High-frequency trading

– impacts of the introduction of the INET platform on NASDAQ OMX Stockholm

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Abstract

The use of high-frequency trading (HFT) has increased dramatically during the last decade. This paper examines the impact on turnover volume and volatility for the high volume shares within OMXS30 at NASDAQ OMX Stockholm (NOMX-St) and Burgundy multilateral trading facility (BURG) at the time of the introduction of the INET trading platform on February 8, 2010, on the NOMX-St stock exchange. Data containing trades and quotes from the Thomson Reuters Tick History database for NOMX-St and BURG has been analyzed for 330 trading days, between June 12, 2009 and September 30, 2010. The findings indicate that the launch of the INET platform has not increased turnover volume or volatility on NOMX-St, in fact, for the companies on the Large Cap included in this study, there has been a decrease in both of these measures.

Keywords: High-frequency trading, turnover volume, volatility

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Contents

1 Research area

For the past ten years we have seen a dramatic increase in the use of high-frequency trading (HFT) and algorithmic trading (AT) on the stock markets worldwide. Estimates has been made that HFT accounts for about 30% of equity trading in the U.K. and between 60-70% of the dollar volume at the U.S. capital markets (Zhang 2010, Foresight 2012). In Sweden, at the NASDAQ OMX Stockholm stock exchange (henceforth referred to as NOMX-St), HFT firms contribute with about 50% of the trading volume (NASDAQ OMX 2011).

In the late 1980s and 1990s more and more traders abandoned the traditional system with broker-dealers or floor brokers when they wanted to close a deal. With the traditional system, if for example a firm wanted to trade 30,000 IBM shares they would either get a broker-dealer or a floor trader. The broker-dealers would try to find a counterparty to execute the full deal, while a floor broker discretely would try to buy smaller parts from different counterparts during the course of the day, not to reveal his clients strategies. With the technological advancements during the 1990s more and more trades were being executed electronically, i.e. electronic trading (ET). Within ET algorithmic trading (AT) became a way for companies to replicate the work methods of the floor broker through a computer by buying smaller parts, for the best prices, spread out and at the same time keeping their competitors unaware of their strategies. (Hendershott et al. 2011)

The term AT most commonly refers to the execution process of a trading decision. If a portfolio manager today would decide to buy 30,000 Apple shares, the algorithm would optimize and execute the trade given to current market conditions. It could decide whether to execute the order aggressively (stock price close to market price) or passively (at a limit price removed from market price), whether the order should be in one trade or be split up in several smaller parts (for example 1,000 stocks in each trade). The decision however whether or not to buy or sell a stock, the portfolio allocation decision, is normally seen as exogenous and done by a human or another system. (Aldridge 2010)

HFT can be seen as computer systems making portfolio allocation decisions by using algorithms that perform quantitative analysis of large amounts of data. The HFT system detects trading opportunities and sends them to the execution algorithm without a portfolio manager involved in the decisions. In this scenario it would be the computer system that analyse the market and then send trading signals, for example to buy 30,000 Apple shares, to the execution algorithm that then would optimize and perform the trade. (Aldridge 2010)

To sum it up, ET can exist without AT, but AT requires ET. In the same way AT can exist without HFT, but HFT requires AT.

Since no humans are involved in the decision making or execution of a trade within HFT it is important that these systems are thoroughly tested and evaluated before they are launched. Normally firms do back testing on at least two years of intraday data to detect any potential pitfalls of the system. Handling this amount of data requires advanced skills in software and algorithm programming. When the system is up and running human supervision make sure that it stays within specified risk boundaries because at this speed huge losses can pile up fast. If problems are detected the supervisor needs to "pull the plug". (Aldridge 2010)

HFT systems can scan several markets at the same time to detect trading opportunities at a speed which is not possible for traditional traders. Therefore HFT firms often have a network of computers connected to multiple markets all over the world. The trading is performed at a very high speed and orders can be made and removed within microseconds. The HFT system predict how the price will change over time intervals as short as 3-4 seconds (Brogaard et al. 2012) and adjust their positions accordingly. To increase the speed to the market it is common among HFT firms to rent space in the computer halls at the stock exchanges to be able to have their computers very close to the exchanges, which is called co-location. For instance this is possible to do at the NASDAQ OMX data centers (NASDAQ OMX 2012*a*). Another opportunity for these firms is to sign an agreement with a brokerage company which already have a co-located server in place, and then have the brokerage company server to execute their trading. Because of the speed at which trades are made these firms normally have high turnover of capital but to reduce the risk close to zero net position overnight. (Aldridge 2010)

In theory according to the efficient market hypothesis asset prices on exchanges worldwide should reflect relevant information (Hull 2012). In practice it obviously takes different time for different markets to have their asset prices adjust to new information. One example of techniques used by HFT firms to generate profit is when their system identifies a trading opportunity that will affect multiple markets, e.g. an event that will affect a company listed on multiple stock exchanges. For a short time interval there will be an arbitrage opportunity until the effect of this information have propagated to all markets around the globe. This is an opportunity the HFT systems try to take advantage of and make profits by being the fastest market participant to trade on new available information. The profit on each trade might not be very big because of the competition, since there are many HFT firms active on multiple markets, but with several thousands of these each day it soon amounts to large numbers.

These firms also try to rapidly follow short-term trends that occur in the market, e.g. to follow a movement in a share, which is called positive feedback trading. This can be seen in contrast to trade against a strong trend.

Another way for HFT firms to profit is to take the role of Supplemental Liquidity Providers (SLPs) on markets. After the fall of Lehman Brothers in September 2008 U.S. stock exchanges introduced the SLP program, which means that the SLP is paid a fee, which is called rebate, for providing liquidity for shares on market exchanges. The thought behind this was to create a more stable market since there was a concern for shares that did not have enough liquidity (SEC 2008). At NOMX-St there is a rebate for firms when they provide liquidity to the market and they pay a lower fee for each of these trades.

These different strategies are often categorized into different subcategories within HFT. Hagströmer & Nordén (2012) use two different subcategories; market making and opportunistic HFT. Opportunistic strategies include arbitrage and trading on directional movements of the share price, while market makers exploit the rebates offered by markets. Market making strategies use their speed and low latency to be the first to place limit orders with the best quotes on both buy and sell side and their profit is the bid-ask spread. Since limit order books prioritize orders and execute them in the order they were placed, being only a couple of microseconds slower than other firms might mean the difference between having your order executed or not. Firms implementing market making strategies, in 2012, represented about 70% of the HFT trading volume in OMXS30, but only a couple of years ago they were not even represented at NOMX-St (Hagströmer & Nordén 2012). A reason could be that the previous SAXESS platform at NOMX-St was not suited for this strategy since market making is the strategy with the fastest turnover of capital and shortest holding periods of all HFT strategies. (Aldridge 2010).

2 Research problem

HFT has become a controversial topic in the finance industry. Firms involved in this form of trading have been accused of destabilizing markets and exacerbating price movement (Brogaard 2012). During the financial crisis 2008-2009 the volatility on the market reached high levels and the HFT firms were often blamed for contributing to that. At the same time HFT market participants defended themselves by claiming they provided important liquidity to the exchanges.

Renowned economist Paul Krugman claimed that HFT was an illustration of "social uselessness".

"The stock market is supposed to allocate capital to its most productive uses, for example by helping companies with good ideas raise money. But it's hard to see how traders who place their orders one-thirtieth of a second faster than anyone else do anything to improve that social function."[1]

Although this criticism is relevant it does not take into account possible effects that HFT has on market quality in terms of liquidity, price discovery or volatility, which are of great importance to traders.

The attention to the possible negative effects that HFT might have on the market has since then increased and in May 6, 2010, an event occurred that is often referred to as the *Flash Crash*. At the time Dow Jones Industrial Average (DJIA) fell about 1,000 points, and then a few minutes later had recovered. It was the largest decline in DJIA history for one day. Most studies agree that HFT did not instigate the crash but disagree whether HFT increased the plunge (Brogaard 2012). U.S. Securities and Exchange Commission (SEC) and the Commodity Futures Trading Commission (CFTC) made an investigation of what happened. Among the conclusions was that HFT contributed to the sharp plunge (SEC & CFTC 2010).

Currently, in the year of 2012, a lot of research is going on in the HFT field which tries to clarify HFT's positive and negative effects on the market by studying their impact on measures such as volatility, liquidity, price discovery, etc. Most likely governments worldwide will decide on more market regulations which will affect HFT activity. Therefore it is of great impor-

[1] New York Times, August 2, 2009. http://www.nytimes.com/2009/08/03/opinion/03krugman.html

tance to get a better understanding of what impact HFT has on the market so that these regulations does not affect the markets in a negative way.

3 Research question

The question this study will try to clarify is how the turnover volume and volatility for the high volume shares within OMXS30 at NOMX-St and Burgundy multilateral trading facility (BURG) have been affected by the launch of the INET trading system at NOMX-St on February 8, 2010.

After the upgrade from the previous SAXESS platform to INET on February 8, 2010, at the NOMX-St stock exchange, the speed for closing a share trade increased by about ten times from approximately 2.5 milliseconds to 250 microseconds (NASDAQ OMX Baltic 2010).

"We expect latency to go down to one tenth and throughput to be five times higher than before, providing the perfect environment for algorithmic and high frequency trading. The INET system is capable of handling one million messages per second at sub-250 microsecond average speeds, the fastest of any exchange or alternative trading system in the world." (NASDAQ OMX 2012*b*)

In accordance to the above statement by NASDAQ OMX our hypothesis is that this speed improvement was welcomed by HFT firms, who highly rely on speed. For a short period of time though we expect that HFT activity will decrease, since the algorithms needs to be optimized to fit with the new market conditions. Following (Hendershott et al. 2011) we will use a proxy to estimate the amount of HFT and by using the INET launch as an exogenous event this study will investigate positive and negative effects of the changed presence of HFT actors on the market. Focus will be on the impact on turnover volume and volatility for the high volume shares within OMXS30, which is a market value weighted index that consists of the 30 most traded stocks at the NOMX-St stock exchange.

The shares at BURG are included for benchmarking purposes. Also shares from the Mid Cap segment are used for benchmarking purposes since those shares have significantly lower volume in comparison to the shares in OMXS30, and since HFT firms want a rapid turnover of their inventories activity is less likely in shares with smaller market capitalization (Hendershott et al. 2011).

4 Aim of study

The aim of this study is to investigate if any effects, positive or negative, regarding the turnover volume and volatility, can be linked to the introduction of the INET trading system and to find empirical evidence of the impact of HFT and AT on NOMX-St and BURG.

5 Limitations

The study will focus on two main variables and have three support variables. The main variables are turnover volume and realized volatility. The support variables are number of messages, number of trades and trading volume kSEK[2]. In this study, these variables will be referred to as *main variables* and *support variables*. All of these variables will be referred to as *all variables*.

Since BURG launched trading of shares from NOMX-St on June 12, 2009, there were 165 trading days before the INET introduction on NOMX-St on February 8, 2010. An equal number of trading days after the INET introduction was included in the analysis, i.e. 165 trading days, which went to September 30, 2010, to get a symmetric interval of data around the INET introduction. Therefore the data material consist of 330 trading days, ranging between June 12, 2009 and September 30, 2010. In this study, the *whole period* refer to those 330 trading days. The actual trading days are listed in appendix D.

The shares analyzed in this study have been limited to the 28 shares that have been included in OMXS30 during the whole period. All these companies are located in the Large Cap segment and have high turnover volume. In this study, the *OMXS30* shares refer to those 28 shares. An equal number of shares, i.e. 28 shares, have been randomly selected among those 71 shares that have been included in the Mid Cap segment during the whole period. In this study, the *Mid Cap* shares refer to those 28 randomly selected shares. All of the selected shares from OMXS30 and Mid Cap are listed in appendix A.

In this study, OMXS30 at NOMX-St, OMXS30 at BURG, Mid Cap at NOMX-St and Mid Cap at BURG will be referred to as four different *indices*.

[2]The abbreviation *kSEK* will be used for SEK 1,000.

6 Literature review

There is a small but growing number of academic papers that address the issue of HFT and AT. Still most of them focus on how to measure the impact HFT and AT has had on market quality regarding volatility and liquidity.

The most common way to measure the effects of HFT on the market is by doing an event study where a change in market structure that is likely to change the intensity of HFT, is used as an exogenous event. Hendershott et al. (2011) uses The New York Stock Exchange automated quote dissemination in 2003, and find that, “for large stocks in particular, AT narrows spreads, reduces adverse selection, and reduces trade-related price discovery.” Boehmer et al. (2012) uses the first availability of co-location for studying the effects of liquidity, short-term volatility and informational efficiency of stock prices in 12,800 different shares in 39 exchanges between the years 2001-2009. Brogaard (2012) use the Short Sale Ban in the USA of September 2008 as exogenous event. Hagströmer & Nordén (2012) uses tick size changes for stocks within OMXS30 at NOMX-St as exogenous instrument for HFT activity.

While most of the studies conclude that HFT plays a positive role in the market, by increasing liquidity, mitigating volatility and more efficient price discovery, Boehmer et al. (2012) conclude that greater AT intensity, while improving liquidity and efficiency, does increase volatility. Some types of volatility can of course be desirable. When markets are more efficient prices adjust faster to new information, which could lead to higher volatility. If AT makes markets more efficient there could be a positive correlation with the desirable volatility connected to faster price discovery. To check this Boehmer et al. hold the informational efficiency level of each stock constant and still find that AT increase volatility.

The fear that HFT/AT creates excessive volatility could be connected to the fact that algorithms has to be pre-programmed to follow certain rules and therefore lack the instincts, judgement and diversity of traditional traders. If multiple algorithms has similar trading instructions they will react to market events in a similar way. This could lead to large amounts of more or less identical orders reaching the market at the same time and create excessive volatility. Chaboud et al. (2011) study this problem by looking at three currency pairs in the foreign exchange market but find no evidence that increased use of HFT/AT leads to excessive volatility. However, they do find that algorithmic strategies are less diverse and that algorithmic trades are more correlated than human trades. They also state that their time interval, 2006-2007, was a relatively calm period in the financial markets and that they are unsure how the algorithms would behave in a crisis.

Brogaard (2012) address the relationship between HFT and price volatility for 120 stocks between 2008 and 2009 by looking at how HFT activity and volatility co-move over different time intervals. His results show that HFT activity varies as volatility changes. During short time intervals HFT activity increase as volatility increase. For increase in longer term volatility the relationship is the reverse and HFT activity decrease. When this connection has been established Brogaard investigate two more issues. Does volatility induce HFT activity? Does HFT activity induce volatility? To answer the first question Brogaard look at two factors that affect price volatility, stock specific news and macro news. There were two distinct patterns; when stock specific news affect volatility HFT firms decrease their liquidity taking and when macro news affect price volatility HFT firms increase their liquidity taking. To answer the second question, whether HFT activity induce volatility, Brogaard uses the Short Sale Ban of September 2008, which removed some of the HFT activity from the market. The results shows that as HFT activity decreased the volatility increased. Another study that connect volatility with HFT activity was done by Hasbrouck & Saar (2011). Their study of high frequency strategies finds that short-term volatility decreases when the order book is more active.

To better understand the impact HFT has on volatility there is a need for more detailed data where individual firms can be identified and their trading patterns can be studied. To our knowledge only two studies so far have been able to work with that kind of data; Kirilenko et al. (2011) and Hagströmer & Nordén (2012).

Kirilenko et al. (2011) try to bring light on what triggered the *Flash Crash* on May 6, 2010, what role did HFT play and how did HFT firms trade on May 6, 2010? In a survey conducted by Market Strategies International after the *Flash Crash* more than 80% of the U.S. retail advisors believed that the crash was due to overconfidence on computers systems and HFT. By studying highly detailed data of the E-mini S&P 500 equity index futures market, where account id's of buyers and sellers as well as order type could be identified, Kirilenko et al. (2011) were able to analyze the trading behaviour of HFT firms on May 6, 2010, as well as three days prior to the crash. Their conclusions were that the crash was caused by an imbalance between fundamental buyers and fundamental sellers. Triggered by large sell programs from fundamental sellers, which normally would have been distributed over time and not all at once. HFTs initially picked up these sell orders and provided liquidity to the market, but since HFT firms don't want to hold large inventories their algorithms soon started selling of positions aggressively, thus competing with the fundamental sellers pushing the price down. Not until opportunistic and fundamental buyers started to buy aggressively did the downward spiral stop and instead started a rapid recovery in prices.

By having access to data directly from NOMX-St Hagströmer & Nordén (2012) were able to study all messages entered into the INET system. Most importantly it gave them the opportunity to identify the different members of the exchange and study the patterns of their messages. This made it possible to separate and categorize different HFT strategies and measure impact on market quality. The results show that the largest part of HFT firms implement a market making strategy which brings liquidity to the market and also decreases volatility. The current proposition by the European Commission on market regulations would hit hard on HFT firms and market making would in most cases become unprofitable, removing important liquidity from the market and in turn increasing volatility.

An important development for HFT-firms during the 21th century has been the fragmentation of financial markets. The Markets in Financial Instruments Directive (MiFID), which was adopted by the European Parliament and Council in April 2004 and had to be implemented by all EU-member countries by November 2007, as well as the RegNMS in the U.S. (implemented in 2005), was created to foster fair competition, transparency and efficient markets for different types of trading platforms (Degryse 2009). Menkveld (2012) study how the rise of new high-tech entrant markets coincided with the rise of HFT. For the first few months after its launch the Chi-X platform only captured about 1-2% of the market share, but when a large global HFT-firm entered both the incumbent markets and the new entrant market Chi-X soon reached double digits. As of 2012, Chi-X is one of the largest equity markets in Europe with a market share of about 25%[3]. Menkveld conclude that one of the reasons for the correlation between the rise of new markets and HFT can be the speed and cost advantage that computer algorithms has over humans in scanning different markets. Prior to HFT the benefits of trading at different markets could not be captured, even if the new markets offered lower fees for trading and more advanced technical platforms, the search process was too costly and a single centralized market was prefered. This created high entry barriers for new markets.

[3]http://www.batstrading.co.uk/venue/market/all_market/

Most of the studies done on HFT have focused on the American markets and while they can serve as a guide for other markets there is a need to study HFT in different regions and markets to get a better understanding of its impacts. One study that does this, is the study conducted by Hagströmer & Nordén (2012) on the impact of HFT on NOMX-St. Their work is of great importance to the understanding of different HFT strategies and the impact on market quality, but focused on a short time interval of only two months (August 2011 and February 2012) and a small data set of stocks (the 30 stocks making up OMXS30).

This study will help to shed light on how the impact of HFT on NOMX-St has evolved over 330 trading days with the launch of the new trading platform INET as exogenous event in the middle of the interval. We will also use a larger data sample including 28 stocks from OMXS30 and 28 stocks from the Mid Cap segment in order to record differences between stocks with larger and smaller market capitalization. In addition, all stocks will be studied on two different platforms, NOMX-St and BURG, with different technological solutions and speed, which are of great importance to HFT firms.

Irene Aldridge's book *High-Frequency Trading* has also been used as a reference when conducting this study. It covers an in-depth background to HFT and AT as well as a vast number of different trading strategies, how to build and implement a HFT system, including mathematical models, data analyzes and potential pitfalls (Aldridge 2010). Though the book gives a good understanding of what HFT is and how it works it does not give any insight on the effects of HFT on the market. We will use this book only as a reference to some general background information on HFT.

7 Theoretical framework

7.1 Turnover volume

Share turnover volume is a way to measure liquidity by calculating the ratio of traded share volume and shares outstanding.

$$Turnover_{i,t} = \frac{\sum_{j=1}^{dt} Vol_{i,j}}{SO_{i,t}} \tag{7.1}$$

Where $Vol_{i,j}$ is the volume for share i on day j and $SO_{i,t}$ are the shares outstanding in the company i at the end of time t (Korajczyk & Sadka 2008). Generally speaking, higher turnover volume indicates a higher liquidity in the share. Liquidity measures how easy it is to buy or sell a share without moving the price of the share.

7.2 Volatility

Within financial theory volatility is a key concept and commonly used to measure financial risk.

Volatility for stocks is calculated by measuring the movement of the share return. Aldridge (2010) concludes that the return is the difference between the share price at two different times divided by the earlier price, which can be written as

$$R_t = \frac{P_t - P_{t-1}}{P_{t-1}} \tag{7.2}$$

R_t is the return for period t, P_t is the price at time t and P_{t-1} is the price one period before t. In financial analysis the log return is often preferred because returns are assumed to follow a normal distribution. Log returns can be written as

$$r_t = ln(R_t) = ln(P_t) - ln(P_{t-1}) \tag{7.3}$$

Where r_t is the log return at time t, $ln(P_t)$ is the logarithm of the price at time t and $ln(P_{t-1})$ is the logarithm of the price one period before time t.

Volatility, in its most simplistic form, can then be calculated as the variance of the log returns

$$\sigma^2 = \frac{1}{T}\sum_{t=1}^{T}(r_t - \mu)^2 \tag{7.4}$$

or as the standard deviation which is the squared root of the variance.

$$\sigma = \sqrt{\sigma^2} \tag{7.5}$$

There are several other more advanced ways of calculating and forecasting volatility but in this study the focus will be on realized volatility.

In 1999 Andersen et al. (2001) presented a way to measure volatility called realized volatility. The traditional way of measuring volatility with low frequency was on a monthly, weekly or daily basis. With the introduction of more frequent intraday data it became apparent that the traditional way of modeling volatility couldn't capture the intraday volatility in a satisfying way and models specified for intraday data failed to capture longer interdaily movements. And thus daily returns were still used to forecast daily volatility even when more frequent data was available (Andersen et al. 2001). As a result Andersen et al. (2001) developed the realized volatility method, which easily computes high frequency intraperiod returns. With the use of high frequency data for the calculation of volatility the importance of the mean μ decreases as the number of observations grows. Therefore Hasbrouck (2007) recommends that we set the μ equal to zero. This theory is utilized in realized volatility and realized volatility can be calculated by just summing up the squared log returns.

$$RV_t = \sum_{i=1}^{n} r_{t,i}^2 \tag{7.6}$$

Where realized volatility for time t is the sum of the squared logarithmic returns for share i at time t.

Even with high frequency data there are certain time intervals that are more interesting to look at than others. Andersen et al. (2001) recommends using so called volatility signature diagrams, which is a form of scatter plot, where volatility for different time intervals can be measured. The signature of the volatility shows the market microstructure. Normally the volatility is pretty constant up to a certain time, 10-20 minutes, and then increase or decrease as higher frequency observations are made, i.e. when we are moving in the left direction in figure 1. More liquid shares tend to have an increase in volatility as for higher frequencies while less liquid shares tend to have a decrease in volatility.

In the volatility signature diagram all of the shares from OMXS30 have an increase in volatility as observation frequency increases. Most of the increase starts at around five minutes and then grows as the sample time intervals become shorter, see figure 1. This indicates that the shares are liquid and that trades occur that move the price either up or down within one minute on a regular basis.

After observing the volatility signature diagrams we have decided to make volatility time series with the volatility measure for one and five minutes intervals for the entire period, see figure 15, 16, 17 and 18. This is a good way to easily identify trends. Time series diagrams for individual shares in OMXS30 and Mid Cap can be found in appendix B.

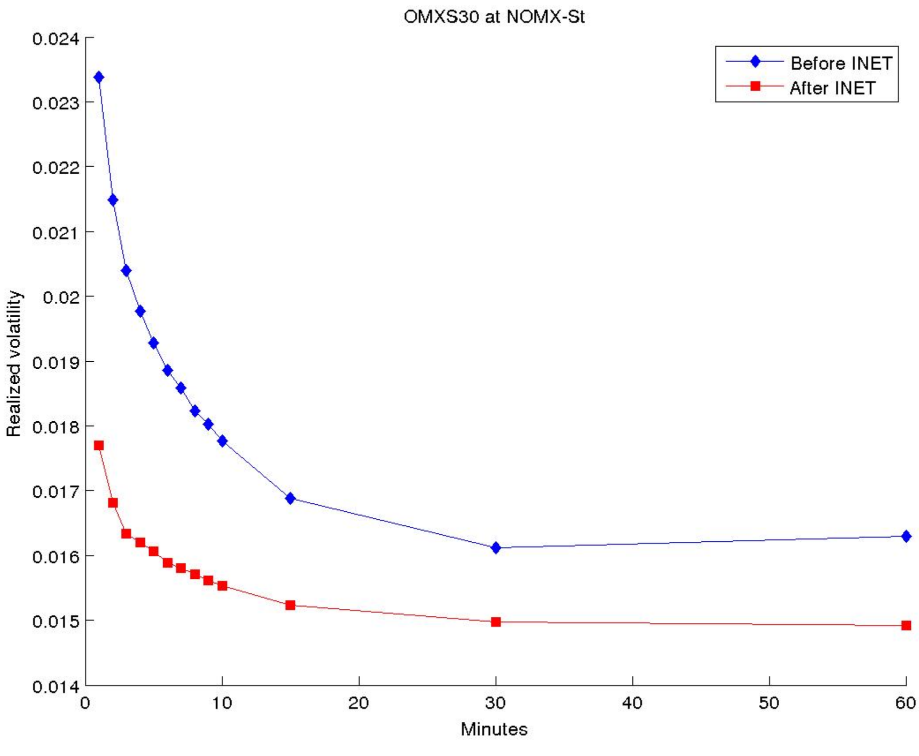

Figure 1: Volatility signature diagram for OMXS30 at NOMX-St.

8 Research design

The methodology that has been used is an event study with a quantitative approach, where the levels of turnover volume and volatility have been compared for the studied shares before and after the launch of the INET trading system on NOMX-St on February 8, 2010. These shares have been studied on both NOMX-St and BURG. To ensure reliability this study has used data from the Thomson Reuters Tick History database, in this way others can access the same data, replicate the calculations and get the same result.

First a mean test has been conducted to determine the change of levels in turnover volume and realized volatility during a period of 165 trading days before and after the event. The levels have also been compared between different months.

A t-test has been used to determine if the changes of levels for turnover volume and realized volatility before and after the event are statistically significant on a significance level of $\alpha = 0.005$. For realized volatility, this has been analyzed for both one and five minutes tick data of transaction prices. The null hypothesis has been that the levels have not been affected by the launch of the INET trading system.

This study has followed Hendershott et al. (2011) and used the number of messages, as well as the number of messages per trading volume kSEK, as a proxy to estimate the amount of HFT/AT. The number of messages entered into the order book are used for the calculations; trades, quotes and cancellations. It is important to note that this proxy not only captures increased presence of AT or HFT but also changes in strategies for these firms, e.g. if a firm wants their algorithms to split orders in several smaller orders or increase the use of orders submitted and canceled this will also have an impact on the proxy by increasing the number of messages.

To get a further understanding of some of the results from the quantitative research there has been correspondence with representatives from both NOMX-St and BURG. Because permission to use the correspondence as references in the study was not granted we have decided to ignore any of the information which was not already public.

9 Method

9.1 Data

Secondary data for the selected shares has been obtained from the Thomson Reuters Tick History database[4] for the whole period. The data are in the form of high frequency data files containing all trades and best quotes (TAQ) and files containing all updates in the order book with ten levels on each side (DEPTH). These files also include various market notifications of less importance for this study. Because of the immense amounts of data it allows for statistically precise observations.

All data together consist of well over one billion rows and uses 212 GB of storage. The TAQ-data consist of about 295 million rows during the whole period, with 171 million at NOMX-St and 124 million at BURG. It have a sheer 36 million trades and 259 million best quotes. The DEPTH-data consist of about 721 million rows during the whole period, with 488 million at NOMX-St and 233 million at BURG. Detailed statistics for the data are available in appendix C.

The data has been restructured for different analysis purposes by the use of Bash Unix shell scripting and regular expressions. Analysis of data and generation of diagrams has been performed with the software MATLAB R2011b (7.13.0.564). Additional analysis has been done in Microsoft Excel 2008.

The shares from OMXS30 to be used in this study has been identified by examining the index review archive at the NASDAQ OMX Nordic website[5]. The shares within the Mid Cap segment have been identified from the monthly equity trading reports presented at the NASDAQ OMX Nordic website[6]. The shares that have been included during the whole period of this study have been selected for both OMXS30 and Mid Cap. This resulted in 28 shares being selected from OMXS30 and 71 shares from Mid Cap. Then 28 shares from those 71 shares in Mid Cap was randomly selected by using the random formula in Microsoft Excel 2008.

Number of shares outstanding has been taken from the monthly equity trading reports presented at the NASDAQ OMX Nordic website[6]. Additional adjustments of dates within a certain month have been done by using in-

[4] http://tickhistory.thomsonreuters.com/

[5] http://nordic.nasdaqomxtrader.com/trading/indexes/index_review_archive/

[6] http://www.nasdaqomxnordic.com/nyheter/statistik/

formation from the annual reports presented at the company's websites. Adjustments have been made for eventual splits, buy-backs or new issues. The data for number of shares outstanding used in this study are available in appendix E.

Actual trading days, including occurrences of half day of trading, has been identified on NOMX-St by consulting the equity trading calendar at the NASDAQ OMX Nordic website[7]. During the whole period the following half day of trading were identified; October 30, 2009, January 5, 2010, April 1, 2010, April 30, 2010 and May 12, 2010. This information is needed when calculating period averages for the variables.

9.2 Calculations

All variables has been calculated for every day during the whole period, then averages for each month, the period before and after the INET introduction and for the full period.

Bash Unix shell scripting and regular expressions has been used to count the number of messages in the DEPTH-data and the number of trades in the TAQ-data. MATLAB has been used to count trading volume kSEK per day for each share in the TAQ-data. Only data appearing within exchange opening hours have been counted, i.e. 9 a.m. to 5:30 p.m. for normal trading days and 9 a.m. to 1 p.m. for half day of trading.

Market capitalization for each share has been calculated by multiplying the closing price of the share at NOMX-St for each trading day with the current number of shares outstanding for that particular day. If there were no trades available during a certain trading day then the last closing price available was used for that day. For six of the shares in Mid Cap at NOMX-St there has been occurrences of trading days with no trading during the whole period; ADDT B, BRIN B, FPAR, ITAB B, SYSR and VBG B. The data for market capitalization used in this study are available in appendix F.

For turnover volume, the total traded volume for each day were aggregated from the TAQ-data. If there were no trades available for a certain day during the studied period then the volume was set to zero for that particular day. Trades that did not affect the volume and turnover on the exchange were sorted out.

[7]http://nordic.nasdaqomxtrader.com/trading/tradinghours/

For volatility, all trades were picked out from the TAQ-data and sampled into one minute tick data with the following properties; date, time, opening price, high, low, closing price and traded volume for each minute. Only trades appearing within exchange opening hours have been counted, i.e. 9 a.m. to 5:30 p.m. for normal trading days and 9 a.m. to 1 p.m. for half day of trading. This was also done because, as Dacorogna (2001) explains, most econometric models are based to work with regular time intervals, presented monthly, weekly, daily, hourly and so on while the TAQ-files are presented in sequential ticks and not evenly over time.

When there were no trades available for a certain minute during the studied period that minute was filled with tick data containing the last available closing price and the volume set to zero to represent no volatility during that minute. If there were no trades available from the start of the studied period, i.e. June 12, 2009 at 9 a.m., those minutes was filled with tick data containing the closing price of the first available trade with the volume set to zero to represent no volatility during that minute.

Volatility has been calculated using the one minute tick data of transaction prices to first get the logarithmic returns, then realized volatility has been computed using equation (7.6). Realized volatility has been calculated on an intraday basis and then aggregated within days for all of the days in the time periods. For the volatility signature diagrams realized volatility has been calculated for 13 different time intervals ranging from one minute up to 60 minutes, an average for the days in each period has then been used. Since realized volatility is a variance measure and volatility often is presented as the standard deviation the square root has been taken from the variance.

10 Results

The focus for the results will be on the performance of the indices. Tables and diagrams for all variables of individual shares and indices are available in appendix B.

10.1 Proxies for HFT

10.1.1 Number of messages

As can be seen there is a steady growth in the number of messages for OMXS30 at NOMX-St before the INET launch. From around one million per day in June 2009 up to almost four million per day right before the INET introduction. As our hypothesis predicted, there is a huge drop in number of messages when the INET platform is launched, and the number of messages falls to the lowest levels during the two months right after the INET introduction.

For the period before INET the average was 1.67 million messages per day in OMXS30 at NOMX-St, and for the period after INET that number falls to 1.22 million messages per day, which is a 27% decrease. Concentrating on the weeks closest to the INET launch the numbers are clear with a peak of 3.96 million messages per day on January 28, 2010, to a record low of 891,000 messages per day on February 15, 2010, a 76% drop.

The number of messages for OMXS30 at BURG goes in the other direction with an increase for the period after the launch of the INET platform. Before the launch there was an average of 532,000 messages per day and after the launch this number has risen to 880,000 messages per day.

For Mid Cap at NOMX-St there is hardly any change in the number of messages before or after INET. With an average of 43,610 messages per day prior to INET and 43,580 messages per day after. For Mid Cap at BURG the average number of messages per day falls from 7,250 before to 4,980 after.

The number of messages are presented as time series to see the development for the whole period. Results for OMXS30 is presented in figure 2 and Mid Cap presented in figure 3. Relative development for all indices are presented in figure 4.

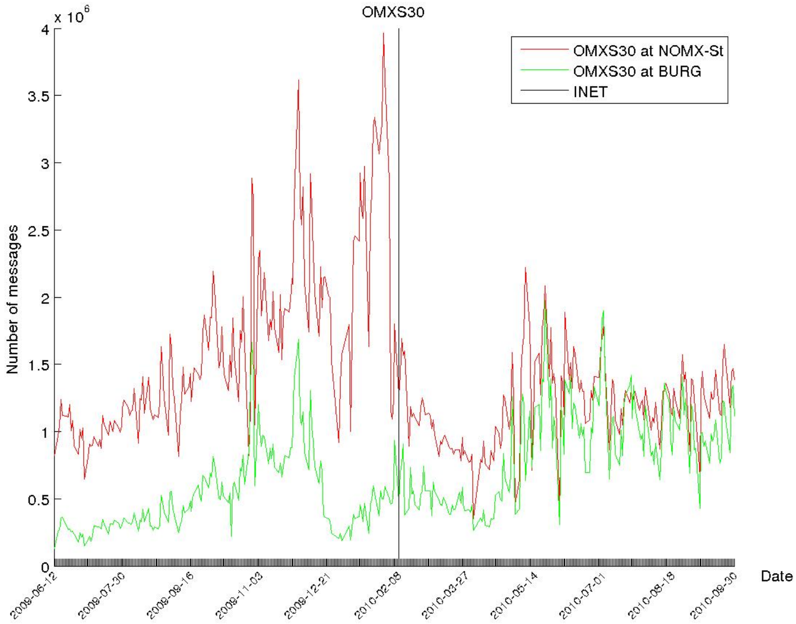

Figure 2: Number of messages for OMXS30 for the whole period.

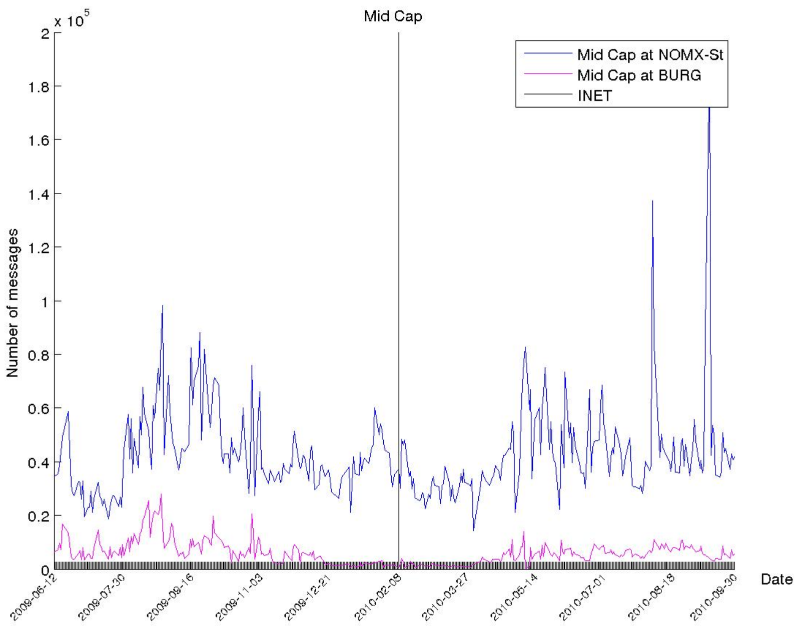

Figure 3: Number of messages for Mid Cap for the whole period.

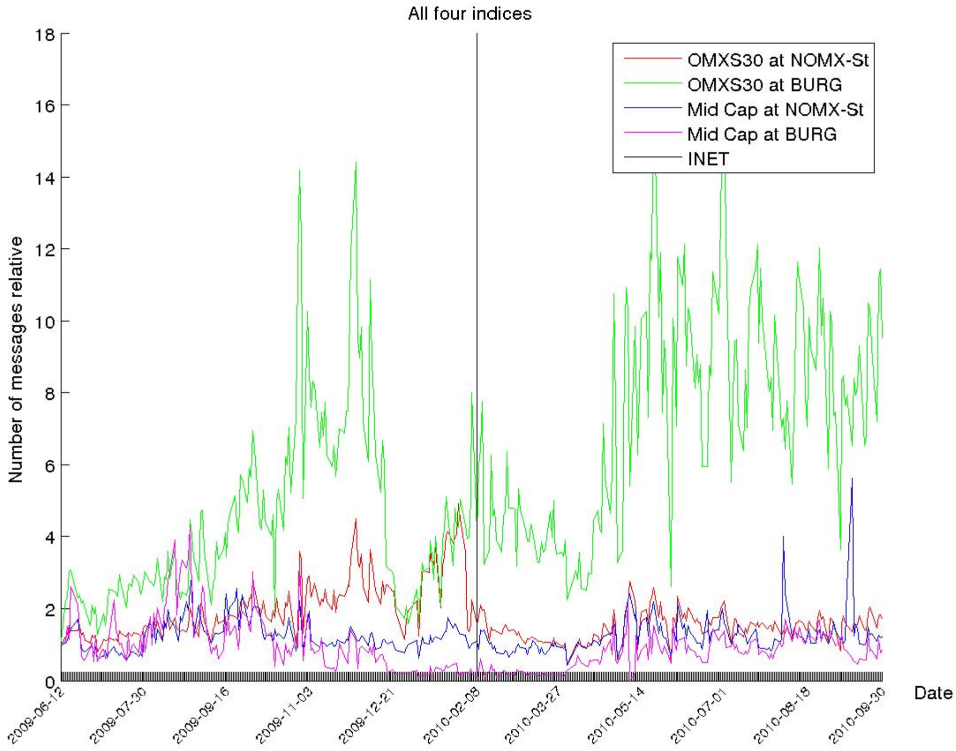

Figure 4: Number of messages relative for all four indices for the whole period.

10.1.2 Number of trades

The number of trades, contrary to the number of messages, did not decrease for any of the indices. For OMXS30 at NOMX-St there is an increase in the daily average for the period after the INET launch of 39% and for OMXS30 at BURG of 105%. For OMXS30 at NOMX-St there was an average of 80,400 trades per day before INET and 112,000 trades per day after. For OMXS30 at BURG there was an increase from 4,210 trades per day before INET to 8,620 trades per day after.

The number of trades are presented as time series for the whole period in figure 5 and relative in figure 6.

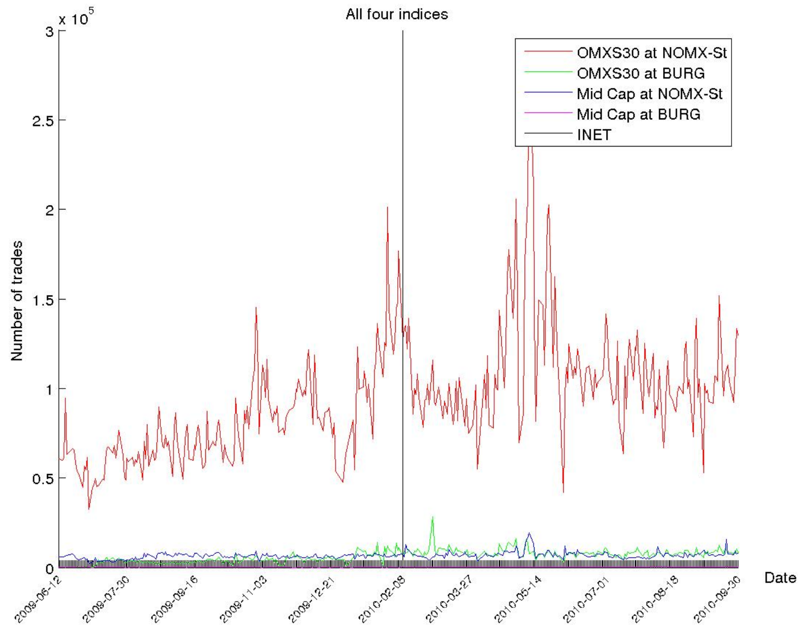

Figure 5: Number of trades for all four indices for the whole period.

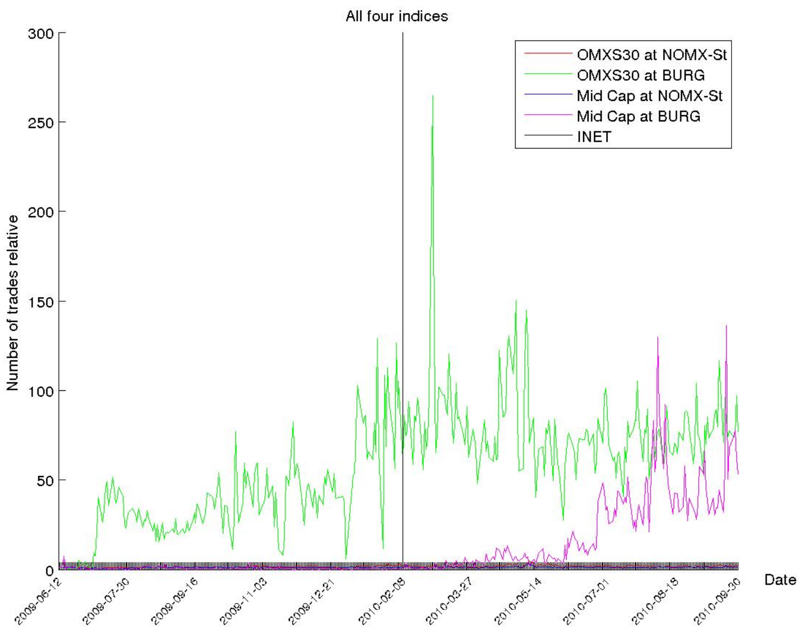

Figure 6: Number of trades relative for all four indices for the whole period.

10.1.3 Trading volume kSEK

There was also an increase in trading volume for all indices. A small increase of 5% for OMXS30 at NOMX-St from 10.6 MSEK[8] before INET to 11.1 MSEK after INET. The increase for OMXS30 at BURG was 135% from 264,000 kSEK before INET to 621,000 kSEK after INET. There was also an increase in trading volume for Mid Cap at NOMX-St of 19%, from 280,000 kSEK before INET to 335,000 kSEK after INET. There was also an increase for Mid Cap at BURG from 2,580 kSEK to 3,130 kSEK, which is an increase of 21%.

Trading volume kSEK are presented as time series for the whole period in figure 7.

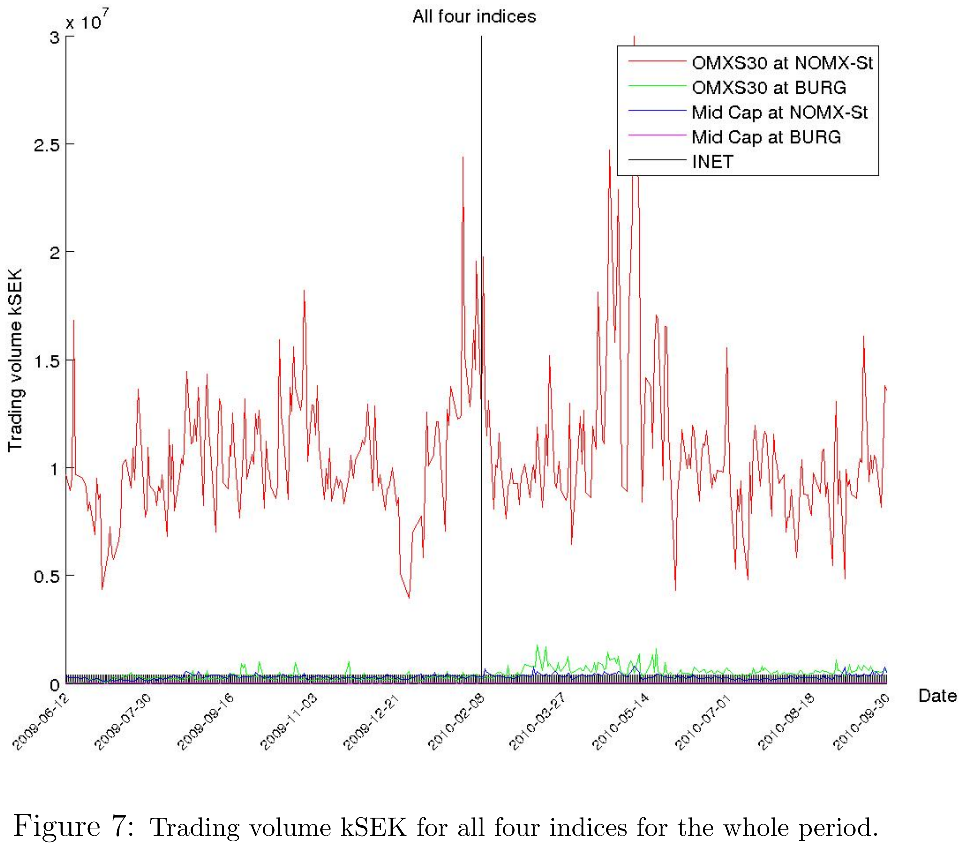

Figure 7: Trading volume kSEK for all four indices for the whole period.

[8]The abbreviation *MSEK* is used for SEK 1,000,000.

10.1.4 Number of messages per number of trades

Before the launch of the INET platform there was an average ratio of 20.8 messages per trade for OMXS30 at NOMX-St which then dropped to 11.2 messages per trade. For OMXS30 at BURG the decrease was even larger with 365 messages per trade before INET to 109 messages after. But in contrast to OMXS30 at NOMX-St the drop in messages per trade for OMXS30 at BURG was not due to a decrease in numbers of messages but an increase in the numbers of trades. By comparison to the shares with large market capitalisation in OMXS30 the message to trade ratio for Mid Cap at NOMX-St was 7.2 before INET and 6.0 after. A correlation analysis between numbers of messages and numbers of trades show a positive correlation of 0.36 for OMXS30 at NOMX-St and 0.40 for OMXS30 at BURG. The correlation for Mid Cap at NOMX-St is 0.45 and 0.08 for Mid Cap at BURG.

The number of messages per number of trades for NOMX-St are presented as time series for the whole period in figure 8.

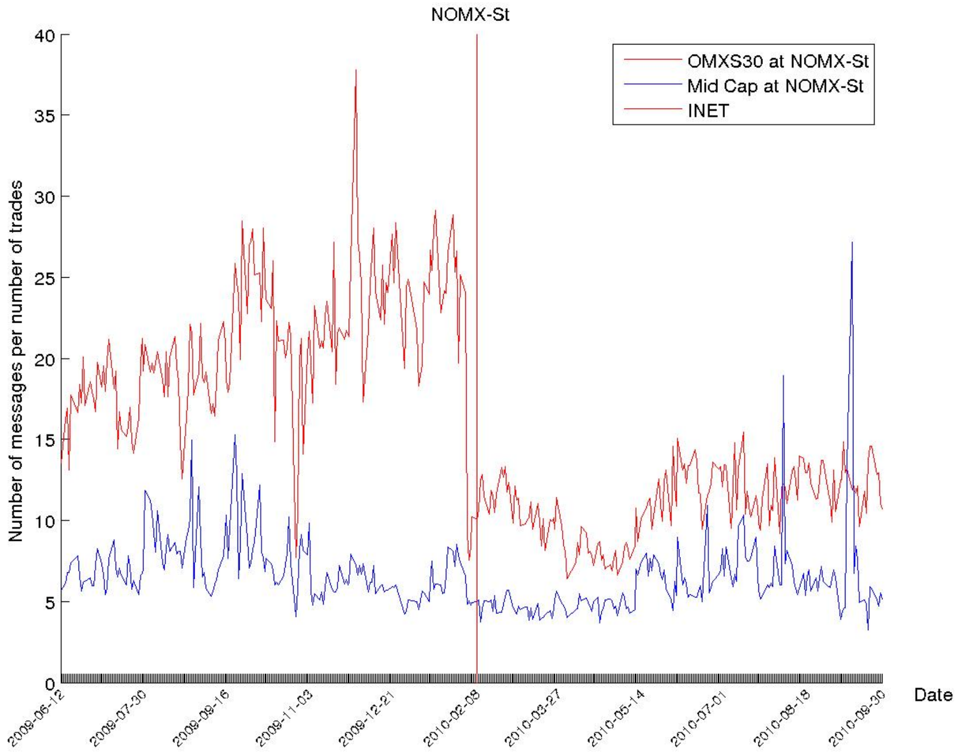

Figure 8: Number of messages per number of trades for NOMX-St for the whole period.

10.1.5 Number of messages per trading volume kSEK

The number of messages per trading volume has decreased for all of the indices. OMXS30 at NOMX-St before INET had a ratio of 0.16 messages per kSEK trading volume to 0.12 after INET, a drop by 28%. OMXS30 at BURG had the largest decrease with a ratio of 2.81 before INET to 1.66 after INET, which is a decrease by 41%. Mid Cap at NOMX-St had a ratio of 0.17 before INET and decreased to 0.15 after INET, a 12% drop.

The number of messages per trading volume kSEK are presented as time series for the whole period in figure 9.

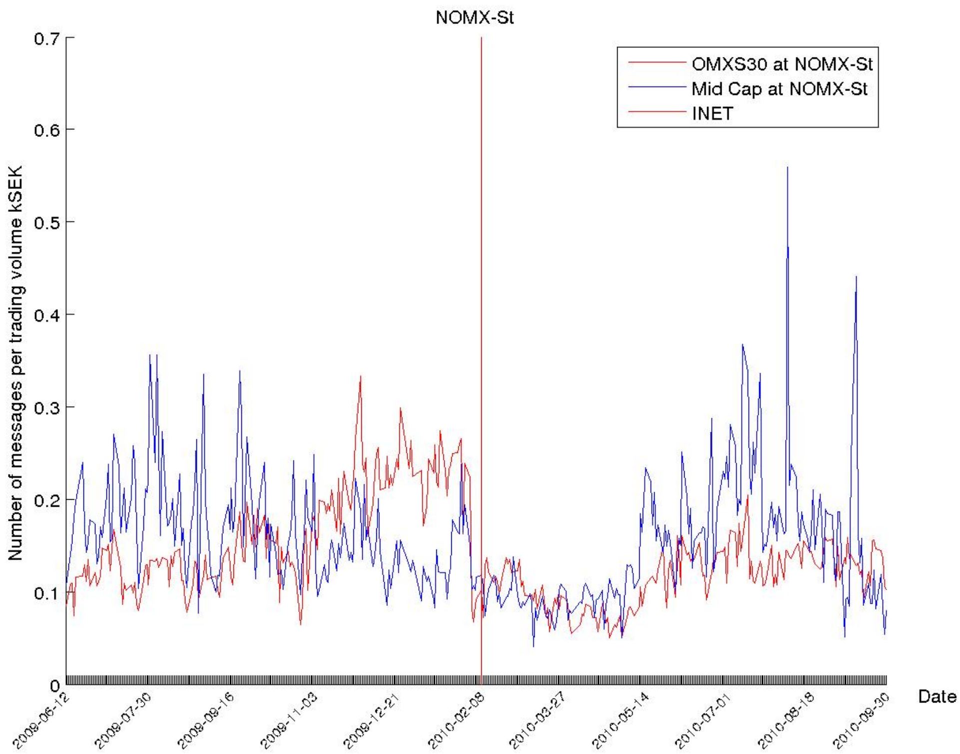

Figure 9: Number of messages per trading volume kSEK for NOMX-St for the whole period.

10.2 Turnover volume

10.2.1 Mean test of daily turnover volume

	NOMX-St				BURG			
	Before*	After*	Total*	Change	Before*	After*	Total*	Change
OMXS30	4,114.8	3,969.4	4,042.2	-3.5%	120.3	233.9	177.0	94.5%
Mid Cap	2,717.0	2,876.8	2,796.8	5.9%	27.6	28.1	27.9	1.8%

Table 1: Mean of turnover volume before/after INET for all four indices. *) The values should be multiplied by 10^{-6} to get actual values.

The results of the mean test of turnover volume before/after INET for all four indices are presented in table 1. All the shares in OMXS30 and Mid Cap have been weighted by market capitalization. OMXS30 shows an average decrease of 3.5% after INET at NOMX-St and a strong increase of 94.5% at BURG. Mid Cap shows 5.9% increase at NOMX-St and 1.8% increase at BURG. For the shares in Mid Cap at BURG there was a relatively small amount of trading during the whole period.

The increase in turnover volume for OMXS30 at BURG after INET is significant in comparison to NOMX-St. All of the shares in OMXS30 increased in turnover volume at BURG after INET. For the Mid Cap shares a mix of increases and decreases can be seen at both NOMX-St and BURG.

By examining monthly statistics in table 2 for OMXS30 a strong increase of 95.2% in turnover volume at BURG can be seen after the INET introduction during March 2010. This increased the average turnover volume to new peak levels which then slowly decreased and at the end of the interval increased again.

Statistics for Mid Cap are available in table 3. During the first days in February 2010, right before the INET introduction, the average turnover volume for Mid Cap at BURG dropped to record low levels. One reason could be that only five trading days are included in this period and since the trading intensity is relatively low for Mid Cap at BURG there might occur days with no trading at all for some shares. After the INET introduction, during the rest of February 2010, the turnover volume increased by 452.7% and the average turnover volume then got back to about the same levels that could be seen in January 2010.

For individual shares, one of the most notably cases of increased turnover volume for OMXS30 at BURG after the INET introduction is the ABB share, presented in figure 14. About one week right after the INET launch, ABB tripled its turnover volume at BURG and kept it at that level for most part of the period, though some spikes and dips do occur.

10.2.2 T-test for turnover volume

To see whether the changes in turnover volume can be confirmed statistically a t-test with the alpha set to 0.005 has been implemented, see table 4. With the null hypothesis that there has been no change in turnover volume before and after the INET launch, the critical t-value for our variables with a total of 330 observation become 3.322. This shows that the only change where the null hypothesis can be rejected is the increase for OMXS30 at BURG. For all the other indices the null hypothesis can not be rejected.

OMXS30						
			NOMX-St		BURG	
Start	End	Days	Average*	Change	Average*	Change
2009-06-12	2009-06-30	12.0	4,152.9	N/A	37.3	N/A
2009-07-01	2009-07-31	23.0	3,550.4	-14.5%	121.4	225.3%
2009-08-01	2009-08-31	21.0	4,083.0	15.0%	113.5	-6.5%
2009-09-01	2009-09-30	22.0	4,234.4	3.7%	182.3	60.6%
2009-10-01	2009-10-31	21.5	4,731.8	11.7%	143.9	-21.1%
2009-11-01	2009-11-30	21.0	3,854.1	-18.5%	98.2	-31.8%
2009-12-01	2009-12-31	20.0	3,411.4	-11.5%	95.3	-2.9%
2010-01-01	2010-01-31	18.5	4,613.4	35.2%	126.3	32.5%
2010-02-01	2010-02-07	5.0	5,636.7	22.2%	138.5	9.7%
INET						
2010-02-08	2010-02-28	15.0	3,974.9	-29.5%	158.1	14.1%
2010-03-01	2010-03-31	23.0	3,561.3	-10.4%	308.6	95.2%
2010-04-01	2010-04-30	19.0	4,958.0	39.2%	305.3	-1.1%
2010-05-01	2010-05-31	19.5	5,631.7	13.6%	276.5	-9.4%
2010-06-01	2010-06-30	21.0	3,855.1	-31.5%	219.4	-20.7%
2010-07-01	2010-07-31	22.0	3,402.3	-11.7%	181.7	-17.2%
2010-08-01	2010-08-31	22.0	3,140.5	-7.7%	180.4	-0.7%
2010-09-01	2010-09-30	22.0	3,570.1	13.7%	227.8	26.2%

Table 2: Mean of turnover volume per period and percentage change from last period for OMXS30 at NOMX-St and BURG. *) The values should be multiplied by 10^{-6} to get actual values.

Mid Cap						
			NOMX-St		BURG	
Start	End	Days	Average*	Change	Average*	Change
2009-06-12	2009-06-30	12.0	2,840.6	N/A	78.7	N/A
2009-07-01	2009-07-31	23.0	1,705.6	-40.0%	19.5	-75.3%
2009-08-01	2009-08-31	21.0	3,347.5	96.3%	27.2	39.7%
2009-09-01	2009-09-30	22.0	3,322.2	-0.8%	20.2	-25.8%
2009-10-01	2009-10-31	21.5	2,976.8	-10.4%	40.4	100.3%
2009-11-01	2009-11-30	21.0	2,505.1	-15.8%	11.4	-71.7%
2009-12-01	2009-12-31	20.0	2,385.2	-4.8%	19.4	69.6%
2010-01-01	2010-01-31	18.5	2,799.3	17.4%	32.5	67.4%
2010-02-01	2010-02-07	5.0	2,557.7	-8.6%	6.1	-81.1%
INET						
2010-02-08	2010-02-28	15.0	2,960.4	15.7%	34.0	452.7%
2010-03-01	2010-03-31	23.0	3,186.0	7.6%	17.2	-49.3%
2010-04-01	2010-04-30	19.0	3,770.8	18.4%	12.3	-28.4%
2010-05-01	2010-05-31	19.5	3,343.8	-11.3%	17.9	45.5%
2010-06-01	2010-06-30	21.0	2,442.0	-27.0%	30.2	68.5%
2010-07-01	2010-07-31	22.0	1,640.7	-32.8%	27.4	-9.3%
2010-08-01	2010-08-31	22.0	2,278.0	38.8%	34.3	25.1%
2010-09-01	2010-09-30	22.0	3,560.8	56.3%	50.8	48.1%

Table 3: Mean of turnover volume per period and percentage change from last period for Mid Cap at NOMX-St and BURG. *) The values should be multiplied by 10^{-6} to get actual values.

T-test for turnover volume				
Index	Before INET	After INET	T-test value	P-value
OMXS30 at NOMX-St	4,114.8	3,969.4	1.225	0.221
OMXS30 at BURG	120.3	233.9	9.299	0.000
Mid Cap at NOMX-St	2,717.0	2,876.8	1.297	0.196
Mid Cap at BURG	27.6	28.1	0.087	0.931

Table 4: T-test for turnover volume before/after INET for all four indices.

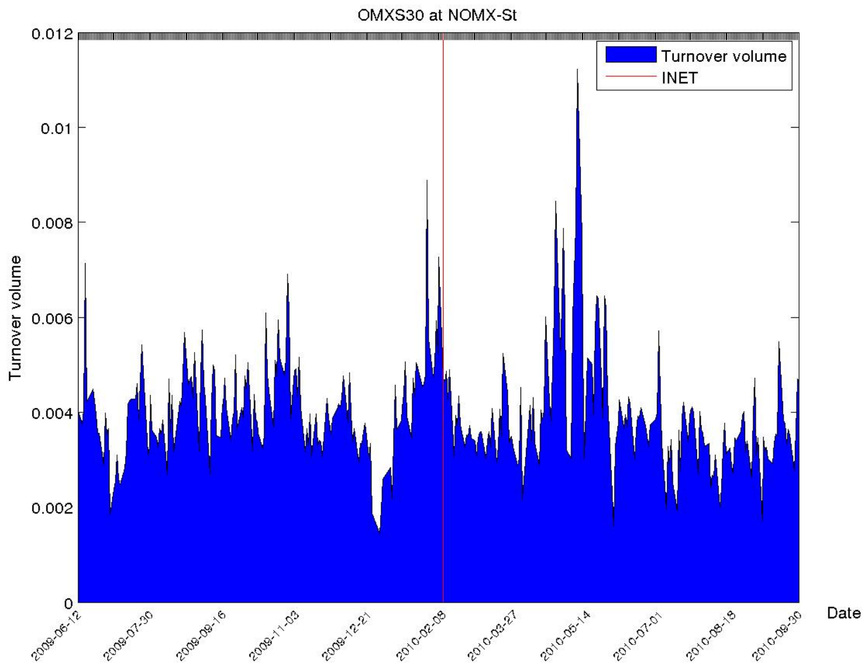

Figure 10: Turnover volume for OMXS30 at NOMX-St for the whole period.

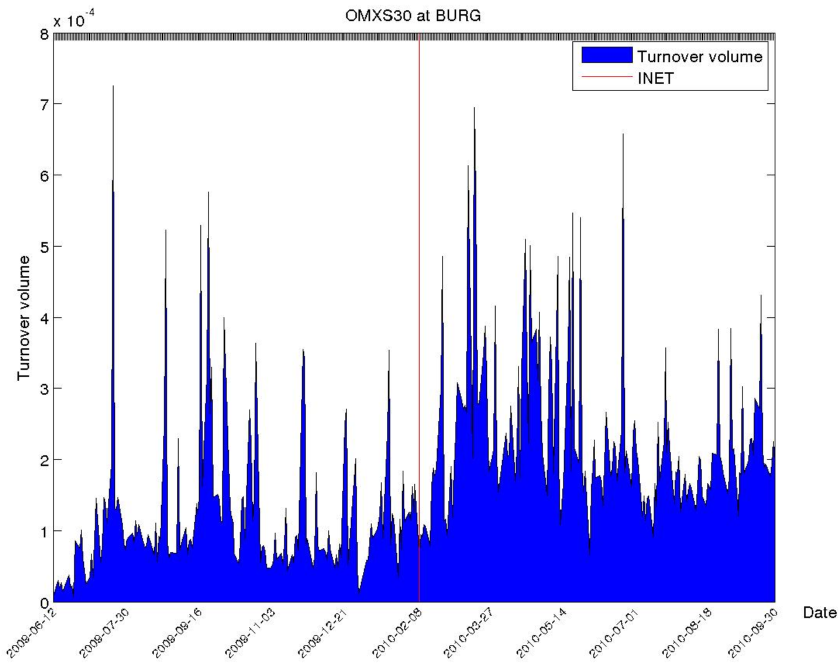

Figure 11: Turnover volume for OMXS30 at BURG for the whole period.

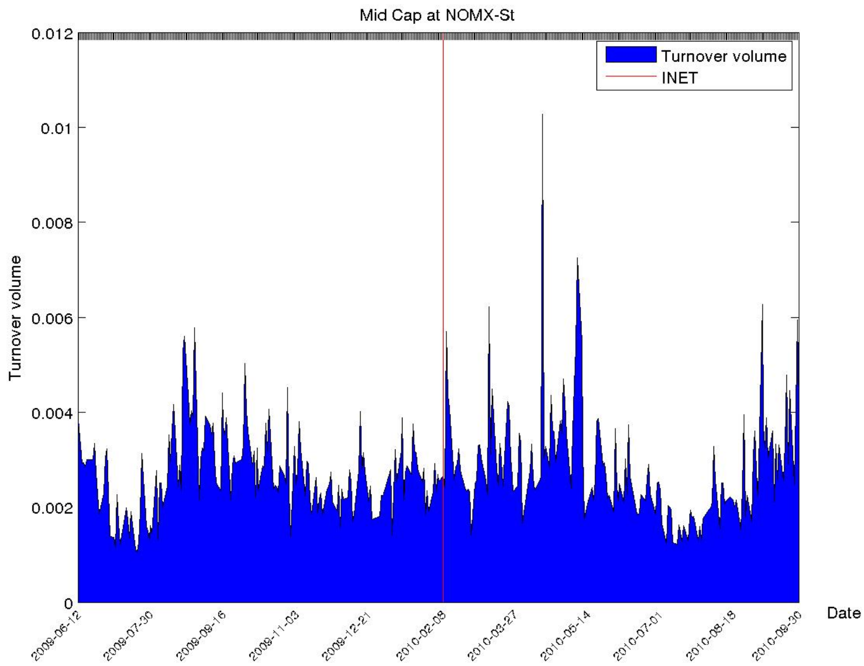

Figure 12: Turnover volume for Mid Cap at NOMX-St for the whole period.

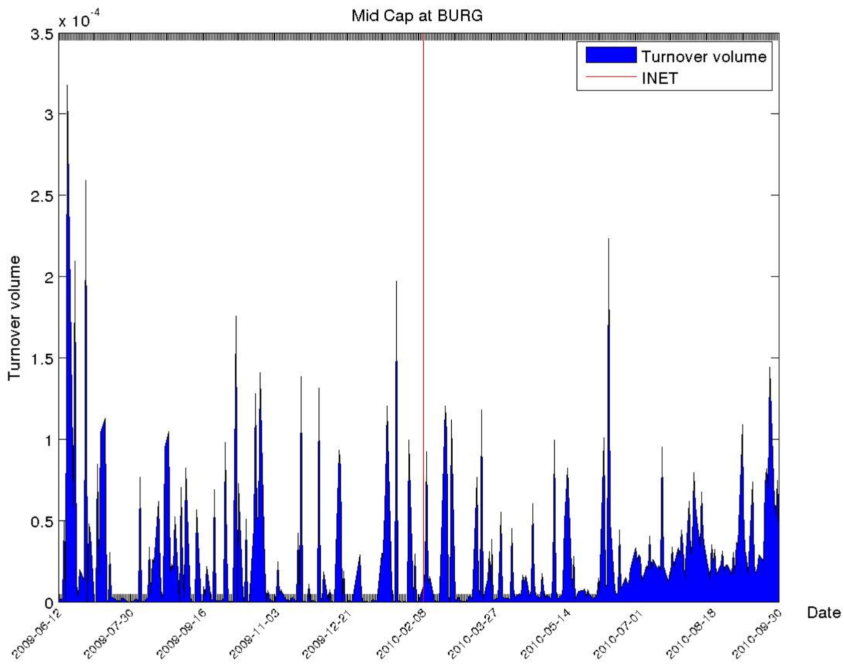

Figure 13: Turnover volume for Mid Cap at BURG for the whole period.

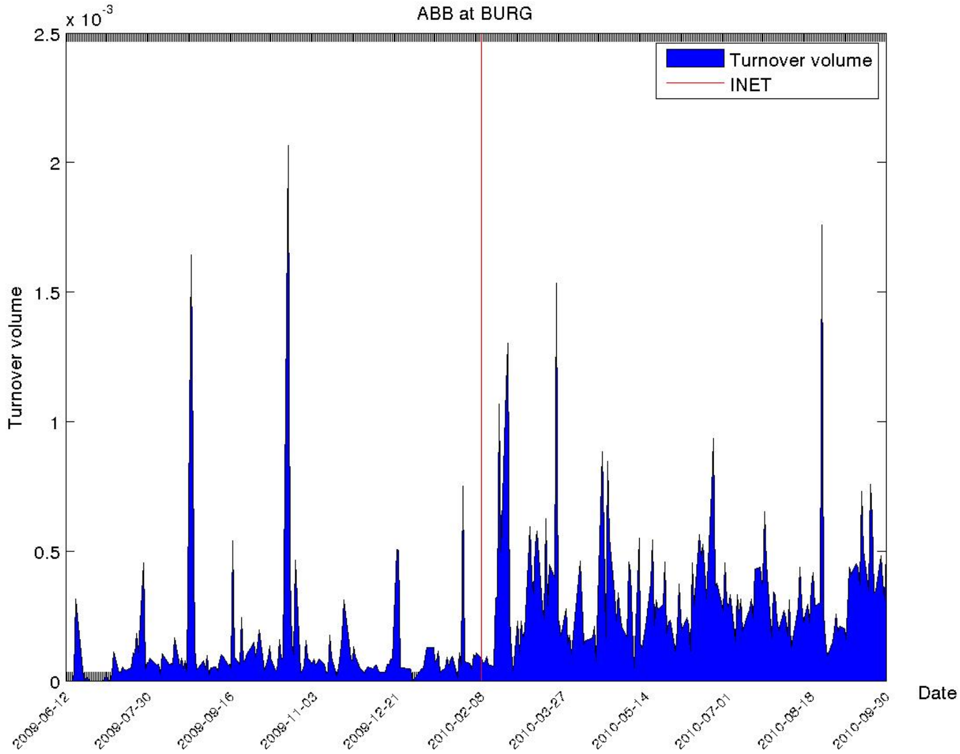

Figure 14: Turnover volume for ABB at BURG for the whole period.

10.3 Volatility

10.3.1 Mean test of daily realized volatility

	NOMX-St				BURG			
1-Min	Before*	After*	Total*	Change	Before*	After*	Total*	Change
OMXS30	23.9	18.0	20.9	-24.6%	18.4	17.9	18.1	-2.8%
Mid Cap	32.7	30.2	31.5	-7.7%	3.7	10.8	7.2	194.9%
5-Min	Before*	After*	Total*	Change	Before*	After*	Total*	Change
OMXS30	20.3	16.0	18.1	-21.3%	18.4	17.2	17.8	-6.7%
Mid Cap	29.8	27.3	28.6	-8.5%	3.7	10.8	7.2	194.6%

Table 5: Mean of intraday realized volatility before/after INET for all four indices. *) The values should be multiplied by 10^{-3} to get actual values.

The results in table 5 and table 6 are pretty consistent over the shares in OMXS30 at NOMX-St. There has been a decrease in volatility for all shares in OMXS30 after the introduction of the INET platform for both one and five minutes intervals, though the largest reduction was in the one minute intervals. In the beginning of the period the one minute interval was slightly above the five minutes interval, but around November 2009 the volatility for both the one minute and five minutes interval started to decrease, at the same time the number of messages started growing rapidly and almost doubled in two months. This could be linked to the findings of Hasbrouck & Saar (2011) that short-term volatility decreases when the order book is more active. A correlation analysis show that there is a negative correlation of -0.34 between the number of messages and the one minute volatility in OMXS30 at NOMX-St before INET. After the INET introduction this trend is broken and instead there is a positive correlation of 0.79 between the number of messages and volatility, but it should be noted that the number of messages is considerably lower during this period.

The results at BURG is a bit different and 13 shares has had an increase in volatility while 15 has had a decrease for the one minute interval. For five minutes interval 20 shares showed a decrease and only 8 an increase.

For the Mid Cap shares on NOMX-St the results have been varying a bit and some shares have an increase in volatility while others show a decrease in volatility. For BURG there has been a steady increase in volatility after the INET introduction which is connected to more frequent trading. By default, if there are no trades in one day there is no recorded intraday realized volatility either.

All of the indices show an increase in realized volatility for the month of May. This was a turbulent month within finance with several macroeconomic news, e.g. the bailout of the Greek economy, as well as the *Flash Crash*, which created uncertainty in the markets.

10.3.2 T-test for realized volatility

A t-test has been conducted to ensure whether there is a difference in volatility before and after the INET introduction, see table 8. The significance level was set to $\alpha = 0.005$, with 165 observations before the INET introduction and 165 observations after the INET introduction the critical t-value becomes 3.320. The null hypothesis was that there was no change in volatility for the two time periods.

The t-test show that there has been a decrease in volatility that is statistically significant for the shares within OMXS30 at NOMX-St. The decrease in volatility for OMXS30 at BURG can not be confirmed in this test and the null hypothesis can not be rejected. The increase in volatility for Mid Cap shares is small but the null hypothesis can be rejected. For Mid Cap at BURG there is no doubt that the increase is statistically safe.

OMXS30						
			NOMX-St		BURG	
Start	End	Days	1-Min*	5-Min*	1-Min*	5-Min*
2009-06-12	2009-06-30	12.0	29.4	24.4	13.1	13.1
2009-07-01	2009-07-31	23.0	27.7	23.2	19.0	20.9
2009-08-01	2009-08-31	21.0	27.7	22.9	22.8	22.3
2009-09-01	2009-09-30	22.0	24.8	20.5	19.5	18.9
2009-10-01	2009-10-31	21.5	26.5	22.0	22.1	21.7
2009-11-01	2009-11-30	21.0	19.6	17.2	16.0	15.9
2009-12-01	2009-12-31	20.0	17.1	15.3	14.3	14.3
2010-01-01	2010-01-31	18.5	19.6	17.7	17.4	17.1
2010-02-01	2010-02-07	5.0	21.9	19.8	19.2	18.9
INET						
2010-02-08	2010-02-28	15.0	17.8	15.6	17.6	17.2
2010-03-01	2010-03-31	23.0	14.1	12.0	12.7	12.3
2010-04-01	2010-04-30	19.0	18.0	15.9	17.4	17.2
2010-05-01	2010-05-31	19.5	25.5	22.0	26.0	24.7
2010-06-01	2010-06-30	21.0	18.6	16.9	19.3	18.0
2010-07-01	2010-07-31	22.0	18.2	17.0	19.8	19.1
2010-08-01	2010-08-31	22.0	17.0	15.0	15.8	15.6
2010-09-01	2010-09-30	22.0	15.7	14.2	15.4	14.5

Table 6: Average intraday realized volatility per period for one and five minutes intervals for OMXS30 at NOMX-St and BURG. *) The values should be multiplied by 10^{-3} to get actual values.

Mid Cap						
			NOMX-St		BURG	
Start	End	Days	1-Min*	5-Min*	1-Min*	5-Min*
2009-06-12	2009-06-30	12.0	38.6	35.1	3.8	3.8
2009-07-01	2009-07-31	23.0	33.3	31.0	2.3	2.3
2009-08-01	2009-08-31	21.0	35.7	32.6	7.8	7.8
2009-09-01	2009-09-30	22.0	33.0	30.1	3.3	3.3
2009-10-01	2009-10-31	21.5	32.8	30.0	3.8	3.8
2009-11-01	2009-11-30	21.0	30.7	28.1	2.5	2.5
2009-12-01	2009-12-31	20.0	28.6	25.9	3.7	3.7
2010-01-01	2010-01-31	18.5	31.1	27.9	3.0	3.0
2010-02-01	2010-02-07	5.0	31.6	29.0	0.9	0.9
INET						
2010-02-08	2010-02-28	15.0	32.9	30.2	6.1	6.1
2010-03-01	2010-03-31	23.0	26.9	24.0	6.9	6.9
2010-04-01	2010-04-30	19.0	30.3	27.1	9.6	9.6
2010-05-01	2010-05-31	19.5	40.0	36.2	12.1	12.1
2010-06-01	2010-06-30	21.0	30.5	27.8	10.3	10.3
2010-07-01	2010-07-31	22.0	28.4	25.8	14.2	14.2
2010-08-01	2010-08-31	22.0	28.4	25.7	13.0	13.0
2010-09-01	2010-09-30	22.0	26.2	23.7	13.0	12.9

Table 7: Average intraday realized volatility per period for one and five minutes intervals for Mid Cap at NOMX-St and BURG. *) The values should be multiplied by 10^{-3} to get actual values.

One minute				
	Volatility mean			
Index	Before INET	After INET	T-test value	P-value
OMXS30 at NOMX-St	23.9	18.0	10.479	0.000
OMXS30 at BURG	18.4	17.9	0.743	0.456
Mid Cap at NOMX-St	32.7	30.2	4.282	0.000
Mid Cap at BURG	3.7	10.8	12.207	0.000
Five minutes				
	Volatility mean			
Index	Before INET	After INET	T-test value	P-value
OMXS30 at NOMX-St	20.3	16.0	8.963	0.000
OMXS30 at BURG	18.4	17.2	1.649	0.100
Mid Cap at NOMX-St	29.8	27.3	4.858	0.000
Mid Cap at BURG	3.7	10.8	12.254	0.000

Table 8: T-test for volatility before/after INET for all four indices for one and five minutes intervals.

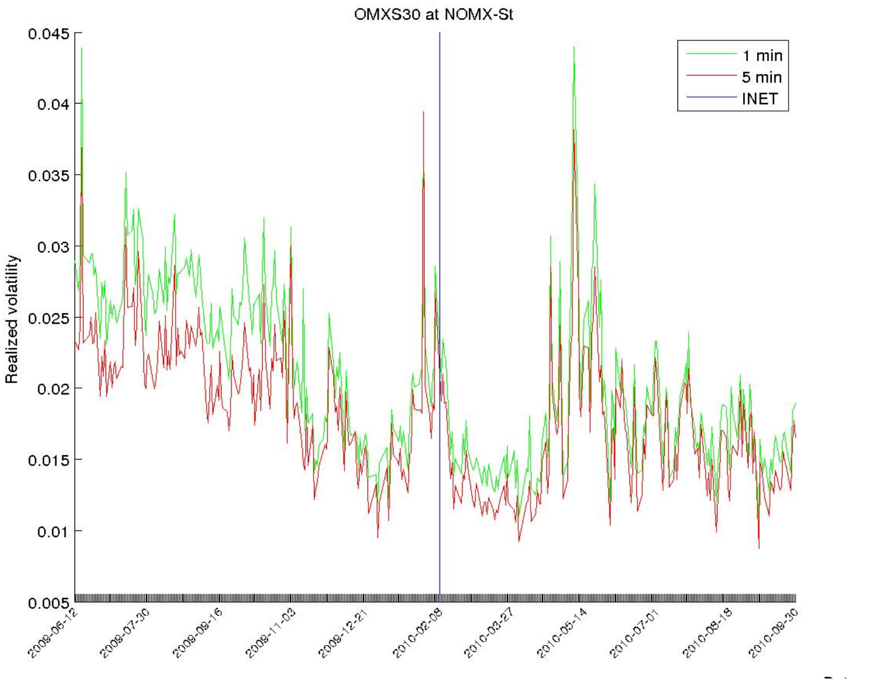

Figure 15: Realized volatility for OMXS30 at NOMX-St for the whole period.

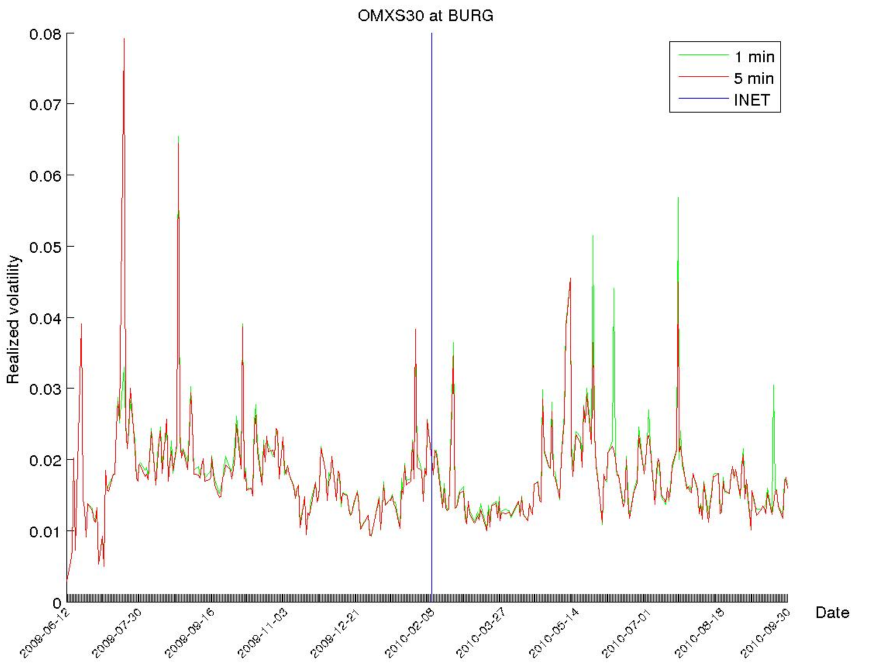

Figure 16: Realized volatility for OMXS30 at BURG for the whole period.

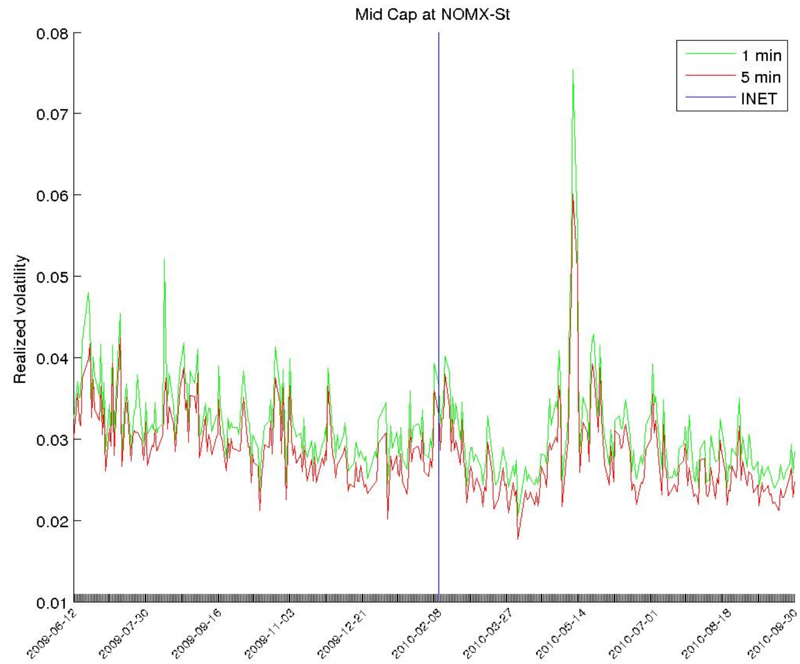

Figure 17: Realized volatility for Mid Cap at NOMX-St for the whole period.

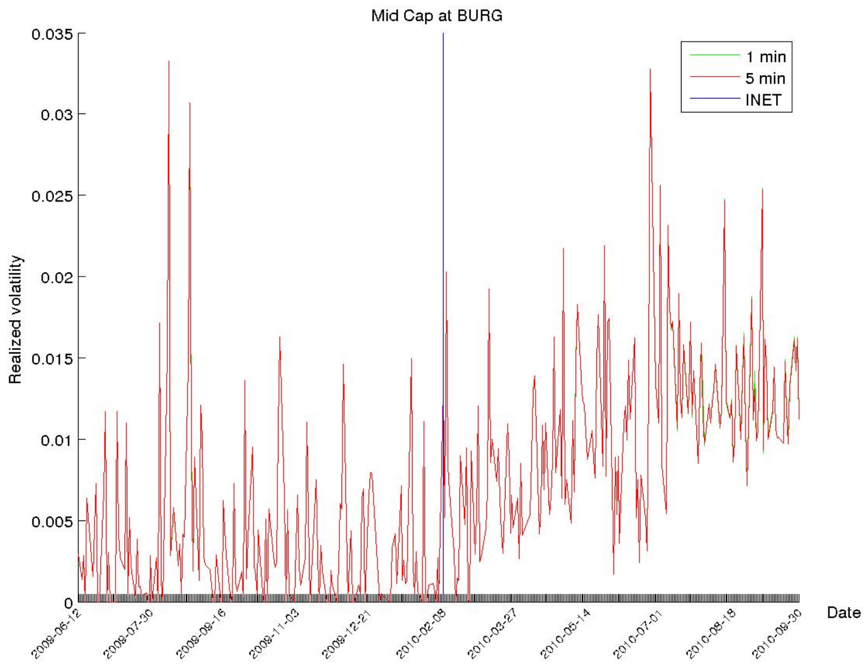

Figure 18: Realized volatility for Mid Cap at BURG for the whole period.

11 Analysis

This study wanted to investigate positive and negative impacts at NOMX-St and BURG around the time of the launch of the INET trading system on the NOMX-St stock exchange with the idea that the increased speed would be welcomed by HFT firms. So far empirical observations made from high frequency tick data, of a 330 days period, shows that the introduction of the INET platform did not increase the level of HFT activity on NOMX-St, at least not within the timeframe of this study. Instead there was a sharp plunge in the number of messages entered into the order book for the shares in OMXS30 at NOMX-St. A reason could be that HFT firms needed to update their systems and optimise their algorithms to fit with the new platform and that could take a while. A small upward trend can be seen from the beginning of April until the end of the period but still far from the numbers recorded before INET.

After the INET introduction the turnover volume and volatility at NOMX-St for the companies within OMXS30 included in this study remained at lower levels while some of the studied companies have started to show an increased turnover volume at BURG. The benchmark shares in Mid Cap, where HFT activity is less likely, does not follow the pattern of OMXS30 at NOMX-St. The HFT proxies does not show any unusual patterns, the number of messages was not affected by the INET launch in any dramatic way, which indicates that HFT activity is unlikely in the Mid Cap companies. There is a small increase in turnover volume for the first few months after the the launch of the INET platform with a peak in April and there are no changes in the volatility until May, which was a very volatile month for all indices.

The results of the mean test of turnover volume, with a decrease at NOMX-St and an increase at BURG, were interesting. The first thought is that this is only due to the fact that BURG had only just launched in the summer of 2009 and grew steadily over the entire period of study. However, when looking at monthly data of the turnover volume, this seems to be only partly true. As shown in table 2 there was a large increase in turnover volume for the OMXS30 companies in February and March right after the INET introduction and from April and forward the number of messages entered into the orderbook at BURG was almost as high as that at NOMX-St. This suggests that HFT companies moved some of their trading and became more active at BURG. Similar to the findings of the study by Menkveld (2012) of the Chi-X market, HFT members active at the incumbent market (NOMX-St) might have become members at the new entrant market (BURG) as well. By being members at both markets their algorithms will analyse the orderbook at both platforms and place their order at the one they find best in each individual case.

The tests in this study show no connection between volatility and our proxies for HFT activity. When the number of messages started increasing rapidly in November 2009 the volatility decreased but at the same time when the HFT activity decreased significantly the volatility did not increase. When the volatility increased significantly in May 2010 there was no large increase in number of messages per number of trades or number of messages per trading volume kSEK, which would suggest that the increase in numbers of messages was merely a result of more trading and not in HFT activity.

HFT firms are often blamed for creating high volatility but as Brogaard (2012) explains it is not sure whether HFT firms create volatility or if they are just more active in volatile markets. Just because there is a relationship between higher HFT activity in more volatile markets it does not answer the question of causality. What is known is that HFT firms change trading activity as volatility changes and that HFT firms seem to specially like short term volatility (Brogaard 2012). If the INET platform made the NOMX-St much less volatile on the one minute interval it could well be that some HFT firms have taken a part of their trading somewhere else, which could explain the decrease of turnover volume on NOMX-St and the increase at BURG.

12 Conclusions

The advances in computer technology since the mid 1990s has radically changed several industries around the world, new faster and cheaper computers has opened up new ways to make businesses. So also in the financial industries. As always when there is something new there is a degree of uncertainty, and with some proponents for and some against the changes, there is a need to study how they actually affect the market.

In this thesis we have studied impacts of HFT on the Swedish stock market regarding two variables; turnover volume and volatility.

Our results indicate that HFT activity has a slightly positive impact on turnover volume. Higher levels of turnover volume was recorded for OMXS30 at both NOMX-St and BURG when there was high HFT activity.

We find no evidence that higher HFT activity would lead to higher volatility. High levels of HFT has been found with both high and low levels of volatility. Also, both high and low levels of volatility has been recorded when there was low levels of HFT.

Our hypothesis was that the new faster INET platform at NOMX-St would be welcomed by the HFT firms, but that a decrease in HFT activity were to be expected for a period of time after the introduction. The first part of the hypothesis could not be confirmed, but second part of the hypothesis showed to be true with a huge drop in HFT activity right at the INET launch. This decrease is connected to the time that it takes for HFT firms to reprogram and test their algorithms to fit with the new technical structure of the market. Events in the financial markets in May 2010, with the *Flash Crash* at the U.S. markets and the uncertainty in the Euro area, probably slowed down this process, with HFT firms being even more careful before releasing their HFT systems onto the market again. This could be one of the reasons why there was no detectable increase in HFT activity after the launch of the INET trading platform up until the end of our studied period.

While HFT firms are fast at trading the results in this study indicates that they might be slow when it comes to adjusting to new market conditions, but more research is needed to be able to draw any safe conclusions.

13 Suggestions for further research

HFT is often looked upon as one trading strategy when in fact it includes several different strategies which affect the market in different ways. Since it is not possible to identify and separate HFT firms from other traders or to subcategorize different HFT strategies with the data provided by Thomson Reuters Tick History database, more studies with data directly from the stock markets, as done by Hagströmer & Nordén (2012), would be welcomed to get a further understanding of the impact these different HFT strategies has on the market.

Further research on whether or not the increase in volume on the BURG market has any connection to the launch of the INET platform, or if there were any other external factors behind the increase would be interesting. A theory could be that HFT firms were members at both platforms and used information from the faster NOMX-St to trade at BURG.

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A Shares

A.1 OMXS30

Short name	Full name	ISIN
ABB	ABB Ltd	CH0012221716
ALFA	Alfa Laval AB	SE0000695876
ASSA B	ASSA ABLOY AB ser. B	SE0000255648
ATCO A	Atlas Copco AB ser. A	SE0000101032
ATCO B	Atlas Copco AB ser. B	SE0000122467
AZN	AstraZeneca PLC	GB0009895292
BOL	Boliden AB	SE0000869646
ELUX B	Electrolux, AB ser. B	SE0000103814
ERIC B	Ericsson, Telefonab. L M ser. B	SE0000108656
HM B	Hennes & Mauritz AB, H & M ser. B	SE0000106270
INVE B	Investor AB ser. B	SE0000107419
LUPE	Lundin Petroleum AB	SE0000825820
NDA SEK	Nordea Bank AB	SE0000427361
NOKI SEK	Nokia Corporation	FI0009000681
SAND	Sandvik AB	SE0000667891
SCA B	Svenska Cellulosa AB SCA ser. B	SE0000112724
SCV B	SCANIA AB ser. B	SE0000308280
SEB A	Skandinaviska Enskilda Banken ser. A	SE0000148884
SECU B	Securitas AB ser. B	SE0000163594
SHB A	Svenska Handelsbanken ser. A	SE0000193120
SKA B	Skanska AB ser. B	SE0000113250
SKF B	SKF, AB ser. B	SE0000108227
SSAB A	SSAB Svenskt Stål AB ser. A	SE0000171100
SWED A	Swedbank AB ser A	SE0000242455
SWMA	Swedish Match AB	SE0000310336
TEL2 B	Tele2 AB ser. B	SE0000314312
TLSN	TeliaSonera AB	SE0000667925
VOLV B	Volvo, AB ser. B	SE0000115446

Table 9: The 28 shares that have been included in OMXS30 for the whole period.

A.2 Mid Cap

Short name	Full name	ISIN
ADDT B	Addtech AB ser. B	SE0000808370
AXIS	Axis AB	SE0000672354
BETS B	Betsson AB ser. B	SE0000102378
BILL	Billerud AB	SE0000862997
BORG	Björn Borg AB	SE0001289190
BRIN B	Brinova Fastigheter AB ser.B	SE0001105487
CARD	Cardo AB	SE0000262982
CLAS B	Clas Ohlson AB ser. B	SE0000584948
ENRO	Eniro AB	SE0000718017
FPAR	Fast Partner AB	SE0000224446
HIQ	HiQ International AB	SE0000461709
HLDX	Haldex AB	SE0000105199
HOGA B	Höganäs AB ser. B	SE0000232175
HPOL B	HEXPOL AB ser. B	SE0002452623
INDT	Indutrade AB	SE0001515552
ITAB B	ITAB Shop Concept AB ser. B	SE0001198714
KAHL	KappAhl AB	SE0001630880
KLED	Kungsleden AB	SE0000549412
MTRS	Munters AB	SE0000416604
NISC B	Niscayah Group AB ser. B	SE0001785197
NOBI	Nobia AB	SE0000949331
REZT	Rezidor Hotel Group AB	SE0001857533
SWEC B	SWECO AB ser. B	SE0000489098
SYSR	Systemair AB	SE0002133975
VBG B	VBG GROUP AB ser. B	SE0000115107
VNIL SDB	Vostok Nafta Investment Ltd, SDB	SE0002056721
WALL B	Wallenstam AB ser. B	SE0000115008
WIHL	Wihlborgs Fastigheter AB	SE0001413600

Table 10: The 28 shares that have been randomly selected among those 71 shares that have been included in the Mid Cap segment for the whole period.

B Tables and diagrams of variables

Tables and diagrams of individual shares and indices for both main variables and support variables are available over the Internet at http://www.ter.se/hft-inet-study/ to limit the size of the appendix. Only the tables for the main variables before/after INET are presented below.

B.1 Tables of main variables before/after INET

B.1.1 Turnover volume

	NOMX-St				BURG			
OMXS30	Before*	After*	Total*	Change	Before*	After*	Total*	Change
ABB	5,648.8	5,253.6	5,451.5	-7.0%	117.7	347.1	232.3	194.9%
ALFA	5,367.0	5,035.6	5,201.5	-6.2%	142.3	258.0	200.1	81.3%
ASSA B	5,720.4	5,769.4	5,744.9	0.9%	88.7	186.2	137.4	109.9%
ATCO A	6,094.5	5,745.5	5,920.3	-5.7%	119.7	241.6	180.6	101.9%
ATCO B	3,110.7	2,781.3	2,946.2	-10.6%	86.6	165.1	125.8	90.7%
AZN	5,621.2	4,852.5	5,237.4	-13.7%	220.4	314.4	267.3	42.6%
BOL	18,973.6	19,001.5	18,987.5	0.1%	521.4	2,280.7	1,399.7	337.4%
ELUX B	10,060.9	8,115.1	9,089.5	-19.3%	297.5	418.6	358.0	40.7%
ERIC B	5,458.0	4,674.9	5,067.0	-14.3%	122.0	227.2	174.5	86.2%
HM B	2,966.5	2,466.8	2,717.1	-16.8%	113.7	152.6	133.1	34.2%
INVE B	4,196.1	4,118.3	4,157.3	-1.9%	127.8	299.8	213.7	134.5%
LUPE	4,649.0	7,526.3	6,085.5	61.9%	119.2	589.1	353.8	394.0%
NDA SEK	2,365.4	2,301.1	2,333.3	-2.7%	38.6	108.6	73.6	181.4%
NOKI SEK	426.5	532.4	479.4	24.8%	14.1	35.9	25.0	153.5%
SAND	5,189.3	5,398.8	5,293.9	4.0%	79.2	206.6	142.8	161.1%
SCA B	3,924.0	4,833.9	4,378.3	23.2%	91.2	210.0	150.5	130.4%
SCV B	2,348.9	3,078.7	2,713.2	31.1%	57.7	185.6	121.5	221.9%
SEB A	5,007.7	4,987.8	4,997.8	-0.4%	129.6	190.4	160.0	46.9%
SECU B	5,596.2	4,731.7	5,164.6	-15.4%	144.0	207.3	175.6	43.9%
SHB A	3,353.2	3,357.8	3,355.5	0.1%	104.3	178.0	141.1	70.7%
SKA B	5,030.4	4,716.7	4,873.8	-6.2%	129.9	257.8	193.8	98.4%
SKF B	8,830.2	8,032.2	8,431.8	-9.0%	194.4	331.2	262.7	70.4%
SSAB A	11,399.7	10,725.6	11,063.1	-5.9%	224.4	607.6	415.7	170.7%
SWED A	16,746.5	7,821.1	12,290.6	-53.3%	272.0	428.8	350.3	57.6%
SWMA	4,801.6	4,152.6	4,477.6	-13.5%	101.1	212.1	156.5	109.9%
TEL2 B	4,781.1	4,376.8	4,579.3	-8.5%	141.7	228.2	184.9	61.0%
TLSN	2,061.2	2,062.9	2,062.1	0.1%	159.6	173.2	166.4	8.6%
VOLV B	6,525.1	5,992.8	6,259.4	-8.2%	402.0	601.3	501.5	49.6%

Table 11: Mean of turnover volume for the 28 shares that have been included in OMXS30 for the whole period at NOMX-St and BURG. *) The values should be multiplied by 10^{-6} to get actual values.

	NOMX-St				BURG			
Mid Cap	Before*	After*	Total*	Change	Before*	After*	Total*	Change
ADDT B	823.0	785.8	804.4	-4.5%	38.7	3.3	21.0	-91.5%
AXIS	2,368.2	2,230.3	2,299.3	-5.8%	6.6	6.7	6.6	1.4%
BETS B	5,384.5	4,473.6	4,929.7	-16.9%	32.8	20.5	26.7	-37.6%
BILL	5,172.6	4,835.9	5,004.5	-6.5%	5.4	16.9	11.2	211.9%
BORG	2,114.8	3,083.7	2,598.5	45.8%	18.2	10.4	14.3	-42.7%
BRIN B	200.9	197.5	199.2	-1.7%	0.0	27.0	13.5	Inf
CARD	971.5	829.2	900.5	-14.7%	55.1	3.5	29.3	-93.6%
CLAS B	1,685.6	2,021.0	1,853.1	19.9%	8.9	44.8	26.8	405.1%
ENRO	11,079.2	24,401.1	17,730.0	120.2%	83.7	472.0	277.5	463.8%
FPAR	224.5	107.7	166.2	-52.0%	0.0	29.2	14.6	Inf
HIQ	3,345.1	2,011.9	2,679.5	-39.9%	0.8	9.3	5.0	1,111.8%
HLDX	3,016.4	4,391.7	3,703.0	45.6%	27.0	27.1	27.1	0.3%
HOGA B	1,503.4	2,889.5	2,195.4	92.2%	13.7	10.6	12.2	-22.9%
HPOL B	1,803.8	1,813.4	1,808.6	0.5%	3.4	9.9	6.6	195.3%
INDT	960.5	971.4	965.9	1.1%	4.6	1.3	3.0	-72.3%
ITAB B	196.2	119.7	158.0	-39.0%	75.1	0.5	37.8	-99.4%
KAHL	5,008.2	6,909.2	5,957.2	38.0%	71.3	122.1	96.6	71.2%
KLED	4,214.8	4,335.8	4,275.2	2.9%	14.1	15.5	14.8	10.1%
MTRS	1,345.3	3,980.6	2,661.0	195.9%	3.8	24.7	14.3	542.1%
NISC B	2,415.9	2,596.2	2,505.9	7.5%	5.4	20.4	12.9	277.7%
NOBI	1,965.4	3,021.3	2,492.5	53.7%	55.4	23.6	39.5	-57.4%
REZT	1,856.9	1,460.5	1,659.0	-21.3%	12.3	6.0	9.1	-51.3%
SWEC B	522.5	322.5	422.6	-38.3%	7.6	0.9	4.3	-87.6%
SYSR	560.0	372.2	466.3	-33.5%	15.8	2.7	9.3	-82.8%
VBG B	446.3	411.2	428.7	-7.9%	0.0	3.6	1.8	Inf
VNIL SDB	3,150.3	1,900.6	2,526.4	-39.7%	181.2	87.1	134.3	-51.9%
WALL B	978.0	847.7	912.9	-13.3%	22.6	12.1	17.4	-46.4%
WIHL	3,974.6	3,324.5	3,650.0	-16.4%	5.0	32.1	18.5	547.5%

Table 12: Mean of turnover volume for the 28 shares that have been randomly selected among those 71 shares that have been included in the Mid Cap segment for the whole period at NOMX-St and BURG. *) The values should be multiplied by 10^{-6} to get actual values.

B.1.2 Realized volatility

1-Min	NOMX-St				BURG			
OMXS30	Before*	After*	Total*	Change	Before*	After*	Total*	Change
ABB	23.2	16.6	19.9	-28.5%	17.0	17.0	17.0	-0.2%
ALFA	21.5	20.6	21.1	-4.3%	18.2	18.6	18.4	2.0%
ASSA B	25.9	18.8	22.4	-27.2%	17.1	17.5	17.3	2.9%
ATCO A	25.5	19.3	22.4	-24.1%	18.6	18.7	18.6	0.6%
ATCO B	25.4	21.0	23.2	-17.5%	19.8	19.2	19.5	-3.4%
AZN	17.5	11.8	14.7	-32.7%	12.9	11.1	12.0	-14.0%
BOL	31.1	22.5	26.8	-27.9%	27.9	23.0	25.5	-17.8%
ELUX B	25.6	20.1	22.9	-21.6%	21.9	19.5	20.7	-10.7%
ERIC B	19.9	17.2	18.6	-13.4%	17.5	18.0	17.7	2.9%
HM B	18.3	13.4	15.8	-26.7%	14.0	13.5	13.8	-4.0%
INVE B	20.4	15.4	17.9	-24.7%	13.9	14.9	14.4	7.1%
LUPE	24.4	22.4	23.4	-8.4%	19.8	23.7	21.7	19.8%
NDA SEK	24.9	20.9	22.9	-16.1%	19.0	20.6	19.8	8.0%
NOKI SEK	22.7	20.1	21.4	-11.8%	19.9	20.5	20.2	2.9%
SAND	30.9	20.2	25.6	-34.6%	22.1	20.3	21.2	-8.0%
SCA B	23.1	18.3	20.7	-20.8%	14.8	17.0	15.9	14.5%
SCV B	28.6	21.8	25.2	-23.8%	19.9	20.6	20.2	3.6%
SEB A	33.0	21.1	27.0	-36.1%	25.5	20.7	23.1	-18.6%
SECU B	23.6	15.8	19.7	-33.1%	14.9	14.1	14.5	-5.0%
SHB A	26.2	17.4	21.8	-33.5%	17.9	16.6	17.3	-7.1%
SKA B	23.4	19.2	21.3	-18.1%	16.5	18.8	17.6	13.8%
SKF B	24.3	18.9	21.6	-22.2%	17.1	18.1	17.6	5.8%
SSAB A	30.5	20.5	25.5	-32.6%	25.1	21.7	23.4	-13.3%
SWED A	42.5	22.3	32.4	-47.6%	35.3	28.2	31.8	-20.2%
SWMA	20.2	13.5	16.8	-33.1%	12.3	12.6	12.4	2.2%
TEL2 B	20.2	18.4	19.3	-8.8%	18.4	18.4	18.4	-0.2%
TLSN	22.2	15.1	18.6	-32.1%	15.2	13.8	14.5	-9.1%
VOLV B	35.3	19.4	27.3	-45.0%	25.3	20.0	22.7	-20.9%

Table 13: Mean of realized volatility for one minute tick data of transaction prices for the 28 shares that have been included in OMXS30 for the whole period at NOMX-St and BURG. *) The values should be multiplied by 10^{-3} to get actual values.

1-Min	NOMX-St				BURG			
Mid Cap	Before*	After*	Total*	Change	Before*	After*	Total*	Change
ADDT B	19.5	23.3	21.4	19.2%	0.2	3.8	2.0	2,391.7%
AXIS	35.7	29.1	32.4	-18.6%	3.4	12.2	7.8	253.9%
BETS B	28.6	31.0	29.8	8.4%	2.8	12.8	7.8	364.1%
BILL	39.6	36.3	38.0	-8.3%	0.6	16.7	8.6	2,557.2%
BORG	40.2	35.6	37.9	-11.4%	0.0	9.6	4.8	Inf
BRIN B	29.8	26.4	28.1	-11.4%	0.0	1.9	0.9	Inf
CARD	33.4	27.8	30.6	-16.8%	2.2	8.6	5.4	293.0%
CLAS B	28.0	24.5	26.3	-12.4%	2.1	10.5	6.3	398.1%
ENRO	41.0	54.2	47.6	32.2%	18.2	40.0	29.1	119.1%
FPAR	12.5	15.2	13.8	22.1%	0.0	1.1	0.5	Inf
HIQ	35.7	34.1	34.9	-4.3%	0.0	7.2	3.6	Inf
HLDX	39.5	36.5	38.0	-7.4%	2.1	18.4	10.2	790.3%
HOGA B	27.3	26.6	27.0	-2.6%	0.0	12.7	6.3	Inf
HPOL B	55.2	38.5	46.8	-30.3%	4.0	7.8	5.9	98.2%
INDT	27.3	26.9	27.1	-1.5%	1.9	5.3	3.6	182.4%
ITAB B	19.1	20.2	19.6	6.1%	0.9	1.7	1.3	93.6%
KAHL	37.7	36.0	36.8	-4.4%	16.0	17.1	16.6	6.9%
KLED	28.4	30.4	29.4	7.1%	5.5	12.6	9.0	129.8%
MTRS	36.8	32.9	34.9	-10.5%	0.0	7.7	3.9	Inf
NISC B	39.2	35.2	37.2	-10.3%	4.7	14.7	9.7	210.5%
NOBI	32.3	37.8	35.0	16.9%	4.4	11.6	8.0	163.1%
REZT	44.6	37.6	41.1	-15.8%	2.7	11.9	7.3	333.6%
SWEC B	35.0	24.1	29.6	-31.1%	0.5	4.4	2.4	729.0%
SYSR	34.3	31.2	32.7	-8.9%	0.1	6.6	3.4	7,098.0%
VBG B	30.4	26.5	28.4	-12.9%	0.0	1.6	0.8	Inf
VNIL SDB	41.4	37.2	39.3	-10.2%	4.4	15.2	9.8	247.4%
WALL B	26.9	22.8	24.9	-15.5%	2.0	8.2	5.1	301.3%
WIHL	22.0	21.6	21.8	-1.9%	2.7	8.7	5.7	222.9%

Table 14: Mean of realized volatility for one minute tick data of transaction prices for the 28 shares that have been randomly selected among those 71 shares that have been included in the Mid Cap segment for the whole period at NOMX-St and BURG. *) The values should be multiplied by 10^{-3} to get actual values.

5-Min	NOMX-St				BURG			
OMXS30	Before*	After*	Total*	Change	Before*	After*	Total*	Change
ABB	18.4	14.0	16.2	-24.0%	16.5	15.5	16.0	-6.0%
ALFA	20.0	18.0	19.0	-10.2%	18.2	18.5	18.3	1.2%
ASSA B	24.1	17.5	20.8	-27.4%	17.2	17.4	17.3	1.0%
ATCO A	21.5	17.3	19.4	-19.5%	18.6	18.5	18.6	-0.4%
ATCO B	23.3	18.7	21.0	-19.9%	19.7	19.1	19.4	-3.1%
AZN	14.0	10.5	12.3	-25.4%	13.0	10.9	12.0	-16.2%
BOL	26.0	20.1	23.1	-22.9%	26.6	21.2	23.9	-20.1%
ELUX B	23.4	18.6	21.0	-20.7%	22.2	19.6	20.9	-11.8%
ERIC B	15.8	15.5	15.6	-1.8%	17.0	16.8	16.9	-0.9%
HM B	14.8	11.9	13.4	-19.3%	13.9	13.0	13.5	-6.3%
INVE B	16.5	13.3	14.9	-19.1%	13.4	14.2	13.8	6.1%
LUPE	22.6	20.8	21.7	-8.1%	19.8	23.3	21.6	18.1%
NDA SEK	22.5	18.3	20.4	-18.8%	19.7	20.3	20.0	2.9%
NOKI SEK	21.1	17.9	19.5	-15.1%	20.1	18.9	19.5	-5.8%
SAND	24.8	18.4	21.6	-26.1%	21.7	19.9	20.8	-8.4%
SCA B	19.3	15.4	17.4	-20.4%	14.8	15.8	15.3	6.2%
SCV B	25.4	19.9	22.7	-21.7%	19.9	20.5	20.2	2.7%
SEB A	27.7	18.7	23.2	-32.6%	24.9	20.3	22.6	-18.5%
SECU B	19.5	14.3	16.9	-26.6%	14.8	13.9	14.4	-6.0%
SHB A	21.5	15.6	18.6	-27.7%	18.7	16.5	17.6	-11.6%
SKA B	20.0	17.0	18.5	-15.0%	17.9	17.9	17.9	-0.3%
SKF B	20.4	16.9	18.7	-17.5%	18.8	17.9	18.3	-4.6%
SSAB A	26.1	18.1	22.1	-30.8%	25.0	21.3	23.1	-14.7%
SWED A	34.5	20.0	27.2	-42.2%	33.8	27.1	30.5	-19.7%
SWMA	17.8	12.6	15.2	-29.4%	11.7	12.6	12.1	7.6%
TEL2 B	18.3	16.8	17.6	-7.9%	18.4	18.3	18.3	-0.5%
TLSN	17.5	12.5	15.0	-28.6%	15.5	12.6	14.1	-18.2%
VOLV B	27.4	17.8	22.6	-35.0%	24.2	18.7	21.4	-22.7%

Table 15: Mean of realized volatility for five minutes tick data of transaction prices for the 28 shares that have been included in OMXS30 for the whole period at NOMX-St and BURG. *) The values should be multiplied by 10^{-3} to get actual values.

5-Min	NOMX-St				BURG			
Mid Cap	Before*	After*	Total*	Change	Before*	After*	Total*	Change
ADDT B	19.3	22.3	20.8	15.6%	0.2	3.8	2.0	2,391.7%
AXIS	32.2	26.3	29.3	-18.3%	3.4	12.2	7.8	254.3%
BETS B	24.8	26.6	25.7	7.1%	2.8	12.9	7.8	365.4%
BILL	35.2	30.8	33.0	-12.4%	0.6	16.7	8.6	2,558.6%
BORG	38.0	32.5	35.3	-14.5%	0.0	9.6	4.8	Inf
BRIN B	28.3	26.1	27.2	-7.9%	0.0	1.9	0.9	Inf
CARD	30.3	25.8	28.0	-14.8%	2.2	8.4	5.3	285.1%
CLAS B	25.2	21.9	23.6	-13.1%	2.1	10.5	6.3	397.9%
ENRO	36.4	46.0	41.2	26.2%	18.1	39.5	28.8	117.6%
FPAR	12.2	15.2	13.7	24.9%	0.0	1.1	0.5	Inf
HIQ	33.3	30.6	31.9	-8.1%	0.0	7.1	3.6	Inf
HLDX	37.9	33.1	35.5	-12.5%	2.1	18.4	10.2	791.8%
HOGA B	26.5	24.2	25.4	-8.4%	0.0	12.7	6.3	Inf
HPOL B	51.8	35.9	43.8	-30.7%	4.0	7.9	5.9	98.5%
INDT	25.7	24.2	25.0	-5.8%	1.9	5.3	3.6	182.4%
ITAB B	18.2	19.7	18.9	8.3%	0.9	1.7	1.3	93.6%
KAHL	32.5	29.9	31.2	-8.1%	16.0	16.9	16.5	5.8%
KLED	24.8	26.3	25.6	6.0%	5.5	12.6	9.0	129.5%
MTRS	32.9	30.3	31.6	-8.1%	0.0	7.7	3.9	Inf
NISC B	34.0	31.9	32.9	-6.2%	4.7	14.4	9.6	205.5%
NOBI	30.0	34.2	32.1	13.7%	4.4	11.6	8.0	163.1%
REZT	41.6	34.0	37.8	-18.2%	2.7	11.9	7.3	333.6%
SWEC B	33.9	23.7	28.8	-30.1%	0.5	4.4	2.4	729.0%
SYSR	33.6	30.0	31.8	-10.6%	0.1	6.7	3.4	7,123.7%
VBG B	29.6	26.8	28.2	-9.6%	0.0	1.6	0.8	Inf
VNIL SDB	38.6	35.3	36.9	-8.5%	4.4	15.3	9.8	247.7%
WALL B	24.4	21.3	22.9	-13.0%	2.0	8.2	5.1	301.5%
WIHL	19.1	19.0	19.1	-0.6%	2.7	8.7	5.7	223.0%

Table 16: Mean of realized volatility for five minutes tick data of transaction prices for the 28 shares that have been randomly selected among those 71 shares that have been included in the Mid Cap segment for the whole period at NOMX-St and BURG. *) The values should be multiplied by 10^{-3} to get actual values.

C Statistics for the data

Segment	Market	Type of data	Size [GB]	Rows [M]	Trades [M]	Quotes [M]
*	*	*	211.5	1,016.5	-	-
OMXS30	*	*	206.4	988.3	-	-
Mid Cap	*	*	5.1	28.2	-	-
*	NOMX-St	*	153.3	659.5	-	-
OMXS30	NOMX-St	*	148.7	635.0	-	-
Mid Cap	NOMX-St	*	4.6	24.5	-	-
*	BURG	*	58.2	357.0	-	-
OMXS30	BURG	*	57.7	353.3	-	-
Mid Cap	BURG	*	0.5	3.7	-	-
*	*	DEPTH	190.0	721.4	-	-
OMXS30	*	DEPTH	185.8	704.7	-	-
Mid Cap	*	DEPTH	4.2	16.7	-	-
*	NOMX-St	DEPTH	140.1	488.2	-	-
OMXS30	NOMX-St	DEPTH	136.3	473.5	-	-
Mid Cap	NOMX-St	DEPTH	3.8	14.6	-	-
*	BURG	DEPTH	49.9	233.2	-	-
OMXS30	BURG	DEPTH	49.5	231.1	-	-
Mid Cap	BURG	DEPTH	0.4	2.1	-	-
*	*	TAQ	21.5	295.1	35.85	258.8
OMXS30	*	TAQ	20.6	283.6	33.60	249.7
Mid Cap	*	TAQ	0.9	11.5	2.26	9.1
*	NOMX-St	TAQ	13.2	171.3	33.73	137.1
OMXS30	NOMX-St	TAQ	12.5	161.4	31.49	129.5
Mid Cap	NOMX-St	TAQ	0.8	9.9	2.24	7.5
*	BURG	TAQ	8.2	123.8	2.12	121.7
OMXS30	BURG	TAQ	8.1	122.2	2.10	120.1
Mid Cap	BURG	TAQ	0.1	1.6	0.02	1.6

Table 17: Statistics for the data of the shares in OMXS30 and Mid Cap for the whole period. There are a total of $3^3 = 27$ different combinations of the arguments *Segment*, *Market* and *Type of data*. Each argument can take one of three different values; *value 1*, *value 2* or *** = both *value 1* and *value 2*.

Column	Description
Segment	OMXS30 (28 shares), Mid Cap (28 shares)
Market	NASDAQ OMX Stockholm (NOMX-St), Burgundy MTF (BURG)
Type of data	Trades and best quotes (TAQ), Updates in order book, ten levels/side (DEPTH)
Size [GB]	Size of data in bytes divided by $1,024^3$ to get size in gigabytes (GB)
Rows [M]	Number of rows in data divided by $1,000^2$ to get amount in million (M)
Trades [M]	Number of trades in TAQ data divided by $1,000^2$ to get amount in million (M)
Quotes [M]	Number of quotes in TAQ data divided by $1,000^2$ to get amount in million (M)

Table 18: Description of the columns used in the statistics for the data.

D Trading days

The data for trading days used in this study are available over the Internet at http://www.ter.se/hft-inet-study/ to limit the size of the appendix.

E Shares outstanding

The data for shares outstanding used in this study are available over the Internet at http://www.ter.se/hft-inet-study/ to limit the size of the appendix.

F Market capitalization

The data for market capitalization used in this study are available over the Internet at http://www.ter.se/hft-inet-study/ to limit the size of the appendix.

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