

Order Book Characteristics and the Volume-Volatility Relation: Empirical Evidence from a Limit Order Market*

Randi Næs

*Norges Bank, Bankplassen 2, 0107 Oslo, Norway and
Norwegian School of Economics and Business Administration (NHH)*

and

Johannes A. Skjeltorp †

*Norges Bank, Bankplassen 2, 0107 Oslo, Norway and
Norwegian School of Management (BI)*

July 12, 2004

Abstract

We examine empirically the relationship between the demand and supply schedules in a limit order book and the volume volatility relation. Several empirical studies find support for the hypothesis that the volume-volatility relation is driven by the arrival rate of new information, proxied by the number of transactions. Our results show that the number of trades and the price volatility are also negatively related to the slope of the order book. One possible interpretation of this finding is that the slope of the book is proxying for dispersed beliefs among investors. If so, this would support models where investor heterogeneity intensifies the volume-volatility relation.

Keywords: Market Microstructure, Equity Trading, Asymmetric Information

JEL Codes: G10, G20

*The views expressed are those of the author and should not be interpreted as reflecting those of Norges Bank. We are grateful to Bernt-Arne Ødegaard, Dagfinn Rime, Thierry Foucault, Richard Lyons and participants at the AFFI 2003 Conference in Lyon for providing useful comments and suggestions. We would also like to thank Sverre Lilleng and Thomas Borchgrevink at the Oslo Stock Exchange for providing us with the transactions data and for being very helpful in the preparation process of the data sample. All remaining errors or omissions are ours.

†Corresponding author. E-mail:johannes-a.skjeltorp@norges-bank.no Phone:(+47)22316740
Fax:(+47)22424062

1 Introduction

In this paper, we examine empirically the relationship between the demand and supply schedules in a limit order book and the volume-volatility relation.

A variety of studies document that there is a positive correlation between price volatility and trading volume for most types of financial contracts including stocks, Treasury bills, currencies and various futures contracts. The main theoretical explanation for this phenomenon is that new information about asset values acts as the driving force (or mixing variable) for both market prices and trading volume.¹ Harris (1986) links this “mixture of distributions hypothesis” to asset pricing theory, and suggests that the mixing variable is the process that directs the rate of flow of information from systematic risk factors into prices and trading volume. However, for many types of financial contracts, movements in prices seem much “too large” to be attributed to movements in the fundamental values of the underlying securities. A suggested explanation for this puzzle is that prices do not change merely because of changes in systematic risk factors and asset payoffs but also because investors have dispersed beliefs about asset values. This dispersion may be due to asymmetric information or to differences of opinion about symmetric information. In any case, theoretical models by Shalen (1993) (asymmetric information) and Harris and Raviv (1993) (symmetric information) show that dispersion of beliefs will intensify the volume-volatility relation, by increasing both trading volume and volatility.

The theoretical explanations for the volume-volatility relation are hard to test. The essence of the mixture of distributions hypothesis is that prices adjust to new equilibria over time as new information is being reflected through trades. Since the arrival rate of information is unobservable, it is difficult to set up an alternative hypothesis. Specifying data implications from the models with dispersed beliefs is also very challenging. Several empirical studies find support for the mixture of distribution explanation under the assumption that the arrival rate of information can be proxied by the daily number of transactions.² Since the daily number of transactions may be driven by factors other than new information, these studies do not rule out the other explanations for the volume-volatility relation. Harris (1987) points out that trading may be self-generating, in which case the daily number of transactions would be the *true* mixing variable rather than a proxy for the unobserved information evolution rate.³ Daigler and Wiley (1999) perform an indirect test

¹The early research into the volume-volatility relation is reviewed in Karpoff (1987).

²See Harris (1987) and Jones et al. (1994)

³A similar effect could be caused by informed traders who camouflage their information, for example by splitting

of Shalen (1993)'s model and find evidence that uninformed traders contribute to price volatility. Bessembinder and Seguin (1993) examine the relation between the volume-volatility relation and market depth, proxied by open interest, in eight physical and financial futures markets. Unexpected volume is found to have a larger effect on volatility than expected volume, and large open interest is found to mitigate volatility. Ghysels and Juergens (2001) measure dispersion of beliefs directly by the dispersion of analysts' earnings forecasts. They also find that dispersion is positively related to volatility.

The main aim of this paper is to investigate the characteristics of the volume-volatility relation in a limit order-driven equity market. To this end we use detailed transactions data from a fully automated limit order-driven trading system in Norway in the period from February 1999 through June 2001. The data sample enables us to rebuild the full order book at any point in time. We are not aware of anyone who has investigated this issue based on a data sample with this property. The demand and supply schedules in an electronic limit order book reveals the depth and reservation prices of the liquidity providers in the market. Thus, a limit order book potentially contains more information about the liquidity provision than a market which is fully or partly driven by dealers. A detailed study of the orders submitted by liquidity providers in a limit order market may therefore contribute to a better understanding of how the supply and demand of liquidity affect trading volume and price volatility.

Several papers investigating order book data are relevant for our work. Biais et al. (1995) analyze in detail the interaction between the order book and order flow on the Paris Bourse. One relevant finding is that the status of the order book is important for order flows and trading volume. Biais et al. (1995) only use data on the cumulative trading interest near the inner quotes, while we use data from the full order book. Goldstein and Kavajecz (2000) provide evidence of a negative relation between the shape of the order book and volatility during a case of an extreme market movement. However, they do not attempt to investigate this relation over a longer time period with varying trading conditions. Our data set spans a relatively long period which included the boom and burst of the internet bubble. Kalay et al. (2003) estimate the demand and supply elasticities for stocks on the Tel Aviv Stock Exchange. Their main findings are that the order book is more elastic at the beginning of the day, and that the demand side is more elastic than the bid side.⁴

their orders into medium sized trades as suggested by the "stealth trading hypothesis" of Barclay and Warner (1993).

⁴The first result is interpreted as supportive to sequential trading models with asymmetric information which predict higher adverse selection at the opening (Glosten and Milgrom, 1985). The second result is interpreted as supportive to the empirical finding that buy orders have larger price impacts than sell orders.

Kalay et al. (2003) estimate supply and demand elasticities based on data from the opening stage of the market. During the continuous trading session, they only have data on the volume at the inner quotes. We are able to study the full supply and demand schedules also during the continuous trading session. Based on a large data sample from the Korean Stock Exchange, Kim et al. (2004) study the changes in estimated demand and supply elasticities for different investor types around several Asian financial crises. The demand and supply curves of domestic individuals are found to be more inelastic than the demand and supply curves of domestic institutions and foreign investors. The elasticities in Kim et al. (2004) are based on the accumulated number of orders submitted each trading day, they do not examine the intraday development of the order book.

We first establish that the standard volume-volatility relation exists in a limit order market, and investigate in detail the composition of the order book at the intra-day level. This exercise documents that the trading structure of the Norwegian equity market exhibits the same features as are found in empirical studies of other countries' stock markets. The features suggest that: informational asymmetries are more pronounced at the beginning of the trading day, there is competition among informed traders, and uninformed traders require a compensation for the higher pick-off risk at the beginning of the day.⁵ These results are systematic across sub-periods, firm sizes, and tick-sizes. We also include some statistics on the use of hidden orders and on the number of active brokers. Hidden orders follow the same U-shaped pattern as the other statistics, i.e. the largest number and size of the hidden orders are submitted at the beginning and end of the trading day. On average, the number of unique brokers submitting new orders is largest at the beginning of the trading day.

The main contribution of our study is that we are able to document several relationships between the volume-volatility relation and the shape of the order book. We measure the order book shape by the average elasticity of the supply and demand schedules in the book. The lower the elasticity (steeper the slope), the less dispersed are the bid and ask prices in the order book.⁶ To examine the effects of the order book slope on volatility, we include the slope measure as an independent variable in a daily cross sectional time series version of the standard regression model used to study the volume-volatility relation. This analysis documents a systematic negative contemporaneous

⁵Our results are in accordance with the results in Kalay et al. (2003) as well as with the results in several studies of time-of-day effects in spreads and price impacts, for example French and Roll (1986), Harris (1986), and Niemeyer and Sandas (1995).

⁶This is in the case of direct demand and supply curves (prices on the x-axis and accumulated volume on the y-axis). In the case of inverted demand and supply curves, the relationship would be opposite.

relation between the average slope of the order book and the price volatility. To investigate the relationship between the slope of the book and the trading activity, we estimate a cross-sectional time series regression with the number of trades as the dependent variable. We find that there is a significant and robust negative relationship between the slope of the order book and the daily number of trades, i.e., a dispersed order book seems to coincide with a high number of trades. Our results on the relation between the order book slope, price volatility, and trading volume are robust to the choice of time period as well as to the choice of elasticity measure.

If the slope of the book is merely a liquidity measure, most of the information contained in the slope should be reflected by the volume close to the inner quotes. To check this, we calculate the slope measure based on different fractions of the order book and re-estimate all the regression models. When we investigate the relation between different slope measures and trading activity, an interesting pattern emerges. In line with the findings in Biais et al. (1995) that thick books at the inner quotes coincide with a higher trading volume, we find a significant *positive* relationship between the slope of the book and the number of trades when the slope is calculated based on the volume at the inner quotes. This result is the opposite of what we get when we use a slope measure based on the full order book. Thus, the slope of the book seems to provide different information depending on what fraction of the book we use in its calculation.

An interesting interpretation of the full order book slope is that it captures dispersion of beliefs about asset values, i.e., steep slopes of the supply and demand schedules indicate that there is a high degree of agreement among investors about the fair value of the security, while gentle slopes indicate that there is greater disagreement among investors about the fair value of the security. Thus, an increase in trading activity when slopes are more gentle could reflect a situation where the volume-volatility relation is driven by self generating trades in addition to new information. This interpretation is supported by a simple regression analysis where we relate the slope of a firm's order book to the coefficient of variation in the forecasts of the analysts covering the firm. A significant negative relationship is found between the slope measure and this variable, suggesting that the greater the disagreement among analysts, the more gentle is the average slope of the order book.

On the other hand, our results can also be explained within a Glosten (1994) type of model where all liquidity suppliers are homogeneous. For a given level of liquidity motivated trading and a given probability of informed trading, the slopes will be more gentle the more volatile assets

are, while a positive relation between the slope at the inner quotes and trading activity could be explained by liquidity traders who are price sensitive for other reasons than valuation uncertainty.⁷ However, the results from the test of the Glosten model in Sandås (2001) do not provide empirical support for this model.

The paper is organized in the following way. Section 2 describes our data sample. Section 3 examines in detail the order flow and order book on an intra-daily basis. Section 4 provides the results from our analysis of the volume-volatility relation in the Norwegian equity market. Section 5 concludes the paper.

2 The Data

2.1 The Norwegian Stock Market

Our data set is from the the Oslo Stock Exchange (OSE) in Norway.⁸ Norway is a member of the European Economic Area, and its equity market is among the 30 largest world equity markets by market capitalization.⁹ Table 2 reports some general statistics for all the companies listed on the OSE. At the end of 2001, 212 firms were listed on the exchange with a total market value of about NOK 677 bill. The OSE is the only regulated marketplace for securities trading in Norway. Since January 1999, it has operated as a fully computerized centralized limit order book system similar to the public limit order book systems in e.g. Paris, Toronto, Stockholm and Hong Kong.

The OSE allows the use of limit orders, market orders, and various customary order specifications. As is normal in most electronic order-driven markets, the order handling rule follows a strict price-time priority. All orders are submitted at prices constrained by the minimum tick size for the respective stocks which is determined by the price level of the stock. For prices lower than NOK 9.99 (Norwegian kroner) the minimum tick size is NOK 0.01, between NOK 10 and NOK 49.9 the tick size is NOK 0.1, between NOK 50 and NOK 999.5 the tick size is NOK 0.5 and for prices above NOK 1000 the tick size is NOK 1.

The trading day of the OSE comprises two sessions: the “pre-trade” session starting at 9:30 and ending with an opening auction at 10:00, and the “continuous trading” session from 10:00 until the

⁷We are grateful to an anonymous referee for pointing this out to us.

⁸We obtained the data directly from the exchange’s surveillance system. The SMARTS[®] system is the core of the exchange’s surveillance operations. Through access to the SMARTS[®] database, we obtained all the information on orders and trades in the market

⁹Source is FIBV (International Federation of Stock exchanges). Notable Norwegian listings include Norsk Hydro, Telenor, and Statoil.

trading closes at 16:00. During the pre-trade session, brokers can register trades that were executed after the close on the previous day as well as new orders. At the opening auction at the end of the pre-trade session, all orders registered in the order book are automatically matched if the prices are crossing or equal. The quoted opening price is thus the price that clears the market. During the continuous trading session, electronic matching of orders with crossing or equal price generates transactions. Orders without a limit price (market orders) have automatic price priority and are immediately executed at the best available prices. At the OSE, market orders are allowed to “walk the book” until they are fully executed. Any remaining part left of the market order is removed from the order book. This is different from the treatment of market orders on e.g. the Paris Bourse, where any remaining part of an unfilled order is automatically converted to a limit order at the current quote. The difference implies that market orders on OSE are more aggressive than market orders at the Paris Bourse. On the Paris Bourse, market orders are essentially marketable limit orders.

[Table 1 about here.]

2.2 The data sample

The dataset consists of every order and trade that occurred on the OSE in the period from February 1999 through June 2001.

The trade data contains, quantity transacted, a time stamp, brokerage house ID on each side, and an ID for the house that initiated the trade as well as whether the house was the buyer or a seller in the transaction. Every trade is linked to the underlying orders through an order ID. Thus, if a large order is executed against many smaller orders resulting in several smaller trades, we can trace each executed part back to the initial order. There are also additional flags attached to each trade that identify special features of the trade such as whether it was an odd-lot trade, an off-exchange trade, a cross (within the same or different brokerage houses), and whether a trade results from a market order or a limit order. The set of order data contains all order entries as well as all deletions and amendments of orders already in the order book.

In table 1 we provide some descriptive statistics of the trade data for our sample period. A large part of the listed firms are traded quite infrequently. Since we want to examine intraday data, including infrequently traded firms would introduce a large amount of noise into our analysis. We therefore filter the firms based on their trading activity through the sample period. The first

filtering criterion is that the firm must have been traded in at least 400 out of 597 days, or about 70 percent of the trading days, and the second criterion is that the firm must have an average of 5 trades per day to be included in our sample. Once the first criterion is applied, the second criterion only removes a few companies from our sample. After the filtering we are left with 108 firms, which constitute our sample throughout the paper. Table 1 shows that there has been an increase in the trading activity during the sample period with the total number of trades having tripled and the volume in Norwegian kroner (NOK) having doubled. Further, the average number of daily trades across firms has more than doubled from 32 in the first half of 1999 to 79 in the first half of 2001.¹⁰ The increase in activity has also been accompanied by a decrease in the average percentage spread. As found in most markets, the average effective spreads are lower than the average quoted spreads. To give a better picture of the diversity of the sample, we divide the sample into four portfolios based on their market capitalization value. The firms are assigned to a market capitalization group based on their market capitalization value at the beginning of each year. The general picture is that the number of trades, the trading volume (both in shares and NOK), the prices and the quoted spread increase across firm size portfolios, while the average daily volatility, the average trade size and the quoted percentage spread decrease.

2.3 Composition of orders

For each order, we have a time stamp, a unique order ID, the disclosed/hidden orders as well as flags indicating whether the order was a buy or sell order, whether the order is a new order, a deletion of an order or an amendment to an existing order (price change and/or volume change). In addition, a unique brokerage house ID is attached to each order. Moreover, our data are not restricted to include placements, amendments and deletions of orders within the inner quotes only, such as the data set used by Biais et al. (1995). We have access to all orders, which makes it possible to reconstruct the full order book at any point of time.

The descriptive statistics discussed in this section are based on 6 hourly spaced snapshots of the entire order book during each trading day for each listed company during our sample period. We rebuild the order book at 10:30, 11:30, 12:30, 13:30, 14:30 and 15:30 each trading day for each firm. Note that the first snapshot is half an hour after the regular trading session starts. Alternatively,

¹⁰At the same time, the average trade size has gone down from 3429 shares to 2648 shares. This decline is most likely related to the introduction and growth of online trading in the sample period. These traders generate a lot of trades of small sizes. During our period, the fraction of total trades coming from pure online brokerage houses increased from 0% to almost 10%.

Table 1: Descriptive statistics of trades

The table provides some descriptive statistics of trades for the whole sample, the five half-year sub-periods, and the four market capitalization groups. Group 1 consists of the 25% smallest firms while group 4 consists of the 25% largest firms. Some firms have experienced large changes in capitalization value during the sample period. To take account of this, we re-sort the market capitalization groups at the beginning of each year. The quoted spread is calculated as a percent of the spread midpoint. The effective spread is calculated as the difference between the execution price and the spread midpoint (in percent of the spread midpoint) multiplied by two.

	Sub-periods (half years)					Market Capitalization (MCAP) groups				
	Whole sample	1999.1	1999.2	2000.1	2000.2	2001.1	1 (small)	2	3	4 (large)
Aggregate statistics:										
Number of firms	108	107	108	108	108	104	27	27	27	27
Sum trades (in thousands)	3724	328	545	946	953	953	390	522	504	2309
Sum shares traded (mill.)	9585	1339	2300	2027	2072	1847	1707	1922	919	5037
Sum NOK volume (bill.NOK)	648	67	131	152	153	146	21	44	68	516
Cross-sectional averages:										
Market cap (mill.NOK)	5259	4120	4714	5507	6127	5836	354	938	2339	13978
Price	88.4	71.8	82.7	102.7	102.3	81.9	23.34	62.43	105.66	150.73
Daily volatility (%)	2.71 %	2.64 %	2.89 %	2.98 %	2.48 %	2.57 %	3.49 %	2.98 %	2.30 %	2.29 %
Shares traded (V) in thousands	151	130	167	155	151	153	116	171	78	288
Trades (N)	58	32	40	72	69	79	28	41	41	148
Tradesize (AV) in shares	2890	3429	3365	2453	2551	2648	4859	2684	1549	1912
Quoted spread (NOK)	1.65	1.55	1.62	1.79	1.78	1.50	0.94	1.63	2.11	1.57
Effective spread (NOK)	1.22	1.12	1.14	1.34	1.36	1.13	0.68	1.20	1.59	1.16
Quoted % spread (% of midpoint)	3.04 %	3.66 %	3.49 %	2.62 %	2.55 %	2.89 %	4.74 %	2.77 %	2.40 %	1.34 %
Effective spread (% of midpoint)	2.22 %	2.67 %	2.48 %	1.92 %	1.89 %	2.15 %	3.38 %	2.03 %	1.85 %	0.99 %

we could end the last snapshot at 16:00, but then the order book would be affected by the large amount of order cancellations at the end of the trading day. To rebuild the order book we start at the beginning of the trading day with the orders still remaining after the opening auction has been executed at 10:00. Then we track all types of orders being submitted throughout the day, and update the order book accordingly. Thus, all deletions and/or amendments of earlier orders, new orders and trade executions are accounted for when we update the order book.¹¹ We exclude order book volumes above/below 100 ticks away from the inner quotes. For a stock trading at NOK 100 with a minimum tick size of NOK 0.5 this would mean that orders above NOK 150 and below NOK 50 are excluded from our calculations. The limit on 100 +/- ticks means that we disregard less than 5 percent of our sample.

To get a general view of the composition of the order-flow, we group the orders into four types based on their trading aggressiveness. “Market orders” are orders with no limit price. “Aggressive orders” are limit orders that are placed at the opposite quote (marketable limit order) or at a price further away from the best quote on the opposite side. “Quote improving orders” are orders that are placed in between the inner quotes, and “Passive orders” are orders that are placed at the best (same side) quote or further away from the market. Panel A in table 3 shows the composition of orders and the order book activity for our data sample. The numbers in the table are daily cross-sectional time series averages of order volumes (in shares), and the number of orders submitted. The numbers are averaged over each of the three years in the sample as well as over market capitalization quartiles. Each firm is assigned to a market capitalization quartile at the beginning of each year.

[Table 2 about here.]

Panel A of table 3 shows the distribution of order placements in the market. The use of market orders is modest. However, market orders and aggressive limit orders together constitute around 40 percent of the average daily number of submitted orders. Measured in number of shares, there is considerable variation in the size of the submitted orders across order groups. A part of this variation can probably be explained by differences in the price level of the stocks, both over time and over firm size. On average, quote improving orders are the largest while market orders are the smallest. This is the case for the entire sample as well as for each market capitalization group, and is also a systematic pattern across sub-periods (not shown in the table). Measured over the

¹¹The original dataset includes order book data for the best 5 quotes on each side whenever a new order is submitted or there is a deletion or amendment of an existing order. We use this information to check that our order book is correct for these 5 levels of the book.

whole sample, on average 94 orders are submitted during a trading day for one firm. The activity is considerably higher for the largest firms than for firms in the other three groups. The average daily number of orders submitted for the largest firms was 224, while the similar average for the three other groups ranged from 45 to 53. For comparison, Biais et al. (1995) report an average of 160 orders for the Paris Bourse in 1995.

In Panel B in table 3, we show the distribution of volume in the order book averaged across all firms and dates. At each tick level, the fraction of total shares in the order book is averaged over the 6 order book snapshots.¹² The table shows the order book distribution across minimum tick sizes and market capitalization quartiles.¹³ Around 35 percent of the order book depth is concentrated at the quotes or plus/minus one tick from the quotes. This is quite stable both across tick sizes and across market cap quartiles. However, when we separate the bid and ask sides, we find that the volume on the bid side is more concentrated at the inner quotes than the volume on the ask side. This is in line with the findings in other studies, and is consistent with the interpretation that the price impact is larger for buy orders than for sell orders.¹⁴ Note that the depth within +/- 5 ticks, which is what Biais et al. (1995) investigate, only includes 56 percent of the total order book depth in our sample. There does not seem to be large differences in order depth across market capitalization quartiles. The largest tick size category is special in that it only contains one, highly volatile and very actively traded, company.¹⁵ One interesting thing to note about this firm is that as much as 30 percent of the order book depth lies between 50 and 100 ticks away from the quotes, even though it has been one of the most heavily traded companies at the exchange during our sample period.

Hidden orders

[Table 3 about here.]

The order statistics presented in table 3 includes hidden orders. When an order is submitted as a hidden order, only a specified fraction of the underlying order is visible to the market. When

¹²For instance, on the ask side of the book for one company/snapshot, we divide the aggregate number of shares at each tick by the total number of shares supplied (offered) at that time/snapshot. We do this for each snapshot, and average across all snapshots on the particular date to obtain the average fraction supplied on each tick for the security. Since we limit the order book to orders within +/- 100 ticks from the bid/ask midpoint, the fraction of aggregate volume at +/- 100 ticks is 100%.

¹³If a firm trades across two minimum tick size regimes on the same day, we remove that company for that day from the sample. The results do not change if we include these observations.

¹⁴See Chan and Lakonishok (1993), Chan and Lakonishok (1995), and Kalay et al. (2003)

¹⁵The company is Opticom (OPC).

the visible part of a hidden order is executed, it is replaced by a new part of the hidden order with the same price. The new order loses time priority.

Table 4 presents similar statistics when orders are split into “regular” orders and “hidden” orders. As can be seen from the table, hidden orders are about 4 times larger than regular orders. The visible part of the hidden orders is also slightly larger than regular orders. Apart from that, hidden orders are quite similar to regular orders: total number of orders increases with MCAP, order size decreases with MCAP and average order size has declined during the sample period. A similar pattern is also evident across MCAP quartiles and over time. One interesting pattern is that the average size of hidden orders increases with order aggressiveness. Panel B of table 4 reports that 5% of all submitted orders (whole sample) has a hidden part. This fraction has increased during the sample period, and seems to be larger for high MCAP stocks. About 19% of submitted total share volume is hidden. This fraction has also increased over time, and seems to be increasing across MCAP quartiles.

[Table 4 about here.]

Table 5 shows some descriptive statistics for executed trades involving hidden orders. 951 thousand trades (of a total of 3724 thousand trades) involved at least one order (one side in the trade) with a hidden volume. This constitutes about 26% of all trades for the whole sample period. This fraction, which is highest for high MCAP stocks, has increased by 10 percentage points during the period. Overall, the information about hidden orders shows that this type of order is an important component of the total market liquidity.

3 Intraday analysis of the order book

In this section, we first discuss how we measure the shape of the demand and supply schedules in the order book. We then present intraday statistics on orders, trades, and market volatility, including the intraday characteristics of the elasticity/slope of the order book.

3.1 Measuring the shape of the order book

To obtain a daily measure of the shape of the order book for each company, we start out by building the order book from the remaining orders after the opening auction is finished at 10:00 a.m. each trading day. We then update the order book with new incoming orders, amended orders, deleted

orders, and execution of existing orders during the day. The slope/elasticity estimate for each company are calculated based on snapshots of the order book at the end of each of the six time intervals described in section 2.

Essentially, what we want to measure is the elasticity $\partial q/\partial p$ describing how quantity (q) supplied in the order book changes as a function of the price (p). These elasticities will generally change along the curves. What we want is a measure that describes the average elasticity across all price levels with positive volumes in the order book. To find this measure, our calculation is done in the following steps:

1. Firstly, for each side of the order book, and each snapshot, we accumulate the aggregate number of shares supplied/demanded at each price level, such that at each price level we get the total volume supplied (demanded) at that price or lower (higher).
2. Secondly, we calculate the “local” elasticity at each price level.
3. Thirdly, we average the “local” elasticities/slopes across all price levels for the bid and ask side separately to obtain an average elasticity/slope for the bid and ask side for the respective snapshot.
4. Finally, we take the average of the bid and ask slope to get one slope measure for the respective snapshot, and average across the 6 snapshots to obtain one daily average slope for each company.¹⁶

Figure 1 illustrates how the local elasticities, Δ_τ^A and Δ_τ^B , are calculated at each price level τ . For illustrative purposes, the order book in the figure stretches only across 4 price levels on each side. In the figure, p_1^A is the best available ask price (inner ask quote) with volume of V_1^A supplied at that ask price. The volume at the next tick level (V_2^A) is thus the accumulated volume supplied at price p_1^A and p_2^A . The local elasticity of the supply curve at p_1^A would thus be the slope Δ_2^A in the figure.

More formally, the slope used in the main analysis is calculated in the following way. Let N_A and N_B be respectively the total number of bid and ask prices (tick levels) containing orders. Let τ denote the tick level, with $\tau = 1$ representing the best quote with a positive volume. Furthermore, let p_1^B and p_1^A be, respectively, the best bid and ask prices, and p^M denote the bid-ask midpoint.

¹⁶Having one daily average slope overcomes the problem that one snapshot (e.g. at noon) is biased, either due to large trades having temporarily reduced the liquidity of one side of the book or due to systematic time of day effects.

Finally, let v_{τ}^B and v_{τ}^A be, respectively, the natural logarithm of total share volumes at each tick level on the bid and ask side of the book.

The average elasticity for the supply curve, SE, on day t at snapshot time $s \in [1..6]$ for company i is calculated as,

$$SE_{i,t}^s = \frac{1}{N_A + 1} \left\{ \frac{v_1^A}{p_1^A/p^M - 1} + \sum_{\tau=1}^{N_A} \frac{v_{\tau+1}^A/v_{\tau}^A - 1}{p_{\tau+1}^A/p_{\tau}^A - 1} \right\} \quad (1)$$

Similarly, the demand curve, DE, is calculated as,

$$DE_{i,t}^s = \frac{1}{N_B + 1} \left\{ \frac{v_1^B}{|p_1^B/p^M - 1|} + \sum_{\tau=1}^{N_B} \frac{v_{\tau-1}^B/v_{\tau}^B - 1}{|p_{\tau-1}^B/p_{\tau}^B - 1|} \right\} \quad (2)$$

For both equations, the first term expresses the slope between the bid-ask midpoint and the best bid and ask prices, while the second term expresses the sum of the local elasticities for the rest of the order book. The average daily elasticity of the order book for company i on date t is calculated as,

$$SLOPE_{i,t} = \frac{1}{6} \sum_{s=1}^6 \left\{ \frac{SE_{i,t}^s + DE_{i,t}^s}{2} \right\} \quad (3)$$

The order book is rebuilt at 10:30, 11:30, 12:30, 13:30, 14:30 and 15:30 each trading day for each firm. We exclude order volumes above/below 100 ticks away from the inner quotes existing in the order book at each snapshot time. For a stock trading at NOK 100 with a minimum tick size of NOK 0.5 this would mean that orders above NOK 150 and below NOK 50 are excluded from our calculations.

The more gentle (steeper) the slope, the more widely distributed (concentrated) are the bid and ask prices in the order book. Note that we use the inverse of the demand and supply schedules, with prices on the x-axis and accumulated volumes on the y-axis, as in Biais et al. (1995). There is a close relationship between our slope measure and the liquidity of the underlying stock. Less liquid firms generally have a higher volatility since the order book does not contain enough volume to absorb large trades without moving prices too much. In addition, less liquid stocks generally have a higher spread since investors require a discount when buying and a premium when selling the stock. Thus, a positive relationship between order book elasticity and volatility is expected a

priori. We also examine several alternative slope measures to check the robustness of our results. These slope measures are described in appendix A.

[Figure 1 about here.]

3.2 Intraday Statistics

Table 6 presents intraday statistics for data sample. The statistics are calculated over seven time intervals corresponding to the six snapshots used to rebuild the order book. The numbers include our measure of the order book slope, the price volatility (measured by the absolute value of hourly returns between midpoint prices closest to the end of each time interval), the quoted and the effective spread, the number of trades executed during the time interval, the trade and order sizes measured in shares, the number of orders submitted during the time interval, the number of hidden orders submitted during the time interval, and the average sizes of the hidden and visible parts of hidden orders. All numbers are daily averages across all firms in the sample.

[Table 5 about here.]

Notable characteristics of the intraday statistics in table 6 are;

- The average slope increases at a decreasing rate throughout the day.
- The quoted and the effective spread both have a U-shape, with the highest spread at the beginning of the day.
- The average trade size is smallest at the beginning of the day, and increasing throughout the trading day.
- The average number of orders and trades both follow a U-shape, with fewer orders being placed and trades being executed in the middle of the day, and most orders being placed and trades being executed at the beginning of the day.
- The hidden orders follow the same U-shaped pattern as the other statistics, with largest number of hidden orders and size of the hidden orders at the beginning and end of the trading day.

These regularities are also found to be systematic over sub-periods.¹⁷ Similar systematic intraday regularities have been found in other markets as well (e.g. US, France, Hong Kong, Sweden).¹⁸ Following the sequential trading model in Glosten and Milgrom (1985), these data features can be explained by higher uncertainty about other traders' valuations at the beginning of the trading day than during the day. A patient liquidity trader who fears to be picked off by informed investors at the beginning of the day has two main options. If she believes that the probability of trading with informed traders will diminish during the day, she can act strategically and delay her trading. Alternatively, she can submit her orders at the beginning of the day and take account of the increased probability of incurring a loss by placing them at prices including a discount (buys) or a premium (sells). This can explain the higher spread at the beginning of the trading day. The increase in spreads towards the end of the day may be due to higher liquidity demand and possibly more cancellation of orders just before the close. Assuming that informed traders are trying not to reveal their information too quickly, we would also expect to see a higher number of small trades at the beginning of the trading day (stealth trading).

To obtain a measure of order aggressiveness during the trading day, we calculate a separate index similar to the one used in Harris and Hasbrouck (1996), where the aggressiveness of a limit order is measured by the average number of ticks the order is placed away from the best quote (on the same side). Thus an index number of zero means that the average order is placed at the quote, a positive index number means that the order is placed above (below) the bid (ask), and a negative number means that the average order is placed below (above) the bid (ask). Formally, for an order of type k , the aggressiveness of a buy order with a limit price p^B is calculated as,

$$\lambda_k^{\text{buy}} = (p^B - \text{bid})/\text{ticksize} \quad (4)$$

Similarly, a sell order with a limit price p^S is calculated as,

$$\lambda_k^{\text{sell}} = (\text{ask} - p^S)/\text{ticksize} \quad (5)$$

where `bid` and `ask` are the best bid quote and best ask quote, respectively, when the order is submitted.

¹⁷The results are both qualitatively and quantitatively similar when we calculate the intraday statistics over sub-periods of years, half-years and quarters.

¹⁸For the US, see French and Roll (1986) and Harris (1986). For Sweden, see Niemeyer and Sandas (1995).

Table 7 reports the intraday patterns in order aggressiveness, average number of orders, order type composition, and order sizes, while figure 2 illustrates graphically the intraday patterns in order aggressiveness, order size, order book slope, quoted and effective spread, and order type composition. Systematic differences in the aggressiveness of different types of orders during the course of the trading day are documented.

[Table 6 about here.]

[Figure 2 about here.]

Assuming a tendency for uninformed (informed) investors to submit passive (aggressive) orders, our data indicates that uninformed traders submit orders with more passive limit prices at the beginning of the trading day, and then, at prices closer to the midpoint prices later in the day. This is consistent with a Glosten and Milgrom (1985) type of model where trading is sequential and uncertainty is greatest at the opening of the trading session. Under such conditions, uninformed investors are induced to require a higher compensation for trading early in the day relative to later in the day. Another interpretation is that uninformed traders have not yet processed all publicly available information (e.g. newspapers, new analyzes, gossip etc.), and are more passive when submitting their orders before they have been able to read and interpret this information. Orders that are more aggressive, and likely to stem from better informed investors or pre-committed liquidity traders, are relatively more aggressive at the beginning of the day than later in the day. A trader demanding liquidity, needs to be relatively more aggressive at the beginning of the day to get his order executed if liquidity traders submit more passive orders. The pattern is also consistent with a situation where informed investors are competing to extract profits from the same information. At the end of the trading day, all types of orders are submitted closer to the inner quotes. This characteristic, which is also evident from the intraday pattern in the relative fraction of each order type, provides another indication that the adverse selection costs are reduced during the trading day. Assuming that all other cost components of the spread are fixed throughout the day, this hypothesis is also supported by the decrease in spreads during the day.

The average number of passive orders and market orders decrease throughout the day, while the average number of quote-improving orders and aggressive orders have a U-shape. The sizes of the most aggressive limit orders and market orders increase throughout the day. If informed investors mainly use aggressive limit orders and market orders, this may indicate that they submit smaller orders when their information is the most valuable (stealth trading).

The evidence that there is more asymmetric information at the beginning of the trading day is also captured by the intraday pattern of our slope estimate. The slope increases across the day, with a minimum at the beginning of the day and a maximum at the end of the day, which indicates that the order book is more dispersed in the morning relative to later in the day. Over time windows, the average slope increases at a diminishing rate as the order book becomes more concentrated and inelastic at the end of the day.

Table 8 examines the aggressiveness of the hidden orders separately. The general intraday pattern for hidden orders is similar to the pattern for all orders. To get a picture of the diversity of liquidity providers in the market, we also calculate the number of different brokers who are active in the market during the trading day. Table 9 shows the number of unique broker ID's who is submitting new limit orders within each time interval. The number of unique broker ID's during a trading hour is typically five or six. The intraday pattern has a U-shape, but a downward trend over the day. This pattern is systematic when we calculate the numbers over sub-periods. Hence, on average there is a larger number of traders at the beginning and at the end of the trading day.

[Table 7 about here.]

[Table 8 about here.]

4 The Volume-Volatility Relation

In this section, we first document that there exist a volume-volatility relation in the Norwegian equity market similar to the relation found for the US by e.g. Jones et al. (1994) and in the UK by Huang and Masulis (2003). When we decompose volume into trades and order size, and interpret the number of trades as a proxy for the mixing variable, we find support for the MDH. We then investigate the relationship between volume, volatility and the slope of the order book.

4.1 The Volume-Volatility Relation in a Limit Order Market

In table 10, we report the average correlation coefficients between the trading volume, the trade size and the number of transactions. The correlation structure in our sample is quite similar to the one documented for the US market in Jones et al. (1994). On average, the correlation coefficient between the average trade size and the number of trades is low, while both the average trade size and the number of trades are highly positively correlated with share volume. Hence, the

two components of share volume seem to contain different information about volume. The same structure is evident when we calculate the correlation coefficients over quarterly sub-periods and over market capitalization quartiles.

[Table 9 about here.]

To investigate whether there is a volume-volatility relation in our data sample, we follow the regression approach in Jones et al. (1994). First, we measure the daily return volatility using the standard procedure in similar empirical studies,¹⁹ by running the following regression for each firm i ,

$$R_{i,t} = \sum_{k=1}^5 \alpha_{i,k} D_{k,t} + \sum_{j=1}^{12} \beta_{i,j} R_{i,t-j} + \hat{\epsilon}_{i,t} \quad (6)$$

where $R_{i,t}$ is the return of security i on day t , and $D_{k,t}$ is a day-of-the-week dummy for day k . To avoid measurement errors due to the bid-ask bounce, we calculate returns from the average of bid-ask prices at the close. The 12 lagged return regressors estimate short-term movements in conditional expected returns. The residual, $\hat{\epsilon}_{i,t}$, is our estimate of the unexpected return of security i on date t . The absolute value of this measure constitute our measure of volatility. Next, we estimate the regression equations suggested in Jones et al. (1994) to determine the relative effects of number of trades (N) and trade-size (AV) for volatility,

$$\textbf{Model I: } |\hat{\epsilon}_{t,i}| = \alpha_i + \alpha_{i,m} M_t + \beta_i AV_{i,t} + \sum_{j=1}^{12} \rho_{i,j} |\hat{\epsilon}_{i,t-j}| + \eta_{i,t} \quad (7)$$

$$\textbf{Model II: } |\hat{\epsilon}_{t,i}| = \alpha_i + \alpha_{i,m} M_t + \gamma_i N_{i,t} + \sum_{j=1}^{12} \rho_{i,j} |\hat{\epsilon}_{i,t-j}| + \eta_{i,t} \quad (8)$$

$$\textbf{Model III: } |\hat{\epsilon}_{t,i}| = \alpha_i + \alpha_{i,m} M_t + \beta_i AV_{i,t} + \gamma_i N_{i,t} + \sum_{j=1}^{12} \rho_{i,j} |\hat{\epsilon}_{i,t-j}| + \eta_{i,t} \quad (9)$$

The $\rho_{i,j}$'s measure the persistence in volatility across 12 lags. M_t is a dummy variable that is equal to 1 for Mondays and 0 otherwise, $AV_{i,t}$ is the average trade size (total number of shares traded divided by the number of transactions for stock i on date t), and $N_{i,t}$ is the number of transactions in security i on date t . The regressions are run for each firm and then the parameter estimates are averaged across firms.

¹⁹See Schwert (1990), Bessembinder and Seguin (1993), Jones et al. (1994), and Daigler and Wiley (1999).

The first part of table 11 provides the results from the estimation of regression equations 7-9 using daily returns for all companies in our filtered sample. Overall, our results are very much in line with the results in Jones et al. (1994). The explanatory power of model 2, where volume is measured by the average number of daily trades, is almost the double of the explanatory power of model 1, where volume is measured by the average trade size. Moreover, the average trade size has little marginal explanatory power when volatility is conditioned on the number of transactions in model 3. These results are further supported by the characteristics of the sampling distributions of individual-firm coefficients and t-statistics of the two variables. In model 3, 95.4 percent of the coefficients for the average number of trades are statistically significant, and 99.1 percent of the average number of trades coefficients were greater than zero. Similar numbers for the average trade size are respectively 24.1 percent and 57.4 percent.

As a robustness check we also estimate the equations for sub-periods of half-years. Although not reported in a table, the results from the whole sample regression are confirmed in the sub-sample regressions. Most notably, the $\hat{\gamma}$ estimates of the effect of trades (N), as well as their distributional properties, are very stable across sub-periods. The $\hat{\beta}$ estimates, however, vary considerably across sub-periods and are less significant than $\hat{\gamma}$ for model 1 relative to model 3.

Jones et al. (1994) find that trade size has some information content for some of the smaller Nasdaq-NMS firms. This finding is interpreted as supportive of the notion that private information based trading is important only for the smallest firms on the stock market. To check for similar features in our data sample, we re-estimate the three regression models on the four size portfolios. The results from these estimations are presented in the second part of table 11. In general, the results from estimating separate regression models for each size portfolio are similar to the results from running one regression for the whole sample. However, we find the opposite result from Jones et al. (1994) that the explanatory power of trade size is the strongest for the largest firms. On the other hand, only about half of the parameter estimates for trade size in the single firm regressions are greater than zero, indicating that the effect may not be very systematic across firms.

[Table 10 about here.]

4.2 Volume, volatility and the limit order book

We now turn to the question whether the slope of the order book affect volatility and trading activity. The reported results are based on the equally weighted slope described above. Table 13

provides some descriptive statistics on the distribution of the daily slope estimate over the whole sample, for the separate years, and for the four market capitalization groups.

[Table 11 about here.]

[Table 12 about here.]

Table 12 shows that the slope measure has the expected close relationship to measures of liquidity such as market capitalization (positive correlation of 0.44) and quoted percentage spread (negative correlation of -0.33). Thus, larger firms are generally more liquid, with a smaller spread and a steeper slope. One reason for this may be that larger firms generally are easier to value, making the dispersion of prices in the order book more concentrated around the midpoint price. Table 13 shows that larger and more liquid stocks have a higher fraction of the order book volume concentrated at or around the best quotes, while smaller firms have more elastic order books. This is also evident from panel B in table 3.

Figure 3 illustrates the relationship between the daily slope and the contemporaneous daily price changes at an aggregate level. Daily price changes are measured as the average daily absolute return over the trading day.²⁰ Both variables are daily equally weighted averages across all traded securities. Interestingly, even at this aggregate level the figure indicates that the price volatility is higher (lower) when the average daily slope of the order book is low (high). Another notable feature is that the average slope is steeper in the first half of the sample, with an average slope of about 354, than during the second part of the sample when the average slope drops to about 260.²¹ These two periods coincide quite well with the boom and burst of the internet bubble. It is not obvious that increased trading activity due to arrival of new information can explain the volatility pattern during this period. If the slope proxies for valuation uncertainty, the pattern in the figure reflects greater agreement among traders about asset values during the build-up of the bubble than during the subsequent market down-turn.

[Figure 3 about here.]

4.3 Daily volatility and order book shape

To examine whether our slope measure can explain the contemporaneous volatility across firms and time, we estimate modified versions of the volume-volatility regression equations in section

²⁰cf equation 6.

²¹The average volatility in the two periods was respectively 2.59 percent and 2.46 percent.)

4.1. More specifically, we estimate 3 different versions of the following cross-sectional time-series regression model with one-way fixed effects,

$$|\epsilon_{it}| = \sum_{k=1}^K \mathbf{X}_{itk} \beta_k + \eta_{i,t} \quad (10)$$

where $|\epsilon_{it}|$ is the daily volatility estimate from equation 6, \mathbf{X}_{itk} is the matrix of explanatory variables (k) across time (t) for each company (i) and $\eta_{i,t} = \nu_i + \epsilon_{i,t}$ defines the error structure with ν_i as the non-random fixed, firm-specific, effect. Since we use one-way fixed effects specification, the estimation is analogous to a least-squares dummy variable (LSDV) regression with firm-specific constants ν_i . Since not all firms are traded every day, our sample is unbalanced²². However, results from estimating the same models on a balanced sample are quantitatively similar.²³

As indicated by the correlation structure in table 12, our slope measure may also proxy for liquidity. We therefore control for other liquidity measures in the regression model. The estimated model can be written as;

$$|\epsilon_{i,t}| = \beta_0 M_{i,t} + \beta_1 N_{i,t} + \beta_2 AV_{i,t} + \beta_3 MCAP_{i,t} + \beta_4 SPR_{i,t} + \beta_5 OV_{i,t} + \beta_6 SLOPE_{i,t} + \sum_{j=1}^{12} \rho_{i,j} |\epsilon_{i,t-j}| + \eta_{i,t}. \quad (11)$$

where SLOPE is our slope estimate, MCAP is the natural logarithm of the market capitalization value, SPR is the quoted percentage midpoint spread, and OV is the average order book volume in thousand shares and $\eta_{i,t} = \nu_i + \epsilon_{i,t}$ defines the error structure with ν_i as the non-random fixed, firm-specific, effect. Results from the estimation for the full sample period are provided in panel A of table 14. Model 1 is essentially the same as in the analysis in section 4.1, but with the addition of the slope variable and the additional variables accounting for stock liquidity (SPR, MCAP, and OV). In model 2, we estimate the model excluding the two variables which are highest correlated with the slope (SPR and MCAP), and in model 3 we exclude the trading activity (mixing) variables. We also estimate the same regression equation across 3-month sub-periods. The results from this estimation are reported in panel B of the table. Because we use lagged versions of the dependent

²²We use the TSCSREG procedure supplied with SAS v.8.2 for estimating the models. The procedure is capable of processing data with different numbers of time-series observations across different cross sections.

²³In the unbalanced sample, all firms with 400 trading days or more throughout the sample period of 597 days are included. In the balanced sample, we filter out all firms which are not traded every day during the sample period. This filter reduces the sample to 27 firms. See appendix B for estimation results for the balanced sample.

variable, $|\epsilon_{i,t-j}|$, as explanatory variables to adjust for autocorrelations in volatility, we choose a fixed effects model.²⁴ To check for autocorrelation in the residuals, we run simple OLS regressions for each company. The hypothesis of no autocorrelation cannot be rejected for any of the single company regression models. When we test for normality, we find that the assumption is violated for less than half of the companies. The violations are due to outliers in the sample. There do not seem to be any problems related to skewness.

The first thing to note in Panel A in table 14 is that the slope variable (SLOPE) is negative and highly significant across all three model specifications. Thus, volatility increases the more gentle the slope are. This may be linked to differences of opinion about public news, “noise trading” from uninformed investors²⁵, or pick-off risk.²⁶ We will discuss several interpretations of our findings at the end of the section.

The total volume in the order book (OV) is shown to have a significant positive effect on volatility. This result is consistent with the result in Biais et al. (1995) that more trades are executed when the order book is thick. The correlation coefficients shown in table 12 between order book volume and trade volume (0.44) and between the order book volume and trades (0.19) also suggest that the volume-volatility relation depends on the incoming order flow and the state of the order book. Finally, the estimation results show that larger firms have less volatile prices than smaller firms, and that higher spreads coincide with higher volatility.

One important issue to note is that there is an indeterminacy with respect to the causality between volatility and several of the explanatory variables such as the average order book volume, number of trades, the spread and the slope measure. Although this probably is most important at the transaction level, several of our measures are averages across hourly snapshots. Thus, dynamic interactions between order submissions and the status of the order book, as examined in detail by Biais et al. (1995), is left out of our regression model. For instance, Biais et al. (1995) find that a thin book attracts new orders while a thick book increases trading activity. Another example is that a higher volatility may reduce the number of orders coming into the market, which again lowers the average slope of the book on that day. To examine this issues, we run simple Granger

²⁴For a random-effects model to be applicable, the firm-specific constants, ν_i , must be uncorrelated with the regressors. This requirement is likely to be violated by the lagged variables. Later in the paper, we test whether we should use a random-effects model more formally by running Hausman tests.

²⁵A problem could be that a steeper slope implies a less pronounced bid-ask bounce, and thus a lower volatility. However, as outlined in section 4.1, we try to avoid measurement errors due to the bid-ask bounce by calculating returns using the average of bid-ask prices.

²⁶If some liquidity suppliers are informed about the volatility, as in the Foucault et al. (2003) model, they may find it optimal to bid less aggressively when they know that the volatility is high.

causality tests between our slope measure and various order types and trading activity variables, both on an hourly and a daily frequency. Overall, we are unable to determine a clear one-way Granger causality relation between the variables, rather we find a two-way Granger causality for most variable combinations.

[Table 13 about here.]

The estimation results for models 2 and 3 are essentially the same as for model 1. The important thing to note is that the parameter estimate for SLOPE is significantly negative and relatively stable across the three model specifications. The slope parameter is most negative and most significant in model 2, when we remove the spread (SPR) and market capitalization (MCAP) variables. This suggests that the slope captures liquidity effects captured by these variables. Both the F-test of no firm-specific effects (firm-specific constants) and the Hausman specification test of whether a random-effects model would be more appropriate relative to the fixed effects specification, are rejected at the 1 percent level for all three models.²⁷ The reason for this is most likely that we use lagged versions of the dependent variable, which makes our firm-specific dummies, ν_i , correlated with the regressors.

To examine the stability of the slope measure, we estimate model 1 for non-overlapping sub-periods of three months through the entire sample period. The results from these regressions are reported in panel B in table 14. We only report the parameter estimates and tests for the slope variable, number of trades, and trade size. The SLOPE parameter is remarkably stable across the sub-samples. In addition, it is significant at the 1 percent level within all sub-samples, except for the first. Also, the number of trades is highly significant across all sub-periods while the average trade size is significant at the 1 percent level only in half of the sub-sample regressions, suggesting that the number of trades is the important component of volume in the volume-volatility relation, as is also suggested by our analysis in section 4.1. The parameter estimate for the number of trades decreases over the sample period. This is most likely due to the fact that the mean number of trades across companies increases throughout the sample period. F-tests of no fixed effects within each sub-period regression is rejected at the 1 percent level.²⁸ In appendix A, we show that the main

²⁷The Hausman test compares an inefficient but consistent OLS estimator (the fixed effects case) to an efficient GLS estimator (the random effects case). Thus, the Hausman test is a test of H_0 , that random effects would be consistent and efficient, versus H_1 , that random effects would be inconsistent. Rejecting H_0 would suggest that we should use a fixed effects specification.

²⁸In addition, the Hausman test rejects a random effects specification at the 1 percent level for each sub-sample model.

results presented here are invariant to several alternative ways of measuring the slope. Overall, our results suggest that, in addition to trading volume, both the order flow and the status of the order book are significantly related to contemporaneous volatility .

A robustness check In a limit order market, most trades originate from limit orders, i.e. there must be a strong relationship between order book shape, volatility and trading volume. One interpretation of our slope measure is that it is essentially a liquidity measure, and that the inner part of the order book is capturing the main effect on volatility. A useful way to check this is to examine whether the slope calculated from different sets of the order book contain different information about volatility. One way of doing this is to calculate the slope based on truncated versions of the order book.

We re-calculate the slope measure based on two different subsets of the book. The resulting estimate distributions are shown in figure 4. Figure 4a shows the frequency distribution of slope estimates calculated from an order book which is truncated to 5 ticks away from the best quotes.²⁹ Figure 4b shows the distribution of daily slope estimates when we calculate the average slope based on twice as much of the order book (+/- 10 ticks). Finally, figure 4c shows the frequency distribution when we base our slope estimates on the entire order book (+/- 100 ticks). The slope decreases the more of the order book we use. This is expected, if the supply and demand curves in the order book are concave.³⁰ The mean slope when we use the full order book is about 304 (median 231), while it increases to 417 (median 355) and 584 (median 496) when we calculate it from the order book truncated to +/- 10 and +/- 5 ticks respectively.

[Figure 4 about here.]

To examine whether the inner part of the order book captures the relationship between volatility and slope, we re-estimate the regression models in table 14 with slope measures calculated from the two sub-sets of the order book. Panel A in table 15 reports the estimation results. The results when we use the slope calculated from the order book truncated to +/- 10 ticks (SLOPE10) from the best quote on each side are reported in model 1a, and the results when we truncate the order book to +/- 5 ticks (SLOPE5) are reported in model 1b. All other variables are identical to the previous analysis. Panel B of the table shows the correlation between each slope measure and

²⁹That is, we use only the cumulative volume at the five first ticks on each side of the order book when we calculate the average slope.

³⁰Concave when we have price on the x-axis and volume on the y-axis.

other variables. The main result from the estimation is that the slope parameter remains negative and significant. In addition, the parameter estimates become smaller compared to the case where we used the full order book. The decrease in parameter size is mainly due to the fact that the mean of the slope estimates increases (as shown in figure 4) while the dependent variable remains unchanged. Thus, the relationship seems to be similar when we use only the inner levels of the order book to calculate the slope. Also R-squared of the different models does not change when we change the slope variable. Overall, our results suggest that the different slope measures capture mainly the same relationship.

Panel B in table 15 shows the correlations between the three slope measures and the activity and liquidity variables. One interesting thing to note is that the correlation between the slope and number of trades and between the slope and the trade volume in shares increases substantially the more we truncate the order book. This may reflect that the relationship found in Biais et al. (1995), that a thicker (more concentrated) order book results in trades, is more pronounced when we evaluate the relationship closer to the inner quotes.

[Table 14 about here.]

Table 16 shows the estimation results when estimating the model using the truncated slope measures across sub-periods. Similar to our findings when we estimate the model over the whole sample period, we find that the size of the parameter estimate as well as its significance declines the more we truncate the order book. For model 1b, when we truncate the order book to 5 ticks, the slope estimate is only significantly different from zero for half of the sub-samples. Thus, the significance of the slope variable is greatly reduced within sub-periods when we only use the inner part of the book. When we use the slope based on the full order book, the relationship between volatility and slope is stronger across sub-periods, as shown in panel B in table 14.

[Table 15 about here.]

4.4 Number of trades and order book shape

In this sub-section, we examine the relationship between the slope and the contemporaneous trading volume.

In table 17 we estimate a cross-sectional time series regression with the number of trades as the dependent variable. As before, we control for liquidity variables which we expect are important for

the number of trades. When we base our slope measure on the the full order book (model 1 in panel A), a significant negative relationship between the slope and the number of trades is documented. Thus, the more gentle the order book slope, the higher the trading volume represented by the number of trades. Models 2 and 3 in table 17 are estimated with slope measures calculated from the truncated order books. Interestingly, we find that the parameter estimate switches sign and becomes more positive the closer we get to the inner quotes. Thus, the slope at the inner quotes is positively related to the number of trades, while the average slope for the full book is negatively related to trade executions. In other words, the relationship between liquidity and trading activity becomes more evident when we restrict the analysis to the inner part of the order book.

We also find that the number of trades is lower on Mondays, that the average trade size is unrelated to the number of trades, and that larger firms are more frequently traded. In addition, we find that there is less trading when the quoted percentage spread is large, and that there are more trades when the volume of shares in the order book is high. Again, one caveat with respect to the analysis is that we do not take into account the dynamic interactions between the order flow and status of the order book. For example, as found by Biais et al. (1995), a thinner book may attract new orders which in the next step increases the number of transactions.

The most interesting result from the estimation is that a slope measure calculated on the basis of the full order book seems to provide different information compared to a slope measure calculated on the basis of the volume at the inner quotes. This result is in contrast to the finding in the previous sub-section that the relationship between price volatility and the full order book slope is well proxied by a slope measured over the inner part of the book only.

[Table 16 about here.]

4.5 Interpretation of the results

One interesting feature documented in this study is that, although most of the activity in a limit order book occur at the inner part of the book, many firms experience that this liquidity reflects only a modest part of the total liquidity supplied in the order book. A second interesting feature is that the characteristics of the order book vary systematically over the trading day as well as across the firms in the sample. In particular, for our measure of the slope of the order book we find the following systematic variations:

- a more gentle slope (more dispersed order book) coincide with a higher volatility over time

and across firms.

- The relationship between the number of trades and the slope of the book depends on which subset of the order book is used.
 - When we use the slope from the inner book (+/- 5 ticks) there is a positive relationship in which a steep slope coincide with a high number of trades.
 - When the entire order book is used (+/- 100 ticks), the relationship is reversed, i.e. a more gentle slope coincide with a higher number of trades.

A natural question is why orders with limit prices far from the inner quotes persist? One reason may be that traders are slow in revising their orders in response to new information. Another reason suggested by Sandås (2001) is that the placement of orders deep in the book are based on strategic choices where, in a multi-period setting, the gains from obtaining price priority of the orders further out in the book are traded off the costs of monitoring them. A problem with both explanations is that they do not explain why we observe such large variation in the slope estimates over time and across companies.

The systematic patterns found may be related to asymmetric information. In general, we find that smaller firms have order books with a gentler slope than larger firms. This finding supports the hypothesis that there is more private information in smaller than in larger firms, i.e., the gentler slopes in small firms reflect pick off risk. This explanation is in line with the existing theoretical literature on limit order markets, such as Glosten (1994). Here, the status of the order book is related to the order submission strategies of homogeneous liquidity providers and how they provide the limit order book when there is a probability of informed trading. Sandås (2001) tests the predictions in Glosten (1994) in the Swedish market which is very similar to the Norwegian market. He finds strong evidence that there is insufficient depth in the observed order book relative to the theoretical prediction. In other words, the slopes of the empirical demand and supply schedules at the inner quotes are much too gentle to be explained by theory.

Another interpretation is that different shapes of the limit order book across firms reflect valuation uncertainty and heterogenous valuations among the liquidity suppliers.³¹ This provides an interesting explanation for why the order volumes observed in the limit order book are more dispersed than predicted by Glosten (1994). If the uncertainty about the value of a firm is high and

³¹The shape of the order book reflects the reservation prices of liquidity suppliers.

liquidity traders differ in their private valuations, they may submit their orders over a wider range of prices relative to the case when there is greater agreement about the true value.

Although no models exist that offer any predictions to how the full limit order book would look like in a market with heterogenous liquidity suppliers, models assuming strategic behavior of uninformed investors provide an interesting framework which could motivate such an interpretation. Shalen (1993) shows that the strategic behavior of liquidity traders may be an important contributor to both volume and volatility in addition to information arrivals. In her model, when uninformed investors have dispersed beliefs about asset values, they are faced with a signal extraction problem, making them react to all types of trades in the order-flow which may or may not be related to informed trading. Due to this, they increase both trading volume and price volatility above what would be expected in equilibrium. Thus, the relationship between volume and volatility is not merely due to the information arrival process (as in the mixture of distributions framework), but also due to strategic trading by uninformed traders. The higher the fraction of uninformed traders in the population, the greater the dispersion of beliefs, and the greater the excess volume and excess volatility.

[Figure 5 about here.]

Figure 5 shows the average order books for two companies listed on the OSE. The order books are averaged over the five last trading days in May 2001, and are normalized in the sense that they show the percentage of shares in all orders within an increasing/decreasing number of ticks away from the quotes (zero in the figure is the best quote on each side of the market). The upper graph shows the average order book for Norsk Hydro (NHY) while the lower graph shows the average order book for Opticom (OPC). Both companies are among the most liquid on the exchange.³² Norsk Hydro is a leading energy, aluminium and fertilizer company, based in Norway. It has 50,000 employees in 60 countries worldwide. The company's operations are well known and there is a large amount of available information about the company, including experts' analysis. Opticom, on the other hand, is a relatively new IT company which currently has under 100 employees. The company describes its business concept as pioneering research and development in new technology in electronics. The company has no cash flow and very uncertain future income possibilities. Discussions in the popular

³²During the period illustrated in the figure, both companies traded in prices around NOK 400-500 and had a tick size of NOK 0.5. For Norsk Hydro the calculated average order book is based on around 2000 orders with a share volume of around 400 000 shares. For Opticom the similar calculations are based on around 4000 orders with a share volume of around 200 000 shares.

press have been largely focused on how difficult it is to value the company, and there have been large differences in analysts' valuations. The picture shows that the order book of the two companies are quite different: while on average about 50 percent of the orders for Norsk Hydro has limit prices which lie within 5 ticks from the quoted spread, the similar percentage for Opticom is only about 10 percent.

One reason for the difference in the average shape of the order book between the two companies may be that investors are more uncertain about the true value of Opticom than Norsk Hydro, and that this is reflected in orders being submitted over a wider range of prices in Opticom than in Norsk Hydro. The difference in the order book shapes may also come from pick-off risk, i.e. the reservation prices reflect a compensation for the risk of being picked off by better informed traders. Probably, both effects contribute to explaining the pictures. However, one could argue that pick-off risk should mainly concern the orders submitted close to the midpoint price. Thus, pick-off risk should affect the spread and volumes at the inner ticks, not the distribution of orders across the the entire order book.

To investigate this issue a bit further we perform some simple tests to evaluate whether our slope measure is related to the measure of dispersion of beliefs used in Ghysels and Juergens (2001). More specifically, we run a monthly panel regression where we relate the average monthly SLOPE for each company to the spread in analyst earnings forecasts (FORECAST). We also consider the number of analysts covering the stock. The analyst forecast data is obtained from Datastream/IBES. The variation in analyst forecasts is calculated as the standard deviation of the estimates for the month as a percent of the mean estimate for that month. Thus, it is a measure of the relative dispersion of estimates around the mean estimate. A small dispersion imply a tight consensus among the analysts, while a large dispersion indicates that analysts disagree on the company's future.

Panel A of table 18 shows the results from two versions of this regression model. We control for the size of the firm and the number of analysts covering the firm. However, as can be seen from panel B, the size of the firm and the number of analysts is highly positively correlated. Although the analysis is simple, it reveals a significant negative relation between SLOPE and the variation in analyst forecasts. In other words, the greater the disagreement among analysts, the more gentle is the average slope of the order book. Thus, there seem to be a relationship between the two variables that are in line with our interpretation about the shape of the order book capturing valuation uncertainty.

[Table 17 about here.]

If valuation uncertainty coincide with a more gentle order book slope, our results support several predictions from Shalen (1993). First, increased dispersion of beliefs is predicted to increase (excess) trading volume. Our finding that a more gentle slope coincide with a greater number of trades is in line with this prediction. Second, a peak volume and volatility is predicted at the beginning of the trading day because dispersion of beliefs is greater when the price signal is more noisy. As shown in section 3, the slope of the order book is relatively more gentle in the beginning of the trading day than later in the day. However, this feature of the data may also be due to adjustments in liquidity demand.

From a more practical point of view, the discussions in the popular press about the value of companies, and sometimes very different buy and sell recommendations by analysts for the same stock, suggest that the differences in valuations may be an important factor driving trading activity in financial markets. In any case, our findings provide a motivation for future research on this topic.

5 Conclusions

A positive correlation between price volatility and trading volume has been documented in a variety of studies. Investigating plausible explanations for this relation is important because it can enhance our understanding of how information is disseminated into market prices.

There are two, mainly complementary, hypotheses relating trading volume and volatility. The mixture of distributions hypothesis states that the volume-volatility relation is driven by a directing process that can be interpreted as the flow of information. The dispersion of beliefs hypothesis states that both trading volume and volatility should be higher the greater the dispersion of beliefs about security values among investors. One explanation behind this statement is based on asymmetric information and strategic investor behavior. Uninformed traders cannot distinguish informed trades from liquidity trades, and by reacting to trades with no information content, they increase both volume and volatility relative to equilibrium values in a situation with symmetric information. A positive relation between dispersion of beliefs and the volume-volatility relation can also be explained in a non-informational setting where investors have different opinions about the value of the same news. Thus, while the mixture of distributions hypothesis states that trading volume and price movements result from new information arrivals, the dispersion of beliefs hypothesis

also relates a part of the volume-volatility relation to increased trading by uninformed traders or symmetrically informed investors who disagree on the same news.

We investigate these issues using a detailed data sample from the Oslo Stock Exchange (OSE). A unique feature of our data sample is that we can rebuild the whole order book at any time during the trading day. This enables us to investigate whether the characteristics of the limit order book contain information about the volume-volatility relation. We first document that our data exhibit a standard volume-volatility relation. Moreover, we show that the result in Jones et al. (1994), that the average size of trades has little marginal explanatory power when volatility is conditioned on the number of daily transactions, also applies in a limit order market.

Our main findings show that more gentle demand and supply schedules increases volatility and trading volume in a cross-sectional time series setting. One possible interpretation of this is that the number of trades is not a proxy for the mixing variable, but the mixing variable itself as suggested in models with heterogenous agents.

A Calculation of alternative slope measures

To examine whether changing the way of calculating the slope measure affects our results, we calculate four alternative measures in addition to the measure SLOPE used in the main analysis and described in section 3.1. The results from running the regressions with alternative slope measures are shown in table 19.

The “RAW SLOPE” is calculated by using the volume at each tick level instead of its natural logarithm. This measure is calculated as in equations 1-3.

The “NOSH SLOPE” is calculated based on an order book which is normalized with respect to the total number of outstanding shares on date t for company i . This is similar to the elasticity measure used in Kalay et al. (2003), and assumes that all shares in the firms are for sale and that the prices are too low for those shareholders that are not trading on the particular day. For e.g. the ask side the order book on day t at snapshot time $s \in [1..6]$ for company i , the average slope is calculated as,

$$SE_{i,t}^s = \left\{ \frac{V_1^A / \text{NOSH}_{i,t}}{p_1^A / p^M - 1} + \sum_{\tau=1}^{N_A} \frac{(V_{\tau+1}^A - V_{\tau}^A) / \text{NOSH}_{i,t}}{p_{\tau+1}^A / p_{\tau}^A - 1} \right\} \quad (12)$$

where $\text{NOSH}_{i,t}$ is the number of outstanding shares for company i on day t .

“OV SLOPE” is calculated based on an order book which is normalized relative to the total market wide share volume in all orders coming into the market on that day. This measure is similar to the normalization used in Kim et al. (2004), where we instead of using the number of outstanding shares in equation 12 use the total share volume of all orders coming into the market on day t .

In the final measure, “NORM SLOPE”, we normalize the order book for a company at each snapshot relative to the total number of shares supplied in the order book at that snapshot. For one snapshot, this measure only changes the volume at each price level in the order book to the percentage volume at each tick. However, across companies, it implicitly standardize the order book relative to firm size and firm liquidity.

To explain the “NORM SLOPE” calculation more specifically, let N_A and N_B be respectively the total number of bid and ask prices (tick levels) containing orders. Let τ denote the tick level, with $\tau = 1$ representing the best quote with a positive volume. Furthermore, let p_1^B and p_1^A be respectively the best bid and ask prices, and p^M denote the bid-ask midpoint (which is the average of p_1^B and p_1^A). Let v_{τ}^B and v_{τ}^A be respectively the percentage of total share volume at each tick

level on the bid and ask side of the book. E.g. $v_{\tau=1}^A=0.1$ would mean that 10% of the total number of shares supplied on the ask side of the order book is located at the best ask quote at that point in time.

The average elasticity for the supply curve, SE, on day t at snapshot time $s \in [1..6]$ for company i can then be represented as,

$$SE_{i,t}^s = \left\{ \frac{RV_1^A}{p_1^A/p^M - 1} + \sum_{\tau=1}^{N_A} \frac{RV_{\tau+1}^A/RV_{\tau}^A - 1}{p_{\tau+1}^A/p_{\tau}^A - 1} \right\} \quad (13)$$

where RV_{τ}^A is the fraction of total share volume on the ask side in the order book at snapshot s at price level τ . This fraction is thus calculated for each level at the e.g. ask side as,

$$RV_{\tau}^A = V_{\tau}^A / \sum_{\tau} V_{\tau}^A \quad (14)$$

where V_{τ}^A is the number of shares supplied at price level τ .

B Balanced sample estimation

To examine the robustness of our results, we restrict our sample to firms that were traded every day through the sample period of 572 trading days. This leaves us with a balanced sample of 27 firms with 572 time series observations each. In addition, the filtering leaves us with a sample of the largest, most liquid and actively traded firms on the exchange. If the previous results are mainly due to noise or outliers introduced by small illiquid firms or the unbalanced dataset, the balancing of the sample should reveal this. In table 19 we re-estimate model 1 in panel A of table 14 and model 1a and 1b in panel A of table 15 for the balanced sample. The estimation results are quantitatively similar to the results when we use the full sample. Most interestingly, the parameter estimate for SLOPE is negative and of similar size as before. In addition, the SLOPE estimate becomes smaller (less negative) the more we truncate the order book. As before, this is mainly due to the increase in the size of the slope estimates the more the order book is truncated. Also the significance of the SLOPE is also reduced the less of the order book we use. The largest difference between the models estimated for the balanced and unbalanced sample is that the R-squared of the models is much higher for the balanced sample, suggesting that there is more noise in the unbalanced sample.

In table 20 we re-estimate the model for trading activity (number of trades, N) in panel A of table 17 for the balanced sample. Although the parameter estimates change more in size than what was the case for the volatility models, the parameters are qualitatively similar. Most importantly, the SLOPE parameter estimate is negative when it is calculated using the full order book, and becomes less negative and less significant the more the order book is truncated. Thus, also for the balanced sample, the results suggests that the more dispersed prices are across the order book, the more trades are executed.

[Table 18 about here.]

[Table 19 about here.]

C Alternative slope measures and separate bid and ask slope regressions

As a robustness check, we examine whether different ways to calculate the slope change our results in table 14. The calculation of the different slope measures is explained in appendix A.

[Table 20 about here.]

We also examine the effects from separating the slope of the bid and ask side of the order book, both in the balanced and unbalanced case as well as for the various truncations of the order book. In panel A of table 22 we report slope estimates for the volatility regressions, and in panel B we report slope estimates for the trading activity regressions. As before, the estimates using the average of the bid and ask slopes are negative and significant both for in the balanced and unbalanced case. However, when examining the slope estimates for the bid and ask side separately we find that it is mainly the bid side of the order book that is related to contemporaneous volatility. In the two next columns (when we use the truncated order books for calculating the slope) the results are essentially similar. In panel B of table 22 we perform a similar analysis for the trading activity regressions. Also here there seem to be an asymmetry between the bid and ask side of the order book.

[Table 21 about here.]

References

- Barclay, M. and J. Warner (1993). “Stealth trading and volatility: which trades move prices?” *Journal of Financial Economics*, 34, 281–305.
- Bessembinder, H. and P. Seguin (1993). “Price volatility, trading volume, and market depth: Evidence from futures markets.” *Journal of Financial and Quantitative Analysis*, 28(1), 21–39.
- Biais, B., P. Hillion, and C. Spatt (1995). “An empirical analysis of the limit order book and the order flow in the Paris Bourse.” *Journal of Finance*, 50, 1655–1689.
- Chan, L. and J. Lakonishok (1993). “Institutional trades and intra-day stock price behavior.” *Journal of Financial Economics*, 33, 173–199.
- Chan, L. and J. Lakonishok (1995). “The behavior of stock prices around institutional trades.” *Journal of Finance*, 50, 1147–1174.
- Daigler, R. and M. Wiley (1999). “The impact of trader type on the futures volatility-volume relation.” *Journal of Finance*, 54, 2297–2316.
- Foucault, T., S. Mainas, and E. Theissen (2003). “Does anonymity matter in electronic limit order markets.” Unpublished paper.
- French, K. and R. Roll (1986). “Stock return variances. the arrival of information and the reaction of traders.” *Journal of Financial Economics*, 17, 5–26.
- Ghysels, E. and J. L. Juergens (2001). “Stock market fundamentals and heterogeneity of beliefs: tests based on a decomposing of returns and volatility.” Unpublished paper, University of North Carolina.
- Glosten, L. (1994). “Is the electronic open limit order book inevitable?” *Journal of Finance*, 49, 1127–1161.
- Glosten, L. and P. Milgrom (1985). “Bid, ask and transaction prices in a specialist market with heterogeneously informed traders.” *Journal of Financial Economics*, 14, 71–100.
- Goldstein, M. and K. Kavajecz (2000). “Liquidity provision during circuit breakers and extreme market movements.” Working Paper, The Rodney L. White Center for Financial Research.

- Harris, L. (1986). “Cross-security tests of the mixture of distributions hypothesis.” *Journal of Financial and Quantitative Analysis*, 21(1), 39–46.
- Harris, L. (1987). “Transaction data tests of the mixture of distributions hypothesis.” *Journal of Financial and Quantitative Analysis*, 22(2), 127–141.
- Harris, L. and J. Hasbrouck (1996). “Market orders vs. limit orders: The superdot evidence on order submission strategy.” *Journal of Financial and Quantitative Analysis*, 31(2), 213–231.
- Harris, M. and A. Raviv (1993). “Differences of opinion make a horse race.” *Review of Financial Studies*, 6, 473–506.
- Huang, R. D. and R. W. Masulis (2003). “Trading activity and stock price volatility: evidence from the London Stock Exchange.” *Journal of Empirical Finance*, 10, 249–269.
- Jones, C., G. Kaul, and M. Lipson (1994). “Transactions, volume, and volatility.” *Review of Financial Studies*, 7, 631–651.
- Kalay, A., O. Sade, and A. Wohl (2003). “Measuring stock illiquidity. An investigation of the demand and supply schedules at the TASE.” *Journal of Financial Economics*, Forthcoming.
- Karpoff, J. (1987). “The relation between price changes and trading volume: A survey.” *Journal of Financial and Quantitative Analysis*, 22(1), 109–126.
- Kim, J.-W., J. Lee, and R. Morck (2004). “Heterogeneous investors and their changing demand and supply schedules for individual common stocks.” NBER Working Paper Series, no 10410.
- Niemeyer, J. and P. Sandas (1995). “An empirical analysis of the trading structure at the stockholm stock exchange.” Working Paper No. 44, Stockholm School of Economics.
- Sandås, P. (2001). “Adverse selection and competitive market making: empirical evidence from a limit order market.” *Review of Financial Studies*, 14(3), 705–734.
- Schwert, G. (1990). “Stock volatility and the crash of ‘87.” *Review of Financial Studies*, 3, 77–102.
- Shalen, C. T. (1993). “Volume, volatility, and the dispersion of beliefs.” *Review of Financial Studies*, 6(2), 405–434.

Figure 1: Calculation of the demand and supply elasticities

The figure illustrates how the local slopes/elasticities on the bid and ask side of the order book are calculated for one "snapshot" time on one date for one company. There are only 4 price levels on both sides of the book. The left y-axis shows the aggregate share volume on the demand (bid) side of the order book at each tick level. Similarly, the right y-axis shows the aggregate share volume on the supply (ask) side of the order book at each tick level. The solid step-line is the supply (right) and demand (left) curves over the various price levels. On the x-axis, we have the various price levels. p^M is the bid/ask midpoint. Prices greater than p^M are ask prices and prices below p^M are bid prices. The difference between p_1^B (best bid) and p_1^A (best ask) is the quoted spread. The dotted line-segments connecting each level of the order book have local slopes denoted by Δ_s .

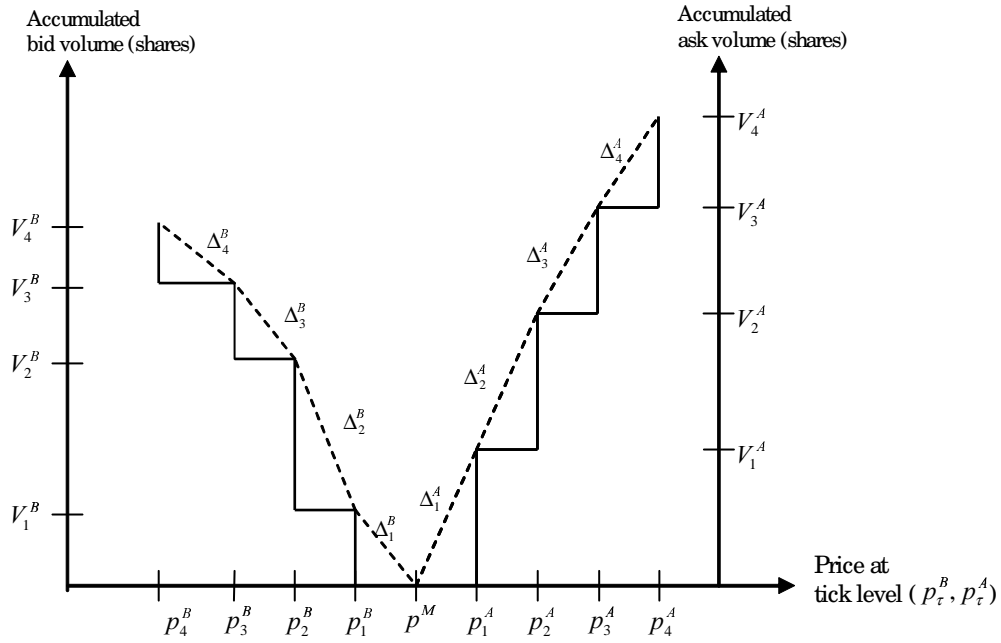


Figure 2: Intraday characteristics of the order book

The figures shows cross-sectional averages across 7 intraday windows for various measures. The windows and numbers correspond to those in tables 6 and 7. Note that windows 1 and 7 are half-hour intervals from 10:00 to 10:30 and 15:30 to 16:00 respectively, while windows 2 to 6 are hourly intervals starting every half hour. Figure (a) shows the average aggressiveness of different order types. The first type of orders, "passive orders", are placed at or away from the quote on the same side of the book. This would be e.g. a buy order with a price (bid) equal to or lower than the current best bid, or a sell order with a price (ask) equal to or higher than the best ask price. The second type of orders, "quote-improving orders", are orders that improve the best quote (on the same side). This would be e.g. a buy order with a price higher than the current best bid, but lower than the best ask quote. The third type of orders, "aggressive orders", are orders placed at the opposite quote or higher(buys)/lower(sells). Figure (b) shows the average order size within each limit order group and the average order size of market orders. Figure (c) show the average slope on the left axis and the average quoted and effective spreads on the right axis. Note that the slope is calculated from the order book snapshot taken at the end of each window. Figure (d) shows the fraction of each order category which is placed within each window.

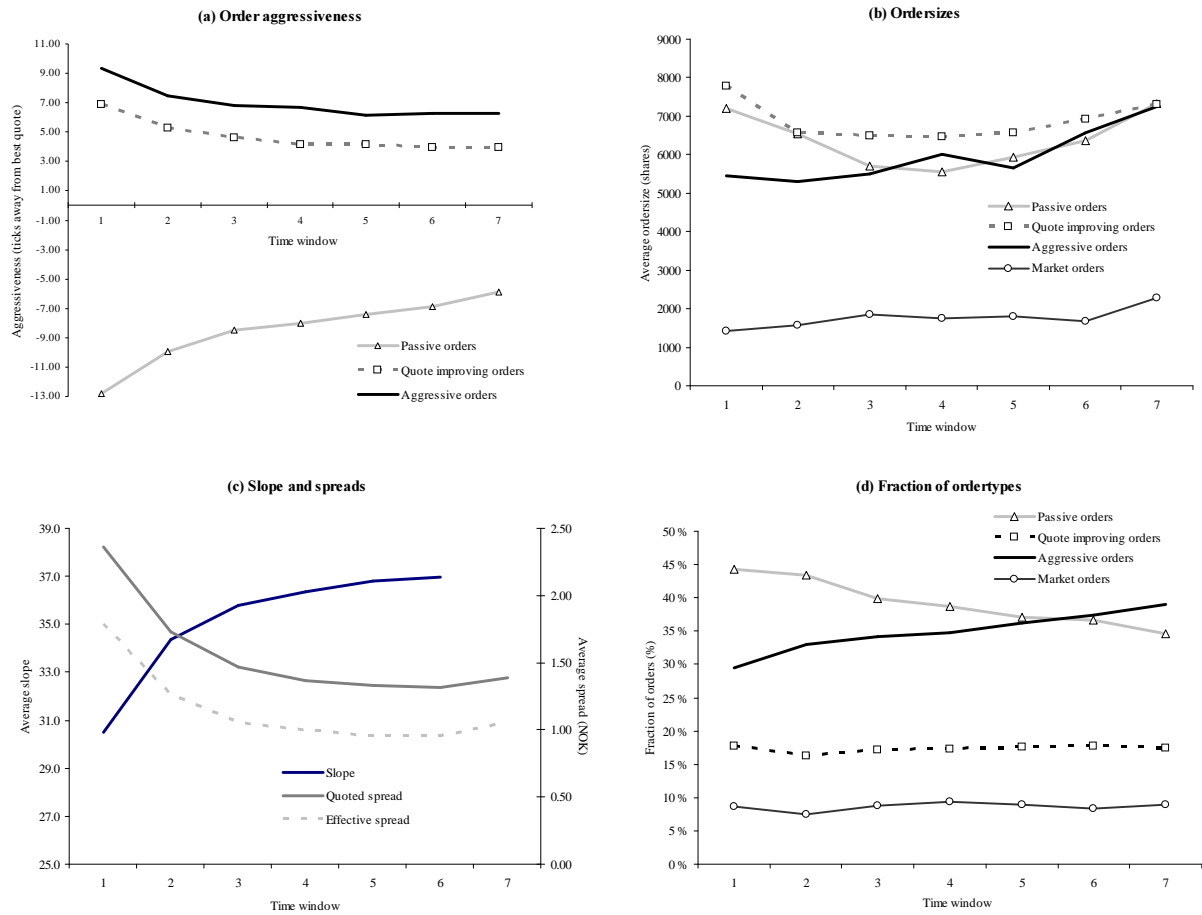


Figure 3: Average slope and volatility

The figure illustrates the relationship between the estimates of the average daily slope of the order book and the contemporaneous daily price changes. The left axis measures the equally weighted average absolute return across firms traded on the respective date. The right axis measures the slope estimate calculated as the daily equally weighted slope, averaged over all companies that were traded during the trading day.

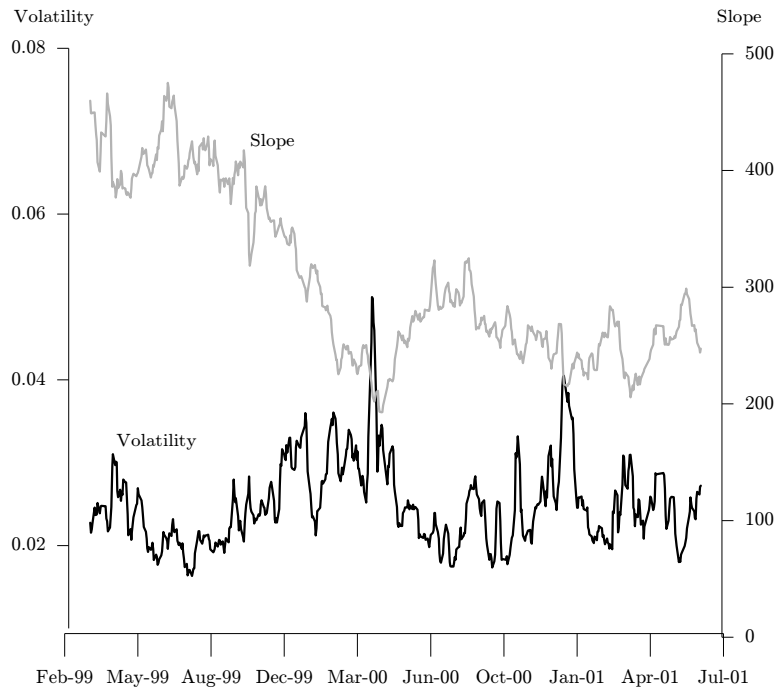


Figure 4: Frequency distribution of slope estimates

The figures show the frequency distributions for (average) daily equally weighted normalized slope estimates for all firms for the entire sample period. In figure (a) the slope calculations are calculated using only the first 5 levels of the order book, in figure (b) we use the first 10 levels of the order book and in figure (c) we use the entire order book up to 100 tick levels.

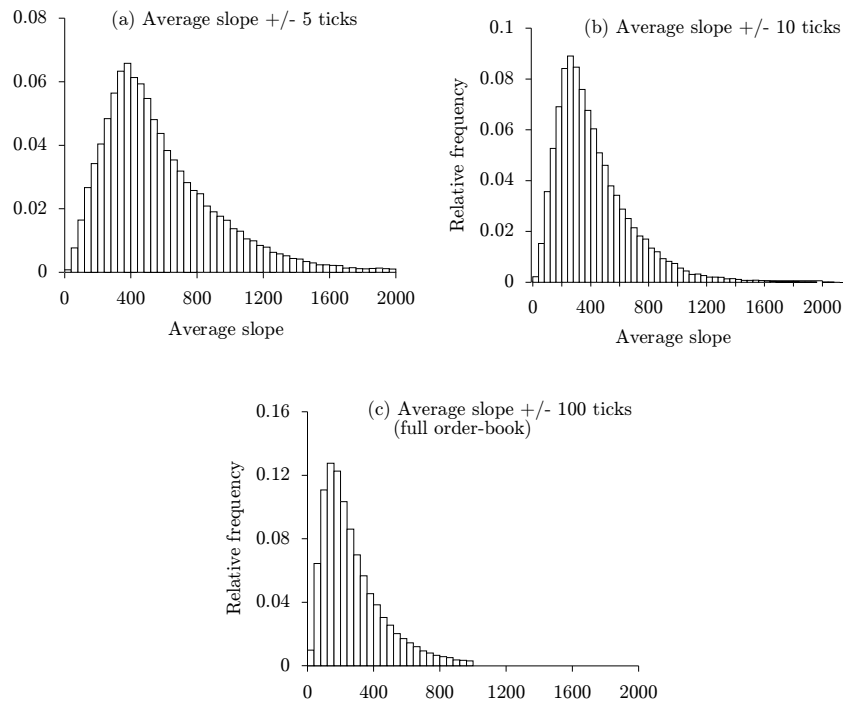


Figure 5: Average order books for Norsk Hydro and Opticom

The figure illustrates the order books for two different companies listed on the OSE. The upper graph shows the average normalized (with respect to the total number of orders in the order book) order book for Norsk Hydro (NHY), a large Norwegian blue chip company, and the lower picture shows the average normalized order book for Opticom, a Norwegian IT company. The order books are averaged over the last five days of May 2001. (For each day the average order book is calculated from hourly snapshots of the book.) The picture shows the percentage of shares in all orders within varying ticks away from the quotes. Zero represents the best quote on each side of the market.

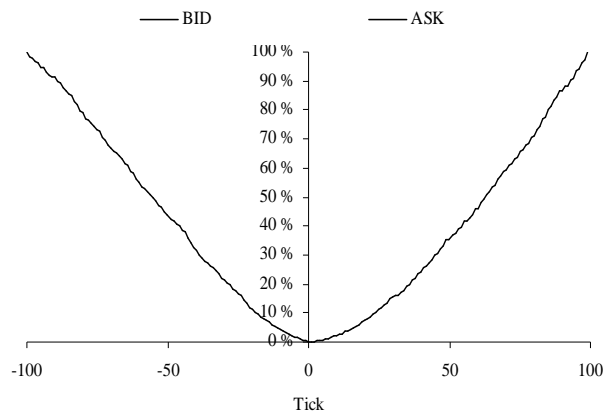
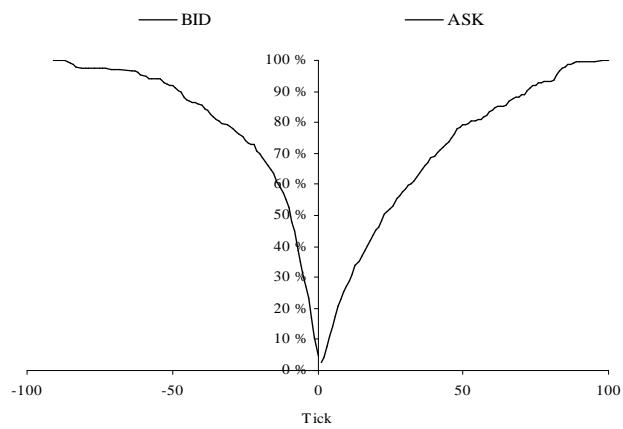


Table 2: Oslo Stock Exchange (OSE) - General statistics

Descriptive statistics for the Oslo Stock Exchange for the period 1999 to 2001. All numbers in the table are official statistics obtained from the OSE annual reports (available at www.ose.no).

	1999	2000	2001
Number of listed firms	215	214	212
Market capitalization (bill. NOK)	582.94	637.86	677.03
NOK/USD exchange rate ^a	7.81	8.81	8.99
Turnover velocity ^b	88.6	96.7	86.4
Total dividends (mill. NOK)	14443	12194	13767
<i>Market development</i>			
Market index level (TOTX)	1153.74	1366.05	933.22
OSE benchmark index	189.76	195.79	167.18
OSE benchmark index return (%)	48.45	3.18	-14.61

^aAverage midpoint rate for the respective year. ^bTurnover velocity: Average of annualized turnover per month divided by market value at the end of each month.

Table 3: Descriptive statistics of the order book

Panel A shows the daily average number of submitted orders and the daily average order size for different types of orders. The numbers are averaged over companies and time. We also report averages over the four market capitalization groups. Group 1 consists of the 25% smallest firms while group 4 consists of the 25% largest firms. Some firms have experienced large changes in capitalization value during the sample period. To take account of this, we re-sort the market capitalization groups at the beginning of each year. Limit orders are classified into three different types based on their aggressiveness. “Passive orders” are orders that are submitted at the best (same side) quote or further away from the market. “Quote improving orders” are orders that are submitted in between the inner quotes prevailing at order submission, and “aggressive orders” are orders that are submitted at the opposite quote (marketable limit order) or at a price further away from the market on the opposite side. “Market orders” constitute a separate group. The numbers in parentheses are each order class’ fraction of total orders. Panel B provides descriptive statistics on the distribution of order book volume. The numbers are daily average fractions of accumulated volume, and are reported for all firms, for the bid and ask side separately, for minimum tick sizes, and for the four market capitalization groups.

PANEL A: Order types and order sizes

	Firms	Submitted orders				Order sizes				
		Total orders	Passive orders	Quote improving orders	Aggressive orders	Market orders	Passive orders	Quote improving orders	Aggressive orders	Market orders
All firms	108	94	42 (0.44)	15 (0.16)	34 (0.36)	4 (0.04)	6428	7063	5882	1715
<i>Market capitalization quartiles</i>										
1 (small)	27	45	22 (0.45)	10 (0.21)	14 (0.31)	3 (0.06)	10708	11501	9824	4341
2	27	52	23 (0.43)	10 (0.19)	18 (0.34)	3 (0.05)	6244	7460	5634	1382
3	27	53	22 (0.41)	10 (0.19)	19 (0.37)	3 (0.05)	3437	3900	3038	531
4 (large)	27	224	100 (0.45)	31 (0.14)	87 (0.39)	7 (0.03)	5324	5392	5032	605

PANEL B: Order book volume distribution (normalized)

Minimum tick size	ATQ	+/- 1 tick	+/- 5 tick	+/- 10 tick	+/- 20 tick	+/-50 tick	+/-100 tick
All firms	20.9%	34.7%	56.8%	69.4%	78.4%	88.6%	100.0%
Bid side	23.0%	40.0%	62.9%	73.8%	81.4%	89.7%	100.0%
Ask side	20.8%	29.3%	50.8%	64.9%	75.5%	87.4%	100.0%
<i>Minimum tick size</i>							
0.01	20.2%	30.8%	37.8%	49.0%	60.1%	82.2%	100.0%
0.1	22.2%	34.2%	53.2%	67.4%	79.4%	91.7%	100.0%
0.5	22.3%	39.1%	65.8%	78.4%	88.1%	95.5%	100.0%
1	7.0%	10.7%	17.6%	25.1%	38.8%	70.0%	100.0%
<i>Market capitalization quartiles</i>							
1 (small)	19.1%	29.7%	45.2%	56.6%	68.2%	84.0%	100.0%
2	21.6%	34.9%	56.3%	69.6%	79.9%	91.1%	100.0%
3	23.6%	38.3%	62.7%	75.5%	83.8%	92.6%	100.0%
4 (large)	19.3%	34.6%	62.9%	75.9%	84.3%	91.0%	100.0%

Table 4: Hidden orders at the OSE

Statistics for order submissions for the whole sample period, half year periods and market capitalization (MCAP) quartiles. Panel A shows the total number of “regular” orders and “hidden” orders, the average order size for the two types of orders as well as for orders grouped relative to their aggressiveness. All order sizes are reported in thousands of shares. For the hidden orders, we also calculate the average order size for the hidden (undisclosed) part and visible (disclosed) part of the orders. Panel B shows the fraction of total volume due to hidden orders both with respect to the number of orders as well as share volume.

PANEL A: Number of orders and order size of regular and hidden orders

	Whole sample	Subperiods (half years)					MCAP quartiles			
		1999.1	1999.2	2000.1	2000.2	2001.1	1	2	3	4
”Regular” orders (thousands)	5429	536	853	1362	1353	1325	636	827	768	3197
order size (1000 shares)	5	7	7	4	4	4	8	7	3	4
- size of <i>passive orders</i>	4	7	7	4	4	3	9	6	3	3
- size of <i>quote improving</i>	5	7	8	4	5	4	8	7	3	5
- size of <i>aggressive orders</i>	6	7	8	6	6	4	8	8	4	6
”Hidden” orders (thousands)	291	26	40	68	78	79	24	44	48	174
order size (1000 shares)	22	30	31	20	19	18	43	30	16	18
- order size hidden part	16	22	22	15	14	13	32	22	11	13
- order size visible part	6	9	9	5	5	5	10	8	4	5
<i>size of passive orders</i>	20	29	28	18	17	17	43	28	14	15
- order size hidden part	14	21	20	13	13	12	33	21	11	11
- order size visible part	5	8	8	5	5	4	10	7	4	4
<i>size of quote improving orders</i>	24	31	34	24	20	19	39	34	17	22
- order size hidden part	17	22	25	18	14	14	30	25	12	16
- order size visible part	7	9	10	6	5	5	10	9	4	6
<i>size of aggressive orders</i>	26	36	40	24	22	23	46	34	19	23
- order size hidden part	19	24	29	17	16	17	34	25	14	16
- order size visible part	7	11	12	7	6	6	12	9	5	7

PANEL B: Fraction of orders with hidden volume

	Whole sample	Subperiods (half years)					MCAP quartiles			
		1999.1	1999.2	2000.1	2000.2	2001.1	1	2	3	4
Fraction of hidden orders to total number of orders										
All hidden orders	0.05	0.05	0.04	0.05	0.05	0.06	0.04	0.05	0.06	0.05
Quote improving	0.08	0.07	0.07	0.08	0.09	0.09	0.06	0.08	0.10	0.08
Aggressive	0.02	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Passive	0.07	0.07	0.06	0.06	0.07	0.07	0.04	0.06	0.08	0.07
Fraction of share volume in hidden orders to total share volume in all orders										
All hidden orders	0.19	0.17	0.17	0.19	0.19	0.23	0.16	0.20	0.24	0.19
Quote improving	0.29	0.25	0.26	0.34	0.29	0.32	0.22	0.30	0.35	0.29
Aggressive	0.07	0.04	0.06	0.07	0.08	0.12	0.08	0.08	0.09	0.07
Passive	0.24	0.23	0.21	0.24	0.25	0.28	0.18	0.24	0.31	0.28

Table 5: Trades involving hidden orders

The table shows the volume of executed trades where at least one side of the trade comes from an order with hidden volume. The table also shows the fraction of total trading volume where a part of a hidden order is involved.

	Whole sample	Subperiods (half years)					MCAP quartiles			
		1999.1	1999.2	2000.1	2000.2	2001.1	1	2	3	4
Trades involving hidden orders										
Number of trades (thousands)	951	63	107	231	269	282	81	133	136	601
Shares volume (mill. shares)	2436	262	473	528	591	583	367	464	268	1336
NOK volume (bill. NOK)	188	15	28	44	50	51	5	13	22	148
Fraction of total volume										
number of trades	0.26	0.19	0.20	0.24	0.28	0.30	0.21	0.25	0.27	0.26
share volume of trades	0.25	0.20	0.21	0.26	0.29	0.32	0.21	0.24	0.29	0.27
NOK volume of trades	0.29	0.22	0.21	0.29	0.33	0.35	0.23	0.30	0.32	0.29

Table 6: Intraday statistics

The table provides intraday statistics calculated over seven time intervals corresponding to the six snapshots used to rebuild the order book. Note that the first and last intervals are half an hour while the rest of the time intervals are hourly. The statistics include the slope of the book calculated at the end of each time interval, the price volatility measured by the absolute value of hourly returns between midpoint prices closest to the end of each time interval, the quoted spread, the effective spread, the number of trades executed during the time interval, the trade size (in shares), the number of orders submitted during the time interval, and the order size (in shares). In addition, the table reports the average number of hidden orders as well as the average sizes of the hidden and visible part of these orders.

	Time window						
	10:00 to 10:30	10:30 to 11:30	11:30 to 12:30	12:30 to 13:30	13:30 to 13:30	13:30 to 14:30	15:30 to 16:00
Slope	256.0	288.2	298.0	304.0	305.8	306.5	
Price volatility	-	1.34 %	0.81 %	0.72 %	0.74 %	0.88 %	0.86 %
Quoted spread	2.36	1.73	1.47	1.37	1.33	1.31	1.39
Effective spread	1.79	1.27	1.05	1.00	0.95	0.95	1.05
Trades	10.38	11.81	9.38	9.05	9.52	10.81	10.40
Trade size (shares)	2314	2653	2759	2774	2834	3027	3123
Orders	15.45	18.16	13.10	12.36	12.47	14.02	11.66
Order size (shares)	6858	6385	5723	5818	5795	6383	6706
Hidden orders	1.71	1.79	1.60	1.60	1.62	1.72	1.58
- hidden size (shares)	28559	21276	20679	22673	19636	20998	24900
- visible size (shares)	7983	7170	7316	7209	7066	7781	7600

Table 7: Order aggressiveness

The table provides intraday statistics on order aggressiveness. All orders are decomposed into four groups based on their aggressiveness. The least aggressive orders, “passive orders”, are orders placed at or away from the quote on the same side of the book. This would be e.g. a buy order with a price (bid) equal to or lower than the current best bid, or a sell order with a price (ask) equal to or higher than the best ask price. The second type of orders, “quote-improving orders”, are orders that improve the best quotes. This would be e.g. a buy order with a price higher than the current best bid, but lower than the best ask quote. The third type of orders, “aggressive orders”, are orders placed at the opposite quote or higher(buys)/lower(sells). The table reports the average number of orders of each type within each time window, the percentage of all orders of each type, and the average order size in shares and NOK. For each type of order we also calculate an aggressiveness index equal to the average number of ticks away from the best quote (on the same side) that an order is submitted. Thus an index number of zero means that the average order is placed at the quote, a positive index number means that the order is placed above/below the bid/ask, and a negative index number means that the average order is placed below/above the bid/ask. We do not calculate the aggressiveness for market orders since these by definition do not have any limit price. Note that the first and last time windows are half an hour while the rest of the time windows are hourly.

Order type	Time window						
	10:00 to 10:30	10:30 to 11:30	11:30 to 12:30	12:30 to 13:30	13:30 to 14:30	14:30 to 15:30	15:30 to 16:00
<i>Aggressiveness</i> (avg. ticks away from best quote)							
Passive orders	-12.81	-9.96	-8.45	-8.02	-7.44	-6.90	-5.87
Quote-improving orders	6.90	5.30	4.65	4.17	4.16	3.94	3.96
Aggressive orders	9.36	7.46	6.82	6.68	6.17	6.29	6.29
Average aggressiveness (weighted)	-1.69	-1.00	-0.25	-0.06	0.20	0.52	1.11
<i>Average number of orders</i>							
Passive orders	8.2	9.1	6.4	5.9	5.7	6.2	5.0
Quote-improving orders	3.3	3.4	2.7	2.6	2.7	3.0	2.5
Aggressive orders	5.4	6.9	5.5	5.3	5.5	6.3	5.6
Market orders	1.6	1.6	1.4	1.4	1.4	1.4	1.3
<i>% of orders of type</i>							
Passive orders	44.2%	43.4%	39.9%	38.7%	37.2%	36.7%	34.6%
Quote-improving orders	17.7%	16.3%	17.1%	17.3%	17.6%	17.7%	17.4%
Aggressive orders	29.4%	32.9%	34.2%	34.7%	36.2%	37.3%	39.0%
Market orders	8.6%	7.4%	8.8%	9.3%	9.0%	8.3%	8.9%
<i>Order size (shares)</i>							
Passive orders	7202	6548	5716	5557	5938	6370	7317
Quote-improving orders	7793	6568	6486	6470	6561	6915	7294
Aggressive orders	5461	5301	5498	6008	5649	6569	7239
Market orders	1412	1576	1855	1751	1795	1678	2281
<i>Order size (1000 NOK)</i>							
Passive orders	275	235	222	221	242	267	346
Quote-improving orders	274	253	258	265	274	290	328
Aggressive orders	188	204	204	214	227	376	307
Market orders	36	39	46	42	40	43	69

Table 8: Aggressiveness of hidden orders

The table shows the average aggressiveness for the submitted orders with hidden volume. The least aggressive orders, “passive orders”, are orders placed at or away from the quote on the same side of the book. This would be e.g. a buy order with a bid price equal to or lower than the current best bid, or a sell order with an ask price equal to or higher than the best ask price at submission. The second type of orders, “quote improving orders”, are orders that improve the best quotes. This would be e.g. a buy order submitted at a price higher than the current best bid, but lower than the best ask quote. The third type of orders, “aggressive orders”, are orders placed at the opposite quote or higher (for buys)/lower (for sells).

	Time window						
	10:00 to 10:30	10:30 to 11:30	11:30 to 12:30	12:30 to 13:30	13:30 to 13:30	13:30 to 14:30	15:30 to 16:00
Aggressiveness (avg. ticks away from best quote)							
Passive orders	-9.85	-5.74	-3.14	-3.25	-3.35	-2.60	-2.27
-1999	-13.77	-8.12	-2.88	-2.92	-2.92	-2.50	-1.39
-2000	-7.03	-4.53	-2.79	-2.73	-3.03	-2.60	-2.02
-2001	-8.69	-4.58	-3.82	-4.17	-4.14	-2.70	-3.49
Quote improving orders	7.39	5.41	4.22	4.06	4.15	4.18	3.97
-1999	9.16	6.56	4.78	4.78	5.36	5.80	4.97
-2000	5.83	4.60	3.98	3.79	3.57	3.53	3.43
-2001	7.16	5.05	3.89	3.57	3.47	3.13	3.45
Aggressive orders	6.68	5.26	5.54	5.05	4.19	4.52	5.14
-1999	7.01	6.37	7.26	6.69	4.40	5.56	6.81
-2000	6.08	5.06	5.22	4.48	4.40	4.36	4.61
-2001	7.10	4.36	4.23	4.00	3.66	3.61	4.05

Table 9: Number of unique brokers submitting new orders

The table shows statistics for the average (cross sectional) number unique broker IDs for brokers submitting new limit orders within each time interval.

	Time window						
	10:00 to 10:30	10:30 to 11:30	11:30 to 12:30	12:30 to 13:30	13:30 to 13:30	13:30 to 14:30	15:30 to 16:00
Number of active brokers							
Min	1.94	2.04	1.72	1.79	1.71	1.77	1.43
Median	4.45	5.20	4.16	3.93	3.96	4.06	3.35
Mean	5.99	6.69	5.48	5.24	5.27	5.56	4.83
Max	23.04	23.75	19.40	18.20	19.40	20.98	18.15
std.dev mean	4.55	4.84	3.93	3.72	3.87	4.19	3.84
Separate years (mean)							
-1999	4.89	5.43	4.41	4.25	4.28	4.54	3.74
-2000	6.50	7.39	6.08	5.72	5.76	6.04	5.25
-2001	6.46	6.96	5.56	5.42	5.41	5.73	5.18

Table 10: Correlations between the components of trading volume

The table shows Pearson's correlation coefficients for the various components of daily trading volume. *AV* is the average trade size in shares, *N* is the number of trades and *V* is the total volume in shares. The table shows the correlation coefficients for the whole sample, for three month (non overlapping) sub-periods, and for market capitalization quartiles.

	Corr(<i>AV</i> , <i>N</i>)	Corr(<i>V</i> , <i>N</i>)	Corr(<i>V</i> , <i>AV</i>)
Whole sample	-0.061	0.525	0.330
Sub-periods (quarters)			
1999.1	0.045	0.660	0.358
1999.2	0.051	0.591	0.438
2000.1	-0.091	0.724	0.290
2000.2	-0.085	0.568	0.288
2001.1	-0.084	0.442	0.201
Market Capitalization groups			
1 (small)	-0.116	0.690	0.393
2	0.280	0.480	0.932
3	0.172	0.847	0.504
4 (large)	-0.066	0.365	0.759

Table 11: A volume-volatility regression model

The table reports the results from the estimation of three regression models of the volume/trade size -volatility relation. The models are estimated on the whole data sample and separately for each market capitalization group. The models are based on Jones et al. (1994):

$$\text{Model I: } |\hat{\epsilon}_{t,i}| = \alpha_i + \alpha_{i,m} M_t + \beta_i AV_{i,t} + \sum_{j=1}^{12} \rho_{i,j} |\hat{\epsilon}_{i,t-j}| + \eta_{i,t}$$

$$\text{Model II: } |\hat{\epsilon}_{t,i}| = \alpha_i + \alpha_{i,m} M_t + \gamma_i N_{i,t} + \sum_{j=1}^{12} \rho_{i,j} |\hat{\epsilon}_{i,t-j}| + \eta_{i,t}$$

$$\text{Model III: } |\hat{\epsilon}_{t,i}| = \alpha_i + \alpha_{i,m} M_t + \beta_i AV_{i,t} + \gamma_i N_{i,t} + \sum_{j=1}^{12} \rho_{i,j} |\hat{\epsilon}_{i,t-j}| + \eta_{i,t}$$

Using the Jones et al. (1994) notation we have that $|\epsilon_{t,i}|$ is the absolute value of the return of security i in period t , conditional on its own 12 lags and day-of-week dummies, M_t is a dummy variable that is equal to 1 for Mondays and 0 otherwise, $AV_{i,t}$ is the average trade size, $N_{i,t}$ is the number of transactions for security i on day t , and the coefficients $\rho_{i,t}$ measure the persistence in volatility. Column 3-5 show parameter estimates averaged across all individual firm regression equations, while columns 6-9 show the parameter distribution across firms. $\hat{\beta}$ is the average parameter estimate for the average trade size variable (AV), $\hat{\gamma}$ is the average parameter estimate for the number of trades variable (N). In the distribution of estimates column we report, respectively, the percentage of $\hat{\beta}$ and $\hat{\gamma}$ estimates over all single firm regression equations that are significant. In the last two columns we report the percentage of parameter estimates that are greater than zero. The first part of the table shows the results from running the regression equations over the whole sample. The second part of the table shows the similar results when we split the sample into four size portfolios.

Model	Firms	Parameter estimates			Distribution of estimates			
		$\hat{\beta}$ (AV)	$\hat{\gamma}$ (N)	adj. R ²	%t($\hat{\beta}$)>2	%t($\hat{\gamma}$)>2	% $\hat{\beta}$ >0	% $\hat{\gamma}$ >0
Model I (AV)	108	0.145	-	0.057	26.9%	-	81.5%	-
Model II (N)	108	-	0.031	0.145	-	95.4%	-	100.0%
Model III (AV,N)	108	0.053	0.031	0.149	22.2%	94.4%	58.3%	100.0%
<hr/>								
Model I (AV)								
1 (small)	27	0.145	-	0.080	16.2%	-	78.4%	-
2	27	0.219	-	0.055	18.2%	-	77.3%	-
3	27	0.274	-	0.048	19.0%	-	64.3%	-
4 (large)	27	1.021	-	0.038	30.8%	-	79.5%	-
Model II (N)								
1 (small)	27	-	0.052	0.174	-	89.2%	-	97.3%
2	27	-	0.028	0.147	-	75.0%	-	95.5%
3	27	-	0.036	0.136	-	81.0%	-	95.2%
4 (large)	27	-	0.014	0.174	-	79.5%	-	92.3%
Model III (AV,N)								
1 (small)	27	0.079	0.053	0.175	10.8%	86.5%	64.9%	97.3%
2	27	0.076	0.030	0.148	4.5%	75.0%	54.5%	95.5%
3	27	0.075	0.036	0.140	16.7%	78.6%	45.2%	95.2%
4 (large)	27	0.237	0.014	0.179	30.8%	82.1%	35.9%	94.9%

Table 12: Variable correlations

The table shows Pearson's correlation coefficients between our elasticity variable (SLOPE) and various trading activity and liquidity measures. AV is the average trade size in shares, MCAP is the natural logarithm of the market capitalization, SPR is the quoted spread in percent of the midpoint price, OV is the average number of shares in the order book, V is the trade volume in shares.

	N	AV	MCAP	SPR	SLOPE	OV
AV (trade size)	-0.02					
MCAP (firm size)	0.31	-0.30				
SPR (% spread)	-0.20	0.19	-0.43			
SLOPE	-0.02	-0.08	0.42	-0.33		
OV (order volume shares)	0.19	0.16	0.06	-0.05	0.01	
V (trade volume shares)	0.43	0.33	0.15	-0.13	0.03	0.44

Table 13: Distribution of slope estimates

The table shows the distribution of the slope estimates where each local slope is equally weighted. Panel A reports the estimates for the entire sample and across minimum tick sizes. Panel B reports the estimates across market capitalization groups and years. Each company is assigned to a market capitalization quartile at the end of every trading day. N reflects the number of firm/date observations, MCAP is the average market capitalization in NOK millions, price is the average price, P5, P10, P25, P75, P90, and P95 are the 5th, 10th 25th 75th, 90th and 95th percentiles respectively.

PANEL A

	N	MCAP	Price	Distribution of daily slope estimates							
				P5	P10	P25	Median	Mean	P75	P90	P95
All firms	58202	5561	92	70	92	144	231	304	377	591	771
1999	21586	4875	82	94	128	202	322	392	497	731	925
2000	25820	5911	103	67	86	130	201	264	317	494	659
2001	10796	6096	85	57	77	121	191	249	305	473	641

PANEL B

	N	MCAP	Price	Distribution of daily slope estimates								
				P5	P10	P25	Median	Mean	P75	P90	P95	
MCAP Q1 (small)	14342	260	22	45	58	86	135	172	210	319	424	
1999	5323	195	20	58	74	115	177	216	272	405	502	
2000	6360	301	24	44	57	84	126	158	189	282	378	
2001	2659	292	22	38	47	68	103	134	158	246	321	
MCAP Q2	14618	916	65	84	103	146	216	274	329	499	650	
1999	5415	772	54	116	142	197	285	342	418	602	764	
2000	6493	1019	73	78	94	132	189	241	280	428	578	
2001	2710	958	66	72	90	127	187	245	286	436	584	
MCAP Q3	14476	2243	113	96	122	177	273	344	420	642	845	
1999	5365	1873	110	136	176	256	372	452	550	825	1030	
2000	6422	2444	119	88	110	157	231	291	352	537	690	
2001	2689	2500	102	89	109	156	231	290	351	522	672	
MCAP Q4 (large)	14766	18556	165	125	154	219	333	414	514	749	950	
1999	5483	16400	141	187	231	321	458	522	639	872	1066	
2000	6545	19615	193	116	138	192	283	365	425	643	866	
2001	2738	20346	148	111	133	179	256	324	385	614	763	

Table 14: The relationship between volatility and slope - using full order book

The table shows the results from the panel regression with one-way fixed effects (least squares dummy variable estimation) for the whole sample (Panel A) and for sub-periods of 3 month periods (Panel B). The estimated model (model 1) is,

$$|\epsilon_{i,t}| = \beta_0 M_{i,t} + \beta_1 N_{i,t} + \beta_2 AV_{i,t} + \beta_3 MCAP_{i,t} + \beta_4 SPR_{i,t} + \beta_5 OV_{i,t} + \beta_6 SLOPE_{i,t} + \sum_{j=1}^{12} \rho_{i,j} |\hat{\epsilon}_{i,t-j}| + \eta_{i,t}.$$

where $\eta_{i,t} = \nu_i + \epsilon_{i,t}$ defines the error structure with ν_i as the non-random fixed, firm specific, effects. $|\epsilon_{i,t}|$ is the absolute return adjusted for day of week effects and autocorrelation in returns. M is a dummy variable for Monday, N is the number of transactions, AV is the average trade size in shares, $MCAP$ is the natural log of the market capitalization, SPR is the relative spread (quoted spread in % of the midpoint price), OV is the total number of shares in the order book (sum of all orders on bid and ask side of the order book) and $SLOPE$ is the average slope of the bid and offer side of the order book. Panel A, shows the parameter estimates for 3 variations of the full model (model 1), t-values and standard errors for the parameter estimates. In model 2, we do not control for other liquidity variables ($MCAP$, SPR , OV), and in model 3 we exclude the trading activity (N) and trade size (AV) variables. The table shows the associated t-values as well as the R^2 for each portfolio regression. The autoregressive estimates have been excluded from the table. For the F-tests, ** denotes significance at the 1% level. Panel B, shows the sub-period estimates for model 1 for the $SLOPE$, N and AV variables with associated t-values. For each period, the model R-squared, F-test for fixed effects, and number of cross sectional observations (N) and number of time series observations (T) are reported in the last four rows of the table.

PANEL A: Whole sample regression

Variables	MODEL 1			MODEL 2			MODEL 3		
	Est.	t-value	std.err	Est.	t-value	std.err	Est.	t-value	std.err
M (Monday)	0.035	0.30	0.034	0.041	1.18	0.035	-0.001	-0.03	0.035
N (trades)	0.005	43.71	0.000	0.004	39.05	0.000	-	-	-
AV (trade size)	0.018	4.62	0.004	0.024	6.03	0.000	-	-	-
MCAP (firm size)	-0.046	-1.37	0.034	-	-	-	0.211	6.33	0.033
SPR (% spread)	0.203	38.88	0.005	-	-	-	0.184	34.61	0.005
SLOPE	-0.085	-8.92	0.010	-0.152	-15.92	0.010	-0.111	-11.49	0.010
OV (order volume)	0.026	20.92	0.004	0.024	6.27	0.004	0.053	14.24	0.004
R ²	0.230			0.205			0.199		
N (firms)	108			108			108		
T (time series)	572			572			572		
F-test (no fixed effects)	12.65**			13.06**			10.61**		

PANEL B: Sub-period regression

Quarter	SLOPE		N (trades)		AV (trade size)		Model			
	β_6	t-value	β_1	t-value	β_2	t-value	R ²	F test	N	T
1999.1	-0.125	-1.81	0.016	4.65	0.076	1.65	0.379	2.75**	68	14
1999.2	-0.064	-2.16	0.014	10.89	0.025	2.17	0.281	2.56**	95	59
1999.3	-0.025	-1.03	0.012	11.57	0.061	4.21	0.400	5.92**	107	66
1999.4	-0.126	-3.94	0.013	14.86	0.029	2.60	0.323	5.49**	108	64
2000.1	-0.163	-4.70	0.012	24.69	0.036	2.16	0.308	6.35**	108	65
2000.2	-0.165	-4.35	0.012	19.41	0.023	0.98	0.314	3.77**	108	58
2000.3	-0.114	-4.19	0.009	20.24	0.007	0.67	0.296	5.50**	107	65
2000.4	-0.100	-2.77	0.008	15.84	0.033	2.35	0.225	4.00**	107	63
2001.1	-0.130	-3.62	0.003	6.33	0.005	0.33	0.275	4.48**	103	64
2001.2	-0.131	-3.51	0.002	9.45	0.031	2.14	0.266	3.72**	97	54
Average	-0.114	-3.21	0.010	13.79	0.032	1.93	0.307			

Table 15: The relationship between volatility and truncated order book

The table shows the results from the estimation of two panel regression models where we use slope measures calculated from different sub-sets of the full order book. In model 1a in Panel A, the average slope variable is calculated from the order book truncated to contain only the first 10 tick levels on the bid and ask side. In model 1b in Panel A, the slope is calculated from the order book truncated to quotes and volumes including the first 5 tick levels. All other variables are the same as the ones we use in the regression model described in table 14. The models are estimated with one-way fixed effects for the whole sample. The estimated model is,

$$|\epsilon_{i,t}| = \beta_0 M_{i,t} + \beta_1 N_{i,t} + \beta_2 AV_{i,t} + \beta_3 MCAP_{i,t} + \beta_4 SPR_{i,t} + \beta_5 OV_{i,t} + \beta_6 SLOPE_{i,t} + \sum_{j=1}^{12} \rho_{i,j} |\hat{\epsilon}_{i,t-j}| + \eta_{i,t}.$$

where $\eta_{i,t} = \nu_i + \epsilon_{i,t}$ defines the error structure with ν_i as the non-random fixed, firm specific, effects. $|\epsilon_{i,t}|$ is the absolute return adjusted for day of week effects and autocorrelation in returns. M is a dummy variable for Monday, N is the number of transactions, AV is the average trade size in shares, $MCAP$ is the natural logarithm of market capitalization values, SPR is the relative spread (quoted spread as % of the midpoint price), OV is the total number of shares in the order book (sum of all orders on bid and ask side of the order book) and $SLOPE$ is the average slope of the bid and offer side of the truncated order book. The autoregressive estimates have been excluded from the table. Panel B shows the correlation between various variables and the three slope measures calculated from the full order book as well as the two slope measures calculated from the restricted order books. ** indicates that the F-test from a test of no fixed effects is rejected at the 1 percent level.

PANEL A: Whole sample regression

Variables	MODEL 1a (+/- 10 ticks)			Model 1b (+/- 5 ticks)		
	Estimate	t-value	std.err	Estimate	t-value	std.err
M (Monday)	0.035	0.31	0.034	0.035	0.30	0.034
N (trades)	0.005	44.48	0.000	0.005	44.60	0.000
AV (trade size)	0.017	4.34	0.004	0.017	4.29	0.004
MCAP (firm size)	-0.026	-0.78	0.034	-0.020	-0.59	0.034
SPR (% spread)	0.206	39.16	0.005	0.207	39.28	0.005
SLOPE10 (+/- 10 ticks)	-0.041	-5.93	0.007	-	-	-
SLOPE5 (+/-5 ticks)	-	-	-	-0.024	-4.82	0.005
OV (ordervolume)	0.027	21.30	0.004	0.027	21.40	0.004
Adj. R ²	0.23			0.23		
N (firms)	108			108		
T (time series)	572			572		
F-test fixed effects	12.55**			12.61**		

PANEL B: Variable correlations

	SLOPE (Full order-book)	SLOPE10 (+/- 10 ticks)	SLOPE5 (+/- 5 ticks)
Trades	-0.02	-0.02	-0.02
Trade volume shares (V)	0.03	0.11	0.15
Tradesize shares (AV)	-0.08	-0.06	-0.07
MCAP	0.42	0.43	0.46
SPREAD	-0.33	-0.36	-0.38
Ordervolume shares	0.01	0.05	0.07
Slope (full)	1.00	0.82	0.71
Slope (+/- 10 ticks)	0.82	1.00	0.95
Slope (+/- 5 ticks)	0.71	0.95	1.00

Table 16: The relationship between volatility truncate order book across sub-periods

The table shows the results from estimating the two panel regression model in table 15 for sub-periods of three months. In model 1a, the average slope variable is calculated using an order book truncated to the first 10 tick levels on the bid and ask side. In model 1b, the average slope is calculated using an order book truncated to prices and volumes within the first 5 tick levels. All other variables are the same as the variables used in table 14. The models are estimated with one-way fixed effects for each sub-period. The estimated model is,

$$|\epsilon_{i,t}| = \beta_0 M_{i,t} + \beta_1 N_{i,t} + \beta_2 AV_{i,t} + \beta_3 MCAP_{i,t} + \beta_4 SPR_{i,t} + \beta_5 OV_{i,t} + \beta_6 SLOPE_{i,t} + \sum_{j=1}^{12} \rho_{i,j} |\hat{\epsilon}_{i,t-j}| + \eta_{i,t}.$$

where $\eta_{i,t} = \nu_i + \epsilon_{i,t}$ defines the error structure with ν_i as the non-random fixed, firm-specific, effects. $|\epsilon_{i,t}|$ is the absolute return adjusted for day of week effects and autocorrelation in returns. M is a dummy variable for Monday, N is the number of transactions, AV is the average trade size in shares, $MCAP$ is the market capitalization, SPR is the relative spread (quoted spread as % of the midpoint price), OV is the total number of shares in the order book (sum of all orders on bid and ask side of the order book) and $SLOPE$ is the average slope of the bid and offer side of the restricted order book. The table shows the parameter estimates for 2 variations of model 1 in table 14 with the associated t-value, std.error of the estimate, the model R-squared. ** indicates that the F-test for no fixed effects is rejected at the 1 percent level.

Quarter	Model 1a (+/- 10 ticks)					Model 1b (+/- 5 ticks)				
	β_6	t-value	std.err	model R ²	F-value	β_6	t-value	std.err	model R ²	F-value
1999.1	-0.012	-0.22	0.056	0.376	2.73**	-0.021	-0.44	0.047	0.376	2.74**
1999.2	-0.030	-1.20	0.025	0.280	2.50**	-0.018	-0.90	0.020	0.280	2.50**
1999.3	0.009	0.44	0.020	0.400	5.92**	0.024	1.48	0.016	0.400	5.94**
1999.4	-0.063	-2.61	0.024	0.321	5.45**	-0.044	-2.44	0.018	0.321	5.47**
2000.1	-0.075	-3.36	0.022	0.307	6.27**	-0.052	-3.24	0.016	0.307	6.26**
2000.2	-0.084	-3.42	0.025	0.313	3.71**	-0.063	-3.47	0.018	0.313	3.70**
2000.3	-0.039	-2.25	0.017	0.295	5.35**	-0.016	-1.29	0.013	0.294	5.35**
2000.4	-0.055	-2.48	0.022	0.225	3.96**	-0.035	-2.22	0.016	0.225	3.96**
2001.1	-0.027	-1.27	0.021	0.274	4.36**	-0.013	-0.88	0.015	0.274	4.36**
2001.2	-0.067	-2.91	0.023	0.266	3.74**	-0.043	-2.52	0.017	0.265	3.73**
Average	-0.044	-1.93	0.026	0.306		-0.028	-1.59	0.02	0.306	

Table 17: The relationship between the number of trades and the order book slope

The table shows the results when we estimate the relationship between different slope measures and the number of trades. The model is estimated as a one-way fixed effects model. The estimated model is,

$$N_{i,t} = \beta_0 M_{i,t} + \beta_1 AV_{i,t} + \beta_2 MCAP_{i,t} + \beta_3 SPR_{i,t} + \beta_4 SLOPE_{i,t} + \beta_5 OV_{i,t} + \eta_{i,t}.$$

where $\eta_{i,t} = \nu_i + \varepsilon_{i,t}$ defines the error structure with ν_i as the non-random fixed, firm specific, effects. The dependent variable, N is the number of transactions, M is a dummy variable for Monday, AV is the average trade size in shares, $MCAP$ is the natural logarithm of market capitalization values, SPR is the relative spread (quoted spread in % of the midpoint price), OV is the total number of shares in the order book (sum of all orders on bid and ask side of the order book) and $SLOPE$ is the average slope of the bid and offer side from the full order book, $SLOPE10$ is the slope calculated from the order book truncated to +/- 10 ticks, $SLOPE5$ is the slope calculated from the order book truncated to +/- 5 ticks. Panel A shows the estimation results from the whole sample, while panel B shows the estimation results from sub-periods. ** indicate that the F-test for fixed effects is significant at the 1 percent level.

PANEL A: Whole sample regression

Variables	MODEL 1			MODEL 2			MODEL 3		
	Est.	t-value	std.err	Est.	t-value	std.err	Est.	t-value	std.err
M (Monday)	-6.62	-4.72	1.40	-6.45	-4.58	1.41	-6.23	-4.42	1.41
AV (trade size)	1.10	6.81	0.16	0.92	5.66	0.16	0.87	5.38	0.16
MCAP (firm size)	59.57	43.68	1.36	61.51	44.89	1.37	60.22	43.80	1.37
SPR (% spread)	-2.47	-11.59	0.21	-1.55	-7.21	0.21	-1.08	-5.01	0.22
SLOPE (full book)	-8.97	-23.12	0.39	-	-	-	-	-	-
SLOPE10 (+/- 10 ticks)	-	-	-	-0.41	-1.45	0.28	-	-	-
SLOPE5 (+/- 5 ticks)	-	-	-	-	-	-	1.81	8.64	0.21
OV (order-book volume)	4.98	32.83	0.15	5.09	33.44	0.15	5.11	33.55	0.15
R ²	0.423			0.417			0.418		
N (firms)	108			108			108		
T (time series)	572			572			572		
F-test (no fixed effects)	180.8**			209.6**			203.5**		

PANEL B: Sub-period regression

Quarter	Full order book				+/- 10 ticks				+/- 5 ticks			
	β_4	t-val.	R ²	F-val.	β_4	t-val.	R ²	F-val.	β_4	t-val.	R ²	F-val.
1999.1	-0.37	-0.46	0.84	18.3**	-0.351	-0.53	0.84	18.6**	-0.008	-0.01	0.84	18.4**
1999.2	-1.64	-4.34	0.77	44.6**	-0.858	-2.73	0.77	44.9**	0.067	0.27	0.77	44.3**
1999.3	-1.39	-3.97	0.83	50.3**	-0.611	-2.08	0.83	48.9**	0.130	0.56	0.83	46.3**
1999.4	-1.51	-2.86	0.72	61.7**	0.704	1.76	0.72	63.4**	1.239	4.20	0.72	61.8**
2000.1	-6.39	-6.56	0.59	50.5**	-1.406	-2.24	0.59	57.1**	0.031	0.07	0.59	57.0**
2000.2	-2.03	-2.32	0.74	42.2**	-0.844	-1.48	0.73	45.5**	-0.403	-0.96	0.73	45.1**
2000.3	-2.44	-2.97	0.72	48.0**	-0.585	-1.11	0.71	53.7**	-0.024	-0.06	0.71	53.2**
2000.4	-2.08	-2.01	0.70	85.5**	0.305	0.48	0.70	92.7**	1.297	2.84	0.70	89.9**
2001.1	-0.46	-0.43	0.85	155.2**	1.334	2.11	0.85	162.1**	1.440	3.19	0.85	160.1**
2001.2	-1.21	-0.53	0.69	82.2**	2.864	2.03	0.69	85.9**	3.754	3.60	0.69	83.8**
Average	-1.95	-2.65	0.74		0.06	-0.38	0.74		0.75	1.37	0.74	

Table 18: Spread in analyst forecasts and slope

Panel A of the table shows the results from a monthly cross-sectional time series regression where we relate our slope measure, SLOPE, to the spread in analyst forecasts, FORECAST, the natural logarithm of the number of analysts following the firm, ln(analysts), and the natural logarithm of market capitalization values, MCAP. The spread in analyst forecasts is calculated as the standard deviation of the estimates for the month as a percent of the mean estimate for that month. This is a measure of the relative dispersion of estimates around the mean estimate. A small dispersion imply a tight consensus (or, much agreement among the analysts.) A large dispersion indicates that analysts disagree on the company's future. Panel B shows Pearson's correlation coefficients between the different variables.

PANEL A: Analyst forecast regression

	SLOPE			SLOPE		
	Estimate	Std.err	p-value	Estimate	Std.err	p-value
Intercept	12.328	2.037	<.0.01	4.431	0.486	<.0.01
MCAP	-0.419	0.105	<.0.01	-	-	-
ln(analysts)	-0.741	0.214	<.0.01	-1.081	0.197	<.0.01
FORECAST	-0.008	0.003	<.0.01	-0.008	0.003	<.0.01
R-sq.	0.58			0.58		
F-test	24.79			24.55		
Time series obs.	65			29		
Cross-sections	29			65		

PANEL B: Variable correlations

	SLOPE	ln(analysts)	FORECAST	volatility
ln(analysts)	0.26			
FORECAST	-0.26	-0.05		
volatility	-0.50	-0.18	0.19	
MCAP	0.25	0.71	-0.11	-0.13

Table 19: Volatility/slope regression with balanced data sample

The table shows the estimation results of a cross-sectional time series model for the relationship between different slope measures and the daily volatility when using a balanced sample. The models are similar to those estimated (for the unbalanced sample) in table 14 (Model 1) and table 15. The estimated model is,

$$|\epsilon_{i,t}| = \beta_0 M_{i,t} + \beta_1 N_{i,t} + \beta_2 AV_{i,t} + \beta_3 MCAP_{i,t} + \beta_4 SPR_{i,t} + \beta_5 OV_{i,t} + \beta_6 SLOPE_{i,t} + \sum_{j=1}^{12} \rho_{i,j} |\hat{\epsilon}_{i,t-j}| + \eta_{i,t}.$$

where $\eta_{i,t} = \nu_i + \epsilon_{i,t}$ defines the error structure with ν_i as the non-random fixed, firm-specific, effects. $|\epsilon_{i,t}|$ is the absolute daily return, N is the number of transactions, M is a dummy variable for Monday, AV is the average trade size in shares, $MCAP$ is the natural logarithm of market capitalization values, SPR is the relative spread (quoted spread as % of the midpoint price), OV is the total number of shares in the order book (sum of all orders on bid and ask side of the order book) and $SLOPE$ is the average slope of the bid and offer side from the full order book, $SLOPE10$ is the slope calculated from the order book truncated to +/- 10 ticks, $SLOPE5$ is the slope calculated from the order book truncated to +/- 5 ticks. $|\hat{\epsilon}_{i,t-j}|$ are lagged absolute returns to take into account autocorrelations.

PANEL A: Volatility/slope regressions for balanced sample

Variables	Volatility/slope (full book)			Volatility/slope (+/- 10 ticks)			Volatility/slope (+/- 5 ticks)		
	Est.	t-value	std.err	Est.	t-value	std.err	Est.	t-value	std.err
M (monday dummy)	-0.083	-1.5	0.057	-0.081	-1.4	0.057	-0.078	-1.4	0.057
N (trades)	0.004	34.6	0.000	0.004	35.6	0.000	0.004	35.7	0.000
AV (avg. trade size)	0.017	2.5	0.007	0.014	2.0	0.007	0.013	1.9	0.007
MCAP (market cap.)	-0.015	-2.7	0.006	-0.009	-1.6	0.006	-0.008	-1.4	0.006
SPR (% quoted spread)	0.345	16.3	0.021	0.358	16.9	0.021	0.351	16.6	0.021
SLOPE (full book)	-0.008	-10.0	0.001	-	-	-	-	-	-
SLOPE10 (+/- 10 ticks)	-	-	-	-0.007	-10.6	0.001	-	-	-
SLOPE5 (+/-5 ticks)	-	-	-	-	-	-	-0.005	-9.6	0.001
OV (order book volume)	0.011	3.1	0.004	0.010	3.0	0.004	0.011	3.0	0.004
R ²	37.6%			37.6%			37.5%		
N (cross section)	25			25			25		
T (time series)	572			572			572		
F-test (no fixed effects)	41.6**			41.2**			40.9**		

Table 20: Volume/slope regression for balanced sample

The table shows the results from estimating the relationship between the slope measures based on different truncations of the order book and the number of trades using a balanced sample. The models are similar to those estimated for the full (unbalanced) sample in table 17. The estimated model in panel B is,

$$N_{i,t} = \beta_0 M_{i,t} + \beta_1 AV_{i,t} + \beta_2 MCAP_{i,t} + \beta_3 SPR_{i,t} + \beta_4 SLOPE_{i,t} + \beta_5 OV_{i,t} + \eta_{i,t}.$$

where $\eta_{i,t} = \nu_i + \varepsilon_{i,t}$ defines the error structure with ν_i as the non-random fixed, firm-specific, effects. N is the number of transactions, M is a dummy variable for Monday, AV is the average trade size in shares, $MCAP$ is the natural logarithm of market capitalization values, SPR is the relative spread (quoted spread as % of the midpoint price), OV is the total number of shares in the order book (sum of all orders on bid and ask side of the order book) and $SLOPE$ is the average slope of the bid and offer side from the full order book, $SLOPE10$ is the slope calculated from the order book truncated to +/- 10 ticks, $SLOPE5$ is the slope calculated from the order book truncated to +/- 5 ticks.

PANEL B: Volume/slope regressions for balanced sample

	Trades/slope (full book)			Trades/slope (+/- 10 ticks)			Trades/slope (+/- 5 ticks)		
	Est.	t-value	std.err	Est.	t-value	std.err	Est.	t-value	std.err
M (monday dummy)	-15.05	-3.6	4.224	-14.01	-3.3	4.227	-13.98	-3.3	4.216
AV (avg. trade size)	-0.50	-0.9	0.514	-0.49	-0.9	0.514	-0.34	-0.7	0.513
MCAP (market cap.)	8.10	19.7	0.411	7.41	17.8	0.417	6.89	16.4	0.420
SPR (% quoted spread)	-32.39	-21.0	1.543	-32.47	-21.0	1.545	-32.07	-20.8	1.540
SLOPE (full book)	-0.50	-8.1	0.062	-	-	-	-	-	-
SLOPE10 (+/- 10 ticks)	-	-	-	0.33	6.7	0.049	-	-	-
SLOPE5 (+/- 5 ticks)	-	-	-	-	-	-	0.44	11.3	0.039
OV (order book volume)	3.33	12.8	0.262	3.43	13.1	0.262	3.45	13.2	0.261
R ²	33%			33%			34%		
N cross section	25			25			25		
Time series	572			572			572		
F-test (no fixed effects)	233.2**			224.0**			211.9**		

Table 21: Estimation with different slope measures

The table shows the estimated relationship between the slope of the order book and volatility for various slope measures calculated from the full order book (+/- 100 ticks) and order books truncated at +/- 10 ticks and +/- 5 ticks. SLOPE is the slope measure we applied in the panel regression in table 14. RAW SLOPE is the slope calculated with the raw share volume at each tick. NOSH SLOPE is the slope when we normalize the share volume in the order book relative to the number of outstanding shares of the companies. OV SLOPE is the slope when we normalize the share volume in the order book relative to the total market wide share volume in all orders coming into the market on that day. Finally, NORM SLOPE is the slope when the volume at each tick level is the fraction of total shares in the order book at that snapshot for that company.

	Whole sample					
	Full order book		+/- 10 ticks		+/- 5 ticks	
	Est.	t-value	Est.	t-value	Est.	t-value
SLOPE (%)	-0.085	-8.92	-0.041	-5.9	-0.024	-4.8
RAW SLOPE (mill.)	-0.203	-9.9	-0.114	-8.0	-0.083	-8.1
NOSH SLOPE	-3.886	-8.4	-3.475	-9.1	-3.757	-11.1
OV SLOPE	-5.852	-12.6	-1.630	-7.2	-1.824	-8.5
NORM SLOPE	-0.010	-14.3	-0.003	-6.2	-0.002	-4.6

	February 1999 - March 2000 (13 months)					
	Full order book		+/- 10 ticks		+/- 5 ticks	
	Est.	t-value	Est.	t-value	Est.	t-value
SLOPE (%)	-0.084	-6.0	-0.049	-4.6	-0.031	-3.8
RAW SLOPE (mill.)	-0.216	-6.9	-0.099	-5.2	-0.068	-5.1
NOSH SLOPE	-5.091	-7.1	-5.418	-8.5	-5.422	-9.3
OV SLOPE	-5.636	-8.1	-4.103	-8.1	-3.442	-8.1
NORM SLOPE	-0.010	-9.0	-0.004	-5.1	-0.002	-4.0

	April 2000 - June 2001 (14 months)					
	Full order book		+/- 10 ticks		+/- 5 ticks	
	Est.	t-value	Est.	t-value	Est.	t-value
SLOPE (%)	-0.114	-7.6	-0.045	-4.9	-0.029	-4.4
RAW SLOPE (mill.)	-0.201	-7.1	-0.159	-7.2	-0.133	-7.9
NOSH SLOPE	-4.520	-6.9	-3.478	-6.9	-3.886	-8.9
OV SLOPE	-5.072	-7.3	-0.770	-2.9	-1.109	-4.3
NORM SLOPE	-0.010	-11.0	-0.003	-4.6	-0.001	-3.2

Table 22: Alternative slope measures and the effect of bid and ask slope on volatility and trades
 Panel A of the table shows slope estimates from the volatility/slope regressions (similar to the one in table 14) when the slopes of the bid and ask side are examined separately, for different order book truncations in the balanced and unbalanced sample. Similarly, Panel B shows slope estimates from the trades/slope regressions when the slope of the bid and ask side are examined separately. In both panels SLOPE is the case when we use the average of the slope of the bid and ask side examined earlier in the paper.

PANEL A: Volatility-slope regressions									
	Volatility/slope (full book)			Volatility/slope (+/- 10 ticks)			Volatility/slope (+/- 5 ticks)		
	Estimate	t-value	std.err	Estimate	t-value	std.err	Estimate	t-value	std.err
Full sample:									
SLOPE	-0.085	-8.9	0.010	-0.041	-5.9	0.007	-0.024	-4.8	0.005
-Ask slope	0.018	1.9	0.010	-0.004	-0.6	0.006	-0.010	-2.2	0.004
-Bid slope	-0.101	-14.5	0.007	-0.055	-9.4	0.006	-0.030	-6.4	0.005
Balanced sample:									
SLOPE	-0.104	-6.6	0.016	-0.060	-5.0	0.012	-0.034	-3.9	0.009
-Ask slope	0.023	1.5	0.016	-0.001	-0.1	0.011	-0.012	-1.6	0.008
-Bid slope	-0.104	-9.8	0.011	-0.072	-7.7	0.009	-0.040	-5.3	0.008

PANEL B: Trades-slope regressions									
	Trades/slope (full book)			Trades/slope (+/- 10 ticks)			Trades/slope (+/- 5 ticks)		
	Estimate	t-value	std.err	Estimate	t-value	std.err	Estimate	t-value	std.err
Full sample:									
SLOPE	-8.97	-23.1	0.388	-0.41	-1.5	0.284	1.81	8.6	0.209
-Ask slope	-3.31	-8.4	0.394	0.96	3.7	0.256	1.58	8.7	0.183
-Bid slope	-7.84	-27.7	0.283	-1.42	-5.9	0.239	1.28	6.7	0.191
Balanced sample:									
SLOPE	-22.84	-20.9	1.092	-7.03	-8.2	0.860	-0.90	-1.4	0.630
-Ask slope	-10.20	-9.1	1.125	-2.50	-3.2	0.794	-0.12	-0.2	0.559
-Bid slope	-16.21	-22.1	0.733	-6.74	-10.1	0.670	-1.25	-2.3	0.549