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Topics on market microstructure and asset pricing using intraday data from the Oslo stock market.

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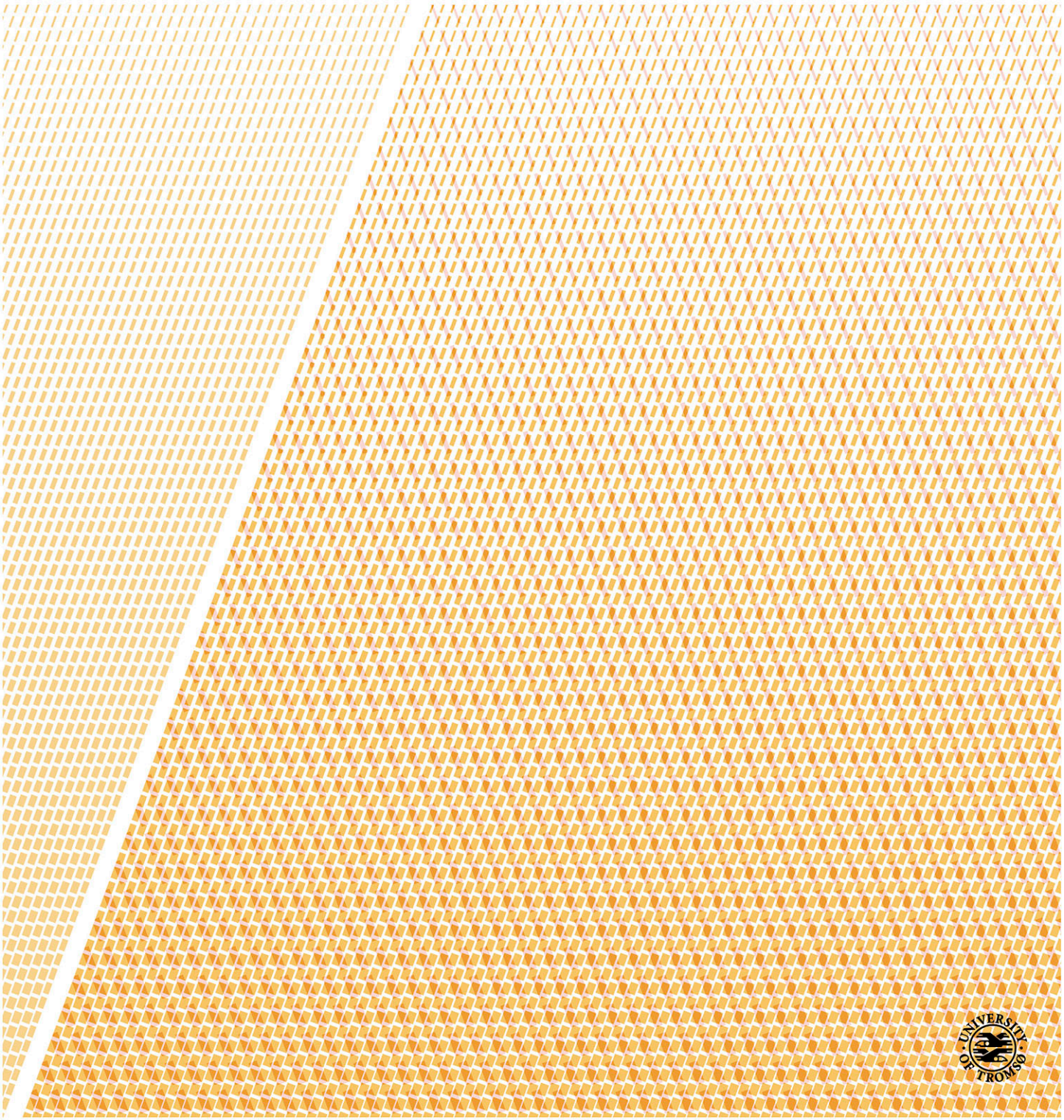

Summary

What drives asset prices in the financial market? How can we predict these prices? Finding the relationship between different factors or between different variables could help to answer these questions. First, links between asset pricing models and other market microstructure variables can be used to investigate sources to explain asset prices. Second, rapid changes in the microstructure of the financial market in which investors can trade with high frequency have provided a platform for researchers to examine the relationship between microstructure variables in high frequency trading. Therefore, this thesis first links two theories, asset pricing and market microstructure, and then focuses on the market microstructure area.

In the first paper, the relationship between returns, risk and liquidity in high frequency trading is investigated. The results of this research mainly suggest that in high frequency trading idiosyncratic risk plays a more important role than systematic risk in asset pricing. In addition, liquidity has a higher effect on idiosyncratic risk than systematic risk. In the second paper, the relationship between the spread and the quoted volume imbalance is investigated. The results suggest that for the liquidity sample the relationship is negative if the imbalance is higher than 1, and positive if the imbalance is lower than -1. This means that if the imbalance is high enough, it affects the spread. For low liquidity samples, there is no obvious relationship between them. In the third paper, we investigate whether asymmetric information appearing in the financial market affects the order imbalance reversal effect; the main results suggest that it does.

Acknowledgements

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Contents

List of papers

Paper 1

Dinh, M.T.H., (2017). The returns, risk and liquidity relationship in high frequency trading: Evidence from the Oslo stock market. *Research in International Business and Finance*, *39*, pp.30-40.

Paper 2

Dinh, M.T.H., (2017). The relationship between volume imbalance and spread. *Research in International Business and Finance*. DOI: http://dx.doi.org/10.1016/j.ribaf.2017.03.003

Paper 3

Sirne, E. and Dinh, M.T.H., (2017). "The OIB-reversal effect and asymmetric information" (submitted).

1. Introduction

The financial market plays a very important role in the smooth functioning of the modern economy and enhances its stability. It can be considered as an important chain in the economy system, and its smooth operation contributes to the flow of the economy.

Stock markets have changed quickly because of the development of computer science and technology. Advanced technology has provided a high frequency and computer-based trading platform for investors. For example, the Oslo stock market has used the Millennium Exchange trading system for trading on the equity market. Millennium Exchange provides a flexible, highly scalable trading platform with ultra-low latency[1]. Because of the evolution of the financial market in which investors can trade with high frequency, examining the sources driving asset prices in this type of trading is currently of great interest to researchers. Although both asset pricing and market microstructure seem to consider different angles of the financial market, both topics try to explain how an asset is priced. Asset pricing is mainly based on the relationship between risk and return to explain asset prices, while market microstructure is focused on how asset prices, volumes, the flow of information and other microstructure variables are set in the financial market. Research on the interaction between these microstructure variables attempts to explain asset prices. Some previous studies also suggest that the price of assets can be investigated by linking these two theories.

Using high frequency data from the Oslo stock market, this thesis focuses on empirical research examining variables that could drive asset prices based on asset pricing models and market microstructure variables. The results of the research confirm that a combination of the traditional asset pricing models and market microstructure variables, and the interaction

[1] Ultra-low latency refers to a computer network processing a huge volume of data packets with an extremely low tolerance for delay (or low latency) and is used in the financial market to support high frequency trading systems.

between market microstructure variables, can help to explain asset prices, and it is suggested that the scope of these findings can be expanded to predict these prices.

Explaining and predicting asset prices is not only extremely important for investors who wish profit from their investments, but also for policy makers and regulators who contribute to the design of efficient financial markets, and to the stability of the economy as a whole.

Author contributions to the papers

	Paper I	**Paper II**	**Paper III**
Concept and idea	MTHD, ES	MTHD	MTHD, ES
Study design and methods	MTHD	MTHD	ES
Data gathering and interpretation	MTHD	MTHD	ES
Manuscript preparation	MTHD	MTHD	MTHD, ES

MTHD = Minh Thi Hong Dinh

ES = Espen Sirnes

2. The market micro-structure literature

Previous studies have made several definitions of what the literature on market microstructure is concerned with. Easley and O'Hara (2003) state that it analyses "the behaviour and information of prices in asset markets", while Stoll (2003) emphasizes the cost of trading securities and its impact in the short run. Madhavan (2000) states that this area of the literature studies "the process by which investors' latent demands are ultimately translated into prices and volume", and Dominguez (2003) explains that it analyses "ways in which specific trading mechanisms affect the price information process".

The following subsections will discuss some of the concepts related to market microstructure.

2.1. Types of markets

There are two main types of markets: dealer markets and limit order markets. These markets are summarized in Figure 1.

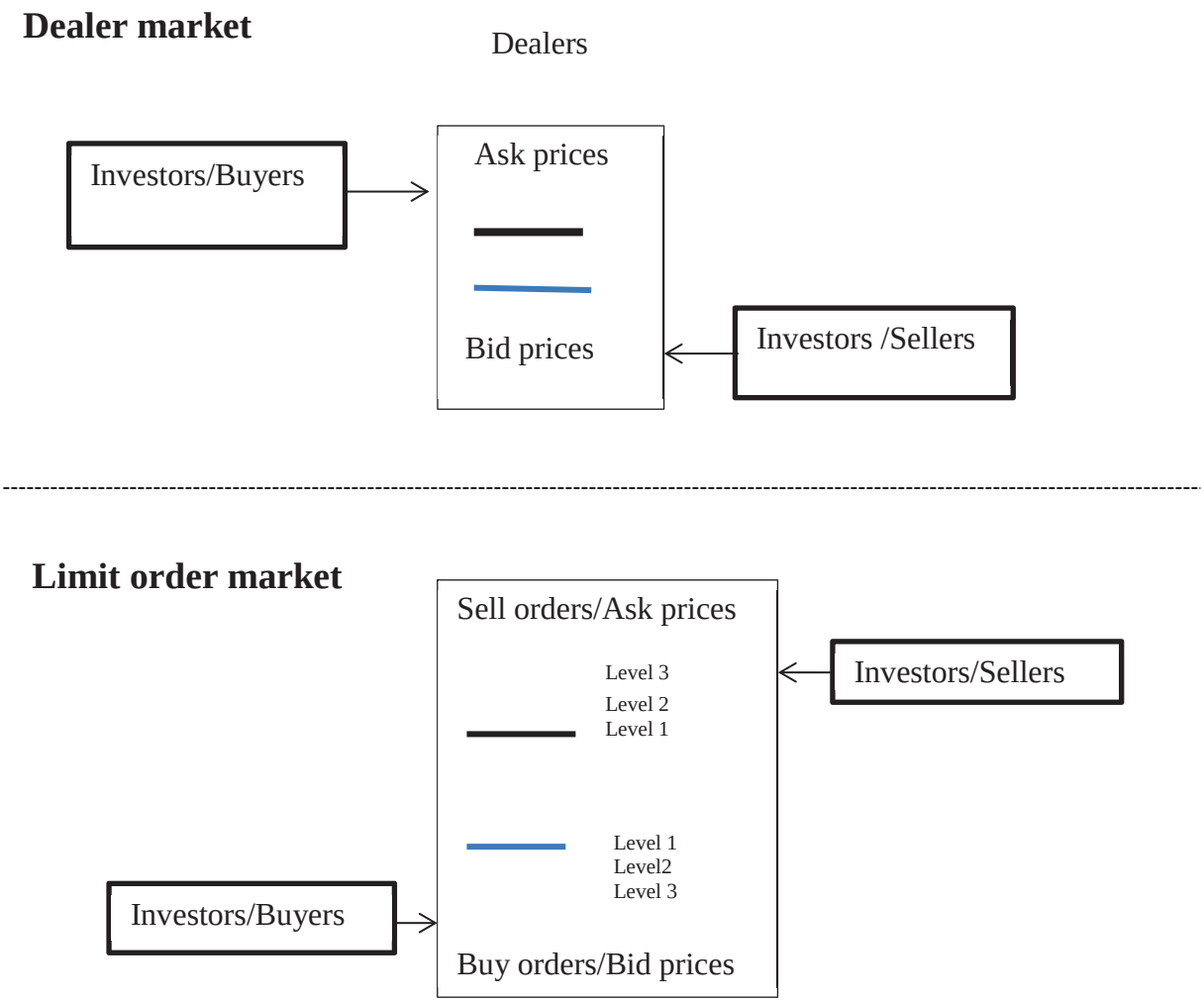

Figure 1: Types of market

As shown in Figure 1, in the dealer market dealers or intermediaries will post bid and ask prices at which public investors can trade. Dealers sell at the ask price and buy at the bid price from public investors, and public investors buy at the ask price and sell at the bid price. In this type of market, investors cannot trade directly with each other.

In the limit order market, investors trade directly with each other without the intervention of dealers. They place orders, including prices and quantity, in the form of limit order or market order. Investors who wish to sell an order will set the selling price on the ask price side, and investors who want to buy an order will set the buying price at the bid price. The trade will occur when the buying price and the selling price are matched. There is more than one level of orders in the order book. The first level of bid and ask orders will establish the market.

2.2. Orders

There are two principle orders: market orders and limit orders. A market order includes quantity and no limit price, so it will trade immediately at the best available prices on the market. A limit order includes quantity and a limit price. An ask limit order is an order with a minimum price that can be accepted; a bid limit order has a maximum price that can be paid. The best bid and ask orders establish the market, and the quantities at those prices are the depth of the market. Trading happens if a new order comes to the market and matches the best limit prices. In the traditional financial market, dealers and brokers can intervene in this process, but in the electronic market trading will be automatically completed, without their intervention.

1.1. Traders

According to Stoll (2003), there are different types of traders, depending on how they are recognized. First, active and passive traders have different attitudes to trading. Active traders "demand immediacy and push prices in the direction of their trading" (Stoll, 2003), while passive traders "supply immediacy and stabilize prices" (Stoll, 2003). In the dealer market, dealers are considered as passive traders who earn profits from active traders.

Second, liquidity and informed traders are recognized when traders decide to trade in the financial market. Liquidity traders are willing to smooth consumption or to adjust the balance between risk and return on their trading portfolios. They buy stocks if they have excess cash, or sell them if they need cash. Informed traders trade when they have private information on stocks, so they evaluate an asset's value based on this information and trade when they know the value of the asset well. Liquidity traders usually trade stock portfolios, while informed traders tend to trade the specific assets on which they have private information. A liquidity trader tends to lose if an informed trader intervenes in his trade.

Third, individual and institutional traders are other types of traders in the financial market. Institutional traders, including pension funds, mutual funds, foundations and endowments, are dominant, and hold and control the majority of assets. These traders tend to trade in large quantities, so they can be faced with high trading costs. They will benefit from any private information on the assets that they are trading in. Individual traders trade in smaller quantities of stocks than institutional investors.

Finally, public traders and professional traders are distinguished by how they place an order. A public trader places an order with a broker's account, while professional traders trade with their own accounts, like market makers or floor traders in traditional financial markets. Recently, advanced technology has provided a high speed trading platform that has changed the trading positions of public and professional traders; public traders can directly trade with each other under the trading codes of a member firm, but without its intervention.

1.2. The trading process

The process of asset trading in the financial market is divided into four stages: information, order routing, execution, and clearing (Stoll, 2003). Information is first provided by the financial market through published information, such as past prices, current quotes, time of

quotes and news. Routing orders are set by brokers who take orders and route them to an exchange or other market centre. Execution is nowadays automated to match orders; if a sell order and a buy order are matched, they will be automatically executed. The clearing process regards "the comparison of transactions between buying and selling brokers" (Stoll, 2003).

1.3. Transaction costs

Transaction costs are divided into two types: explicit and implicit costs. Explicit costs are those related to all the fees that investors have to pay when they trade on the financial market, such as brokers' commissions and stock exchange fees. Implicit costs are types of opportunity costs. If investors cannot trade at the desired time, they have to pay more or to sell at lower prices when they want to push for a quicker transaction. In this case, the investor tries to weaken the patience of his waiting sellers or buyers and make them jump into the trade.

2. The asset pricing literature

Asset pricing theory attempts to understand the prices or values of uncertain payments of assets on the financial market. Normally, an asset with a low price implies a high return. Therefore, this theory tries to explain why some assets pay higher average returns than others (Cochrane, 2001).

Cochrane (2001) posits two approaches to the study of asset pricing: absolute pricing and relative pricing. In absolute pricing, an asset is valued based on the fundamental source of macroeconomic risk – systematic risk. Two types of models, consumption-based and general equilibrium models, such as the CAPM, the intertemporal CAPM, the Fama-French three factor model, and other equilibrium models are used to understand the sources driving asset prices. In relative pricing, the values of assets based on the prices of other assets are established. Black-Scholes option pricing is an example of the relative pricing approach.

Asset pricing is a broad topic; only the CAPM model relative to the studies in this thesis and the widely used one which is the Fama-French three factor model, are basically introduced.

2.1. The capital asset pricing model (CAPM)

This model is based on the mean-variance analysis pioneered by Markowitz (1952) and Tobin (1958), and then expanded to an equilibrium model by Sharpe (1964) and Lintner (1965). It tells us about the trade-off between risk and returns, how systematic risk is priced and how specific risk is not priced (Dybvig and Ross, 2003). An underpinning premise of the CAPM is that risky assets can be combined to become a portfolio which is less risky than any of its components. Therefore, by holding a diversified portfolio, specific risk can be eliminated.

The CAPM shows the relationship between expected return and beta (or systematic risk).

$$E(R_i) - R_f = \beta_i[E(R_m) - R_f] \quad (1)$$

$$\beta_i = \frac{Cov(R_i, R_m)}{\sigma_m^2}$$

where E(R_i) is the stock expected return; R_f is the risk free rate; E(R_m) is the expected return on the market portfolio; β_i is the stock's beta; and $E(R_m) - R_f$ is the market risk premium (Mullins, 1982).

If the index market in model (1) is the true market portfolio, we add α, considered as an abnormal return, on the right hand side of this model.

$$E(R_i) - R_f = \alpha_i + \beta_i[E(R_m) - R_f] \quad (2)$$

If the stock is fairly priced, its alpha must take the value of zero. In fact, however, some securities can generate better or worse returns than the expected ones predicted from the CAPM. According to model (2), superior or inferior returns are exhibited by positive or

negative alpha. “A security is mispriced if and only if its alpha is nonzero – under-priced if alpha is positive and over-priced if alpha is negative ” (Bodie et al., 2011). Because the true market portfolio, including all traded securities in the investable universe[2], cannot be observed, tests of the CAPM use the S&P 500 index proxy for the true market portfolio. The CAPM fails these tests, meaning that the hypothesis, in which the values of alpha are indistinguishable zero at acceptable significance levels, is rejected. For example, it is found that “on average, low-beta securities have positive alphas and high-beta securities have negative alphas ” (Bodie et al., 2011).

2.2. The Fama-French three factor model

The Fama-French three factor model introduced by Fama and French (1993) is currently widely used in empirical research. The three factors in the model: firm size, book to market ratio, and market index are regarded as the systematic factors.

The model is presented below:

$$R_i - R_f = \alpha_i + b_i(R_m - R_f) + s_i\, SMB + h_i HML + \varepsilon_i$$

where $R_i - R_f$ is excess stock returns; $R_m - R_f$ is market risk premium; SMB represents the difference between the return on the portfolio of small stocks and the return on the portfolio of large stocks (SMB means small minus big); and *HML* refers to the difference between the return on the portfolio of high-book to market stocks and the return on the portfolio of low-book to market stocks (HML is high minus low).

According to Fama and French (1996), the book to market equity (HML) and its slope present relative distress. “Weak firms with persistently low earnings tend to have high BE/ME [book equity/market equity] and positive slopes on HML, strong firms with persistently high

[2] For simplicity, a market portfolio generally refers to all risky assets as stocks.

earnings have low BE/ME and negative slopes on HML" (Fama and French, 1996). Therefore, HML in this model is used to explain returns related to relative distress; it is shown in research by Chan and Chen (1991) that there is a covariation in returns on distress that is not captured by market returns. SMB in this model is used to explain returns that compensate the covariation in the returns on small stocks, which is not included in the return on market, found in the research of Huberman and Kandel (1987).

3. Link between market microstructure and asset pricing

Many studies investigate the relation between market microstructure and asset pricing. The fact that expected returns are related to transaction costs was found in research by Stoll and Whaley (1983). Brennan et al. (1998) illustrate that expected returns have a negative relationship with volume, while Amihud and Mendelson (1986) examine the effect of the bid-ask spread on asset pricing. They find that expected return is an increasing and concave function of the spread. Brennan and Subrahmanyam (1996) examine the relationship between stock returns and illiquidity measurements obtained from intraday data, and find a significant relationship between these factors. Stoll (2003) also states that microstructure factors clearly affect asset pricing. He discusses the relationship between stock prices, and informed and uninformed traders, and argues that informed traders will receive a better price than uniformed ones because those with good news will bid up prices, to the disadvantage of uninformed traders selling stocks. Additionally, Easley et al. (2002) examine the role of information-based trading in affecting asset returns. They use the market microstructure model to drive and estimate the measures, and then incorporate them into the Fama-French asset pricing model (1992). Their results illustrate that information does affect asset returns. Easley et al. (2010) also test a private information (PIN) factor in relation to asset returns. They first estimate a PIN factor and show that it successfully explains asset returns.

4. Characteristics of the Oslo stock market

The Oslo stock market was founded in 1819; its main objective is to provide a service as a central market for securities listing and trading in Norway. In 2009, the Oslo Stock Exchange became a strategic partner with the London Stock Exchange Group. The partnership includes the equities, the bond and derivative markets. Since November 2012, the Oslo Stock Exchange has used the Millennium Exchange trading system for trading on the equity market. This provides a flexible, highly scalable trading platform with ultra-low latency and also reduces the cost of trading.

The Oslo Stock Exchange is known as an order-driven market, in which liquidity providers are not dependent on market makers. Investors themselves provide liquidity and set the prices of assets on a market order form or a limit order form. An investor can submit orders to the trading system through the order management systems of a member firm under its trading codes. The member firm cannot manually intervene in the orders.

4.1. Oslo market structure

The Oslo Stock Exchange has 11 segments for equities, which are mainly categorized by the liquidity of stocks or by the types of securities (see in Appendix). The liquidity categories are rebalanced every six months. Therefore, there is a movement of instruments between the segments if their liquidity does not meet its current segment requirement.

The Oslo stock market is a limit order market, with two types of order book: lit order book and dark midpoint order book. The lit order book is the standard order book, with normal visible orders and hidden orders, while the dark midpoint order book is an order book containing some instruments with dark (or unpublished) orders. In this thesis, primarily

information on the lit order book is introduced as it is related to this research, but not the dark midpoint order book[3].

4.2. Types of orders

Five types of orders are used on the Oslo stock market: limit order, market order, iceberg order, hidden (reserve) order, and pegged order.

A limit order is an order with a limit price and a fully visible quantity; it is added to the order book and published. A limit order is executed at a price which is equal to the limit price or better price of it.

A market order is an order without a price attached to it, meaning that it will be traded at the best available prices in the order book during the period of regular trading. If a market order is not fully filled in the regular session, the remainder will expire. If it arises during the auction call session, and if the order book moves to another session, the halt session, then all the remaining market orders expire. In Millennium trading, market supervision may introduce a matching halt for one or more instruments, which is published as a halt session. During this session, orders are not executed, and members may not register or adjust orders, but they may delete orders.

An iceberg order is a limit order; part of the quantity of this type of order is hidden. When this order is submitted, only the disclosed quantity is published in the order book.

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[3] Dark Midpoint Order Book information can be found in Børs (2017).

A hidden (reserve) order is a limit order. There is no disclosed quantity with this order and it is not published in the order book. This type of order is not available for all segments on the Oslo stock market.

A pegged order is a type of hidden order, and it will always be pegged to the visible midpoint of the same instrument. When a pegged order is partially executed, the remainder are still pegged orders. This order is not available for all instruments.

In general, the Oslo stock market allows two types of main order forms: limit order and market order.

4.3. Trading time

The ordinary trading time for shares on the Oslo stock market is from 8:15 to 17:30 and is divided into the following trading sessions. A pre-trading session and opening auction call session lasting 15 minutes take place before the regular trading session. These sessions run from 8:15 to 9:00 and the regular trading session starts at 9:00 and ends at 16:20. Then, a five minute closing auction call session takes place from 16:20 - 16:25. The post close session starts at 16:25 and ends at 17:30.

In the pre-trading and the opening auction call sessions, orders from the closing auction call session of the previous day are published through the market data channels. Orders in this stage can be inserted, amended or deleted, but they are not executed. Pegged orders may be entered and will be parked.

In the regular trading session, all types of limit order and market order can be inserted, adjusted, executed or cancelled. Market orders will not persist in the order book during this session; they will expire after a full, partial or no execution. At the beginning of the regular

session, pegged orders will be removed from the parked queue and will be available for execution if they are inserted in the opening auction call session.

When the closing auction call session starts, all instruments are moved to it. However, all existing pegged orders expire. During this period, orders may be inserted, amended or deleted, but no execution takes place at this time. All disclosed parts of orders are published, and the indicative auction price and volume are continuously computed and published. The closing prices are published at the end of the session, or at the end of the regular trading session if no closing auction call is configured.

In the post close session, no order can be inserted or amended, but can be cancelled. The order book will not be published in the session, but shown as “frozen” via market data.

4.4. Order priority

Prices are the first priority in the lit order book. A buy order with the highest price and a sell order with lowest price will be the first priorities for execution. Market orders hence always have a higher price priority than limit orders. The counterparty is the second priority. Orders at the same price, passive orders owned by a member who owns aggressive orders, have a higher priority for execution. A passive order is a new order, which may be inserted with the indicator “passive only”. This passive order will not be executed if there is a visible order with an equal or better price at order entry. A third priority is considered for the level of visibility. Orders with the same price and counterparty priority will have priority, depending on their visibility, as shown below:

“*First, visible orders and visible parts of iceberg orders*

Second, hidden part of iceberg orders

Third, hidden orders

Fourth, pegged orders"

Source: Børs (2017).

The fourth priority is time, meaning that orders that come first will have higher priority than later orders.

4.5. Information transparency

For all instruments, all visible orders and the visible parts of iceberg orders will be updated and published until the beginning of the post-close session.

Hidden orders, including pegged orders and the hidden parts of iceberg orders, are not published. During the auction call periods, the indicative auction price or equilibrium price will be computed and published.

Each visible order in the lit order book will be published with the information below: instruments, buy or sell, price, quantity, and order ID. No information of orders in the dark midpoint order book is published.

Trades from automatic order execution are published in real time. The following information will be published: instrument, price, volume, trade type, trade day and time, member ID buy and member ID sell.

The Oslo stock market also publishes statistical information, including opening and closing price, cumulative traded quantity, turnover and number of trades, calculation of VWAP[4], and calculation of high and low prices. In addition, other information related to orders and trades is published via the system; for example, all indices calculated by the Exchange (OBX, or OSEBX), and news announced by companies.

[4] Volume weighted average price.

Summary: Lit Order Book

Trading time: 8:15 – 17:30	Types of orders	Order priority
8:15 - 9:00: Pre-trading and opening auction call. Previous day's orders are registered. Orders can be inserted, amended or deleted. **9:00 – 16:20**: Regular trading: orders can be inserted, amended, deleted or executed. **16:20 – 16:25**: Closing auction call. Orders might be inserted, amended or cancelled, but not executed. **16:25 – 17:30**: Post close. Orders cannot be inserted or amended, but can be cancelled.	**Limit order**: quantity and limit price. **Market order**: quantity without price. **Iceberg order**– limit order: part of quantity hidden. **Hidden (reserve) order**- limit order: all quantity hidden. **Pegged order**-hidden order, not available for all instruments.	Price ↓ Counterparty ↓ Level of visibility ↓ Time

5. Description of the Oslo stock market dataset

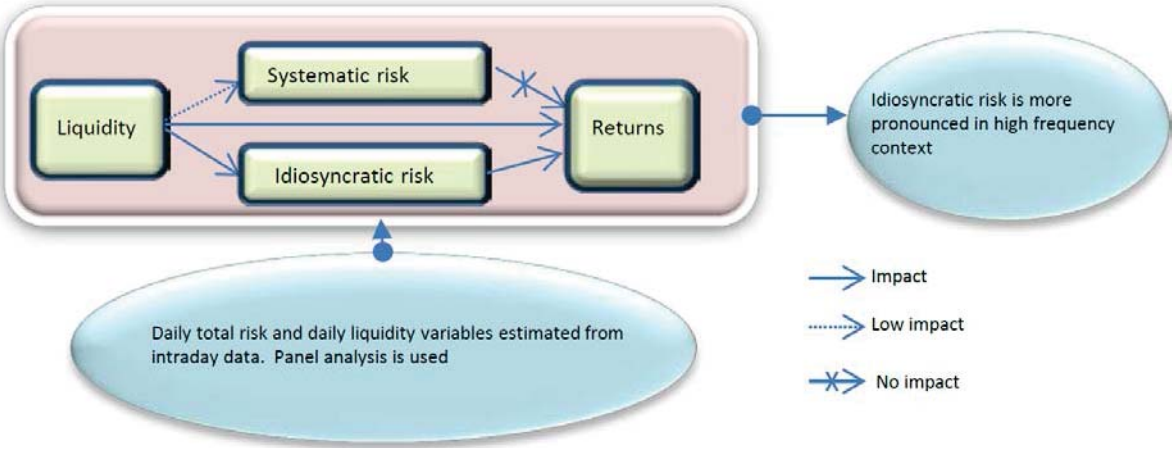
The dataset used in this PhD thesis was extracted from the Oslo Stock Exchange (OSE) during the period 2003 - 2010. The dataset is an intraday one, including both bid and ask orders, recorded in an order book. Both sides in the order book are reconstructed by algorithms if either needs to be added or removed. Then, 60 second intervals of the intraday data are taken for analysis. The dataset includes 150 companies listed on the OSE during this period; there is a substantial variation in size and liquidity between these companies. The largest companies have an average of 15,000 orders and high liquidity, with approximately 3,000 trades each day, while the smallest ones have low liquidity, with approximately 30 trades each day.

6. Summary of the papers in the thesis

6.1. Paper 1

Title of the paper: The returns, risk and liquidity relationship in high frequency trading: Evidence from the Oslo stock market.

Graphic summary of results:



Source: Dinh (2017A).

This paper contributes to the literature in the following ways. It uses higher frequency data than previous studies, of which the highest frequency is daily. In addition, it uses the panel data analysis method to find the relationship between these variables, rather than following the traditional portfolio analysis. The research proves that idiosyncratic risk matters in high frequency trading, and plays a more important role than systematic risk.

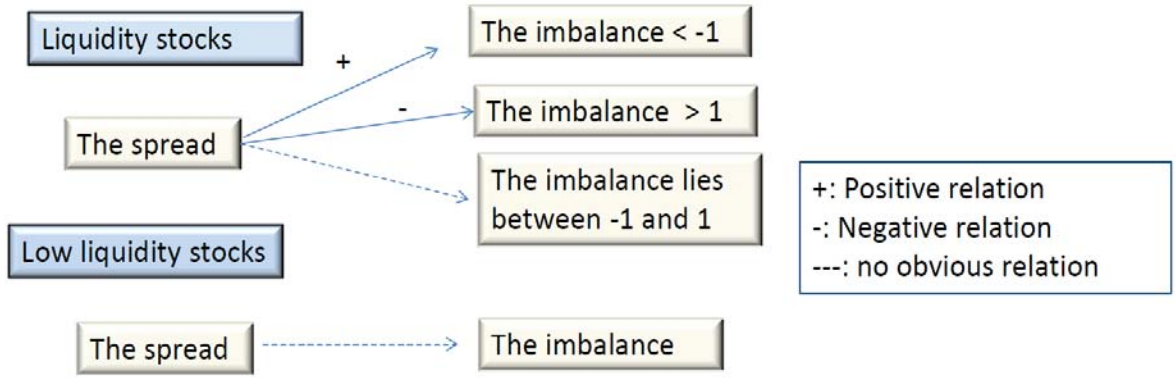
The paper aims to test the relationship between returns, risk and liquidity. Following previous researchers, who have attempted to bridge market microstructure and asset pricing by illustrating that microstructure-related concepts such as liquidity and asymmetric information could play an important role in explaining asset returns, this paper succeeds in connecting these two fields. Two models are considered: first, that returns are the function of risk and liquidity variables; and second, the relationship between the risk and liquidity variables. The panel data analysis method was applied for the two models. The empirical results of the first model show that idiosyncratic risk and the liquidity variable – BindFreq[5] – have a significant relationship with returns at a low significance level α of 1%, but that systematic risk (beta) does not. The empirical results of the second model suggest that the first liquidity variable – the number of trades per day – affects both beta and idiosyncratic risk, but the effect on idiosyncratic risk is at a much lower significance level α than on beta; alpha at 1% for idiosyncratic risk, but at 10% for beta. In addition, the other liquidity variable – BindFreq – only has a significant relationship with idiosyncratic risk at a high significance level α of 10%, but not with beta. It seems to be that this liquidity variable has a weak relation with risk. In conclusion, this research proves that in high frequency trading idiosyncratic risk plays a more important role than systematic risk, and liquidity variables (or market microstructure variables) explain idiosycratic risk and returns.

[5] It is defined as the frequency at which the tick size binds constraint.

6.2. Paper 2

Title of paper: The relationship between volume imbalance and spread.

Graphic summary of results:



Source: Dinh (2017B).

This research contributes to the literature by providing a different view of volume imbalances, which are used as the transacting volumes. Using quoted volumes can avoid the problem of the mis-transactions which occur in the previous research, in which the imbalance is defined as the initiated seller or buyer trade imbalances. In addition, this research confirms a possible level of quoted volume imbalance at which a significant relationship between the imbalance and the spread exists.

The paper is exclusively related to the topic of market microstructure. It investigates the relationship between the quoted volume imbalance at the first level in the order book and the spread. The spread is defined as the difference between ask and bid prices, and the quoted volume imbalances are the log differences between ask and bid volumes at the best five levels in the order book. The Oslo stock market is considered as an order-driven market, in which investors themselves provide liquidity, but not market makers. Therefore, the quoted volume imbalance at the first level in the order book can be considered as the potential supply-

demand imbalance in this research. Intraday data of three stickers, BIRD, STATOIL and REC, are used with different time horizons: one month and one year. The total number of samples in this research after construction[6] are 37, of which 18 are considered as liquidity samples, and 19 as low liquidity ones. The generalized method of moments (GMM) is used to test the relationship between the volume imbalance and the spread after all the samples are divided into quartiles and the endogeneity problem is tested. The empirical results of this research suggest that for the liquidity samples the significant relationship between them occurs when the imbalance is high enough: lower than -1, or higher than 1. For low liquidity samples, there is no obvious relationship between them. In conclusion, the research proves that there are possible levels of the quoted volume imbalance (or the imbalance is high enough) that make them significant in relation with the spread.

6.3. Paper 3

Title: The OIB[7]-reversal effect and asymmetric information.

This paper mainly examines the relationship between asymmetric information and the OIB reversal effects proposed by Chordia et al. (2005). It first confirms the OIB-reversal effect found in Chordia et al. (2005), and then illustrates that private information affects the OIB-reversal effects. The private information proxy by spread is proven to make the OIB-reversal effects stronger when liquidity providers recognize the probability of private information appears in trading on the financial market. In this research intraday data is used to investigate the relationship. Spread is considered as a good measure of the perceived presence of private information, because it captures this information after controlling for other variables, namely liquidity and volatility. We consider two models; the first is an intraday model, and the second a panel data one. We first estimate the intraday OIB reversal effect by regressing the

[6] All samples are constructed by first sorting the quoted volume imbalance at the first level and then dividing them into quartiles.
[7] OIB: order imbalance.

intraday model. The coefficients are estimated with maximum likelihood using Davidon-Fletcher-Powell optimization (Press et al., 1982). The OIB reversal effect is defined as the estimated coefficient of one lag return with the presence of OIBAtAsk and OIBAtBid[8]. We then regress the panel data model - the random effect model. The empirical results of the intraday model show that all the coefficients of one lag return or the OIB reversal effect are significantly negative at the acceptable significance level alpha. The empirical results of the panel data model suggest that the coefficients of the spread proxy for private information have a highly significant relationship with the OIB reversal effect. In conclusion, this research first confirms that in high frequency trading, if more initiated buyers are added onto the bid side of the order book, meaning more buyers, the price falls, and vice versa for the ask initiated volume side. In addition, OIB reversal is a likely protective measure against private information. It appears that traders increase spreads when they recognize a high probability of private information appearing in the market, which shows a stronger reversal effect in absolute values.

[8] OIBAtAsk and OIBAtBid are the sum of initiated orders by sellers and buyers respectively.

Appendix: Segments and market identifier codes

Market	MIC	Segment	Description
OB Equities	XOSL [XOSD]	OBX	This segment includes the constituents of the OBX index – i.e. the most traded stocks at Oslo Børs.
OB Equities	XOSL [XOSD]	OBMA	The OBMA segment includes the securities in liquidity category OB Match i.e. shares with a minimum of 10 trades per day on average, excl. OBX or shares with less than 10 trades but with a liquidity provider agreement.
OB Equities	XOSL [XOSD]	OBST	The OBST segment includes the securities in liquidity category OB Standard i.e. shares with fewer than 10 trades per day on average and without a liquidity provider agreement.
OB Equities	XOSL [XOSD]	OBNW	The OBNW segment includes the securities in liquidity category OB New i.e. newly listed shares.
OB Equities	XOSL [XOSD]	OBPC	The OBPC segment includes the securities in the liquidity category OB Equity Certificates i.e. the listed equity certificates.
OB Equities	XOSL	OBWR	The OBWR segment includes warrants.
OB Equities	XOSL [XOSD]	OBEF	The OBEF segment includes the listed ETFs (Exchange Traded Funds).
OB Equities	XOSL	OBEN	The OBEN segment includes the listed ETNs (Exchange Traded Notes).
OB Equities	XOAS [XOAD]	OAX	THE OAX segment includes the Oslo Axess listed securities. This does not imply any change in Oslo Axess' status as a regulated market.
OB Equities	MERK	MERK	The MERK segment includes securities available for trading on the Merkur Market MTF.
OB Equities	n/a	OBTS	This is a segment including instruments with different instrument types. The details are described in OSLMIT 501 Guide to Testing Services[8]. Please note that access to these instruments may be restricted by Oslo Børs without any prior notice.

Source: Børs (2017).

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