely measured through the *effective spread*, which is calculated as a request of a certain volume of a particular share. By simulating orders of different sizes of each share, and

monitor how the bid-ask spread varies dependent upon these requested order sizes, an effective spread measure is given.

Another measure is investor's willingness to expose orders beneath the prevailing regulations and market microstructure. Investor, who offers liquidity by posing limit orders, exposes themselves to two major risks. First, they risk to deal with better informed traders (adverse selection) and second, they risk being front-run by other traders. As we will discuss in the following section, investor's reluctance to reveal their intentions, expressed as *order exposure*, is very well pronounced.

3.1.2 THE LIQUIDITY TRADE-OFF

Optimal tick size in the equity market has been a topic frequently discussed in academic literature over the last decade. The main focus of the discussion has been related to the different views regarding what actually constitutes an optimal tick size. Despite the large volume of research in this field, there is still no uniform settlement between the market participants.

In theory the effect of the minimum tick-size upon liquidity supply is twofold. Harris remarked in the renowned *Trading & Exchanges* (2003) that a smaller minimum tick size may generally cause a significant reduction in the bid ask-spread, and consequently in an increase in liquidity supply due to lower trading costs.

However, the last couple of years many researchers have found additional support for an opposite direction of the liquidity supply due to a reduction of minimum tick size. Aitken & Comerton-Forde (2004) came to the conclusion that a too small tick size may as well frustrate market participants and cause higher degree of partial trades because of higher negotiation cost, since there will be an increased range of possible prices to trade at. Moreover, a recent published OMX report, *new tick size for OMX exchanges* (2006), came to the conclusion that a too small tick size may complicate the order display on screen, as market data in current practice is restricted to five order book levels.

In addition, Bourghelle & Declerck (2003) stated that by failing to provide sufficient price protection for limit order traders, investors becomes less willing to expose orders, causing reduced market depth due to a restricted price competition. This phenomenon is often referred

to as front-running. Front-runners act on information of others by simply jump ahead in the order book, either by trading previous to others or by increasing the price by the minimum price increment. They are protected from losses; as in scenarios where prices move against them, since they can simply trade with the passive traders of which they have front-run. Thus, a smaller tick size will make it easier to be front-run, and investors who expect to be front-run will be disinclined to submit their orders. Hence, smaller tick size might as well make it more costly to supply liquidity, and the transparency in the market will be reduced as investors will become more careful in revealing their intentions of orders placements.

The conclusion is that the magnitude of the minimum tick size might affect the dimensions of liquidity supply in different directions, thus understanding the trade-off between the width dimension and the depth dimension, is of great importance in finding an optimal tick size level. Therefore, the net effect of a tick size change upon liquidity supply might most importantly depend on exchanges' individual market design and current country specific regulations.

3.2 VOLATILITY

Volatility is, in contrast to liquidity supply, a more straight forward component of market quality. It is simply defined by Schwartz as the tendency for prices to change unexpectedly. A volatile market imposes a risk on investors, but will benefit market intermediaries who will increase their revenue from more frequent trading.

Volatility occurs mainly for two reasons. Either there is an unanticipated change in the underlying value of the instrument, i.e. *fundamental volatility*, or a price change caused by uninformed traders who trades on false information, i.e. *transitory volatility*. Harris (2003) highlights the different effects upon stock prices caused by these two volatility types. Fundamental price changes have a permanent effect in the sense that subsequent price changes are unrelated to previous price changes. Transitory price changes, however, tend to reverse when informed traders act on the difference between prices and fundamental values.

Hence, market participants tend to pay close attention to volatility as large price changes can quickly create, destroy or transfer enormous wealth. Periods of high volatility are indeed very risky, but they may also create opportunities. As large price changes generally are the results

of mistakes that people makes, regulators have to monitor the development of volatility very closely. This is especially true, as the transitory volatility is to some extent correlated with transaction cost. Thus, regulators have a strong incentive to create liquid markets that produce highly informative prices through the volatility measure.

3.2.1 VOLATILITY MEASURE

Statistical models are necessary to identify and estimate the two components of volatility. Variance, standard deviation, or mean absolute deviations of price changes are the most common measures of price and return volatility. However, it is important to separate the two volatility types, as fundamental volatility consists of seemingly random price changes that do not revert, whereas transitory volatility consists of price changes that ultimately revert. Moreover, Harris (2003) points out that transitory price changes are generally correlated with order flows of uninformed liquidity demanding traders, while fundamental price changes are commonly correlated with order flows of informed traders.

3.3 KEY DEFINITIONS

Before we continue to describe the results of our review of previous researches, we summarize the key definitions discussed so far in Table 2. These concepts are important to be familiar with, as they will recur throughout the rest of this thesis.

Table 2 Summary of key definitions

Key definitions
▪ **Tick:** *Smallest price variation*
▪ **Market microstructure:** *Trading rules and systems used by a capital market*
▪ **Liquidity:** A*bility to trade quickly at prices that are reasonable in light of the underlying demand or supply conditions.*
▪ **Width:** *One of the liquidity dimensions. Defined as the bid-ask spread in this thesis*
▪ **Breadth:** *One of the liquidity dimensions .Defined as volume at the best bid and ask price*
▪ **Depth:** *One of the liquidity dimensions. Defined as volume that is available at each price level*
▪ **Bid-ask spread:** *Difference between the best bid and ask price in the order book*
▪ **Effective spread:** *Bid-ask spread dependent upon requested order size*
▪ **Order exposure:** *Risk faced by investors who offer liquidity through limit orders. First, they risk trading with better informed traders. Second, they risk being front-run by other traders*
▪ **Front-running:** *To act on information of others by simply jump ahead in the order book*
▪ **Volatility:** *Tendency for prices to change unexpectedly*

Table 2 summarizes the key definitions that we have discussed so far. These are important to be familiar with as they will recur through the rest of this thesis.

4. PREVIOUS RESEARCH

During the 1990s many stock exchanges around the world decreased their tick size in an anticipation to improve the efficiency and quality of the market. In their footsteps, a number of studies regarding the relationship of reduction in tick size and its affect upon market quality have been undertaken. The majority of the studies have been performed on the North American Exchanges such as the New York Stock Exchange (NYSE), NASDAQ, the American Stock Exchange (AMEX), and the Toronto Stock Exchange (TSE).

The foundation of these studies have had great implications upon what constitutes an optimal tick size level, since market structure on these exchanges differs from other exchanges around the world in two important ways. First, the NYSE, NASDAQ, AMEX, and TSE are all quote-driven dealer markets, where specialist or dealers/brokers are participating in every trade. Most exchanges outside North America are order-driven markets composing an electronic limit order book. Previous studies have argued that quote-driven dealer markets increases the quote matcher problem (Niemeyer & Sandås, 1994), hence market depth and breadth might be affected in different direction in a pure limit order setting instead of market makers.

Second, most exchanges outside North America uses dissimilar tick sizes for different stocks, while exchanges like NYSE and NASDAQ uses a uniform tick sizes applied on all stocks. In order to account for these dissimilarities, we divide our review of previous research in two parts; one related to the North American exchanges and one related two the rest of the world.

In order to study the effects of tick size reductions on market quality and liquidity supply, previous research have focused on a number of parameters. Three of these parameters (*Bid-Ask Spread*, *Market Breadth*, and *Market Depth*) are, as previously discussed, direct components of liquidity. In addition, the second important component of market quality is *volatility*. These four parameters are together, more or less, present in most of the previous research. A comprehensive summary of previous research findings are presented in Table 3 below.

Table 3 Summary of previous research findings

Article	Stock Exchange	Bid-Ask Spread	Effective Spread	Market Breadth	Market Depth	Liquidity Supply	Volatility
North American							
Harris (1994)		↓	↓	↓	-	?	-
Ahn, Cao, and Choe (1996)	AMEX	↓	↓	?	-	Investors ↑ Suppliers ↓	-
Bacidore (1997)	Toronto SE	↓	↓	↓	-	→	-
Bacidore (2001)	-	↓	-	-	-	Trading costs investors ↓	-
Porter and Weaver (1997)	Toronto SE			↓		Large orders ↓ Small orders →	
Ronen and Weaver (1998)	AMEX	↓	↓	→	-	↑	↓
Goldestein and Kavajecz (2000)	NYSE	↓	?	↓	↓	↓	-
Bessembinder (2000)	NASDAQ	↓	↓	-	-	→	↓
Bessembinder (2003)	NYSE and NASDAQ	↓	↓	-	-	→	↓
Jones and Lipson (2001)	NYSE	↓	↓	↓	↓	↓	-
Van Ness, Van Ness and Pruitt (2000)	AMEX, NASDAQ, and NYSE	↓	↓	AMEX & NYSE ↓ NASDAQ ↑	-	AMEX and NYSE ↓ NASDAQ ↑	-
Chakravarty, Harris, and Wood (2001)	NYSE	↓	↓	↓	-	?	→
Chakravarty, Wood, and Van Ness (2004)	NYSE	↓	↓	↓	-	?	↓
World							
Niemeyer and Sandås (1994)	Stockholm SE	↓	↓	↓	-	?	-
Lau and McInish (1995)	SE of Singapore	↓	-	↓	-	-	-
Chan and Hwang (2001)	SE of Hong Kong	↓	-	↓	↑	↑	-
Ahn, Cai, Chan, and Hamao (2002)	Tokyo SE	↓	↓	→	-	-	-
Bourghelle and Declerck (2004)	Euronext Paris	→	→	↓	→	-	-
Purwoto and Tandelilin (2004)	Jakarta SE	↓	-	↓	-	High priced stocks ↓ Low price stocks↑	-
Ke, Jiang, and Huang (2004)	Taiwan SE	↓	-	-	-	-	↓
Aitken and Comerton-Forde (2005)	Australian SE	↓	-	↓	↑	↑	

↓ Decrease / Poorer ***↑ Increase / Better*** ***→ Unchanged*** ***- Not investigated***

Table 3 summarizes previous research findings and the effect of a tick size reduction on various parameters including bid-ask spread, market breadth, market depth, volatility and liquidity.

The starting point in all of the previous studies, and the main reason why exchanges have been reducing the tick sizes, is the level of the bid-ask spread. As we can see, all previous studies except one have observed a decrease in spread following a tick size reduction. The same is true for the effective spread. However, the reduction in spread is followed by a reduction in market breadth in most of the cases. All but four studies have reported a decrease in market breadth. Hence, as previously discussed, this trade-off is the main concern in exchanges decision to reduce the tick size or not.

Regarding market depth, which measures the order volume at all price levels in the order book, there are only a few studies available since most exchanges lack this type of data. However, if we look at the studies that have investigated market depth, there seems to be a difference between the North American studies and the rest of the world.

Goldstein and Kavajecz (2000) argue, in their study of New York Stock Exchange, that the main reason for a reduction in market depth is due to the power of the specialist in the market, which creates an adverse selection problem for the liquidity providers. A larger tick size protects liquidity provider from this since it increases the cost for specialist to trade ahead of the limit orders. A tick size reduction could thus increase the adverse selection problem.

Chan and Hwang (2001), on the contrary, found an increase in the market depth when the tick size was reduced in the Hong Kong stock exchange. They argue that a possible explanation for this difference between the two studies might be caused by the market design differences between the NYSE and the Stock Exchange of Hong Kong. The latter is a pure limit order market, which is working without the intervention of specialists; hence the adverse selection problem should not be as severe for a pure limit order market as for a specialist market such as the NYSE.

Furthermore, there seems to be a mixed verdict regarding the impact upon liquidity supply following a tick size reduction, at least in the North American studies. Hence, this is the reason why there have been such discussion regarding an optimal tick size level. Some studies have come to the conclusion that liquidity have increased following a decrease in tick size, while others have come to the opposite conclusion. An explanation for the more positive tone from the non-American studies might be attributed to the size of the tick size reduction. In

North America the tick size reductions have been very large and uniformed; hence all stocks have been priced at the same tick size indifferent of price level. At first, prices were given in fractions of 1/8 and 1/16 of a dollar, and at the end given in cents (0,01 of a dollar). Criticizers has thus often argued that the decimalization of the U.S. equity market have been too large and that stocks with higher share prices should have larger ticks than stocks with smaller share prices. Hence this constitutes the main source of discussion concerning the optimal tick size level.

Finally, most of the previous researches have found a decrease in volatility following a tick size reduction. This could be seen as an improvement in market quality, since an excessive volatility market is a sign that the market is not functioning on an optimal level (Harris, 2003).

Harris (1990) argues that when prices are limited to fractions or are discrete, the prices tend to differ from their fundamental values since the exact value might deviate from the closest price increment. A reduction in tick size will therefore reduce the possibility for prices to deviate from their fundamental values, since more price levels will be available with smaller tick size. A reduction in tick size should therefore result in lower fundamental volatility.

5. HYPOTHESES

As prevailing researches reveals, the economic insight of a tick size change is that it influences the components of market quality. However, in order to measure the effects of the recent SAXESS tick size reduction upon liquidity, we further consider its dimensions, i.e. the bid-ask spread (section 5.1), market breadth (section 5.2), quoted depth (section 5.3), and order exposure (section 5.4). Hence, these dimensions, together with the main hypothesis pertaining from the effects upon liquidity (section 5.5) and volatility (section 5.6), constitute the background of our six hypotheses formulations. The rest of this section provides an in depth discussion of these hypotheses individually, and the empirical evidence behind them.

5.1 HYPOTHESIS 1: BID-ASK SPREAD

Previous research have shown that a reduction in tick size will result in a reduction in quoted bid-ask spread, since investors will be able to tighten quotes when the minimum price increment become smaller. Thus, we formulate our first hypotheses:

- *H1 (a): Reduction in minimum tick size will lead to reduction in the bid-ask spread.*

However, one would expect that the reduction in tick size will be particularly important in stocks where the spread has previously been constrained by the minimum tick, since investors now can place orders at prices that previously were unavailable. Hence, we expect stocks were the spread was constrained by the minimum tick size prior to the minimum tick size reduction, also will experience larger declines in spread. Thus, we also formulate a more specific hypothesis concerning the bid-ask spread:

- *H1 (b): Reduction in minimum tick size will lead to reduction in the bid-ask spread for the stocks that previously had an average spread that was 1,10 times the minimum tick size or less.*

5.2 HYPOTHESIS 2: MARKET BREADTH

Previous research has found that a decrease in the minimum tick size and a reduction in the quoted spreads will reduce the premium paid to limit orders for providing liquidity to the market. Hence, while a smaller tick size may narrow quoted bid-ask spread, it could adversely affect liquidity provision and thereby reduce the market breadth. As a result, investors and

traders that previously positioned with limit orders at the best bid and ask price may now choose to place their orders further down in the order book to ensure that they continue to capture a larger premium (Goldstein & Kavajecz, 2000). Investors may even choose to shift some or all of their orders away from the best bid and ask price, and thus reducing the number of orders available at these prices, which will result in reduced market breadth.

- *H2 (a): Reduction in minimum tick size will lead to a reduction in market breadth.*

However, when quoted spread is reduced, the number of price levels in the order book will increase. Hence, investor will have a finer price grid available to post their orders when the tick size is reduced. Thus we expect that the market breadth at the new best bid and ask price will reduce since investors can now use this finer price grid to their advantage. Therefore a more reasonable measure of market breadth is to compare volume with the same interval pre- and post trade, i.e. by measuring the top order book volume level before the tick size change, while measuring the top order book volume level together with half of the second order book volume level after the tick size change.

For instance, as the Ericsson share was traded at prices of 25,30 SEK and 25,40 SEK previous to the tick size reduction, we will instead consider order book volume at prices of 25,35 SEK and 25,40 SEK in addition with *half* the volume of 25,30 SEK and 25,45 SEK after the tick size reduction. We will name this parameter modified market breadth in this thesis. Due to lack of complete data, many of the previous studies have not been able to estimate this measure.

- *H2 (b): Reduction in minimum tick size will lead to a reduction in modified market breadth.*

5.3 HYPOTHESIS 3: CUMULATED DEPTH

As previous research has shown, the effect of a reduction in tick size on cumulated depth was mixed, since observations of both increased and decreased cumulated depth have been found. Based on the contradicting results of previous researches, the net effect of a tick size change upon the cumulative depth is still unclear. However, due to the arguments stated in previous research, we hypotheses:

- *H3: A smaller tick size will reduce the cumulated depth, i.e. number of orders available throughout the order book, and therefore increase the transaction costs of large orders*

5.4 HYPOTHESIS 4: ORDER EXPOSURE

Previous research has found that order exposure would decrease with a lower tick size. To cut down order exposure, investors can split their orders into several smaller orders, cancel and/or modify their orders more often, or alternatively use more frequently hidden quantities (off-exchange orders) when the tick size decreases. Hence we hypotheses:

- *H4: A reduction in the minimum tick size will reduce the level of order exposure, i.e. the number of off-exchange orders will increase*

5.5 HYPOTHESIS 5: LIQUIDITY SUPPLY

Previous studies have consistently documented reduced spreads as well as reduced depths; however, given these conflicting effects on liquidity, it is difficult to determine the overall impact of the change on liquidity. For instance, Goldstein and Kavajecz (2000) found that the combined effect of reduced spreads and reduced depths made small orders cheaper to execute, while large investors did not benefit, because investor's incentive to act as liquidity suppliers decreases. The risk/reward on committed capital will decrease due to smaller spreads and thus give less incentive to put capital at risk in the order book by acting as liquidity supplier. On the contrary some studies found that although spreads and depths declined, large investors were not harmed remarkably (Bacidore, 1997). For this reason we are not sure about the outcome of the liquidity change, although we provide this hypothesis based on our expectations:

- *H5: A reduction in the minimum tick size will improve the market quality in terms of liquidity supply.*

5.6 HYPOTHESIS 6: VOLATILITY

With the absence of liquidity in the market, which happens when the cumulative depth is reduced, one could argue that the price variability will increase since one have to go further

down the order book to complete the transaction. Hence according to this, the price will become more volatile if the cumulative depth decreased when the tick size is reduced. However, as a reduction in tick size will reduce the possibility for prices to deviate from their fundamental values, since more price levels will be available with smaller tick size, the majority of previous researches have actually indicated an opposite effect, i.e. the volatility is reduced with smaller tick sizes. Hence we therefore hypotheses:

- *H6: A reduction in tick size will enforce less volatility and thereby increase market quality*

5.7 A SUMMARY OF HYPOTHESES

Our hypotheses formulation reveals an empirical evidence of enhanced market quality, due to improved liquidity supply and decreased volatility. This is supported by a majority of previous research. Table 4 provides a summary of our hypotheses formulations, where hypothesis 5 and 6 are our two main hypotheses.

Table 4 Summary of hypotheses

Hypotheses:
▪ **H1 (a):** *Reduction in minimum tick size will lead to reduction in the bid-ask spread.*
▪ **H1 (b):** *Reduction in minimum tick size will lead to reduction in the bid-ask spread for the stocks that previously had an average spread that was 1,10 times the minimum tick size or less.*
▪ **H2 (a):** *Reduction in minimum tick size will lead to a reduction in market breadth.*
▪ **H2 (b):** *Reduction in minimum tick size will lead to a reduction in modified market breadth.*
▪ **H3:** *A smaller tick size will reduce the cumulated depth, i.e. number of orders available throughout the order book, and therefore increase the transaction costs of large orders.*
▪ **H4:** *A reduction in the minimum tick size will reduce the level of order exposure, i.e. the number of off-exchange orders will increase.*
▪ **H5:** *A reduction in the minimum tick size will improve the market quality in terms of liquidity supply*
▪ **H6:** *A reduction in tick size will enforce less volatility and thereby increase market quality.*

Table 4 summarizes our six hypotheses. H1-H4 constitutes dimensions of liquidity, while H5 and H6 are the main hypothesis referring to the components of market quality, i.e. liquidity and volatility.

6. DATA

In this study, we will use high frequency data, i.e. tick-by-tick data, which have been provided to us through SEB Merchant Banking (see Appendix 5). This database will provide us with market-by-level data for the five best bids and ask price levels. As all orders in the market are displayed in the database, we will divide each trading day in fifteen minutes sub periods and take the average of the whole sample. In previous research, there have been discussions about the length of this sub periods. The conclusion from these studies has been that the optimal time length is in the range of five to thirty minutes.

We will divide the sample in two periods, one period before (pre period) and one period after (post period) the tick size change. To exclude any bias associated with unusual trading behavior at the time of the change, we will exclude a certain transition period consisting of one week before and after the change. The use of this transition period is a common practice in most of the previous research associated with tick size change. Our pre period is between August 21st and September 15th and our post period is between October 2nd and October 27th.

6.1 SAMPLE SELECTION

Our initial sample consisted of 262 stocks, all trading on the Stockholm Stock Exchange. From that we excluded all stocks that crossed a price band during the sampling period, since that would automatically change the tick size for that stock (see Appendix 6). Furthermore, we excluded all stocks were the *coverage rate* was below 90 %, which include stocks that are infrequently traded and therefore does not have sufficient traded daily volume (see Appendix 4). We will also exclude stocks where data is missing for more than 5 days in either the pre or post period. After making these adjustments, we have 109 stocks left in our sample.

In order to study the effects of the change in tick size on SAXESS, we have decided to look at all stocks that were affected by the new tick size table introduced by OMX on September 25th. Of those, we will divide them in three subgroups. The first group will consist of the "most liquid stocks", which include Ericsson A and B share, Nokia SDB, and Nordea. The second and third group will consist of stocks that trade between 100-149,75 SEK, which were the only price band that was affected by the new tick size table. To control for differences in trading volume, we divide this segment in two different groups, high and low volume stocks, where the high volume stocks include stocks with an average daily volume greater than

hundred thousand trades. This is in line with other studies like Goldstein and Kavajecz (2000) and Porter and Weaver (1997), who discussed that frequently traded stocks have smaller tick sizes than infrequently traded stocks. This is also in line with Harris (1994) predictions that the reduced tick size would have largest impact on stocks where the bid-ask spread is constrained by the minimum tick size, which includes highly traded stocks.

To control for changes in the market conditions, we will use control groups, one from each price band that aren't affected by the tick size change. We will also divide these stocks in a high and low control group as well. Descriptive statistics of the event groups and control stocks are shown in Table 5 below and descriptive statistics of each stock in the sample and control groups are showed in Appendix 2.

Table 5 Descriptive statistics of event groups and control stocks

Group	Number of Stocks	Pre Average Market Capitalization (SEK)	Pre Average Daily Trading Volume	Average Midpoint Price (SEK)
Most Liquid Stocks	4	254 680 024 621	34 349 264	71.65
High Volume Stocks	11	28 019 950 778	1 519 398	121.26
Low Volume Stocks	12	5 497 065 897	52 432	120.50
Control Group				
15-50 SEK	18	1 911 041 411	661 842	26.89
50-100 SEK	28	14 832 317 611	694 443	78.30
150+ SEK	32	40 715 974 285	693 930	268.15
High Volume	49	31 021 143 805	1 101 073	154.07
Low Volume	33	7 285 088 407	62 310	113.8

Group	Average Tick Size Pre (SEK)	Average Tick Size Post (SEK)	Tick Size / Price Pre	Tick Size / Price Post	Spread / Tick Size Pre	Spread / Tick Size Post
Most Liquid Stocks	0.24	0.09	0.36%	0.15%	1.11	1.19
High Volume Stocks	0.50	0.25	0.42%	0.19%	1.05	1.19
Low Volume Stocks	0.50	0.25	0.42%	0.20%	1.55	2.58
Control Group						
15-50 SEK	0.10	0.10	0.40%	0.39%	1.90	1.75
50-100 SEK	0.25	0.25	0.33%	0.30%	1.65	1.60
150+ SEK	0.50	0.50	0.20%	0.19%	1.58	1.56
High Volume	0.31	0.31	0.29%	0.27%	1.34	1.31
Low Volume	0.30	0.30	0.32%	0.30%	2.17	2.07

Table 5 shows descriptive statistics including sample size, average market capitalization (pre), average daily volume (pre), average price (pre), average tick size (pre and post), tick size/price (pre and post), and spread/tick size (pre and post) for all event and control stocks.

7. IMPLEMENTATION OF HYPOTHESES

Along the implementation of our hypothesis we give a brief description of the development of each of the parameters estimated in this thesis. To our aid in estimating these parameters, we have designed some tools and application to facilitate the work with a massive amount of data.

7.1 TOOLS AND DEVICES

The tick data is collected from *Reuters*. This tick database captures all high speed streaming content across the Swedish markets, which constitutes the foundation of our research. The database is stored in a SQL server which is then mirrored to an access database. In order to do more advanced estimates we finally imported the database into an excel sheet according to our preferences of chosen parameters. Within various excel sheets we have made immense programming in *Visual Basic for Applications* (VBA) in order to manage the huge amount of accessible raw data and compute our parameter estimations. The output of this device, poses the foundation of our results.

7.2 PARAMETERS

To begin with, we have divided the trading days in 15 minutes sub-periods and seized an average from each of these sub-periods during the trading day to calculate a daily average, in order to manage the immense amount of high frequency data. For each share in the sub-samples, we then calculate an average for both the pre- and post-period, and estimate the percentage change of each share between the pre- and post-period. A cross-sectional equally weighted mean will finally be predicted for each sub-sample.

7.2.1 BID-ASK SPREAD

To measure the bid-ask spread, we have calculate the *quoted spread*, since it has proven to be the most relevant measure of trade execution cost (Bessembinder, 2003). The quoted spread is calculated by taking the absolute value of the difference between the time weighted market bid price and ask price, divided my the mid price, and finally expressed as basis points (by multiplying the decimal value with ten thousand). As we express the intraday data is in fifteen minutes brackets, the time weighted bid-ask quotes are averaged every fifteen minutes and finally averaged one more time to receive an inter-day figure. This inter-day digit is then once again averaged according to our filtering and parameter selection policies in order to receive a

bid-ask spread value for both the pre event period as well as the post event period. The same averaging procedure is done throughout the rest of our parameters.

7.2.2 MARKET BREADTH

The market breadth measure is estimated by summing up the top order book volume at the best bid and ask price and then added up in accordance with the same averaging procedure as previously described in order to arrive at an inter-day average. Basically, there are two ways to express this estimate. Either by dividing the top volume by a constant static figure such as the *total issued number of shares outstanding* in a company, or by a more dynamic figure based on for instance the average daily traded volume of each share. The reason for this division is to construct estimates at same magnitudes for all shares in order to cluster them into forming the event and control groups. We have chosen to apply both the static and dynamic measure figures as there are pros and cons with both these methods.

7.2.2.1 DYNAMIC VERSUS STATIC

The static version measure does not consider the variation in the daily traded frequency; hence the assumption is that the market is rather stable during our information gathering period. By standardize this measure with a static denominator such as the total shares outstanding for every company, we receive a measure in line with previous research and thus available for us to compare with earlier findings. However, the dynamic market breadth measure in contrast does consider the daily variation in the share and thus adjust for possible event happenings such as quarter report periods, institutional traffic and news trading.

7.2.2.2 MODIFIED MARKET BREADTH

As we have previously discussed, the simplest form of the market breadth measure might give an unfair indication of the different volume before and after the tick size reduction. As the tick size is reduced by half for all shares except the Nokia SDB share (reduced from 0,5 SEK to 0,1 SEK), we have modified the market breadth measure by including half the volume at the second order book level as well, in order to capture volume at the same price interval as before the tick size reduction. For Nokia SDB, we have included the top three order book levels in both the bid and ask side in order to compensate a five times smaller tick size. To give a more concrete example, we have created an illustrative example of a fictitious order book as in Table 6 below.

Table 6 Fictitious order book of modified market breath

Order Book Level	Before - 0.50 Tick Size				After – 0.25 Tick Size			
	Bid Price	Size	Ask Price	Size	Bid Price	Size	Ask Price	Size
1	139.50	400	140.00	400	139.50	400	139.75	200
2	139.00	300	140.50	300	139.25	200	140.00	200
3	138.50	200	141.00	200	139.00	100	140.25	200

Table 6 shows that when the tick size is reduced from 0.50 SEK to 0.25 SEK, the differences between the best bid and ask price at the highest order book level (level 1). Since more price levels are now available to trade at, a person who believes that the stock is worth 139.75 SEK can now post his sell order at this price level instead on the 140.00 SEK price level. Hence, order sizes at the best bid and ask price will automatically be reduced, as investors can post orders closer to their estimates of the stock's market value. To correct for this, we split the second order book level in half and thereby assume that half the order size at the second order book level will be posted at 139.375 SEK at the bid side and 139.875 SEK at the ask side. After this correction the price interval will be the same as before the tick size reduction.

7.2.3 CUMULATED DEPTH

Even if the depth at the best bid and ask price changes, the total liquidity supplied to the market may not be affected in the same direction, since investors will now have more price levels to place orders at in the order book. To get better picture of the liquidity in entire order book, we will use the first part of the Aitken and Comerton-Forde (2003) weighted order book value, which measures the value of all orders in the order book weighted by their distribution. Hence, all volumes at bid and ask side of the top five order book levels is divided in a price band depending on its distance to the current market prices. We will then measure the number of the orders in each price band (Table 7 below) as percentage of all orders in the order book.

Table 7 Price band and price range

Price Band	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Price Range (%)	0-1	1-2	2-3	3-4	4-5	5-10	10-20	20-50	50-100

Table 7 shows the different price bands with included price range. The price range is determined as a percentage from the market price.

To understand how large orders are affected by the tick size reduction, we will use an effective spread measure. The effective spread is calculated based on a requested average daily traded volume (ADV). We have considered six percentage levels of ADV ranging between zero and five percent. By requesting to trade a certain level of ADV, we can see how the bid-ask spread, i.e. effective spread varies. Hence, by simulating orders with different levels of ADV, and monitor how the spread cost varies depending on the order size, an effective spread measure is given. Simply, as the orders become large enough to cover all volume at the top order book level, it has to use the second order book level and so on until the whole order is covered. The prices at each order book levels are then multiplied with the

volume to receive an effective bid and ask price respectively. These prices are then averaged in the same manner as the ordinary bid-ask spread in order to receive and intraday group digit.

7.2.4 ORDER EXPOSURE

The order exposure measure the number of orders traded on- and off-exchange. Basically an on-exchange trade includes all trades matched automatically in the equity market to the current market price available. Furthermore, an on-exchange order should not include any forward or future contract, or involve any lending and borrowing. Moreover, it should be immediately traded at only one time and to a price regulated by the market without any interventions. The on- and off-exchange relationship is categorized according to the field description and trading rules classified by tick data provider listed more specifically in Appendix 1, Table 25. In addition to this, we will investigate order sizes by dividing the average daily traded volume for each day by that day's average daily trade frequency.

7.2.5 LIQUIDITY SUPPLY

In order to quantify the trade off between spread and breadth, we will use a framework similar to that of Bacidore (1997), which looked at the breadth-to-spread function. To calculate this ratio, we will divide the modified breadth measure for each day for respective stock by its corresponding spread measure. We have chosen the modified breadth measure because we think that it is a more accurate measure of market breadth. We will interpret the measure that an increase (decrease) in the breadth-to-spread ratio will indicate that the breadth is increasing (decreasing) more than the spreads on average, which implies that the breadth is becoming less (more) costly. Hence if breadth is becoming less costly, it must imply that liquidity has increased and vice versa.

7.2.6 RETURN VOLATILITY

Another measure of market quality includes the variance of return. In general, volatility is negatively related to liquidity, hence in a liquid market, the volatility should be low. To measure intraday return volatility, we will simply estimate the continuously compounded returns. The formulas can be found in Appendix 3.

8. EMPIRICAL RESULTS AND DISCUSSION

In this section, we will present our empirical results. Each hypothesis will be evaluated separately and we will conclude the section by a discussion of the results. In order to test the impact of the tick size change have had on different variables, we will look at the difference between the pre and post period and measure this change in percentage. To test if the difference is statistically significant, we uses two types of tests; the paired t-test and a non-parametric Wilcoxon sign rank test. The paired t-test is based on the assumption of normality, while the Wilcoxon sign rank test controls for any deviations from the normality assumption.

8.1 HYPOTHESIS 1: BID-ASK SPREAD

In Table 8, the change in the bid-ask spread before and after the event date as of September 25th are shown. As we can see, the results are very convincing and are in line with expectations. For both the most liquid stocks and the high and low volume stocks, the bid-ask spread is significantly reduced in the period after the reduction in tick size. The bid-ask spread for the most liquid stocks has declined by 54,96%, and for the high and low volume stocks the spread has declined by 47,18% and 21,75% respectively. These results are statistically significant at the 5% level for both the paired t-test and the Wilcoxon Sign Test.

Table 8 Bid-ask spread

Average Bid-Ask Spread (bps)	***Pre***	***Post***	***Change***	***% Change***	**N**	***P-Value Paired t-test***		***P-Value Wilcoxon Sign Test***	
Most Liquid Stocks	40.54	18.26	-22.28	-54.96%	4	0.002	***	0.069	**
High Volume Stocks	43.41	22.93	-20.48	-47.18%	11	0.000	***	0.003	***
Low Volume Stocks	64.62	50.57	-14.06	-21.75%	12	0.000	***	0.002	**
Control Group									
15-50 SEK	76.03	71.36	-4.67	-6.15%	18	0.137		0.094	*
50-100 SEK	53.81	48.17	-5.64	-10.48%	28	0.001	***	0.001	***
150+ SEK	32.23	29.61	-2.62	-8.13%	32	0.089	*	0.002	***
High Volume	39.48	36.30	-3.18	-8.05%	49	0.000	***	0.000	***
Low Volume	68.93	63.57	-5.36	-7.77%	33	0.026	**	0.021	**
*** Significant at the 1% level			**Significant at the 5% level			*Significant at the 10% level			

Table 8 *provides the bid-ask spread before and after the event date as of 25th September 2006 for both the event groups and control groups. The spreads pre, post, and the change pre-to-post of the tick size change are expressed in basis points. The percentage change pre-to-post is also shown. The sample size (N) and the statically tests are also provided.*

In comparison, the control groups have experienced a much lower reduction in spread, which confirms that the large reduction is likely to be related to the tick size reduction. Hence, we do not reject the H1 (a) hypothesis that the reduction in the minimum tick size will result in a reduction of the bid-ask spread.

Furthermore, as Table 8 shows, high volume stocks seem to be affected in a higher extent by the tick size reduction than the low volume stocks, hence the tick size constrains the bid-ask spread in a larger extent for high volume stocks than for low volume stocks. To investigate this statement, or H1 (b), we have divided the stocks in two groups as showed in Table 9 below. The group with the *constrained stocks* consists of stocks with an average spread *less* than 1,10 times the minimum tick size, while the *non-constrained* group of stocks includes stocks with an average spread *higher* than 1,10 times the minimum tick size. As we can see, the average spread decreases by 50,65% between the pre and post period for the constrained stocks and by 23,98% for the non-constrained stocks. Both are statistically significantly different from zero at the 1% level.

Table 9 Bid-ask spread for constrained stocks

Average Quoted Spread - Constrained Stocks (bps)	***Pre***	***Post***	***Change***	***% Change***	**N**	***P-Value Paired t-test***		***P-Value Wilcoxon Sign Test***	
Constrained	41.46	20.46	-21.00	-50.65%	13	0.000	***	0.000	***
Non-Constrained	62.58	47.58	-15.00	-23.98%	14	0.000	***	0.000	***
Constrained and Non-Constrained	52.41	34.52	-17.89	-34.14%	27	0.000	***	0.000	***
*** Significant at the 1% level			**Significant at the 5% level			*Significant at the 10% level			

Table 9 provides the bid-ask spread for the stocks that previously had an average spread that was 1,10 times the minimum tick size or less before and after the event date.

To test the statistic significance of this difference between the constrained and the non-constrained stocks, hence in order to test the significance between the two event groups which are not matching pairs, we have performed a Wilcoxon Rank Sum Test. The null hypothesis is that the two population distributions have the same central location; hence the difference between the pre and post period for the constrained and the non-constrained stocks are the same. The decision rule at the 5% level is: $\text{Reject } H_0 \text{ if } Z < -1.96$. Since the Z-value is -1,99, we can reject the null hypothesis at the 5% level. Hence, we have statistical evidence that the constrained stocks experience a larger decrease in spread after the tick size reduction than

non-constrained stocks. Thus, we do not reject the H1 (b) hypothesis stating that the average spread for the constrained stocks are reduced in larger extend than the non constrained stocks.

Table 10 Wilcoxon rank sum test

Wilcoxon Rank Sum Test			
Non Constrained Sample		Constrained Sample	
Sample Size	14	Sample Size	13
Sum of Ranks	237	Sum of Ranks	141
Z Test Statistic		-1.989572503	
p-value		0.046637908	

Table 10 *shows the result of a Wilcoxon Rank Sum Test of Constrained- vs Non-Constrained Stocks*

- **Summary 8.1:** We find evidence that the tick size reduction causes a significant decrease in the bid-ask spread, and that this decrease is larger for stocks where the tick size have constrained the bid-ask spread. The economic implication of this is lower transaction costs for investors, which should improve the liquidity supply.

8.2 HYPOTHESIS 2: BREADTH

As we described in the parameter section, we have decided to use two measures of market breadth, one static and one dynamic version. We will discuss each of these two separately.

8.2.1 HYPOTHESIS 2 – STATIC VERSION

The results of the simplest version of the market breadth, the static version, which measures the volume at the top order book level divided by issued capital, are displayed in Table 11 below. The static market breadth measure for the most liquid stocks is reduced by 66,19% after the tick size reduction. The high volume stocks are reduced by 49,50% and the low volume stocks are reduced by 29,73%.

Nevertheless, the significance level varies between the samples. For the high volume stocks, the decrease is significantly different from zero at the 1% level. For the low volume stocks, the decrease is significant at the 5% level, and for the most liquid stocks, the decrease is significant only at the 10% level. However, all control stocks experience an increase rather than a decrease in static market breadth and for the high volume stocks, the increase is statistically significant at the 1% level. The event groups results are in line with our expectations, and hypothesis H2 (a), thus a reduction in tick size will lead to a reduction in market breadth.

Table 11 Market breadth – static version

Breadth – static version (bps)	***Pre***	***Post***	***Change***	***% Change***	**N**	***P-Value Paired t-test***		***P-Value Wilcoxon Sign Test***	
Most Liquid Stocks	11.15	3.77	-7.38	-66.19%	4	0.165		0.068	*
High Volume Stocks	3.08	1.56	-1.53	-49.50%	10	0.000	***	0.005	***
Low Volume Stocks	1,18	0,83	-0,35	-29,73%	11	0,008	***	0.015	**
Control Group									
15-50 SEK	1.69	1.76	0.07	4.33%	16	0.560		0.605	
50-100 SEK	1.22	1.36	0.15	12.03%	27	0.046	**	0.186	
150+ SEK	1.63	1.78	0.15	9.46%	32	0.087	*	0.155	
High Volume	1.50	1.67	0.17	11.66%	47	0.004	***	0.008	***
Low Volume	1.56	1.63	0.07	4.43%	32	0.446		0.970	
*** Significant at the 1% level			**Significant at the 5% level				*Significant at the 10% level		

Table 11 provides the market breadth – static version, i.e. volume at the top order book level, before and after the event date as of 25th September 2006. The market breadth pre, post, and the change pre-to-post of the tick size change are expressed in basis points. The percentage change pre-to-post is also shown. The sample size (N) and the statically tests are also provided.

However, as previously discussed, the static market breadth measure might not provide a fair comparison among the stocks. As we have discussed previously, a modified market breadth measure might capture a more relevant comparison. Table 12 below shows the results of the modified static breadth measure.

Table 12 Modified market breadth – static version

Modified breadth – static version (bps)	***Pre***	***Post***	***Change***	***% Change***	**N**	***P-Value Paired t-test***		***P-Value Wilcoxon Sign Test***	
Most Liquid Stocks	11.15	10.74	-0.41	-3.66%	4	0.214		0.715	
High Volume Stocks	3.08	2.40	-0.69	-22.28%	10	0.001	***	0.007	***
Low Volume Stocks	1,18	1,31	0,12	10,37%	11	0,281		0.060	*
Control Group									
15-50 SEK	1.69	1.76	0.07	4.33%	16	0.560		0.605	
50-100 SEK	1.22	1.36	0.15	12.03%	27	0.046	**	0.186	
150+ SEK	1.63	1.78	0.15	9.46%	32	0.087	*	0.155	
High Volume	1.50	1.67	0.17	11.66%	47	0.004	***	0.008	***
Low Volume	1.56	1.63	0.07	4.43%	32	0.446		0.970	
*** Significant at the 1% level			**Significant at the 5% level				*Significant at the 10% level		

Table 12 *provides the static version of modified market breadth, i.e. volume at the post order book levels corresponding to previous tick size levels, before and after the event date. . The market breadth pre, post, and the change pre-to-post of the tick size change are expressed in basis points. The percentage change pre-to-post is also shown. The sample size (N) and the statically tests are also provided.*

As we can see, only the high volume stocks and the most liquid stocks experience a decline in modified static breadth after the tick size reduction. The modified static market breadth for the high volume event group decreased by 22,28% and for the most liquid stocks by 3,66%. The decrease is only significant for the high volume stocks (at the 1% level). The control groups are indifferent from the regular static breadth measure, as the price grid is the same as before the tick size reduction. From this we can conclude that hypothesis H2 (b) is not rejected for the high volume stocks, but rejected for the low volume stocks.

8.2.2 HYPOTHESIS 2 – DYNAMIC VERSION

The results of the dynamic version, which measures the volume at the top order book level divided by average daily traded volume, are displayed in Table 13 below. Similar to the static version, the dynamic market breadth decreases for all event groups. The most liquid stocks decreases by 39,28%, although only significant at the 10% level. The high volume stocks decreases by 58,07% and the low volume stocks by 48,54%, both significant at the 1% level. Furthermore, all control groups experiences a decline in market breadth. The decrease is statistically significant at 5% level for 3 of 5 control groups. This is the opposite of the static version, where all control groups shows small increases instead of decreases. However, the decrease for the event groups is much higher than for the control groups. Hence, we do not reject hypothesis H2 (a) for neither the static nor the dynamic version. We conclude that there is a sharp decrease in market breadth after the tick size reduction

Table 13 Market breadth – dynamic version

Breadth – dynamic version (%)	***Pre***	***Post***	***Change***	***% Change***	**N**	***P-Value Paired t-test***		***P-Value Wilcoxon Sign Test***	
Most Liquid Stocks	0,34	0,20	-0,13	-39,28%	3	0,303		0.068	*
High Volume Stocks	0,08	0,03	-0,05	-58,07%	10	0,000	***	0.005	***
Low Volume Stocks	0,17	0,09	-0,08	-48,54%	11	0,001	***	0.003	***
Control Group									
15-50 SEK	0.14	0.12	-0.02	-12.27%	16	0.406		0.877	
50-100 SEK	0.12	0.09	-0.02	-18.26%	27	0.197		0.026	**
150+ SEK	0.10	0.08	-0.02	-21.74%	32	0.046	**	0.002	***
High Volume	0.05	0.04	-0.01	-18.69%	47	0.005	***	0.000	***
Low Volume	0.20	0.17	-0.04	-17.45%	32	0.446		0.125	

*** Significant at the 1% level **Significant at the 5% level *Significant at the 10% level

Table 13 provides the dynamic version of market breadth, i.e. volume at the top order book level, before and after the event date as of 25th September 2006. The market breadth pre, post, and the change pre-to-post of the tick size change are expressed in basis points. The percentage change pre-to-post is also shown. The sample size (N) and the statically tests are also provided.

The modified dynamic market breadth measure results are displayed in Table 14 below. As we would expect, the decrease in the modified market breath measure, are not as large as for the regular market breadth measure. The modified market breadth for the most liquid stocks decreases by 9,31%, however the significant level is very low. For the high and low volume stocks, the modified market breadth decreases by 36,11% and 17,36% respectively. Both are statically significant at the 5% level. However, the decrease is in comparison with the control groups relatively small, at least for the low volume stocks. Therefore, as for the static version, hypothesis H2 (b) is not rejected for the high volume stocks but rejected for the low volume stocks.

Table 14 Modified market breadth – dynamic version

Modified Breadth - Dynamic (%)	***Pre***	***Post***	***Change***	***% Change***	**N**	***P-Value Paired t-test***		***P-Value Wilcoxon Sign Test***	
Most Liquid Stocks	0,34	0,37	0,03	9,31%	3	0,592		0.465	
High Volume Stocks	0,08	0,05	-0,03	-36,11%	10	0,000	***	0.005	***
Low Volume Stocks	0,17	0,14	-0,03	-17,36%	11	0,035	**	0.023	**
Control Group									
15-50 SEK	0.14	0.12	-0.02	-12.27%	16	0.406		0.877	
50-100 SEK	0.12	0.09	-0.02	-18.26%	27	0.197		0.026	
150+ SEK	0.10	0.08	-0.02	-21.74%	32	0.046		0.002	**
High Volume	0.05	0.04	-0.01	-18.69%	47	0.005		0.000	***
Low Volume	0.20	0.17	-0.04	-17.45%	32	0.446		0.125	

*** Significant at the 1% level **Significant at the 5% level *Significant at the 10% level

Table 14 provides the dynamic version of modified market breadth, i.e. volume at the post order book levels corresponding to previous tick size levels, before and after the event date. The modified market breadth pre, post, and the change pre-to-post of the tick size change are expressed in basis points. The percentage change pre-to-post is also shown. The sample size (N) and the statically tests are also provided.

- **Summary 8.2:** We find evidence that the tick size reduction causes a significant reduction in the market breadth for all stocks. For the modified version, where we correct for the finer price grid after the tick size reduction, the decrease in market breadth is only significant in the sample of high volume stocks. The economic implication is that this contradicts with the results from the previous section in terms of liquidity supply. Hence, there seems to be a trade-off between a reduced bid ask spread and a reduced breadth. The overall effect upon liquidity supply is therefore uncertain.

8.3 HYPOTHESIS 3: CUMULATED MARKET DEPTH

A possible explanation for the reduction in market breadth at the best bid and ask prices is that investors move their orders away from the best bid and ask prices further down the order book. We will investigate this further by looking at the distribution of orders in the order book.

The order book distribution for the most liquid stocks, as well as the high and low volume stocks before and after the tick size reduction is given in figure 1, 2 and 4 respectively. As illustrated in these figures, the results for the most liquid stocks and high volume stocks are very compelling. The percentage of orders that lies within the 0-1 % price band increases from about 80% to 100% for the most liquid stocks and from about 75% to over 95% for high volume stocks. Thus this implies that investors are taking advantage of the finer price grid and move orders closer to the best bid and ask price, and hence the relative number of orders further down the order book will therefore decrease in relative terms.

The results for the low volume stocks are not as dramatic as for the most liquid and high volume stocks. Although, in a comparison with the control group we still see a significant change from 50-55% before the event date to approximately 65% after the event date. At the same time, neither the high volume control group in figure 3 nor the low volume control group in figure 5 shows any significant differences previous to the tick size change.

Figure 1 Change in depth, most liquid stocks

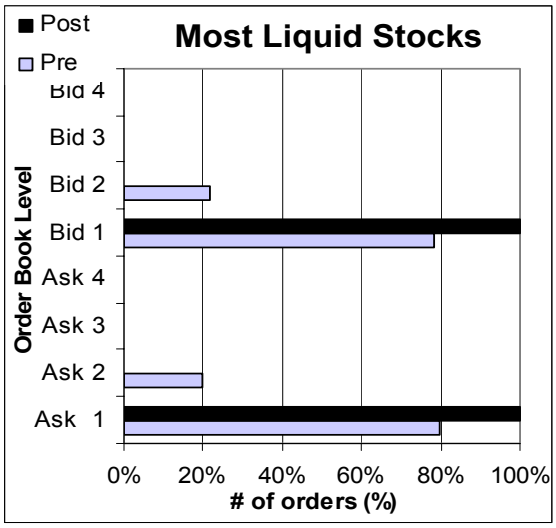


Figure 1-5 displays the distribution of orders in the order book pre and post, where price band 1 (bid 1 and ask 1) includes orders within 0-1% of the current market price. Price band 2 includes orders within 1-2% of the market price; price band 3 includes orders within 2-3% and so on. For a complete definition of all price bands see Table 7.

Figure 2 Change in depth, high volume stocks

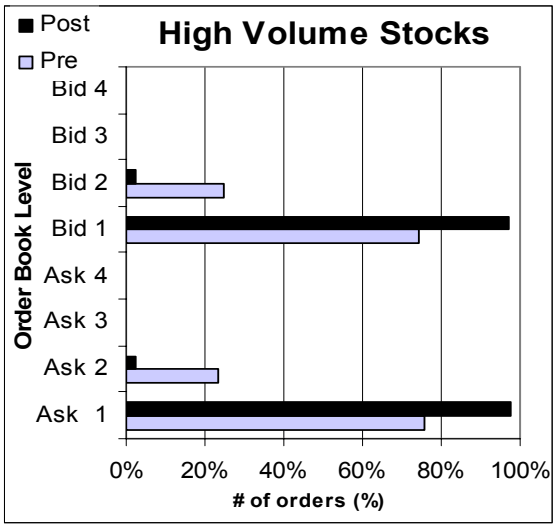


Figure 3 Change in depth, high volume control stocks

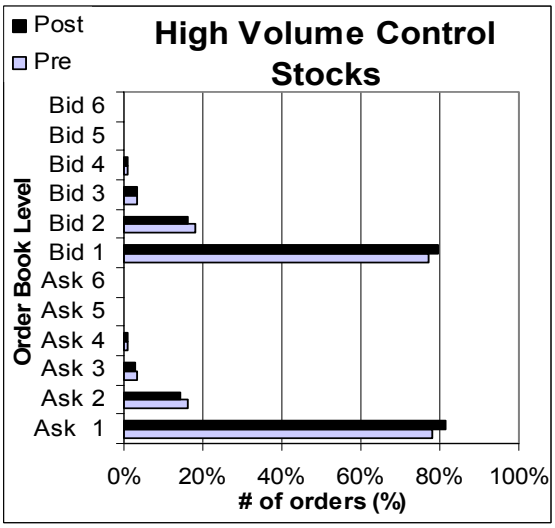


Figure 4 Change in depth, low volume stocks

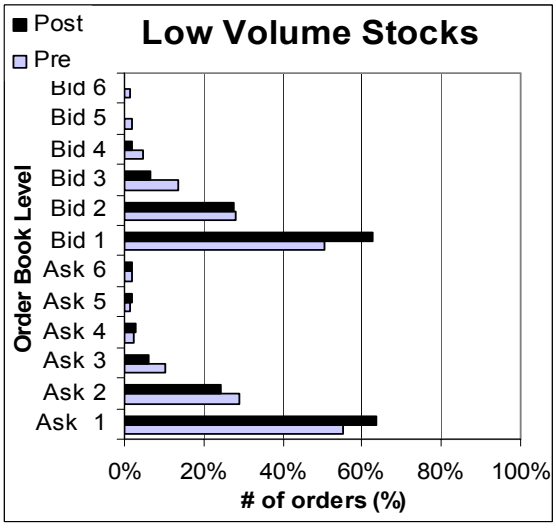
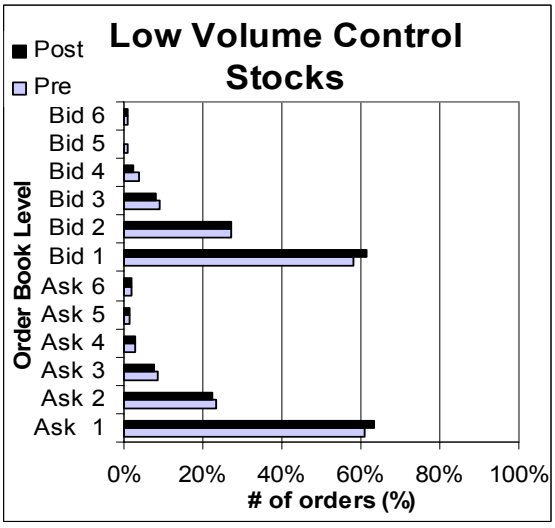


Figure 5 Change in depth, low volume control stocks



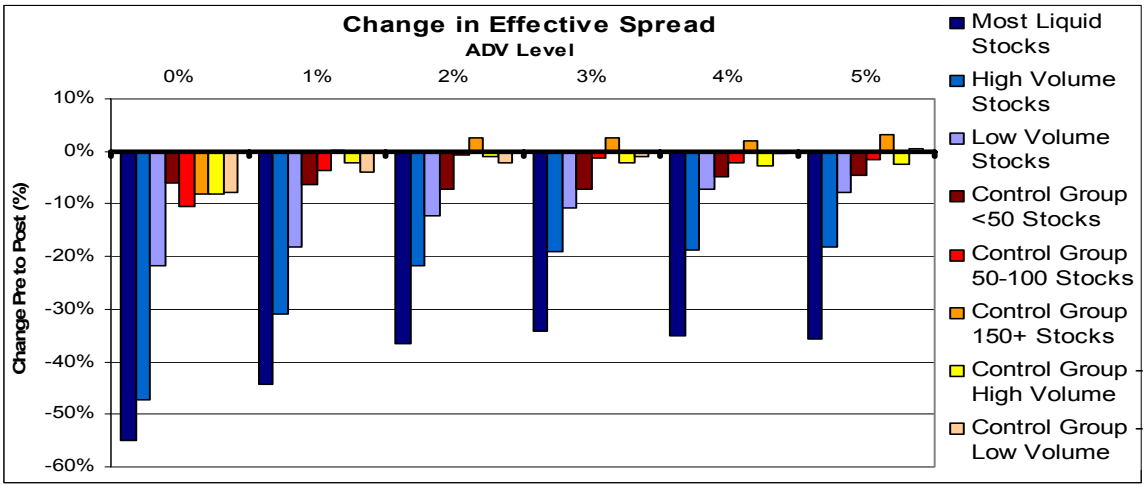
From Figure 1 to 5 we can see that there is clear evidence that the depth in the order book is decreased after the tick size reduction. Hence, we could observe that the relative number of orders in percentage is moved from price bands further down in the order book to the price band closest to the top order book level. This is important to be aware of as the numbers are measured in percentage and not in absolute terms; hence the top order book volume is in fact not necessarily increasing. However, there is a movement of orders from order levels further down in the order book closer to the top of the order book.

Furthermore, since we observe a reduction in the market breadth in section 7.2, at least for the high volume stocks, we argue that there is a decrease in the numbers of orders through out the

order book, hence hypothesis H3 can not be rejected based upon these results. The intuition behind this is in line with Goldstein and Kavajecz (2000) argument that a lower tick size increases the risk of being front-run by quote-matcher. Hence, liquidity suppliers will be less willing to display their orders when the price grid gets finer. Another way to interpret this is that investors take advantage of the new finer price grid and smaller bid-ask spread and therefore move their orders closer to the best bid and ask price.

In order to test how large trade sizes have been affected by the tick size reduction, we have looked at the effective spread for six different ADV levels as described in section 7.2.3 above. The results of these effective spread measures are displayed in Figure 6 below. As we have previously discussed, the effective spread measures the spread change pre-to-post based on different level of requested average daily volume (ADV).

Figure 6 Change in effective spread



The figure shows the change in effective spread of the event and control groups for 6 different requested ADV levels. Beginning from the left of each ADV level (0, 1, 2, 3, 4, 5 %), the first column shows the most liquid stocks, the second the high volume stocks, and the third the low volume stocks. The five next columns show the control groups.

As Figure 6 illustrates, the effective spread decreases for all our event groups after the tick size reduction. The significance level of each ADV level and for each event group is displayed in Table 15 below. For the most liquid stocks, the reduction in spread is between 35% and 45% depending on which percentage of daily traded volume we are requesting. These results are statically significant at the 5% level for all ADV levels except at the 0% level. For the high volume stocks, the effective spread has decreased from about 47% for the 0% ADV level to about 18% for the 5% level. The decrease is statistically significant at the

1% level for all ADV levels. For the low volume stocks, the effective spread has decreased from about 22% for the 0% ADV level to about 8% for the 5% ADV level. However, the decrease is only statically significant from zero at the 5% level up to the 2% ADV level. However, if we compare the results with the control groups, they become relatively significant, since neither of the control groups experiences a statistically significant change in effective spread between the pre and post period for any ADV level between 1% and 5%.

Table 15 Effective spread – significance table

		ADV Level					
		0%	**1%**	**2%**	**3%**	**4%**	**5%**
Most Liquid Stocks	*P-Value*	0.069	0.009	0.019	0.011	0.003	0.001
	Significance	*	***	**	**	***	***
High Volume	*P-Value*	0.003	0.000	0.001	0.003	0.001	0.002
	Significance	***	***	***	***	***	***
Low Volume	*P-Value*	0.002	0.002	0.032	0.077	0.229	0.159
	Significance	***	***	**	*		
Control Stocks							
15-50 Stocks	*P-Value*	0.094	0.086	0.082	0.118	0.256	0.312
	Significance	*	*	*			
50-100 Stocks	*P-Value*	0.001	0.259	0.860	0.772	0.597	0.666
	Significance	***					
150+Stocks	*P-Value*	0.002	0.963	0.615	0.686	0.610	0.484
	Significance	***					
High Volume	*P-Value*	0.000	0.409	0.771	0.481	0.312	0.355
	Significance	***					
Low Volume	*P-Value*	0.021	0.241	0.602	0.873	0.896	0.925
	Significance	**					

*** Significant at the 1% level **Significant at the 5% level *Significant at the 10% level

Table 15 provides the effective spread, i.e. estimated bid-ask spread when various *level of average daily traded volume is requested before and after the event date.*

The conclusion from this is that, although average quoted breadth declines following decimalization, large investors do not appear to be worse off in comparison to smaller investors. The effective spread declines on average for all trade sizes with similar pattern for all our event groups. Hence, the noteworthy point is that the effective spread does decrease significantly for any trade size for the high volume stocks, which compensates for the reduction in the cumulated depth. Hence, the second part of hypothesis H3 that the tick size reduction increases the transaction cost of large orders are difficult to interpret. Obviously, the available market depth decreases through out the order book. The reduction of liquidity in the order book will make it more difficult to execute large orders, and thus increase trading costs. On the contrary, since the effective spread decreases, the cost of each transaction also

decreases after the tick size reduction. The overall effect for large investors is therefore difficult to interpret. However, the results are in line with Bacidore (1997) findings. Similar to us, he found a reduction in depth following the tick size reduction and a decrease in effective spread for all trade sizes. Thus he argues that large investors do not appear to be worse off after a tick size reduction.

- **Summary 8.3:** We find evidence that the tick size reduction causes a significant reduction in cumulated depth, and that investors have shifted orders further up in the order book. The significant decrease in the effective spread for all ADV levels will reduce transaction cost for large orders. The economic implication is thus that large investors should not be worse of after this tick size reduction.

8.4 HYPOTHESIS 4: ORDER EXPOSURE

To see how the order exposure has changed after the tick size reduction, we will start by looking at the off-exchange order exposure. In Table 16 below, the average percentage of off-exchange trades before and after the event date are shown. As we can see, all the event groups face a decrease in the amount of off-exchange trades after the tick size reduction. This means that more trades are executed on-exchange than before. For the most liquid stocks, the off-exchange trades decreases by 34,1% and for the high and low volume stocks, the off-exchange trades are reduced by 27,9% and 20,3% respectively. However, only one of the event groups, the high volume stocks, is significant at the 1% level. The control groups on the contrary shows a very disperse pattern. Only the control group at the lowest price band level, 15-50 SEK, is significantly different from zero at the 5% level.

The insight from this is that for the high volume stocks, the on-exchange trade is higher after the tick size reduction. Hence, investor does not seem to increase their off-exchange trading after the tick size reduction. We can therefore reject hypothesis H4 that the number of off-exchange orders will increase following the tick size reduction. An explanation for this could be attributed to the market design. Since the Stockholm Stock Exchange is a pure limit order market, which is working without the specialist in comparison to the NYSE, thus the adverse selection problem should be less severe. The reason for this is that investors are not as exposed to the risk of being front-run by the specialists as on the NYSE.

Table 16 Average off-exchange trade

Off Exchange Trade (%)	*Pre*	*Post*	*Change*	*% Change*	N	*P-Value Paired t-test*		*P-Value Wilcoxon Sign Test*	
Most Liquid Stocks	4.56%	3.01%	-1.55%	-34.1%	4	0.465		0.715	
High Volume Stocks	2.88%	2.08%	-0.80%	-27.9%	11	0.001	***	0.008	***
Low Volume Stocks	3.09%	2.46%	-0.63%	-20.3%	12	0.297		0.182	
Control Group									
15-50 SEK	2.44%	1.80%	-0.65%	-26.5%	18	0.039	**	0.025	**
50-100 SEK	2.37%	2.32%	-0.05%	-2.1%	28	0.795		0.802	
150+ SEK	2.74%	2.95%	0.21%	7.7%	32	0.416		0.421	
High Volume	2.02%	2.15%	0.13%	6.5%	49	0.344		0.496	
Low Volume	3.11%	2.76%	-0.35%	-11.1%	33	0.218		0.183	

*** Significant at the 1% level **Significant at the 5% level *Significant at the 10% level

Table 16 provides the off-exchange trade, which includes all trades that is not matched automatically in the equity market to the current market price available. The percentage of off-exchange trades' pre, post, the change pre-to-post, the sample size and test statistics are all shown.

- **Summary 8.4:** We find evidence that the tick size reduction do not cause a reduction in order exposure, i.e. the number of off-exchange orders do not increase. The economic intuition is that investor does not seem to change their behavior in order to protect themselves from trading with informed traders, which previous research has raised concerns about.

8.5 HYPOTHESIS 5: LIQUIDITY SUPPLY

As previous studies have documented as well as the results from section 8.1, 8.2, and 8.3 the conflicting effects of reduced spread as well as reduced breadth and depth causes difficulties to determine the overall impact of the tick size reduction upon liquidity. As we discussed in section 7.2.5, a decrease (increase) in the breadth-to-spread ratio would indicate that breadth is declining (increasing) more than spreads on average, or more intuitively, that breadth is becoming more (less) costly. The results for the breadth-to-spread analysis are presented in Appendix 7.

Since the regular breadth measure is not adjusting for the increase in the order book levels, the modified breadth measure is more adequate from a pre-post comparison perspective. Hence, by looking at the modified (static and dynamic) breadth-to-spread ratio we found that the changes for the event groups are consistently larger than for the control groups. For the most liquid stocks, the modified static breadth-to-spread ratio is increasing by 54,50% and the

modified dynamic breadth-to-spread ratio by 90,97%. However, the significance level is low due to the small sample size.

For the high volume stocks, the modified static and modified dynamic breadth-to-spread ratio has increased by 50,34% and 19,05% respectively. The results are both statically significant at the 5% level. Regarding the low volume stocks, the modified static and modified dynamic breadth-to-spread ratio has increased by 57,12% and 4,62% respectively. The increase for the static version is significant at the 1% level. The control groups show smaller increases or even decreases, hence the increase in breadth-to-spread ratio seems larger for the event groups than for the control groups.

Thus, the economic interpretation due to an increase in breadth-to-spread ratio is that the spread must decrease more than the breadth, implying that breadth becomes less costly. This is in line with previous findings by Bacidore (1997) and we can therefore conclude that after the tick size reduction, the market quality, in terms of liquidity supply, have improved. Therefore, we do not reject hypothesis H5 that a reduction in tick size will improve liquidity supply.

- **Summary 8.5:** We find evidence that the tick size reduction causes an increase in the breadth-to-spread ratio, hence breadth becomes less costly. The economic intuition is therefore that the reduction in tick size will improve the overall liquidity supply.

8.6 HYPOTHESIS 6: VOLATILITY

The outcome of the intraday return volatility difference before and after the event date is illustrated in Table 17 below. The result shows that the volatility is reduced for all event groups. For the most liquid stocks, the volatility is reduced by 23,1% after the tick size reduction and for the high and low volume stocks, volatility is reduced by 9,9% and 4,1% respectively. However, the significance level is rather low. The most liquid stocks and the high volume stocks are only significant at the 10% level, while the low volume stocks are not statically significant different from zero at all.

The control groups show opposite outcomes in the majority of the cases. None of the results are significantly different from zero as the magnitude of the changes is very low. Hence, the conclusion from this is that the intraday return volatility seems to decline for the high volume

stocks, with enhanced market quality as a result. No conclusive result is found for the low volume stocks.

From this, we can conclude that we found weak evidence for hypothesis H6 for both the most liquid stocks and high volume stocks. However, for the low volume stocks, we reject the hypothesis. From the discussion in section 4.6, these results are not surprising since there are arguments both for and against a decrease in volatility after a reduction in tick size. However, for the most liquid stocks and high volume stocks, the arguments for a decrease seems to dominate those against, hence the increase in volatility caused by the reduction in cumulated depth is off-set by more correctly priced stocks due to the finer price grid.

Table 17 Average (return) volatility

Average Return Volatility (%)	***Pre***	***Post***	***Change***	***% Change***	**N**	***P-Value Paired t-test***		***P-Value Wilcoxon Sign Test***	
Most Liquid Stocks	0.18%	0.14%	-0.042%	-23.1%	4	0.043	**	0.068	*
High Volume Stocks	0.20%	0.18%	-0.020%	-9.9%	11	0.076	*	0.091	*
Low Volume Stocks	0.19%	0.18%	-0.008%	-4.1%	12	0.619		0.388	
Control Group									
15-50 SEK	0.26%	0.24%	-0.013%	-5.3%	18	0.384		0.500	
50-100 SEK	0.20%	0.20%	0.003%	1.6%	28	0.813		0.524	
150+ SEK	0.17%	0.18%	0.003%	1.7%	32	0.557		0.627	
High Volume	0.20%	0.21%	0.002%	1.2%	49	0.573		0.800	
Low Volume	0.21%	0.20%	-0.007%	-3.2%	33	0.619		0.993	
*** Significant at the 1% level			**Significant at the 5% level			*Significant at the 10% level			

Table 17 *provides the average return volatility, which is simply measured as the variance of the stock returns, before and after the event date.*

- **Summary 8.6:** We find evidence that the tick size reduction reduces the return volatility for the high volume stocks. No effect is found on low volume stocks. The economic implication of this is that market quality should increase for the high volume stocks due to the reduction in volatility following the reduction in tick size.

8.7 SUMMARY AND DISCUSSION OF RESULTS

Our hypothesis formulation reveals an empirical evidence of enhanced market quality, due to improved liquidity supply and decreased volatility. Table 18 provides a summary of our results and our hypothesis. As previously described in our hypotheses discussion (section 5), our main hypotheses are hypothesis 5 (liquidity supply) and 6 (volatility), which both are our proxies for market quality.

Table 18 Summary of result

Hypotheses	**Result**
H1 (a): Reduction in minimum tick size will lead to reduction in the bid-ask spread.	*Not Rejected*
H1 (b): Reduction in minimum tick size will lead to reduction in the bid-ask spread for the stocks that previously had an average spread that was 1,10 times the minimum tick size or less.	*Not Rejected*
H2 (a): Reduction in minimum tick size will lead to a reduction in market breadth.	*Not Rejected*
H2 (b): Reduction in minimum tick size will lead to a reduction in modified market breadth.	*Not Rejected for High Volume Stocks.* *Rejected for Low Volume Stocks*
H3: A smaller tick size will reduce the cumulated depth, i.e. number of orders available throughout the order book, and therefore increase the transaction costs of large orders	*Inconclusive*
H4: A reduction in the minimum tick size will reduce the level of order exposure, i.e. the number of off-exchange orders will increase	*Reject*
H5: A reduction in the minimum tick size will improve the market quality in terms of liquidity supply	*Not Rejected*
H6: A reduction in tick size will enforce less volatility and thereby increase market quality	*Not Rejected for High Volume Stocks* *Rejected for Low Volume Stocks*

Table 18 shows a summary of the results of our hypotheses.

Our results are similar to previous studies on the subject, and particular to that of Niemeyer and Sandås (1994) who also studied how tick size affected the Stockholm Stock Exchange. Similar to our results, their conclusion was that a decrease in tick size lowers the bid-ask spread and the market breadth (depth). In addition, they raised concern that this should benefit small investors, since they could take advantage of the smaller bid-ask spread, but that the reduction in breadth (depth) could offset the gains by the reduced bid-ask spread for larger investors. Our results confirms this as well but since the reduction in effective spread are very large, we believe that large investors should not be worse off. Finally, for the high volume stocks, we found a reduction in volatility, which should be seen as an improvement in market quality

In previous research (section 4), we can observe a differences between the North American and non-North American studies regarding the effects of a tick size reduction on the liquidity supply. In line with previous studies outside North America, we find an increase in liquidity supply, which differs from the majority of the studies on the North American exchanges. The difference is likely to be related to the exchange specific market design, and the magnitude of the tick size change. As earlier described previously, the front-running problem should not be as severe on a pure limit order market compared to a dealer market. Furthermore, the tick size reduction on the SSE is smaller in magnitude than the decimalization of the North American exchanges, where the tick size was reduced from 1/16 of a dollar to 1/100 of a dollar. There are reasons to believe that the recent tick size change on SSE should have moved the current tick size closer to its optimum level.

Finally, the economic incentives for an investor following this tick size reduction is mostly related to the large decrease in bid-ask spread. For an investor who buys a small amount of shares in a liquid stock, the economic saving in terms of trading costs should be approximately equal to half the reduced spread times the number of shares bought. However, as the rest of the components of liquidity, as well as the volatility measure, changes in different direction following this tick size reduction, the actual saving of trading cost is estimated to slightly deviate from the decrease of the quoted bid-ask spread. The magnitude of the saving for various stocks independently is thus dependent upon the liquidity supply, volatility, and the related price band, before and after this tick size change.

9. ROBUSTNESS ANALYSIS

In order to better compare the event groups with the control groups, and test if our results are robust, we have performed a robustness analysis. This will provide us with evidence on conditional relations between the event and control groups. Hence, we will compare the pre-to-post difference of the event groups with the same pre-to-post difference for the control groups, and test if this difference is significant. This will help us to verify our results from section 8. We will use a probit regression model, where the dependent variable will be equal to 1 for those stocks who have experience a tick size change (event groups) and 0 for those have not change the tick size (control groups). We will then regress this binary dependent variable on the various types of parameters (spread, breadth, ADV/trade frequency, off-exchange trade, and breadth/spread ratio) that we used as proxy for liquidity. Since the dependent variable is binary, we need to transform each of the independent variables by using the cumulative distribution function. Based on this, we will estimate the following regression model:

$$\begin{aligned}\Pr(TickChange_i = 1) = F(&\beta_1 Spread_i + \beta_2 StaticBreadth_i + \beta_3 StaticModifiedBreadth_i + \\ &+ \beta_4 DynamicBreadth_i + \beta_5 DynamicModifiedBreadth_i + \beta_6 Volatility_i + \\ &+ \beta_7 ADV/TradeFrequency_i + \beta_8 OffExchangeTrade_i + \beta_9 StaticBreadth/Spread_i + \\ &+ \beta_{10} StaticModifiedBreadth/Spread_i + \beta_{11} DynamicBreadth/Spread_i + \\ &+ \beta_{12} DynamicModifiedBreadth/Spread_i)\end{aligned} \quad \textbf{(1)}$$

where $TickChange_i$ is a variable that equals 1 if company i stock have experience a tick size change and 0 if the tick size is unchanged. F(.) is the cumulative distribution function of each stock based on the difference between the pre and post period of each of the independent variable (Pagano et. al., 1998). This implies that if there is a large negative difference pre-to-post for the event group (as with the spread) and no difference pre-to-post for the control group, the cumulative distribution function value will be close to zero (see Appendix 8 for further description). On the other hand, if there is a large positive difference pre-to-post for the event group and no difference for the control group, the cumulative distribution value will be close to one. Hence, if there is a significant difference between the event and control group, the regression coefficient should be statistical negatively different from zero for a negative difference and statically positively different from zero for positive difference.

However, since there are very large correlations among many of these independent variables, the results from this regression, equation (1) become very unreliable (see Appendix 9). So to increase the power of the test, we will divide the lowest correlated independent variables in pairs of two. Hence equation (1) will be split in 6 new regressions with 2 independent variables in each regression. The regression results are shown in Table 19 to Table 24 below.

$$\Pr(TickChange_i = 1) = F(\beta_2 StaticBreadth_i + \beta_{12} DynamicModifiedBreadth / Spread_i) \quad \textbf{(2)}$$

Table 19 Regression Results – Equation (2)

	High Volume Stocks		Low Volume Stocks	
	B_2	**B_{12}**	**B_2**	**B_{12}**
Predicted Sign	↓	↑	↓	→
Coefficient Estimate	**-1.392**	**0.587**	**-1.473**	**0.367**
Standard Error	0.131	0.207	0.450	0.225
P-Value	*0.000*	*0.006*	*0.002*	*0.110*

Table 19 shows the regression results for equation (2) for the high and low volume stocks. The corresponding coefficient estimate, standard error, and probability value are shown.

$$\Pr(TickChange_i = 1) = F(\beta_1 Spread_i + \beta_4 DynamicBreadth / Spread_i) \quad \textbf{(3)}$$

Table 20 Regression Results – Equation (3)

	High Volume Stocks		Low Volume Stocks	
	B_1	**B_4**	**B_1**	**B_4**
Predicted Sign	↓	↓	↓	↓
Coefficient Estimate	**-1.172**	**-0.493**	**-0.471**	**-0.425**
Standard Error	0.124	0.244	0.203	0.223
P-Value	*0.000*	*0.048*	*0.025*	*0.065*

Table 20 shows the regression results for equation (3) for the high and low volume stocks. The corresponding coefficient estimate, standard error, and probability value are shown.

$$\Pr(TickChange_i = 1) = F(\beta_3 StaticModifiedBreadth_i + \beta_6 Volatility_i) \quad \textbf{(4)}$$

Table 21 Regression Results – Equation (4)

	High Volume Stocks		Low Volume Stocks	
	B_3	**B_6**	**B_3**	**B_6**
Predicted Sign	↓	↓	→	→
Coefficient Estimate	**-1.053**	**-0.522**	**0.235**	**-0.227**
Standard Error	0.173	0.193	0.402	0.244
P-Value	*0.000*	*0.009*	*0.562*	*0.358*

Table 21 shows the regression results for equation (4) for the high and low volume stocks. The corresponding coefficient estimate, standard error, and probability value are shown.

$$\Pr(TickChange_i = 1) = F(\beta_4 DynamicBreadth_i + \beta_9 StaticBreadth / Spread) \quad \textbf{(5)}$$

Table 22 Regression Results – Equation (5)

	High Volume Stocks		Low Volume Stocks	
	B_4	**B_9**	**B_4**	**B_9**
Predicted Sign	↓	↓	↓	→
Coefficient Estimate	**-1.618**	**-0.525**	**-0.488**	**-0.150**
Standard Error	0.294	0.189	0.214	0.456
P-Value	*0.000*	*0.008*	*0.028*	*0.745*

Table 22 shows the regression results for equation (5) for the high and low volume stocks. The corresponding coefficient estimate, standard error, and probability value are shown.

$$\Pr(TickChange_i = 1) = F(\beta_5 DynamicModifiedBreadth_i + \\ + \beta_{10} StaticModifiedBreadth / Spread_i) \quad \textbf{(6)}$$

Table 23 Regression Results – Equation (6)

	High Volume Stocks		Low Volume Stocks	
	B_5	**B_{10}**	**B_5**	**B_{10}**
Predicted Sign	↓	↑	→	↑
Coefficient Estimate	**-0.777**	**0.636**	**-0.176**	**0.988**
Standard Error	0.424	*0.232*	0.224	0.448
P-Value	*0.073*	*0.008*	*0.438*	*0.033*

Table 23 shows the regression results for equation (6) for the high and low volume stocks. The corresponding coefficient estimate, standard error, and probability value are shown.

$$\Pr(TickChange_i = 1) = F(\beta_7 ADV / TradeFrequency_i + \beta_8 OffExchangeTrade_i) \quad \textbf{(7)}$$

Table 24 Regression Results – Equation (7)

	High Volume Stocks		Low Volume Stocks	
	B_7	**B_8**	**B_7**	**B_8**
Predicted Sign	→	↓	→	→
Coefficient Estimate	**-0.186**	**-0.769**	**-0.146**	**0.008**
Standard Error	0.252	0.195	0.234	0.227
P-Value	*0.463*	*0.000*	*0.536*	*0.972*

Table 24 shows the regression results for equation (6) for the high and low volume stocks. The corresponding coefficient estimate, standard error, and probability value are shown.

The interpretation of probit regression models is often confusing to many (Liao, 1994). Here, the results and especially the magnitude of coefficients are hard to interpret. The main point of the analysis is to test if the difference between the event group and control sample found in section 8 are robust. Therefore, the main concern is the sign of the coefficient and if it's

statistically different from zero or not. A statically significant negative (positive) beta coefficient implies that the independent variable has decreased (increased) in a larger extent for the event group than for the control group.

The conclusion from this robustness analysis is that our results from section 8 are robust, which means that the results should not be related to any market related factors, hence only to the tick size change itself. For the high volume stocks, all variables have their predicted sign. The significance level is also very high (5% or better) for all variables except for the dynamic modified market breadth (regression 6), which is significant at the 10% level. The only variable that is not statistically significant different from zero is the ADV-to-trade frequency variable. The reduction in volatility is significant at the 1% level, hence we do not reject hypothesis H6 for the high volume stocks.

For the low volume stocks, the results are somewhat different. Both the static and dynamic modified breadth measure is not statistically significant (regression 4 and 6), hence we reject hypothesis H2 (b) for the low volume stocks. The modified breadth-to-spread ratio is positive (regression 2 and 6); however the dynamic version is only significant at the 11% level (regression 2). Neither of the ADV-to-trade frequency or the off-exchange trade variable is significant different from zero. Finally, we reject hypothesis H6 for the low volume stocks since the volatility variable is not significantly different from zero (regression 4).

Finally, there are mainly two things that could affect the robustness of our results. First, in order to examine the various parameters affecting liquidity supply, we have used a set of proxies for liquidity. We have chosen the definition that we believe are the most accurate, however as we have shown (static versus dynamic market breadth), there could be some difference between the various types.

Second, since we use high frequency data, we have to divide the trading days in sub periods, which are in line with previous research. As we previously described, we divided the trading days in 15 minutes sub periods. This had implication on our sample selection since for low volume stocks; there were non sufficient amount of trades to provide reliable results. We therefore had to exclude the least frequently traded stocks, i.e. with coverage rate below 90%.

10. CONCLUSION

On September 25th, 2006, OMX changed the tick size in a number of stocks trading at the Stockholm Stock Exchange (SSE). Our study shows what impact this particular tick size reduction has had upon market quality, defined in terms of liquidity supply and intraday volatility. We find that this tick size reduction has a positive effect on both the liquidity supply and volatility, and hence an overall positive effect on the market quality of the SSE, at least for the high volume stocks. For less frequently traded stocks, the results are not as strong as for the high volume stocks, implying that the tick size reduction have benefited high volume stocks in a higher extend than the low volume stocks.

In order to measure the liquidity supply, we have used a set of parameters, including the bid-ask spread, market breadth and depth, order exposure, and order size, as proxies. In line with previous research, we find a significant reduction in the bid-ask spread, market breadth and depth following the tick size reduction. In previous research, the trade-off between spread and breadth has been extensively discussed. We find that the decrease in bid-ask spread seem to dominate the decrease in market breadth. We also find a significant decrease in effective spread, hence large investors does not seem to be worse off. Finally, we find no change in investor's behavior regarding order exposure.

In summary, our overall conclusion is that this tick size reduction has improved the market quality of the SSE and should therefore benefit its investors, which could take advantage of the reduction in spreads and the improved liquidity supply. Our study has shown that tick size have an important role in order to facilitate an efficient capital market, hence tick size does matter!

Furthermore, since international stock markets have become more and more integrated, the competitiveness of SSE relative to other exchanges should have improved following the tick size reduction. The tick size reduction, in combination with the introduction of the new Nordic listing should benefit the companies listed at SSE. A more liquid market and an expanded investor base should at the end result in an overall reduction of the cost of capital for the listed firms.

10.1 FURTHER RESEARCH

Along with our studies about the tick size we have realized there is a plenty of aspects and angle of approaches to this field. A more in depth analysis could cover the trade-off between the timing risk and market impact of different order sizes in order to capture the impact of larger and smaller investors. Same starting point could be applied on market exposure were further researches might capture to which extent this will be affected, due to the different incentives of larger and smaller investors. Additionally approach is to do a cross-sectional comparison where we could compare firms with memberships in several markets, and thus compare if the impact on a certain market propagates to another. Finally, an interesting aspect is to discuss the current tick size reduction in the Swedish market in the light of the previous changes within the Nordic market, in order to capture their individual contribution on liquidity supply, volatility and transaction cost.

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APPENDIX 1 – SSE TRADE TYPE DESCRIPTION

Table 25 SSE trade type field description for equities (Source: Reuters)

TRADE TYPE	DESCRIPTION	VALUE IN FID 374
Automatic Order Matching	On-Exchange trading, used on the Equities and Fixed-Income Markets.	99
OX Standard	Off-Exchange trade. A trade concluded on standard market terms in respect of price, time of the trade and with standard delivery and settlement schedule.	125
OX Standard	Off-Exchange trade. A trade concluded on standard market terms in respect of price, time of the trade and with standard delivery and settlement schedule.	32
OX Standard average based	Off-Exchange trade. A trade based on average prices calculated and published by the stock exchange.	121
OX Standard average based	Off-Exchange trade. A trade based on average prices calculated and published by the stock exchange.	42
OX Non Standard settlement	Off-Exchange trade. A trade that deviates from the standard settlement and delivery period.	33
OX Option Expiration	Off-Exchange trade. Exercise of option in connection with delivery upon the expiry of option contracts.	34
OX Futures Expiration	Off-Exchange trade. Exchange of securities in connection with a previously established futures or forward contract.	38
Changed Market condition	Off-Exchange trade. Change of the spread in the order book from the time of the trade and the actual time the trade is reported.	35
Exchange granted trade	Off-Exchange trade. A trade pursuant to an individual or general authorization from the Norex Exchange(s).	36
Exchange of substitute mortgage bonds	Off-Exchange trade. A trade where a mortgage bond is exchanged.	44
Accumulated orders	Off-Exchange trade. An Order traded as several sub-orders, stretched over a period of time.	40
Loan transactions	Off-Exchange trade. A trade in which an instrument has been borrowed or lent.	39
Repurchase agreement	Off-Exchange trade. Agreement between two parties that regulates the lending and return of the same nominal amount of instruments.	43
Old trade	Off-Exchange trade. A trade which for technical reasons was not reported in time.	41
Excluding dividend rights	Off-Exchange trade. A trade in which the seller reserves the right to dividends or share issues.	37
Volume weighted average price	Off-Exchange trade. A trade which is based on more orders, and a number of sub-trades settled at an average price.	46
Cancelled trade	The trade is cancelled.	11

Table 25 shows how the on- and off-exchange relationship is categorized according to the field description and trading rules classified by tick data provider.

APPENDIX 2 – DESCRIPTIVE STATISTICS

Table 26 Descriptive statistics of the event group

Most Liquid Stocks	**Average Daily Volume**	**Average Midprice**	**One Tick Spreads (%)**
ERICSSON A	248 323	25.23	5.00%
ERICSSON B	141 472 540	25.27	100.00%
NORDEA BANK	9 438 984	95.21	100.00%
NOKIA SDB	3 116 493	146.02	100.00%
Average	**38 569 085**	**72.93**	**76.25%**
Standard Dev.	**68 709 657**	**58.84**	**47.50%**
Price Band 100-150 High Volume	**Average Daily Volume**	**Average Midprice**	**One Tick Spreads (%)**
ASSA ABLOY B	2 740 209	132.50	100.00%
ELECTROLUX B	3 762 148	119.61	100.00%
GETINGE AB	591 677	132.77	100.00%
JM	365 864	126.70	85.00%
OMX AB	1 071 881	124.99	85.00%
SKANSKA B	1 837 836	122.98	100.00%
SKF B	4 882 763	109.84	100.00%
SSAB B	307 283	136.53	20.00%
STORA ENSO R	992 004	111.55	65.00%
SWEDISH MATCH	2 070 185	120.40	100.00%
TRELLEBORG B	625 450	141.24	90.00%
Average	**1 749 755**	**125.37**	**85.91%**
Standard Dev.	**1 503 053**	**9.90**	**24.48%**
Price Band 100-150 Low Volume	**Average Daily Volume**	**Average Midprice**	**One Tick Spreads (%)**
ADDTECH	28 940	108.15	0.00%
ANGPANNEFOREN B	81 310	114.73	5.00%
AVANZA	77 340	119.65	5.00%
BILLERUD	110 124	112.15	30.00%
HAKON INVEST	48 872	122.98	10.00%
HALDEX AB	86 886	138.97	5.00%
INVIK & CO	36 391	124.58	5.00%
ORESUND	29 509	138.53	0.00%
PARTNER TECH	23 076	131.59	5.00%
PEAB B	82 101	122.78	30.00%
SKISTAR AB	45 233	125.44	10.00%
WIHLBORGS FAST	59 613	128.26	10.00%
Average	**59 116**	**123.98**	**9.58%**
Standard Dev.	**28 004**	**9.59**	**10.10%**

Table 26 shows the average daily volume, the average mid price, the percentage of one tick spreads for the event stocks including the most liquid, high and low volume stocks.

Table 27 Descriptive statistics of the control group

Price Band 15-50	**Average Daily Volume**	**Average Midprice**	**One Tick Spreads (%)**
ADDNODE AB	42 376	24.84	10.00%
AUDIODEV	31 313	19.75	0.00%
CONCORDIA B	72 092	47.14	0.00%
HIQ	381 452	35.55	5.00%
IBS B	235 703	23.96	0.00%
KLOVERN	116 326	23.78	0.00%
NORDNET	339 744	22.90	25.00%
NOVESTRA	54 797	21.70	0.00%
OBSERVER	245 182	33.24	0.00%
OLD MUTUAL PLC	530 012	22.81	25.00%
OXIGENE INC	71 497	27.63	0.00%
PA RESOURCES AB	856 610	43.65	15.00%
PROFFICE B	193 508	17.60	5.00%
READSOFT B	75 412	26.21	0.00%
SCAN MINING	312 085	18.81	5.00%
TELECA B	256 972	29.82	0.00%
WM-DATA B	6 647 524	26.11	100.00%
ZODIAK TV B	101 961	22.05	5.00%
Average	**586 920**	**27.09**	**10.83%**
Standard Dev.	**1 526 759**	**8.13**	**23.72%**
Price Band 50-100	**Average Daily Volume**	**Average Midprice**	**One Tick Spreads (%)**
ABB	2 537 552	99.33	85.00%
ACTIVE BIOTECH	68 607	75.46	0.00%
AXIS	132 595	67.46	5.00%
BILIA A	51 575	95.64	0.00%
CASTELLUM AB	292 277	81.30	5.00%
ENIRO	1 241 948	87.31	50.00%
GUNNEBO	76 733	74.44	10.00%
HUFVUDSTADEN A	101 269	60.87	10.00%
HUSQVARNA B	2 058 114	83.96	100.00%
INTRUM JUSTITIA	313 911	69.31	10.00%
KAUPTHING BANK	112 187	88.91	0.00%
KINNEVIK B	714 922	87.39	65.00%
KUNGSLEDEN	390 216	84.49	60.00%
LINDEX	807 828	95.65	20.00%
LUNDIN PETROLEUM	1 809 860	80.25	100.00%
MEKONOMEN B	31 810	87.33	0.00%
MICRONIC LASER S	182 634	71.56	0.00%
NEW WAVE GROUP	57 894	81.43	10.00%
NIBE INDUSTRIER	113 093	87.72	0.00%
ORC SOFTWARE	146 609	70.17	10.00%
SANDVIK	8 319 536	85.22	100.00%
SAS AB	210 358	94.78	5.00%
SECO TOOLS B	28 747	92.13	0.00%
SECTRA	90 930	66.24	5.00%
SEMCON AB	116 299	61.07	15.00%
TELE2 B	2 972 871	73.67	95.00%
TRANSCOM B	132 630	73.68	10.00%
WALLENSTAM B	55 517	103.91	5.00%
Average	**827 447**	**81.45**	**27.68%**
Standard Dev.	**1 678 713**	**11.54**	**36.75%**

Table 27 shows the average daily volume, the average mid price, the percentage of one tick spreads for the control stocks including all price bands, high and low volume stocks.

Table 28 Descriptive statistics of the control group

Price Band 150+	**Average Daily Volume**	**Average Midprice**	**One Tick Spreads (%)**
ALFA LAVAL	513 870	247.67	20.00%
AUTOLIV INC SDR	271 066	410.22	0.00%
ATLAS COPCO A	4 835 890	194.92	100.00%
ATLAS COPCO B	1 044 169	185.39	55.00%
AXFOOD	174 354	222.45	15.00%
ASTRA ZENECA	1 367 223	461.30	5.00%
CARDO	45 233	216.81	0.00%
GANT COMPANY	37 077	197.87	0.00%
HEXAGON AB B	114 808	260.35	5.00%
H & M B	2 147 637	298.36	100.00%
HOGANAS B	49 015	192.37	0.00%
HOLMEN B	303 917	313.68	15.00%
INDUSTRIV. A	62 280	222.62	10.00%
INDUSTRIV. C	80 620	211.76	10.00%
LUNDIN SDB	507 813	220.42	5.00%
LUNDBERGS B	22 224	386.95	0.00%
MILLICOM INTN	189 041	304.74	0.00%
MTG B	209 750	383.21	0.00%
MUNTERS	55 613	286.30	0.00%
NOBIA	171 323	244.27	20.00%
ORIFLAME COSMTCS	211 144	250.01	0.00%
SAAB B	142 439	184.69	15.00%
SCA B	1 114 818	329.29	95.00%
SCANIA A	563 086	419.39	0.00%
SCANIA B	2 490 114	415.44	70.00%
SEB A	3 424 557	195.98	95.00%
SEB C	11 720	188.73	0.00%
SHB A	3 616 882	195.16	100.00%
SHB B	22 482	196.67	5.00%
TIETOENATOR	302 937	208.32	0.00%
VOLVO A	184 232	443.25	0.00%
VOLVO B	2 493 788	431.90	100.00%
Average	**836 910**	**278.77**	**26.25%**
Standard Dev.	**1 249 320**	**91.70**	**38.40%**

Table 27 shows the average daily volume, the average mid price, the percentage of one tick spreads for the control stocks including all price bands, high and low volume stocks.

Table 29 Descriptive statistics of the control group

High Volume Control Stocks	**Average Daily Volume**	**Average Midprice**	**One Tick Spreads (%)**
ABB	2 537 552	99.33	85.00%
ACANDO B	228 295	12.22	0.00%
ALFA LAVAL	513 870	247.67	20.00%
ANOTO GROUP AB	415 879	12.56	0.00%
AUTOLIV INC SDR	271 066	410.22	0.00%
ATLAS COPCO A	4 835 890	194.92	100.00%
ATLAS COPCO B	1 044 169	185.39	55.00%
AXFOOD	174 354	222.45	15.00%
ASTRA ZENECA	1 367 223	461.30	5.00%
BIOINVENT INT	139 482	7.39	5.00%
CASTELLUM AB	292 277	81.30	5.00%
ENIRO	1 241 948	87.31	50.00%
H & M B	2 147 637	298.36	100.00%
HIQ	381 452	35.55	5.00%
HOLMEN B	303 917	313.68	15.00%
HUSQVARNA B	2 058 114	83.96	100.00%
IBS B	235 703	23.96	0.00%
INTRUM JUSTITIA	313 911	69.31	10.00%
KINNEVIK B	714 922	87.39	65.00%
KUNGSLEDEN	390 216	84.49	60.00%
LINDEX	807 828	95.65	20.00%
LUNDIN PETROLEUM	1 809 860	80.25	100.00%
LUNDIN SDB	507 813	220.42	5.00%
MILLICOM INTN	189 041	304.74	0.00%
MTG B	209 750	383.21	0.00%
NIBE INDUSTRIER	113 093	87.72	0.00%
NOBIA	171 323	244.27	20.00%
NORDNET	339 744	22.90	25.00%
OBSERVER	245 182	33.24	0.00%
OLD MUTUAL PLC	530 012	22.81	25.00%
ORIFLAME COSMTCS	211 144	250.01	0.00%
PA RESOURCES AB	856 610	43.65	15.00%
PROFFICE B	193 508	17.60	5.00%
SANDVIK	8 319 536	85.22	100.00%
SAS AB	210 358	94.78	5.00%
SCA B	1 114 818	329.29	95.00%
SCANIA A	563 086	419.39	0.00%
SCANIA B	2 490 114	415.44	70.00%
SCAN MINING	312 085	18.81	5.00%
SEB A	3 424 557	195.98	95.00%
SHB A	3 616 882	195.16	100.00%
TELELOGIC	1 768 571	13.34	35.00%
TELECA B	256 972	29.82	0.00%
TELE2 B	2 972 871	73.67	95.00%
TIETOENATOR	302 937	208.32	0.00%
TRANSCOM B	132 630	73.68	10.00%
WM-DATA B	6 647 524	26.11	100.00%
VOLVO A	184 232	443.25	0.00%
VOLVO B	2 493 788	431.90	100.00%
Average	**1 236 811**	**160.80**	**35.10%**
Standard Dev.	**1 708 211**	**141.77**	**40.03%**

Table 27 shows the average daily volume, the average mid price, the percentage of one tick spreads for the control stocks including all price bands, high and low volume stocks.

Table 30 Descriptive statistics of the control group

Low Volume Control Stocks	**Average Daily Volume**	**Average Midprice**	**One Tick Spreads (%)**
ACTIVE BIOTECH	68 607	75.46	0.00%
ADDNODE AB	42 376	24.84	10.00%
AUDIODEV	31 313	19.75	0.00%
AXIS	132 595	67.46	5.00%
BILIA A	51 575	95.64	0.00%
CARDO	45 233	216.81	0.00%
CONCORDIA B	72 092	47.14	0.00%
GANT COMPANY	37 077	197.87	0.00%
GUNNEBO	76 733	74.44	10.00%
HEXAGON AB B	114 808	260.35	5.00%
HOGANAS B	49 015	192.37	0.00%
HUFVUDSTADEN A	101 269	60.87	10.00%
INDUSTRIV. A	62 280	222.62	10.00%
INDUSTRIV. C	80 620	211.76	10.00%
KAUPTHING BANK	112 187	88.91	0.00%
KLOVERN	116 326	23.78	0.00%
LUNDBERGS B	22 224	386.95	0.00%
MEKONOMEN B	31 810	87.33	0.00%
MICRONIC LASER S	182 634	71.56	0.00%
MUNTERS	55 613	286.30	0.00%
NEW WAVE GROUP	57 894	81.43	10.00%
NOVESTRA	54 797	21.70	0.00%
ORC SOFTWARE	146 609	70.17	10.00%
OXIGENE INC	71 497	27.63	0.00%
READSOFT B	75 412	26.21	0.00%
SAAB B	142 439	184.69	15.00%
SEB C	11 720	188.73	0.00%
SECO TOOLS B	28 747	92.13	0.00%
SECTRA	90 930	66.24	5.00%
SEMCON AB	116 299	61.07	15.00%
SHB B	22 482	196.67	5.00%
WALLENSTAM B	55 517	103.91	5.00%
ZODIAK TV B	101 961	22.05	5.00%
Average	**74 627**	**116.81**	**3.94%**
Standard Dev.	**41 236**	**91.79**	**4.96%**

Table 27 shows the average daily volume, the average mid price, the percentage of one tick spreads for the control stocks including all price bands, high and low volume stocks.

APPENDIX 3 – RETURN VOLATILITY

$r_{it}^{s} = \ln\left(p_{it}^{s} / p_{it}^{s-1}\right)$, where p_{it}^{s} is the last price paid in s^{th} 15-minute interval.

Then we will use the following equations to calculate the return volatility σ_s^2:

$\sigma_{is}^2 = \frac{\sum_{t=1}^{T}\left(r_{it}^{s} - \bar{r}_i^{s}\right)^2}{(T-1)}$, $\bar{r}_i^{s} = \frac{\left(\sum_{t=1}^{T} r_{it}^{s}\right)}{T}$, and $\sigma_s^2 = \frac{\sum_{i-1}^{N}\sigma_i^{s}}{N}$, where T is the number of sample days for stock *i* and N is the number of sample firms.

APPENDIX 4 – EXCLUDED STOCKS: TOO LOW COVERAGE

Table 31 Excluded stocks – Too low coverage

Too Low Coverage <50 Price band	*Too Low Coverage 50-100 Price band*
ACADEMEDIA B	BALDER B
A-COM	BEIJER ALMA B
ACSC	BONG LJUNGDAHL
BERGS TIMBER B	CATENA AB
BETSSON B	CONNECTA
BIOGAIA	ELEKTRGRUPP BK B
BIOLIN AB	EXPANDA
BORAS WAFVERI B	FENIX B
BRIO B	HUMAN CARE H C
BTS GROUP B	JEEVES INFO SYS
CONSILIUM B	LUXONEN SDR
CTT SYSTEM	MIDWAY B
CYBERCOM	MEDIVIR
DIOS FAST AB	NEFAB B
DUROC B	NETONNET
FAST PARTNER	NOLATO B
HAVSFRUN B	PROFILGRUPPEN B
INTELLECTA B	NOTE
LAGERCRANTZ	SARDUS
NEONET	SINTERCAST A
NOVOTEK B	SVEDBERG/DALSTOR
ORTIVUS AB B	SVOLDER B
PROACT IT	TRACTION B
PREVAS B	TRANSCOM A
PROBI AB	VBG B
RORVIK TIMBER B	
SALUS ANSVAR B	
SCRIBONA B	
SKANDITEK IND	
THALAMUS NETWORK	
TICKET TRAVEL	
VITROLIFE	
WILH. SON B	

Too Low Coverage 100-150 Price band	*Too Low Coverage 150+ Price band*
BEIJER ELECTRON	ACTIVE CAPITAL B
BERG & BEVING B	BALLINGSLOV
BRINOVA FAST	G&L BEIJER AB B
ELANDERS B	CLOETTA FAZER B
FAGERHULT	GEVEKO B
HL DISPLAY B	GUNNEBO IND
HOME PROP	HAGSTROM&QVIBERG
KABE B	HEBA B
KAROLIN MACHINE	LATOUR B
RAYSEARCH LAB B	LJUNGBERGGRUP B
SKF A	MEDICOVER HLDG
STORA ENSO A	MTG A
XANO INDUSTRI B	NOBEL BIOC. HLDG
XPONCARD GROUP	OEM INTL B
	OREXO AB
	PERGO
	POOLIA B
	SAKI
	SCA A
	SWECO B
	STUDSVIK AB
	WESTERGYLLEN B

Table 31 shows the excluded stocks due to too low coverage.

APPENDIX 5 – DATA STATISTICS

Table 32 Data statistics

Number of stocks...	
Initial set (21/8 2006)	302
Collected for intra-day analysis	262
Excluded due to insufficient data	53
Included in analysis	207
Orders Collected	40 899 377

Number of parameters...	
Initial set stored in SQL	60
Estimated for analysis	42
Utilized in thesis	29

Table 32 shows data statistics including number of orders collected

APPENDIX 6 – EXCLUDED STOCKS: CROSSED PRICE BAND

Table 33 Excluded stocks – Crossed price band

Crossed Price Band <50	*Crossed Price Band 50-100*
BOSS MEDIA	KAPPAHL HLD
KARO BIO	LAWSON SOFT
EPICEPT CORP	
FINGERPRINT B	*Crossed Price Band 150+*
KNOW IT	BROSTROM B
OPCON	FABEGE
TELIASONERA	INVESTOR A
	INVESTOR B
Crossed Price Band 100-150	NCC A
BOLIDEN AB	NCC B
CAPIO	RETAIL AND BRAND
CLAS OHLSON B	TRADEDOUBLER
D CARNEGIE	UNIBET GRP
DIAMYD MEDICAL	VOSTOK NAFTA SDB
ELEKTA B	
HEMTEX	
INDUTRADE AB	
MEDA	
Q-MED	
PROTECT DATA	
RATOS B	
SECURITAS B	
SSAB A	

Table 33 shows excluded stocks due too crossing between price bands.

APPENDIX 7 – BREADTH-TO-SPREAD RATIO

Table 34 Static Breadth to Spread Ratio

Static Breadth to Spread Ratio	*Pre*	*Post*	*Change*	*% Change*	N	*P-Value Paired t-test*		*P-Value Wilcoxon Sign Test*	
Most Liquid Stocks	0.206	0.191	-0.016	-7.6%	3	0.712		0.465	
High Volume Stocks	0.071	0.070	-0.002	-2.1%	10	0.654		0.575	
Low Volume Stocks	0.021	0.021	0.000	-0.3%	11	0.977		0.583	
Control Group									
15-50 SEK	0.027	0.029	0.002	8.0%	16	0.454		0.679	
50-100 SEK	0.031	0.039	0.008	26.1%	27	0.008	***	0.013	**
150+ SEK	0.054	0.068	0.014	26.0%	32	0.030	**	0.021	**
High Volume	0.048	0.061	0.013	26.4%	47	0.003	***	0.001	***
Low Volume	0.026	0.030	0.004	13.6%	32	0.235		0.654	
*** *Significant at the 1% level*			**Significant at the 5% level*			*Significant at the 10% level*			

Table 34 *provides the static breadth to spread ratio before and after the event date as of 25th September 2006. The breadth to spread ratio pre, post, and the change pre-to-post of the tick size change are showed. The percentage change pre-to-post is also shown. The sample size (N) and the statically tests are also provided.'*

Table 35 Static Modified Breadth to Spread Ratio

Static Modified Breadth to Spread Ratio	*Pre*	*Post*	*Change*	*% Change*	N	*P-Value Paired t-test*		*P-Value Wilcoxon Sign Test*	
Most Liquid Stocks	0.206	0.319	0.112	54.50%	3	0.134		0.068	*
High Volume Stocks	0.071	0.107	0.036	50.34%	10	0.001	***	0.005	***
Low Volume Stocks	0.021	0.032	0.012	57.12%	11	0.009	***	0.002	***
Control Group									
15-50 SEK	0.027	0.029	0.002	8.00%	16	0.454		0.679	
50-100 SEK	0.031	0.039	0.008	26.09%	27	0.008	***	0.013	**
150+ SEK	0.054	0.068	0.014	26.05%	32	0.030	**	0.021	**
High Volume	0.048	0.061	0.013	26.41%	47	0.003	***	0.001	***
Low Volume	0.026	0.030	0.004	13.61%	28	0.235		0.654	
*** Significant at the 1% level			**Significant at the 5% level			*Significant at the 10% level			

Table 35 provides the static modified breadth to spread ratio before and after the event date as of 25th September 2006. The breadth to spread ratio pre, post, and the change pre-to-post of the tick size change are showed. The percentage change pre-to-post is also shown. The sample size (N) and the statically tests are also provided.

Table 36 Dynamic Breadth to Spread Ratio

Dynamic Breadth to Spread Ratio	*Pre*	*Post*	*Change*	*% Change*	N	*P-Value Paired t-test*		*P-Value Wilcoxon Sign Test*	
Most Liquid Stocks	0.006	0.017	0.0108	167.0%	3	0.536		0.593	
High Volume Stocks	0.002	0.001	-0.0004	-21.8%	10	0.006	***	0.013	**
Low Volume Stocks	0.003	0.002	-0.0010	-34.8%	11	0.006	***	0.006	***
Control Group									
15-50 SEK	0.002	0.002	0.0001	4.5%	16	0.679		0.379	
50-100 SEK	0.002	0.002	-0.0002	-8.0%	26	0.454		0.200	
150+ SEK	0.003	0.002	-0.0004	-13.0%	32	0.247		0.005	***
High Volume	0.002	0.001	-0.0002	-14.0%	46	0.052	*	0.016	**
Low Volume	0.003	0.003	-0.0002	-5.4%	32	0.597		0.340	
*** Significant at the 1% level			**Significant at the 5% level			*Significant at the 10% level			

Table 36 provides the dynamic breadth to spread ratio before and after the event date as of 25th September 2006. The breadth to spread ratio pre, post, and the change pre-to-post of the tick size change are showed. The percentage change pre-to-post is also shown. The sample size (N) and the statically tests are also provided.

Table 37 Dynamic Modified Breadth to Spread Ratio

Dynamic Modified Breadth to Spread Ratio	*Pre*	*Post*	*Change*	*% Change*	N	*P-Value Paired t-test*		*P-Value Wilcoxon Sign Test*	
Most Liquid Stocks	0.006	0.012	0.0059	90.97%	3	0.352		0.109	
High Volume Stocks	0.002	0.002	0.0003	19.05%	10	0.033	**	0.022	**
Low Volume Stocks	0.003	0.003	0.0001	4.62%	11	0.597		0.657	
Control Group									
15-50 SEK	0.002	0.002	0.0001	4.5%	16	0.679		0.379	
50-100 SEK	0.002	0.002	-0.0002	-8.0%	26	0.454		0.200	
150+ SEK	0.003	0.002	-0.0004	-13.0%	32	0.247		0.005	***
High Volume	0.002	0.001	-0.0002	-14.0%	46	0.052	*	0.016	**
Low Volume	0.003	0.003	-0.0002	-5.4%	32	0.597		0.340	
*** Significant at the 1% level			**Significant at the 5% level			*Significant at the 10% level			

Table 37 provides the dynamic modified breadth to spread ratio before and after the event date as of 25th September 2006. The breadth to spread ratio pre, post, and the change pre-to-post of the tick size change are showed. The percentage change pre-to-post is also shown. The sample size (N) and the statically tests are also provided.

APPENDIX 8 – PROBIT REGRESSION DESCRIPTION

In order to investigate a setting where the dependent variable is discrete (binary) rather than continuous, we have used a probit regression model. The model is specified as follow:

$$\Pr ob(TickChange_i = 1) = F(\beta' x)$$

where F(.) is defined by the cumulative distribution function of each of the independent variables β'x. The dependent variable will take value 1 if the stock has changed its tick size and 0 otherwise. By taking the cumulative distribution function of each of the independent variables, the independent variable β'x for a particular stock will take a value between 1 and 0 dependent of its magnitude compared to the other stocks in the sample. If the independent variable is significantly larger (smaller) than the mean value for the sample, the cumulative distribution function F(Bx) should be close to one for larger values and (zero) for a (smaller) values (see Figure 7 below). In our case, where we are looking at differences pre to post for each of the independent variables, and since we expect zero difference pre-to-post for the control stocks (dependent variable = 0), F(Bx) should be close to 0,5 for the control stocks. For the event stocks, where the tick size has changed, the independent variables should take values different from zero; hence there should be a change pre-to-post. This implies that for large negative values of the independent variable (B'x) pre-to-post for, F(Bx) should be close to zero and for large positive values, F(Bx) should be close to one.

Figure 7 Model for a probability

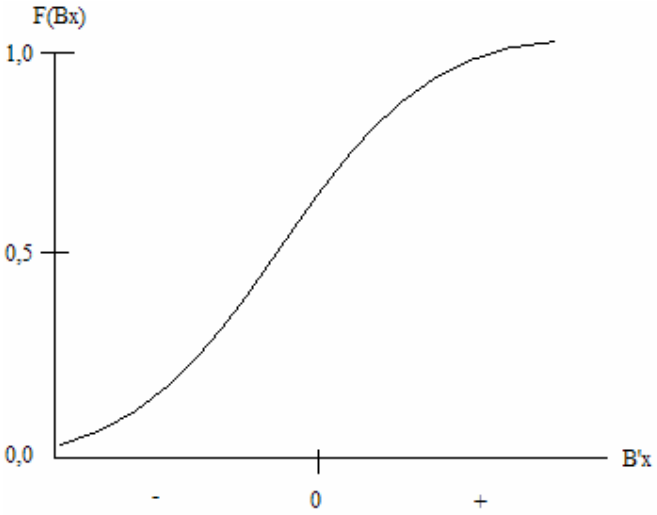

Figure 7 Model for a probability shows the continuous probability distribution of a standard normal variable.

APPENDIX 9 – REGRESSION RESULTS

Table 38 Regression Results, all stocks

All Stocks

	Spread	Static Breadth	Static Modified Breadth	Dynamic Breadth	Dynamic Modified Breadth	Volatility	ADV / Trade Frequency	Off-Exchange Trade	Static Breadth / Spread	Static Modified Breath / Spread	Dynamic Breadth / Spread	Dynamic Modified Breadth / Spread
		-1.408										**0.394**
2		0.152										0.143
		0.000										*0.007*
	-0.852										**-0.435**	
3	0.119										0.160	
	0.000										*0.008*	
			-0.724			**-0.448**						
4			0.183			0.158						
			0.000			*0.006*						
				-0.707					**-0.342**			
5				0.165					0.192			
				0.000					*0.078*			
					-0.297					**0.829**		
6					0.177					*0.182*		
					0.097					*0.000*		
							-0.218	**-0.352**				
7							0.174	0.153				
							0.212	*0.023*				

Table 38 shows the regression results based on all stocks including regression coefficient (bold), t-statistics, and probability value (italic) for each regression given in section 9. The regression number is given in the left column and the independent variables are shown in the top row.

Table 39 Correlation matrix independent variables, all stocks

	Spread	Static Breadth	Static Modified Breadth	Dynamic Breadth	Dynamic Modified Breadth	Volatility	ADV / Trade Frequency	Off-Exchange Trade	Static Breadth / Spread	Static Modified Breath / Spread	Dynamic Breadth / Spread
Static Breadth	0,266	1,000									
Static Modified Breadth	0,011	0,905	1,000								
Dynamic Breadth	0,332	0,326	0,232	1,000							
Dynamic Modified Breadth	0,232	0,219	0,223	0,945	1,000						
Volatility	0,323	0,197	0,046	-0,190	-0,269	1,000					
ADV / Trade Frequency	-0,179	0,247	0,257	-0,162	-0,243	0,067	1,000				
Off-Exchange Trade	0,336	0,197	0,180	0,264	0,227	-0,021	0,110	1,000			
Static Breadth / Spread	-0,186	0,587	0,732	0,098	0,060	-0,095	0,289	0,131	1,000		
Static Modified Breath / Spread	-0,538	-0,100	0,190	-0,084	-0,019	-0,327	0,111	-0,070	0,650	1,000	
Dynamic Breadth / Spread	0,046	0,211	0,197	0,844	0,830	-0,387	-0,125	0,139	0,133	0,033	1,000
Dynamic Modified Breadth / Spread	-0,265	-0,120	0,050	0,565	0,714	-0,525	-0,205	0,000	0,044	0,251	0,836

Table 39 shows the correlation matrix of each of the independent variables based on data from all stocks