Throttling hyperactive robots - Order to Trade Ratios at the Oslo Stock Exchange

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Abstract

We investigate the effects on market quality from the introduction of a fee on excessive order to trade ratios (OTR) at the Oslo Stock Exchange (OSE). Traders reacted to the regulation, increasing the size of the average order, reducing order to trade ratios. Market quality, measured with such common measures as depth, spreads, and realized volatility, remained largely unchanged. This differs sharply from the experience in other market places, such as Italy and Canada, where similar regulatory changes were accompanied by worsening liquidity. The unchanged market quality at the OSE is likely due to a better design of the regulation, which is designed to encourage liquidity supply.

Algorithmic trading in general, and High Frequency Trading (HFT) in particular, is the aspect of current financial markets that raises most concerns among market participants and regulators. For example, the European Parliament headlined their press release about the updated MiFID regulation *"Deal to regulate financial markets and products and curb high-frequency trading"*.[1] The majority of market commentators seems to agree that financial markets have become more competitive, and that trading costs have gone down as a consequence of the increased computerization of the trading process. However, there are concerns that the increased fragmentation of equity trading, where liquidity is mainly provided by computerized traders, has lead to a fragile system where the high speed traders have an unfair advantage. As the title of the above mentioned press release indicates, there is a perceived need to "do something" about HFT. This need is expressed by politicians and regulators as well as buy-side market participants.

In this paper we look specifically at one regulation argued by many market watchers to be the preferred way of curbing high frequency trading – an introduction of a fee on excessive Order to Trade Ratios (OTRs). This is a fee that penalizes market participants that enters an excessive number of orders into the exchange's order book *without* resulting in a sufficient number of trades.[2]

Such a fee can be justified by standard economic arguments. High frequency traders will in the course of their trading day continuously place, update, and withdraw orders in the exchange's limit order book. Certain strategies submit order instructions at micro- or nanosecond intervals, without intention of execution. The most extreme strategies makes the order visible in the order book for such a short time that only other computers can react to it. The presence of such fleeting trading opportunities makes it necessary for other market participants to make large IT investments to keep up with this information in real time. The same is true for stock exchanges, which need to invest in improved infrastructure and computing power. There may be other costs involved, such as costs associated with monitoring and limited attention.[3] These costs represent an economic externality for all but the fastest traders. Standard theory

[1]Press release - European Parliament - Economic and monetary affairs - 14-01-2014 - 23:47.

[2]Other common terminology for such ratios are "Message to Trade Ratio" and "Order to Executed Ratio."

[3]The need to spend more time "watching the screen" means less time for analyzing other news, or watching other stocks. See for example Corwin and Cougenour (2008).

of taxation tells us that externalities should be paid for by those imposing negative externalities on others.

From an exchange's point of view, it wants to identify the traders which use the exchange's system excessively without any intention of providing actionable quotes. The chosen way to measure this is to calculate the ratio (Order to Trade Ratio - OTR) of the number of orders (submissions, updates and withdrawals in the exchange's limit order book) to the number of trades executed. Traders with a very high OTRs are argued to be the ones imposing a negative externality on other traders, and should be charged accordingly.

We specifically look at the introduction of an OTR fee by the Oslo Stock Exchange (OSE) in 2012. The fee was imposed on traders whose OTR exceeded 70, and only applies to trading at the OSE. There are a large number of alternative market places, both lit (other limit order books), and dark (OTC/Dark Pools), where OSE listed stocks can be traded. Since the OTR calculation by the OSE only accounts for the orders and trades at the OSE, this may cause HFT traders to change their strategies to trade less at the OSE, or just stop trading at the OSE altogether. We ask whether market quality is affected by the introduction of the OTR fee. We do so by first studying what happens to market quality at the OSE, before analyzing the alternative market venues where OSE-listed firms are traded. We thus analyze the impact on market quality for the whole market for OSE listed firms.

For the OSE, we find that market participants react to the new fee by reducing the number of messages to the order book; the average OTR falls and order sizes increase. We however find no evidence of any significant effects on market quality. We construct common measures of market quality such as spreads (quoted, effective, and realized), estimates of transaction costs, and realized volatility. None of these metrics indicate a worsening of market quality at the OSE.

We also look at trading in alternative market places. We first look for evidence of traders moving away from Oslo. While there is a reduction in turnover at the OSE, this seems due to a general decline in trading activity over the sample period. When we look at OSE's *market share* relative to its competitors around the introduction of the fee, we find no evidence that OSE's market share falls. We look at alternative European Limit Order Markets, such as Stockholm (Nasdaq OMX), Chi-X and the like, and find that the OSE maintains its market share relative to these. Our study also adds to the literature by incorporating data from unlit (OTC/Dark Pool) trading in the analysis. We find no signs of additional "leakage" to OTC markets linked to the introduction of the OTR.

We also evaluate changes in market quality for the different alternative market places, and find no significant effects. Our results remain the same whether we use simple pre- and post-intervention comparisons or a more thorough Difference-in-Difference (DiD) approach in order to estimate a causal effect of the introduction of the regulation.

Overall, we find no evidence that the market quality worsens at the OSE after the introduction of the OTR fee. This finding is an important contribution to the literature, as it is a very different outcome from other markets where similar schemes have been introduced. Studies on Italy (Friederich and Payne, 2015) and Canada (Malinova, Park, and Riordan, 2013) find a significant deterioration of market quality around the introduction of fees intended to curb HFT activity. The comparison with the Italian scheme is the most pertinent. The main difference between the OSE scheme and the Italian one is that the OSE is not including *all* orders in the basis for their calculation of a monthly OTR ratio. For example, it does not include price-improving orders, or orders that rests for more than a second in the limit order book. Italy's OTR tax has more a flavor of a blanket transaction cost. It is calculated on a daily basis, and all orders count. The OSE scheme thus has more carrots and less sticks than the Italian one, and seems more successful in achieving its aim. In fact, no trader at the OSE has yet paid the fee.

The important takeaway from our research is pointing out the complexity of imposing regulatory changes on market places. Even minor differences in regulatory design may lead to significant different outcomes with respect to market participants' responses, and the overall effect on market quality.

The structure of the remainder of the paper is a follows. Section 1 provides a more detailed discussion of the theoretical aspects behind the a fee on Order to Trade Ratios. Section 2 gives some background information on the Oslo Stock Exchange, and details our data sources. Section 3 looks the details of the announced OTR fee scheme, and give some descriptive background for evaluating the effect of the OTR. We split the discussion of the results in two. First, in section 4, we examine how the traders *react*. Then, in section 5, we examine the impact on *market quality*. Section 6 concludes.

1 Background

The backdrop of this research is the technological evolution of trading in financial markets in the last few decades. We can think of this as a two step process. In the first step, trading went from a floor based exchange, where much of the trading was done physically on the exchange, to a centralized electronic limit order system. In the beginning, the limit order book coexisted with the physical market place, but the traders soon left the exchange. Once the traders were submitting the orders from their own terminals, they found they could also automate this process.

The second step was the *fragmentation* of trading. This step was driven both by technological innovations and the regulatory push towards competition between market places. In the US, Reg NMS, and in Europe, MiFID, both resulted in increased fragmentation of the trading process, away from the traditional exchanges, to other competing exchanges, alternative market places such as MTFs and ATSs (both lit and dark) and the OTC market.

The end result of this technological evolution is a world of interconnected financial markets, with trading of the most active stocks split across numerous market places, and where *speed* has become a central competitive factor in equity trading. Such events as the "Flash Crash" has however lead to worries about the fragility of the system. The new market environment has come under severe criticism in the popular financial press, particularly after the publication of "Flash Boys" by Michael Lewis, with claims of a "unlevel playing field" where the fastest traders are perceived to have an “unfair” advantage.

The resulting public debate has lead to calls for more regulation of the High Frequency segment of trading. Suggested regulatory incentives include transaction taxes (Tobin taxes), minimum resting times for orders, increased tick sizes, call auctions, market making obligations, circuit breakers, and fees on high order to trade ratios.[4] Few of these proposals are directly linked to an identified inefficiency or malfunction of the market. The exception is order to trade ratios, which, as we did in the introduction, may be argued to be a reasonable taxation of an externality. The same point was made by Jones (2013), who argued that *“If excessive messages imposes negative externalities on others, fees are appropriate. But a message tax may act like a transaction tax, reducing share prices, increasing volatility, and worsening liquidity.”*

In this paper we evaluate the effects of one specific variant of a such a tax on high Order to Trade Ratios, designed by the Oslo Stock Exchange. Like most empirical evaluations of such policy interventions, we study changes to the trading process around the introduction of the fee, particularly what happens to the *quality* of the trading process. To frame the analysis, let us consider possible reactions of market participants.

A natural way to structure the discussion is to ask is how the OTR potentially affects the behaviour of different *types* of traders. If a high message activity is required to provide services most exchanges view as benign (e.g. market making) one would expect liquidity provision to be hurt if these traders respond to the OTR by reducing their activity. On the other hand, if the OTR increase the cost for the most hyperactive traders, those that engage in more speculative trading strategies such as “spoofing”, “quote stuffing” and similar strategies,[5] we may expect liquidity to be improved if these traders reduce their activity. The disappearance of such traders may stabilize the quotes and depths and reduce adverse selection. Furthermore, the operational stability of the exchanges systems may improve.

Thus, depending on the design of the OTR one may generate very different implications and responses for different types of traders. The academic literature on algorithmic trading points to the presence of both types of traders. For example, Menkveld (2013) and Hagströmer and Nordén (2013) shows that a majority of HFT traders are running market making strategies. On the other hand, Biais, Foucault, and Moinas (2015), argues that the speed of the high frequency traders are giving them an exploitable informational advantage, which may be excerburated by quotes that are not “bona fide.” We thus do not have an unambiguous theoretical prediction of how traders will react to an OTR. For our investigation, the net effect will depend on the composition of traders at the OSE.

Similar fees related to the difference between the number of messages to the exchange’s systems, and the number of transactions, for an individual trader, have been introduced in other market places. We will relate our findings to two academic studies of such introductions.

First, the case of Italy, which introduced an OTR fee on 2 April 2012. This was the object of an study by Friederich and Payne (2015), from which we gather the details of the Italian scheme. The Italian ratio is calculated on a *daily* basis. For ratios below 100:1 there is no fee.

[4] See The (UK) Government Office for Science (2012) for a survey of the proposals.

[5] See e.g. Biais and Foucault (2014) for an accessible introduction to such terms.

For ratios between 100:1 and 500:1 the charge is €0.01. If the ratio is even higher, between 500:1 and 1000:1, the charge is €0.02, and for ratios above 1000:1 the charge is €0.025. The fee is capped at €1,000 per firm-day. Friederich and Payne (2015) find clear negative effects on liquidity linked to the tax, and concludes: *"We find a clear picture of reduced liquidity supply, with quoted depth affected across the board and dramatically so for large stocks, whether at the best quotes or beyond. The price impact of trades increases significantly and more so for smaller stocks. HF firms may be more significant contributors to depth than previously thought."*

Second, the case of Canada, studied in Malinova et al. (2013). Canada introduced a fee with similar implications as an OTR ratio. Canadian traders are paying the exchange a fee for surveillance services. This fee was initially calculated on the basis of number of trades. The fee calculation was in 2012 changed to be based on both trades and orders (messages) into the limit order book. At the time of the introduction of the measure in Canada it was unclear how the calculation actually was to be done, with corresponding uncertainty from market participants about the fee they would end up paying at the end of the month.

Malinova et al. (2013) concludes that *"The decline in activity was accompanied by an immediate, sharp increase in the market-wide bid-ask spread."*, and that *"The per-message fee in Canada appears to have strongly affected the "good," liquidity-providing HFTs, and subsequently significantly intra-day returns of retail investors dropped."*

Both studies thus finds strongly negative effect on market *quality* linked to the introduction of fees on high OTR ratios. Looking ahead to what we will show in our results for Norway, we find no such negative effects, and will investigate what can lead to such differences in outcomes.

2 Market place and data

2.1 The Oslo Stock Exchange

Norway is a member of the European Economic Area (EEA) and its equity market is among the 30 largest world equity markets by market capitalization. Notable Norwegian listings include Statoil, Telenor, and Norsk Hydro. The OSE is the only regulated marketplace for securities trading in Norway. Unlike the other Scandinavian exchanges, the OSE has remained relatively independent, but has been in strategic partnership with the London Stock Exchange (LSE) since March 2009.

Since January 1999 it has operated as a fully computerized limit order book.[6] 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.[7] The trading day at the OSE comprises three sessions: an opening call period, a continuous trading period, and a closing call period. There might also be call auctions in the continuous trading period for any

[6] For further background on the trading at the OSE and the companies on the exchange, see Bøhren and Ødegaard (2001), Næs and Skjeltorp (2006), and Næs, Skjeltorp, and Ødegaard (2011)

[7] The tick size is determined by the price level of the stock. The current regime went into effect in 2010, and involves the following schedule: 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.

security if triggered by price monitoring or to restart trading after a trading halt. During the auction call periods orders may be inserted, deleted and modified, but no executions will occur before at the end - the UN-crossing. The UN-crossing takes place at a random time within a 30 second interval. For the opening and closing calls, the sequence of the securities will be random. The orders are matched in accordance with their priority which is price-visibility-time for round-lot orders.[8] In September 2012 the continuous trading session was changed from 09:00 to 17:20 to 09:00 to 16:20.

2.2 Migration of trading to alternative market places

Post MiFID, the trading of stocks with a main listing at the OSE has become increasingly fragmented across various alternative market places. Let us first look at the market places with pre-trade transparency, i.e. limit order books. In the period, the largest European competitors are the Stockholm Stock Exchange (Nasdaq OMX Nordic), Chi-X, Bats, and Turquoise.[9] Due to the strategic partnership with LSE, there is little direct competition between LSE and OSE in stocks with a main listing at the OSE. Some of the largest stocks at the OSE are also traded overseas, such as New York. In this paper we will not consider trading outside of Europe, as this tend to be in other time-zones, with little overlap in opening hours.[10]

In addition to these market places with pre-trade transparency there are also numerous alternative market places, where transparency is only ex post. The common terms for such trading is OTC or Dark Pool trading. These market places are required to report their trades to a MiFID compliant reporting facility. We will use all trades reported through a major reporting facility, Markit BOAT, to proxy for OTC trading in our sample of OSE listed stocks.

Not all stocks listed at the OSE are traded outside of Oslo. Only the larger companies on the exchange are interesting for the competing market places. The OSE lists between 200 and 300 stocks, of which only about 50 has much trading outside the OSE. The main interest centers around constituents of the OSE index OBX, a stock market index containing the 25 most actively traded stocks.

We use data from Thomson Reuters to give some evidence on the extent of fragmentation. Thomson Reuters provides an Europe-wide summary of trading through their "XBO" identifier. This is a summary of the trades in the same stock across public limit order markets. In figure 1 we use these data to illustrate the evolution of fragmentation of trading in stocks with a main listing at the OSE. The figure show the proportions of the total trading volume executed in the various markets. The proportion of trading at the OSE has been falling throughout the post-MiFID period.

[8]With the OSE's migration to TradElect in partnership with the London Stock Exchange Group in April 2010 the OSE offers its members the opportunity to preferentially trade with themselves before trading with other participants when there is more than one order at a given price level. This means that orders submitted for a trader configured to use Own Order Preferencing will execute in the following order: Price-Counterparty-Visibility-Time.

[9]Some of these exchanges have since merged.

[10]Between 2009 and September of 2012 there was an overlap of one hour between trading in Oslo and New York, which disappeared when Oslo moved their closing time from 17:20 to 16:20 local time. In our empirical work we only look at trading when the OSE is open.

[Figure 1 about here.]

2.3 Data Sources

We rely on a number of datasets to analyze the trading in stocks with a main listing at the OSE. First, we use a dataset from the order book at the OSE provided by the market surveillance department at the exchange. This dataset provides information about all trades and orders at the exchange. The dataset also includes various additional information about each order such as order cancellations, order modifications (volume and/or price updates), hidden orders, etc. which makes it possible to construct Order to Trade Ratios.

Second, we use the ThomsonReuters Tick History Database, containing information for all European market places where stocks with a main listing at the OSE are traded. While this dataset also contains orders, trades and the state of the order book, there is less additional information compared to the OSE data. For lit market places (markets with pre-trade transparency) the dataset includes the ten best levels of the bid and ask side of the limit order book. However, the data does not allow us to construct approximations of Order to Trade Ratios, as there is not a complete record of order messages to the different exchanges. The Thompson-Reuters data also includes information about OTC trading of OSE shares, through inclusion of trades reported through Markit BOAT (a MiFID-compliant trade reporting facility).

Finally, we have data from the Oslo Stock Exchange Information Service (OBI) which provide daily price observations together with information about corporate events, corporate announcements, and accounts.

In the analysis we include data for equities with a main listing at the OSE. We only use common equity (not ETFs and other equity-like instruments). In 2012, there was a total of 243 equities listed. We remove the least liquid stocks by only including stocks with a minimum of 100 trading days in a year, which reduces the sample to 119 stocks.

2.4 Market quality measures

We estimate a number of standard empirical measures of trading quality.

Firstly, we calculate market *Depth* as the the sum of trading interest at the best bid and ask, in NOK. In the analysis we use the daily average of the depth at each time with an update of the order book.

We estimate a number of spread measures, calculated using the full trading record. The *relative spread* is the difference between the current best ask and best bid, divided by the average of these. We use all times with an update of the state of the limit order book. For each such update we calculate the relative spread using the currently best bid and best offer. Our estimate of that day's relative spread is the sample average of these relative spreads during the day.

The *Effective Spread* relates transaction prices to the spread when the order is submitted. We calculate the effective proportional spread as $q_{jt}(p_{jt} - m_{jt})/m_{jt}$, where q_{jt} is an indicator variable that equals $+1$ for buyer-initiated trades and -1 for seller-initiated trades, p_{jt} is the trade price, and m_{jt} is the quote midpoint prevailing at the time of the trade. To determine whether the order is buyer or seller initiated we compare the price to the midpoint. If the price is above the midpoint, we classify it as buyer initiated. Otherwise, we classify it as seller initiated. In the analysis we use the daily average of effective spreads for all trades during the day.

The *Realized Spread* is calculated as $q_{jt}(p_{jt} - m_{j,t+5\text{min}})/m_{jt}$, where p_{jt} is the trade price, q_{jt} is the same buy/sell indicator as that used for the effective spread, m_{jt} is the prevailing midpoint, and $m_{j,t+5\text{min}}$ is the quote midpoint 5 minutes after the t'th trade. Similarly to the effective spread, we calculate the daily average of realized spreads for all trades during the day.

To measure the variability of prices, we use the *Realized Volatility*, estimated as the second (uncentered) sample moment of the return process over a fixed interval of length 10 minutes, scaled by the number of observations n. We calculate the realized volatility on a daily basis.

Finally, we calculate a rougher measure of trading costs, the *Roll* measure. This is an estimate of trading cost that uses the autocovariance induced by bid/ask bounce to estimate the size of the implicit spread between bid and ask prices. Our motivation for the inclusion of the Roll measure is that it can be calculated in situations where we do not have an order book, just prices. This is the case for the OTC data, which is only reported post-trade. We calculate the Roll measure based on the returns r_t calculated from transaction-to-transaction prices during a day. The Roll spread estimator is $\hat{s} = 2\sqrt{-\text{cov}\,(r_t, r_{t+1})}$. We only use observations where the autocovariance is negative.

In table 1 we describe these measures using data for the period before the introduction of the regulation, 2010–2011. The measures are averages of daily estimates, both for the whole market, and for size sorted portfolios.

[Table 1 about here.]

3 Introduction of the "Order to Executed Order Ratio" at the OSE

3.1 Specifics of the regulation

The introduction of the fee on excessive Order to Executed Order Ratios (OEOR) was announced by the exchange on May 25, 2012. The announcement justified the introduction on efficiency grounds, arguing that excessive order activity was imposing negative externalities on all market participants. The full text of the press release is given in figure 2.

[Figure 2 about here.]

In addition to the press release, the OSE also gave more details about the actual fee structure and how the calculation is done.[11] The calculation is done on a monthly basis. The actual fee is NOK 0.05 per message that exceeds a ratio of 70:1 on a monthly basis. In the calculation

[11] *Oslo Børs to Implement Order to Executed Ratio*, downloadable from the OSE web site (oslobors.no).

the OSE does not count every message. Specifically, orders with the following characteristics are not counted:

- Orders that rest unchanged for more than one second from entry.
- Order amendments that improve price, volume, or both.
- Execute and Eliminate (ENE) and Fill or Kill (FOK) orders

Orders that have the following features *are* counted:

- Orders residing less than one second, from order insert or the last amendment, before cancelation
- Order amendments that degrade price, volume, or both, of an order that has resided for less than one second in the trading system.

The way executed orders are counted is also specified as:

- Orders that result in one or many transactions are counted as one executed order
- Executed orders, orders that have been involved in one or more trade, but with total executed value of less than NOK 500 will not be counted as an executed order.

The specifics of the Norwegian regulation makes it clear that the exchange wants to differentiate between different types of HFT strategies. These rules will clearly be less onerous for market making strategies. To see that, recall that market making involve placing orders to buy and sell in the limit order book, hoping to earn the spread. When prices change, these orders are updated. If the market maker maintains the spread and places new bids and asks centered around a different price, either the bid and ask will be price improving and hence not counted. So, for market makers maintaining the same spread, only *half* of the new orders will count in the calculation of the OEOR. Similarly, when there is little activity in the market, market makers' quotes are likely to stay in the order book for longer than one second and will therefore also not count in the calculation of the OEOR.

A HFT strategy that is more likely to get a high OEOR is a "relative value strategy." Here, the traders react to price discrepancies between two or more market places. The strategy is then to send orders to both exchanges at current prices, orders that needs to be filled immediately. Such orders are neither price improving nor long lived and will all count in the calculation of the OEOR.

It is apparent that the calculation of the fee is designed to reward liquidity *provision*. In that sense it is similar to the "payment for order flow" used at other exchanges, where those orders judged to provide liquidity will get a cost advantage.

Note that the OEOR ratio is a calculation done for each individual trader on the exchange. In the following, we use OEOR when we are discussing this specific calculation, and OTR as a more generic term, typically applied to market-wide aggregates.

3.2 How strict is the ratio of 70:1?

To evaluate the effects of the introduced regulation we need some background to see how market participants are likely to react. The first issue we look at is the ratio itself, a ratio of 70:1. Compared to Italy, where traders start paying at a ratio of 100:1, the Norwegian ratio actually seems harsher. There are however two crucial differences. First, the Italian fee's are based on a *daily* calculation of the ratio, unlike Norway, where the fee is based on a monthly calculation. Second, as discussed above, not all messages count in the Norwegian calculation, unlike the Italian.

The reaction of traders at the OSE clearly depends on how "binding" the OTR constraint of 70 is. If it is viewed as non-binding by all traders in the market, it should not have much impact. We would then expect no major changes to liquidity prevailing in the market place.

To evaluate this we look at the conditions in the market place just *before* the regulation. We calculate the OTR ratio for the whole market by, for each stock, counting the number of messages (order submissions, order withdrawals and order modifications) to the exchange's limit order book and divide by the total number of executed trades in the stock. Note that this is across all traders in this particular stock. This number will therefore represent a lower bound for the OEOR for the more active traders on the exchange.

[Figure 3 about here.]

Figure 3 show two histograms for the OTR's for 2011, the year before the OEOR introduction. The picture on the left shows the distribution of OTR's across all trading days and stocks. The first thing to note is that there are very few stock/days for which the ratio is above 70. To check if this is concentrated in just a few stocks, we construct a second histogram. Here we first find the largest OTR in the year for each stock, and then plot the frequency distribution of these largest OTR's. This is shown in the histogram on the right. We see that it is not just a few stocks with a high OTR ratio. More than a quarter of the stocks on the exchange had a day with an OTR above 70 during 2011.

To investigate the distribution of OTR further we group the shares on the OSE into four portfolios sorted by firm size. In figure 4 we show time series of monthly averages of OTR for these four size sorted groups for the two years before the regulation. The OTR is clearly increasing in firm size. It is the largest firms on the OSE which have high Order to Trade Ratios. These are also the stocks with a significant amount of trading outside the OSE. For the group of largest stocks the average is increasing over time, and almost reaches 50.

[Figure 4 about here.]

The result that the OTR increases with firm size, suggest that it would be interesting to look closer at the largest firm on the exchange to ask whether an OTR of 70 is a reasonable threshold for a fee. Figure 5 therefore shows daily estimates of OTR's for Statoil, the largest company on the OSE, for the two years leading up to the introduction of the OEOR. Here we see that there are days when the *market-wide* OTR for Statoil is *above* 70. Given some variation in trading strategies used by the traders at the OSE, some of the traders in Statoil on these days must have had an OEOR significantly above 70.

[Figure 5 about here.]

The distribution of the maximal OTR's over the previous year, and the Statoil example, shows that although 70 seems like an unrealistic high ratio for most stocks, it is actually a binding constraint for the largest, most important stocks on the exchange, and a constraint one would have "bumped into" for at least a quarter of the firms on the OSE in 2011. The time series trend of OTR estimates, which are pointing upwards, particularly for the largest stocks, confirm that 70 is a number that HFT market participants at the OSE will view as binding.

3.3 Are traders likely to move away from the OSE?

The introduction of the OTR is only done on the OSE and only applies to activities recorded at the OSE. Hence, an easy way to avoid the OTR fee is to move trading activities to other trading platforms. This can be other limit order markets, or OTC/Dark Pool Trading. For the Norwegian listed stocks we look at, the most active alternative limit order markets are NASDAQ OMX Stockholm, BATS, Chi-X and Torquise. Professional trading firms will have links into all these market places, and it is easy for them to change the routing of their order.

The potential extra costs from using the OSE may encourage high frequency traders to trade elsewhere. The degree to whether such traders *actually* move elsewhere depends on whether the costs to these traders of staying below the OTR of 70 are large, and the size of the fees when they break the 70 OTR barrier.

Another question is to what degree alternative market places are viable alternatives. In particular, the OSE is the *main* market for most of these stocks. To what degree are trading strategies such as market making viable if they avoid the main market? The potential for moving trading to other market places varies across stocks at the OSE. For the largest stocks on the OSE, all the exchanges mentioned above are actively competing for order-flow in Norwegian stocks. For smaller, less liquid stocks, the interest from competing limit order markets is lower.

All these factors motivate an analysis of the cross-sectional differences across stocks. Are the effects different for stocks with active trading outside of the OSE (larger stocks) versus those stocks where essentially *all* trades are done at the OSE (smaller stocks).

4 Results – Trader's reactions

In this section we look at the reactions of market participants. Are there signs of traders changing behaviour, potentially linked to the introduction of the OTR constraint?

We do so by investigating averages before and after the introduction. The fee on traders with an OTR above 70 was introduced in September 2012. We use the period Sep-Nov 2012 ("Fall '12") to measure behavior *post* introduction. This is compared to two alternative "pre" periods: The corresponding period (Sep-Nov) the year before ("Fall '11") as well as the period from the beginning of 2012 till the announcement of the OTR tax in May of 2012 ("Spring '12"). If there are seasonalities in trading, the cleanest comparison will be the previous fall. The spring is however closer in time. We therefore consider both.

Table 2 shows aggregate measures across these three time periods. We first investigate what the regulation is written around, Order to Trade Ratios. There is a significant fall from the corresponding period the year before, Fall '11, where the average OTR was 21.2, to the number after the regulation, an average OTR of 16.3.

One obvious way for traders to react is to increase order size. Modern strategies for trading larger quantities in automated markets typically involve splitting one order into many smaller pieces, which explains the gradual decline in order sizes in the last decade.[12] To investigate this, we look at the average order size, which shows a significant increase for the "post" period relative to both "pre" periods.

Finally, we look for signs that traders are leaving the OSE, by looking at turnover. Here we see that turnover has fallen significantly "post" the OTR introduction. It is however not obvious that this decline in turnover necessarily is linked to the OTR introduction. It may be due to an economy wide lowering of interest in equity trading, linked to business condition. We will therefore instead look at the OSE *market share* relative to its competitors, which will be a cleaner test for effects due to the OTR introduction.

[Table 2 about here.]

4.1 Crossectional differences at the OSE

Magnitudes of OTR's at the OSE covary with firm size. The largest, and most actively traded stocks, are those with the highest OTR's. It is therefore of interest to look separately at firms of different sizes, particularly the largest stocks (which are also the ones with trading at market places other than the OSE). To this end we group the stocks on the OSE into four groups of increasing market capitalization. The first two groups are smaller stocks, which are almost exclusively trading at the Oslo Stock Exchange. It is only in the two groups with the largest firms (3 and 4) where we find significant trading outside the OSE.

Panel B of table 2 shows the same numbers as those calculated in panel A for the four size-sorted portfolios. There are some interesting differences. The stocks for which the OTR has been significantly reduced are those in quartile 4, the largest stocks on the exchange. Among these stocks the average OTR has fallen from above 30 to around 19. This is the group with the most risk of actually hitting the OEOR of 70, so this result is consistent with traders changing their behavior to avoid the OTR constraint. Looking at order size, we find that for the largest quartile traders are not changing order size. So the reduction in OTR then would seem to be achieved by reducing the frequency of orders, not by increasing order size. Interestingly, for the medium sized shares order sizes are increasing. These are groups with less competition from other market places.

[12] See Angel, Harris, and Spatt (2011, 2015) for some US evidence. A similar pattern is true for Norway. In 1999, the average trade at the OSE was for 361 thousand NOK. By 2010, this had fallen to 74 thousand.

To dig deeper into how traders are changing their algorithms, we consider an alternative crossectional sort, namely by by OTR intensity. We look separately at stocks that experienced high OTR's in the period before the regulation. To implement this, we use the maximal OTR ratios shown in the right-hand histogram in figure 3. We group the firms on the exchange into three. Those where the maximal OTR during the last year was less than 50, those where it was between 50 and 70, and those with a maximal OTR above 70. Panel C of table 2 shows the results for this grouping of stocks. A most interesting observation concerns the change in the OTR ratio after the introduction of the regulation. It is the group with OTR above 70 where the fall is large, from an average of 34.7 the previous fall down to 21.6 after the introduction of the ratio. Note also the pattern for trade size, which is the same. It is stocks with a high OTR last period for which trade sizes increase.

To conclude the crossectional analysis, the traders at the OSE seem to react to the introduced regulation by changing their behaviour, particularly for those stocks which the constraint is likely to "bite". One of the ways in which traders react is to increase the average order size.

4.2 Are traders moving to other market places?

As we discussed when looking at turnover, a better way to investigate whether trading moves from the OSE to other market places is look at *market share*. To this end we concentrate on stocks with significant trading at other "lit" market places. We also include numbers for post-trade reported transactions(OTC trading). For each of these stocks we calculate the fraction traded at

1. The OSE
2. All "Lit" markets (including the OSE)
3. OTC markets (proxied by Markit BOAT).

[Table 3 about here.]

In table 3 we report averages of these estimated fractions. There are certainly no sudden shift to OTC type markets. Compared to the spring there is seems to be a large decline in OTC trading, from 19.5% to 15.7% of trades. A good deal of this OTC trading is however due to trading around ex-dividend dates, which seem to happen exclusively on OTC markets. Dividends are mainly paid in the second quarter, so the spring numbers are inflated from that. The more relevant comparison is therefore Fall '11 to Fall '12, where we see a decline from 17.3% to 15.7% in the OTC market share. There is a small decline in the market share of OSE, from 70.3 to 69.2. Hence, our results show no marked *aggregate* movement in trading from the OSE to alternative market places.

5 Results – Market Quality

The most important question is whether market quality is affected by the OTR introduction. To investigate this, we calculate market quality measures (depth, spread measures, realized volatility, and the Roll measure), for the same time periods we looked at when investigating trader reactions, i.e. comparing Pre: Fall '11, Spring '12 to Post: Fall '12.

5.1 Changes at the OSE

We first look at the OSE in isolation. Table 4 shows averages for the whole market. Essentially, all market quality measures shows improvement after the introduction of the OTR. With the exception of the relative spread, all of the quality measures are significantly improved relative to both the previous spring and fall.

[Table 4 about here.]

As we did for the characteristics of trading, we also look at this across different size groups at the OSE. Table 5 shows similar numbers to those in table 4, but for the four size-sorted portfolios. Here, the picture is not as unanimous as for the marketwide averages. Most of the size-based portfolios show significant improvement in liquidity, but there are some cases with the opposite picture.

[Table 5 about here.]

Let us also group the stocks on the exchange by their OTR intensity. If quality deteriorates for stocks where the OTR is binding, we can attempt to identify this by looking separately at the stocks for which it is expected to bind. We therefore look separately at stocks where the OTR has exceeded the limit of 70 at least once during the previous year (2011). If we compare to the previous fall, all market quality measures show significant improvement. For the comparison between the spring and the fall of '12, the picture is less unanimous, but all significant estimates show a quality improvement for the groups with max OTR > 70, those most likely to bump into the constraint.

[Table 6 about here.]

So, looking at the OSE in isolation, there seem to be little evidence of negative effects on market quality coinciding with the introduction of the OEOR ratio, the picture seems to be more of an *improvement* in market quality. To complete the picture, we also look at potential effects on trading in other market places.

5.2 Changes at the OSE and other market places

As we have discussed, trader's reactions to the OTR regulation may also involve how orders/trades are distributed between OSE and alternative market places. Given that there is a potential fee in Oslo, and no fees elsewhere, traders have an obvious incentive to send orders away from Oslo. But that is not the only possible outcome. Our results on market share actually contradict this prediction, since the market share of OSE did not change. We therefore need to also consider explanations for why traders are not moving away from Oslo. For example, if the fee leads to a reduction in "harmful" orders being sent to Oslo, the prices in Oslo may become more informative, leading traders to prefer trading there. Oslo is after all the primary listing market for these shares.

We do several investigations looking at market quality across market places. We first attempt to measure *aggregate* market quality across all lit markets. To do this we use Reuter's aggregate summary of trading across Europe, their XBO feed. This is a record of time-stamped trades at all European market places. It is only constructed for stocks with significant cross-exchange trading, so it is only a subset of all stocks used in the previous estimates from the OSE. The feed only include prices and quantities, there is no attempt of building an aggregate order book. We are therefore limited to indicators that can be estimated from trade sequences. In table 7 we show averages of two such market quality indicators, realized volatility and the Roll trading cost estimator. The realized volatility has fallen significantly after the introduction of the OTR. The Roll measure seems relatively unchanged, the estimate for the Fall of '12 is between the previous fall and spring. Again, we see no evidence of major problems following the introduction of the OTR.

[Table 7 about here.]

A problem with this aggregate analysis is that it is less informative than the OSE analysis. It is more informative to compare detailed liquidity measures for individual stocks. This is the setting for our last analysis, a comparison of the trading quality in Oslo with the quality of trading the same stock at another exchange. This has the added benefit that it allows us to formulate the estimation of the effect of the policy change at the OSE as a standard "diff in diff" analysis, which can identify causal effects. We calculate measures of market quality pre (Fall '11 or Spring '12) and post (Fall '12), and compare these quality measures on the OSE with the same measure on an alternative exchange. As this exchange has not introduced the OSE regulation, the *difference* of these measures on the two exchanges is a "diff in diff" measure that isolates the effect of the policy intervention. To make a fair comparison we compare trading at the OSE with trading at the exchange with the largest (in volume terms) trading outside of Oslo.

The econometrically optimal measure to use here is actually the *simple* difference in differences estimator, the difference in mean changes. Let us explain this a bit carefully. We use the notation in (Greene, 2012, pg 933). We want to look at determinants of a liquidity measure, or some other measure of trading quality y_{it}:

$$y_{it} = \theta_t + \mathbf{X}_{it}'\beta + \gamma C_i + u_i + \epsilon_{it} \quad (1)$$

The liquidity measures y_{it} can be explained by a set of controls $\mathbf{X}_{it}$. In our application this will be variables related to the stock, such as its variability, the size of the underlying company, degree of asymmetric information, and so on. The treatment variable is indicated by the dummy variable C_i, equal to one for "Oslo Fall '12." In this formulation u_t is some unobserved individual effect. To get rid of this individual effect analysis is done on the differenced version of the regression (1):

$$\Delta y_{it} = (\theta_t - \theta_{t-1}) + (\Delta \mathbf{X}_{it})'\beta + \gamma \Delta C_i + \Delta \epsilon_{it} \tag{2}$$

This will remove any *individual* effects. However, in our application we can simplify this estimation further. We have a matched sample of observations of trading of the *same* stock in two markets, for example Statoil in Oslo vs Statoil in Stockholm. When we take the difference of the *matched* observations in equation (2), since the control variables ($\mathbf{X}_{it}$) are the *same* for both cases, the control variable falls out of the estimation. We can therefore use

$$\widehat{\gamma} = [\overline{\Delta y}|(\Delta C = 1)] - [\overline{\Delta y}|(\Delta C = 0)],$$

the simple *difference in differences* estimator, to estimate the effect of the policy intervention.

[Table 8 about here.]

Table 8 shows the results of this difference–in–difference analysis.[13] In terms of signs, they are mostly in the "right" direction from the OSE's point of view, market quality is improving at the OSE relative to its competitors. However, none of the coefficients are consistently significant. The lack of significance may be due to the relatively few observations. There are just above 30 stocks with significant trading outside the OSE.

Thus, this sophisticated analysis of the policy intervention confirms the story from the more simple analysis of market-wide aggregates. We do not find any negative effects on market quality associated with the introduction of the OTR ratio.

6 Conclusion

We have investigated the introduction by the OSE of a fee specifically targeted at HFT strategies. The fee was payable by traders whose messages to the exchange's limit order book exceeded 70 times the number of actual trades these orders resulted in. Such a fee has been proposed by several policy makers and market participants as a way for the most active users of the exchange's infrastructure to pay some of the costs they are imposing on the system (and other traders).

The fee was introduced at the OSE in September of 2012. In our empirical work we characterized the market before and after the introduction of the fee. We find that the average Orders to Trade Ratio for the market fell markedly and that the typical trade size (number of shares

[13] The full details of this analysis is provided in an Internet Appendix.

traded per order) increased. This is consistent with the traders making changes to their order submission strategies to lower the risk of paying the fee.

The risk of introducing a fee based on an OTR is that it negatively affects the *quality* of trading at the exchange. To investigate this we calculate a number of measures for market quality such as depth, spread, trading costs, volatility, and turnover. Overall we find no negative changes in market quality that coincides with the introduction of the fee. In the aggregate, all quality measures, with the exception of relative spread, actually is significantly improved post the reform. We also investigate crossectional differences, sorting stocks by their size and OTR intensity. Also here (with a few exceptions), most of the results show a significant improvement in market quality following the regulation.

Since professional traders can easily avoid the OSE fee by moving their trading to other market places, a possible reaction is for trading to increase (and liquidity to improve) on alternative market places. We investigate this hypothesis using data from Thomson Reuters on trading of OSE listed stocks on other market places. We implement a difference-in-differences analysis where we compare the evolution of market quality measures at the OSE with the *same* stocks on the largest lit market outside of the OSE. Again, we find no sign of a worsening of market quality at the OSE, if anything the trading quality worsens at the alternative exchanges.

The experience of the OSE seem to be very different from the experience when a similar measure was introduced in Italian and Canadian equity markets. In both of these cases we saw a decline in liquidity around their introduction of the new fee. At the OSE the picture is the opposite, improvement in liquidity. This may be due to differences in the design of the fees, where the OSE design is more aimed at encouraging liquidity provision such as HFT market making strategies.

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Figure 1 Norwegian stocks traded at the OSE and other lit markets

The figures illustrate where Norwegian stocks are trading. The figure shows fractions of trading in each market. The bottom line is the fraction of the XBO traded at the OSE. The other exchanges adds to the total. The fractions sum to one (we have left out some very small market places). Here OSE is the Oslo Stock Exchange, STO is Nasdaq OMX, BTE is Bats, TRQ is Turquoise, CHI is Chi-X and LSE is the London Stock Exchange.

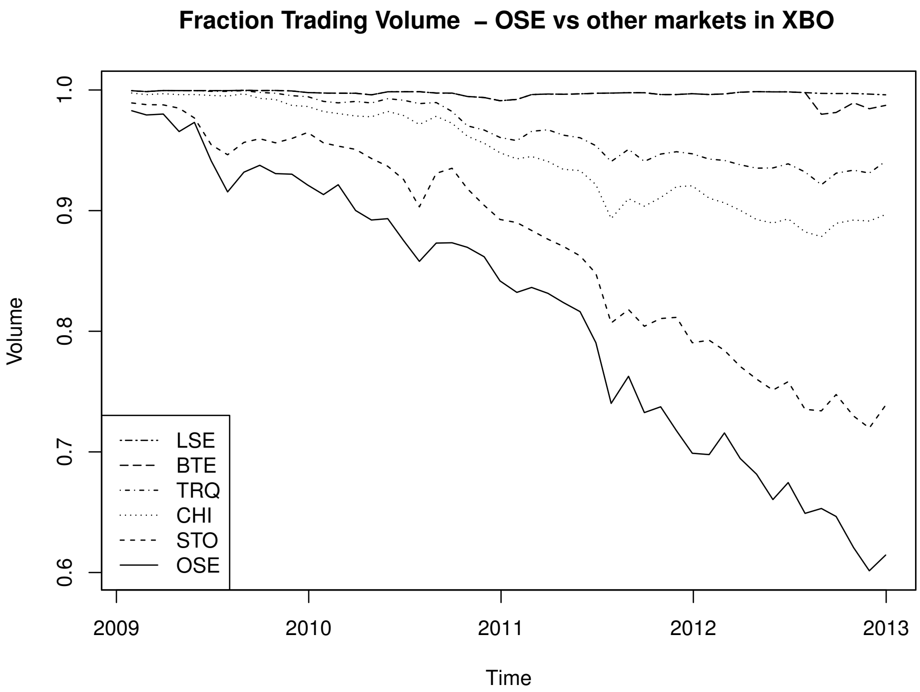

Figure 2 Press Release, 25 may 2012, from the Oslo Stock Exchange

With effect from 1 September, Oslo Børs will introduce a fee that will affect unnecessarily high order activity in the stock market. The purpose of the fee is to discourage orders that do not contribute to the effective and sound conduct of stock market trading. Order activity at unnecessarily high levels has the effect of reducing the transparency of the order picture and so reducing confidence in the market.

Competition and technological development have played a role in radical changes in trading behaviour in the stock market over recent years. Increased use of algorithms as a tool for carrying out various kinds of trading strategy has resulted over time in a steady reduction in the average order size, combined with an increase in the number of order events relative to the number of trades actually carried out. This creates both direct and indirect costs for all market participants, due in part to greater volumes of data and the requirements this creates in terms of investment in infrastructure and greater bandwidth.

"Oslo Børs takes the view that high order activity is not in itself necessarily negative for the market, but we are keen to encourage a situation in which all types of trading contribute to maintaining confidence in the marketplace," comments Bente A. Landsnes, President and CEO of Oslo Børs.

"It is in general the case that a market participant does not incur any costs by inputting a disproportionately high number of orders to the order book, but this type of activity does cause indirect costs that the whole market has to bear. The measure we are announcing will help to reduce unnecessary order activity that does not contribute to improving market quality. This will make the market more efficient, to the benefit of all its participants," explains Bente A. Landsnes.

The fee will be linked to an "Order to Executed Order Ratio (OEOR)" of 1:70. This means that the fee will be charged where the number of orders input relative to each order carried out exceeds 70. The order activity that will be included in the calculation of this ratio will principally relate to orders that are cancelled or amended within one second, and where the change does not contribute to improved pricing or volume.

Accordingly, orders that remain open in the order book for some time, or which are updated in a manner that makes a positive contribution to market quality by reducing the spread between best bid and best offer or by increasing order book depth will not be included in the calculation of the type of activity that Oslo Børs wishes to make the subject of the additional fee.

Figure 3 Distribution of Daily Order to Trade Ratios, OSE 2011

Histogram showing the distribution of daily Order to Trade Ratios. For each stock on the exchange, we sum the number of messages into the exchange's system for this stock, and divided by the number of actual trades. The lefthand figure shows the distribution of these daily estimates. We use data for all trading days of 2011. In the righthand figure we first find the largest OTR for each stock during 2011. The histogram shows the distribution of this largest OTR. We do not illustrate OTR estimates above 150. The sample excludes illiquid stocks, stocks with less than a hundred trading days in a year.

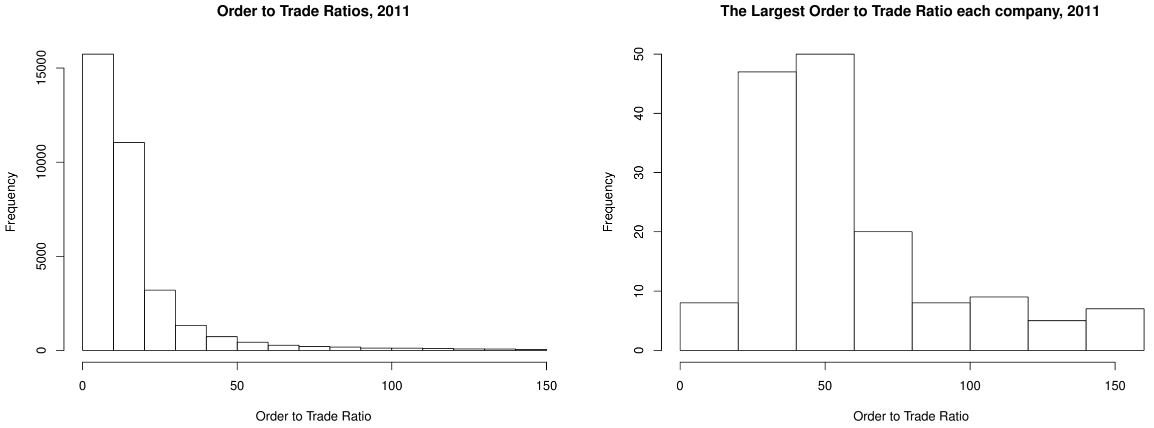

Figure 4 Monthly Order to Trade Ratios, Size Portfolios

The figure show time series of average Order to Trade Ratios for four size-based portfolios on the OSE for the period 2010–2012:5. The portfolios are numbered in increasing order of size, so portfolio 4 are the large stocks, and 1 the small stocks. For each stock on the exchange, we sum the number of messages into the exchange's system for this stock, and divided by the number of actual trades. We calculate monthly averages of these daily OTR's. The sample excludes illiquid stocks, stocks with less than a hundred trading days in a year.

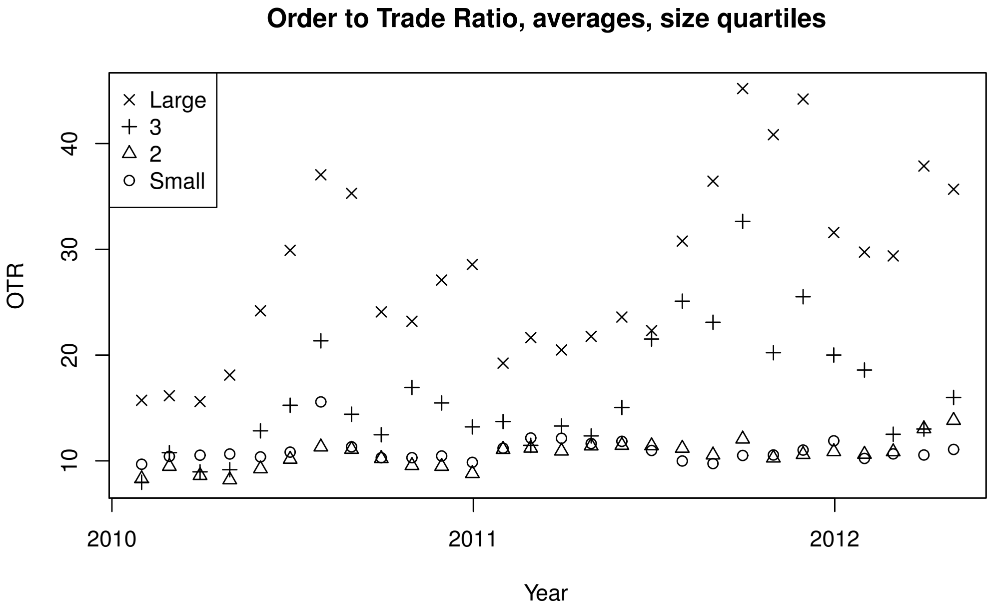

Figure 5 Daily Order to Trade Ratios for Statoil, 2010-2012:5

The figure show time series of Order to Trade Ratios for the stock Statoil for the period 2010–2012:5. Each day, we sum the number of messages into the exchange's system for this stock, and divide it by the number of actual trades.

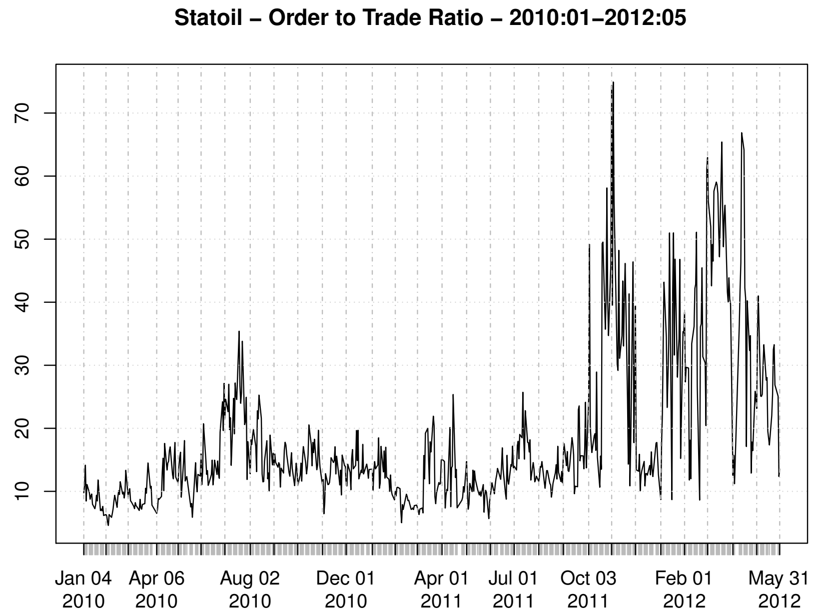

Table 1 Descriptive Statistics for the Market Quality Measures, 2010–2011.

We describe the measures of market quality used in the analysis. Each measure is calculated on a daily basis. The numbers in the tables are averages of daily estimates. Depth is the sum of trading interest (in thousands NOK) at the best bid and best ask. The relative spread is the difference between best bid and best ask scaled by the prevailing midpoint. The effective spread is transaction prices minus the prevailing midpoint just before the transaction. The realized spread is the transaction price minus the prevailing midpoint five minutes after the transaction. Both realized and effective spreads are multiplied with a trade direction indicator, and scaled by the prevailing midpoint. Daily depth and spread measures are calculated as averages across intraday observations. The realized volatility is the (uncentered) second moment of ten-minute returns. The Roll measure is calculated from the autocovariance of trade to trade returns. The sample excludes illiquid stocks, stocks with less than a hundred trading days in a year.

	Whole	Size Portfolio			
	sample	1 (small)	2	3	4
Depth(thousands NOK)	279	104	176	326	547
Relative Spread(%)	2.95	4.94	4.39	1.99	0.81
Effective Spread(%)	0.87	1.86	1.02	0.51	0.25
Realized Spread(%)	0.32	0.73	0.31	0.20	0.10
Realized volatility(%)	0.64	1.10	0.68	0.47	0.39
Roll(%)	0.47	1.05	0.45	0.30	0.12

Table 2 Describing trader's reactions to the regulation.

The table summarizes properties of trading for three subperiods: Fall '11: Sep-Nov 2011; Spring '11: Jan-May 2012; Fall '12: Sep-Nov 2012. For each measure we calculate it on a daily basis for all stocks in the sample. The reported numbers are averages of these daily estimates. Panel A shows averages for the whole period. Panel B shows averages for four size-sorted portfolios. Panel C groups the stocks on the exchange by the largest measured OTR over the previous year (2011). The numbers reported are: The The trade size is the Number of Shares traded times Stock Price. The turnover is the number of Shares outstanding in one day relative to number of shares outstanding. The sample excludes illiquid stocks, stocks with less than a hundred trading days in a year.

Panel A: Whole Market

	Averages			Test for equality(p-value)	
				Fall '11	Spring '12
	Fall '11	Spring '12	Fall '12	vs Fall '12	vs Fall '12
Order to Trade Ratio	24.4	17.3	16.7	-11.5 (0.00)	-1.4 (0.17)
Trade size (thousands NOK)	26	30	31	8.1 (0.00)	1.4 (0.17)
Turnover(%)	0.19	0.22	0.16	-5.3 (0.00)	-9.9 (0.00)

Panel B: Size sorted Portfolios

	Size	Averages			Test for equality(p-value)	
	Quartile				Fall '11	Spring '12
		Fall '11	Spring '12	Fall '12	vs Fall '12	vs Fall '12
Order to Trade Ratio	1 (small)	10.7	10.8	11.1	1.9 (0.06)	1.4 (0.15)
	2	13.8	11.8	15.8	3.3 (0.00)	7.3 (0.00)
	3	55.6	32.8	25.8	-10.6 (0.00)	-4.7 (0.00)
	4	48.6	27.8	20.3	-9.7 (0.00)	-9.1 (0.00)
Trade size (thousands NOK)	1 (small)	12	15	14	4.0 (0.00)	-3.7 (0.00)
	2	25	32	36	5.5 (0.00)	2.1 (0.04)
	3	30	35	48	3.6 (0.00)	2.5 (0.01)
	4	39	42	39	-0.2 (0.88)	-3.5 (0.00)
Turnover(%)	1 (small)	0.12	0.28	0.14	2.5 (0.01)	-9.5 (0.00)
	2	0.14	0.17	0.14	0.1 (0.95)	-3.7 (0.00)
	3	0.22	0.21	0.23	0.9 (0.37)	1.3 (0.18)
	4	0.33	0.27	0.18	-17.0 (0.00)	-12.5 (0.00)

Panel C: OTR sorted portfolios

	Max OTR '11	Averages			Test for equality(p-value)	
					Fall '11	Spring '12
		Fall '11	Spring '12	Fall '12	vs Fall '12	vs Fall '12
Order to Trade Ratio	OTR<50	12.0	11.2	11.8	-0.9 (0.36)	3.2 (0.00)
	OTR∈[50,70]	12.0	12.0	12.0	-0.3 (0.79)	-0.0 (0.99)
	OTR>70	47.4	28.3	23.6	-12.9 (0.00)	-5.2 (0.00)
Trade Size (thousands NOK)	OTR<50	29	33	44	3.4 (0.00)	2.4 (0.01)
	OTR∈[50,70]	16	23	19	4.9 (0.00)	-4.7 (0.00)
	OTR>70	28	32	31	2.8 (0.01)	-1.7 (0.10)
Turnover(%)	OTR<50	0.19	0.22	0.16	-4.8 (0.00)	-8.0 (0.00)
	OTR∈[50,70]	0.19	0.26	0.20	0.8 (0.41)	-5.0 (0.00)
	OTR>70	0.19	0.21	0.16	-4.8 (0.00)	-7.0 (0.00)

Table 3 Comparing market share across venues, before and after

The table show average market shares for three groups of market places: 1) The OSE. 2) All "lit" markets (including the OSE). 3) OTC trading. Numbers are calculated for all OSE listed stocks with significant trading outside of OSE. The numbers are averages of these fractions for three subperiods: Fall '11: Sep-Nov 2011; Spring '11: Jan-May 2012; Fall '12: Sep-Nov 2012. Note that these averages are not supposed to sum to 100, they are (equally weighted) averages of fractions for each stock.

	Fall '11	Spring '12	Fall '12
Oslo	70.3	68.1	69.2
All lit markets	79.6	79.1	78.9
OTC/Dark markets	17.3	19.5	15.7

Table 4 Comparing trade quality measures before and after regulation

The table summarizes properties of liquidity for three subperiods: Fall '11: Sep-Nov 2011; Spring '11: Jan-May 2012; Fall '12: Sep-Nov 2012. For each measure we calculate it on a daily basis for all stocks in the sample. The reported numbers are averages of these daily estimates. Depth is the sum of trading interest (in thousands NOK) at the best bid and best ask. The relative spread is the difference between best bid and best ask scaled by the prevailing midpoint. The effective spread is transaction prices minus the prevailing midpoint just before the transaction. The realized spread is the transaction price minus the prevailing midpoint five minutes after the transaction. Both realized and effective spreads are multiplied with a trade direction indicator, and scaled by the prevailing midpoint. Daily depth and spread measures are calculated as averages across intraday observations. The realized volatility is the (uncentered) second moment of ten-minute returns. The Roll measure is calculated from the autocovariance of trade to trade returns.

	Averages			Test for equality(p-value)	
				Fall '11	Spring '12
	Fall '11	Spring '12	Fall '12	vs Fall '12	vs Fall '12
Depth(thousands NOK)	200	267	291	19.7 (0.00)	4.8 (0.00)
Relative Spread(%)	3.43	2.84	2.82	-24.1 (0.00)	-0.8 (0.42)
Effective Spread(%)	1.08	0.81	0.66	-24.1 (0.00)	-9.6 (0.00)
Realized Spread(%)	0.34	0.31	0.19	-12.6 (0.00)	-9.5 (0.00)
Realized volatility(%)	0.81	0.60	0.51	-21.3 (0.00)	-8.3 (0.00)
Roll(%)	0.54	0.42	0.36	-10.2 (0.00)	-4.4 (0.00)

Table 5 Comparing trade quality measures before and after regulation – size sorted portfolios

The table summarizes properties of liquidity for three subperiods: Fall '11: Sep-Nov 2011; Spring '11: Jan-May 2012; Fall '12: Sep-Nov 2012. For each measure we calculate it on a daily basis for all stocks in the sample. The reported numbers are averages of these daily estimates for four size sorted portfolios. Depth is the sum of trading interest (in thousands NOK) at the best bid and best ask. The relative spread is the difference between best bid and best ask scaled by the prevailing midpoint. The effective spread is transaction prices minus the prevailing midpoint just before the transaction. The realized spread is the transaction price minus the prevailing midpoint five minutes after the transaction. Both realized and effective spreads are multiplied with a trade direction indicator, and scaled by the prevailing midpoint. Daily depth and spread measures are calculated as averages across intraday observations. The realized volatility is the (uncentered) second moment of ten-minute returns. The Roll measure is calculated from the autocovariance of trade to trade returns. The sample excludes illiquid stocks, stocks with less than a hundred trading days in a year.

	Size Quartile	Averages			Test for equality(p-value)	
		Fall '11	Spring '12	Fall '12	Fall '11 vs Fall '12	Spring '12 vs Fall '12
Depth(thousands NOK)	1 (small)	80	124	115	11.7 (0.00)	-2.2 (0.03)
	2	175	197	226	5.8 (0.00)	3.5 (0.00)
	3	220	322	357	12.6 (0.00)	3.0 (0.00)
	4	354	484	501	13.4 (0.00)	1.4 (0.15)
Relative Spread(%)	1 (small)	5.82	5.40	5.64	-3.0 (0.00)	3.5 (0.00)
	2	5.13	3.82	3.72	-22.6 (0.00)	-1.5 (0.13)
	3	2.06	1.77	1.71	-12.0 (0.00)	-1.8 (0.07)
	4	0.91	0.69	0.65	-17.5 (0.00)	-3.4 (0.00)
Effective Spread(%)	1 (small)	2.48	1.91	1.65	-16.1 (0.00)	-5.5 (0.00)
	2	1.21	0.82	0.59	-22.7 (0.00)	-9.7 (0.00)
	3	0.57	0.50	0.45	-10.1 (0.00)	-4.2 (0.00)
	4	0.25	0.21	0.16	-9.2 (0.00)	-6.7 (0.00)
Realized Spread(%)	1 (small)	0.91	0.76	0.47	-13.9 (0.00)	-9.1 (0.00)
	2	0.32	0.28	0.17	-9.4 (0.00)	-8.4 (0.00)
	3	0.17	0.19	0.12	-4.7 (0.00)	-7.1 (0.00)
	4	0.08	0.09	0.04	-4.8 (0.00)	-7.5 (0.00)
Realized volatility(%)	1 (small)	1.39	1.16	0.99	-12.7 (0.00)	-6.0 (0.00)
	2	0.87	0.59	0.47	-23.2 (0.00)	-8.3 (0.00)
	3	0.54	0.44	0.39	-13.0 (0.00)	-5.1 (0.00)
	4	0.50	0.33	0.28	-6.4 (0.00)	-1.7 (0.09)
Roll(%)	1 (small)	1.36	1.01	0.77	-11.3 (0.00)	-5.8 (0.00)
	2	0.51	0.38	0.35	-10.2 (0.00)	-2.5 (0.01)
	3	0.29	0.27	0.25	-3.0 (0.00)	-1.2 (0.25)
	4	0.12	0.09	0.10	-0.7 (0.49)	0.3 (0.79)

Table 6 Comparing trade quality measures before and after regulation – OTR sorted portfolios

The table summarizes properties of liquidity for three subperiods: Fall '11: Sep-Nov 2011; Spring '11: Jan-May 2012; Fall '12: Sep-Nov 2012. For each measure we calculate it on a daily basis for all stocks in the sample. The reported numbers are averages of these daily estimates for three different groups: Stocks with max OTR<50, max OTR $\in [50, 70]$, max OTR>70 Depth is the sum of trading interest (in thousands NOK) at the best bid and best ask. The relative spread is the difference between best bid and best ask scaled by the prevailing midpoint. The effective spread is transaction prices minus the prevailing midpoint just before the transaction. The realized spread is the transaction price minus the prevailing midpoint five minutes after the transaction. Both realized and effective spreads are multiplied with a trade direction indicator, and scaled by the prevailing midpoint. Daily depth and spread measures are calculated as averages across intraday observations. The realized volatility is the (uncentered) second moment of ten-minute returns. The Roll measure is calculated from the autocovariance of trade to trade returns. The sample excludes illiquid stocks, stocks with less than a hundred trading days in a year.

	Max OTR '11	Averages			Test for equality(p-value)	
					Fall '11	Spring '12
		Fall '11	Spring '12	Fall '12	vs Fall '12	vs Fall '12
Depth(thousands NOK)	OTR<50	202	272	321	15.5 (0.00)	6.2 (0.00)
	OTR∈[50,70]	133	206	206	11.5 (0.00)	-0.0 (0.98)
	OTR>70	218	288	279	10.2 (0.00)	-1.5 (0.13)
Relative Spread(%)	OTR<50	4.14	3.50	3.54	-14.0 (0.00)	0.9 (0.39)
	OTR∈[50,70]	5.01	3.90	4.16	-10.1 (0.00)	3.0 (0.00)
	OTR>70	2.36	1.87	1.74	-21.3 (0.00)	-4.3 (0.00)
Effective Spread(%)	OTR<50	1.27	1.00	0.71	-19.0 (0.00)	-12.7 (0.00)
	OTR∈[50,70]	1.81	1.15	1.06	-14.5 (0.00)	-2.2 (0.03)
	OTR>70	0.79	0.61	0.53	-20.0 (0.00)	-5.5 (0.00)
Realized Spread(%)	OTR<50	0.34	0.37	0.18	-8.6 (0.00)	-10.2 (0.00)
	OTR∈[50,70]	0.62	0.42	0.28	-10.4 (0.00)	-6.1 (0.00)
	OTR>70	0.28	0.24	0.17	-8.8 (0.00)	-6.2 (0.00)
Realized volatility(%)	OTR<50	0.87	0.68	0.51	-16.0 (0.00)	-11.7 (0.00)
	OTR∈[50,70]	1.21	0.81	0.75	-12.2 (0.00)	-2.1 (0.04)
	OTR>70	0.67	0.50	0.45	-17.6 (0.00)	-4.8 (0.00)
Roll(%)	OTR<50	0.42	0.43	0.28	-5.9 (0.00)	-7.2 (0.00)
	OTR∈[50,70]	0.92	0.66	0.48	-7.2 (0.00)	-4.2 (0.00)
	OTR>70	0.51	0.36	0.34	-9.4 (0.00)	-0.8 (0.45)

Table 7 Comparing aggregate European trading and liquidity before and after

The table shows averages of market quality measures across European Exchanges. For each stock where Reuters provide an aggregate (XBO), we calculate the market quality measures on a daily basis. The table report averages across three subperiods: Fall '11: Sep-Nov 2011; Spring '11: Jan-May 2012; Fall '12: Sep-Nov 2012. The Roll measure is calculated from the autocovariance of trade to trade returns. The realized volatility is the (uncentered) second moment of ten-minute returns.

	Averages			Test for equality(p-value)	
				Fall '11	Spring '12
	Fall '11	Spring '12	Fall '12	vs Fall '12	vs Fall '12
Realized volatility (%)	0.58	0.40	0.35	-20.7 (0.00)	-6.1 (0.00)
Roll (%)	0.12	0.10	0.11	-3.5 (0.00)	3.8 (0.00)

Table 8 Comparing market quality measures in Oslo and alternative exchanges

The table shows results of diff-in-diff estimates. For each market quality measure, we calculate its *change* at the OSE (the column marked Oslo), and its change at the Comparison Exchange – the exchange with the largest trading volume for that particular stock (The column marked "Comparison") The "Diff in diff" is the average of the difference between these two. We report mean, p-values for a test whether the variable is equal to zero (in parenthesis), and medians. Depth is the sum of trading interest (in thousands NOK) at the best bid and best ask. The relative spread is the difference between best bid and best ask scaled by the prevailing midpoint. The effective spread is transaction prices minus the prevailing midpoint just before the transaction. The realized spread is the transaction price minus the prevailing midpoint five minutes after the transaction. Both realized and effective spreads are multiplied with a trade direction indicator, and scaled by the prevailing midpoint. Daily depth and spread measures are calculated as averages across intraday observations. The realized volatility is the (uncentered) second moment of ten-minute returns. The Roll measure is calculated from the autocovariance of trade to trade returns. The analysis is done for stocks with significant trading outside of OSE, which is implemented as cases where the volume at the exchange outside OSE must be 5% of the OSE volume.

	Fall '11 vs Fall 12			Spring '12 vs Fall '12			
	Oslo	Comparison	$\widehat{\gamma}$ (Diff in diff)	Oslo	Comparison	$\widehat{\gamma}$ (Diff in diff)	n
Depth (thousand)							
Average change	47	-3	50	-97	-77	-20	34
	(0.30)	(0.88)	(0.09)	(0.10)	(0.26)	(0.39)	
Median change	26	9	27	-15	-9	-2	
Relative Spread (%)							
Average change	-0.041	0.068	-0.109	0.038	0.128	-0.090	34
	(0.11)	(0.38)	(0.12)	(0.04)	(0.02)	(0.08)	
Median change	-0.043	0.002	-0.025	0.008	0.036	-0.020	
Relative Effective Spread (%)							
Average change	0.003	-0.038	0.041	0.014	-0.041	0.056	34
	(0.77)	(0.29)	(0.23)	(0.11)	(0.55)	(0.44)	
Median change	-0.007	-0.021	0.010	0.004	0.001	0.004	
Relative Realized Spread (%)							
Average change	0.022	-0.003	0.025	0.018	0.020	-0.001	34
	(0.00)	(0.92)	(0.37)	(0.02)	(0.09)	(0.91)	
Median change	0.012	0.008	0.001	0.006	0.007	0.002	
Roll(%)							
Average change	-0.005	-0.022	0.017	-0.009	0.016	-0.026	31
	(0.81)	(0.18)	(0.44)	(0.76)	(0.05)	(0.42)	
Median change	-0.017	-0.006	0.002	0.002	0.007	-0.011	
Realized Volatility(%)							
Average change	-0.249	-0.185	-0.063	-0.034	-0.025	-0.009	33
	(0.00)	(0.00)	(0.02)	(0.13)	(0.21)	(0.60)	
Median change	-0.208	-0.190	-0.033	-0.045	-0.033	-0.015	