Closing Call Auctions at the Index Futures Market

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Abstract

This paper investigates how the introduction of a closing call auction in the OMXS 30 index futures market influences market quality and price accuracy. Index futures markets are characterized by traders with no or little private information. Limit order book models where trader patience (rather than private information) determines trading strategies, predict that a closing call auction increases trader patience and hence improves closing price accuracy and end-of-day market liquidity. We analyze market liquidity in three dimensions: tightness, depth, and resiliency. Our empirical results show that the closing call auction indeed leads to increased trader patience and successfully improves the closing price accuracy. However, tightness and resiliency are unaffected by the regulatory change, and depth is decreasing. We hypothesize that the depth effect is due to an "order fishing" phenomenon, which is not considered in current theoretical models. When the potential of large market orders is high, opportunistic patient traders post limit orders in the depth of the order book to profit from impatient traders. In line with our hypothesis, order fishing activity increases sharply in the last minute of the trading day. When the closing call auction is introduced, and trader patience increases, the order fishing behavior vanishes.

Key words: Call auctions; Index futures; Trader patience; Liquidity; Price discovery

JEL codes: G14, G15

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1 INTRODUCTION

In recent years, closing call auctions have been introduced in stock markets all over the world.[1] The closing call auction mechanism is popular since it mitigates liquidity demand shocks at the end of the trading day caused by discretionary traders with incentives to trade at the closing price. In the absence of a closing call auction, such shocks can lead to bad price discovery and low liquidity. The closing call auction collects limit orders over a specified time interval and executes all matching orders in one trade, typically letting this last trade of the day represent the reference closing price. In this way, the closing call auction improves price discovery (Schwartz, 2001), reduces information asymmetry problems (Madhavan, 1992), and improves the market's ability to absorb liquidity shocks (Pagano and Schwartz, 2003; Barclay et al., 2008). In addition, a call auction is often advocated as the best solution to handle order imbalances towards the end of the trading day (Economides and Schwartz, 1995).

In spite of their stock market popularity, closing call auctions are still rare in futures markets. Recently, in June 2009, the NASDAQ-OMX options and futures exchange introduced a closing call mechanism in the trading of OMXS 30 index futures. This natural experiment provides this paper with a unique opportunity for studying the impacts of the closing call auction on futures market liquidity, trading activity, and price discovery.[2]

The closing of index futures markets is important because it typically determines the daily futures settlement price. The futures settlement price is widely used as a reference price to determine the value of other index derivatives contracts and for marking investment portfolios to market value (e.g., to measure performance of portfolio managers and investment funds). As a consequence,

[1] Kandel et al. (2010) provide an extensive list of different stock markets' closing mechanisms.

[2] To our knowledge, the only futures markets, apart from the OMXS 30 index futures market, applying a call auction as their closing mechanism are the KRX index futures in Korea and the TAIFEX index futures in Taiwan. Unlike the recent introduction of a closing call auction procedure at the already well-established Swedish index futures market, the Korean and Taiwanese closing call mechanisms were introduced at the same time as the futures themselves (in 1998).

many investors have incentives to execute their trades as close to the settlement price as possible. This includes for example mutual funds that need to handle their investors' withdrawals and injections of funds, index funds that need to rebalance and hedge their portfolios and arbitrageurs who need to trade futures close to the settlement price. Some investors may also have incentives to manipulate the futures settlement price to deviate from the market price (see Hillion and Suominen, 2004, for a thorough discussion on such behavior on stock markets).

We study the effects of the closing call auction introduction from three different but interrelated perspectives of market dynamics: trader behavior, liquidity, and price discovery. We base our empirical analysis on the theoretical framework in Foucault et al. (2005) and Roşu (2009), where the latter provides a continuous time extension of the former. The framework constitutes a liquidity-based model of a limit order book, within which traders' relative patience determines their order submission strategies, and thus the liquidity provision to the market. The liquidity-based model allows us to link trader behavior to liquidity and price discovery, in order to formulate testable hypotheses on the impacts of the closing call auction introduction. Unlike information-based models (e.g., Admati and Pfleiderer, 1988; Kaniel and Liu, 2006), the liquidity-based framework assumes no information asymmetry among traders.

The OMXS 30 futures market is order driven, and we base our trader behavior analysis on limit order book and transaction data. From these data sets we infer the different order types that traders submit. Data on order types can be used to determine traders' patience, but such inference is typically complicated by the fact that impatience as an incentive for trading cannot be separated from trading motivated by private information. However, in a stock index futures market, information-driven trading is to a large extent diversified away, making index futures attractive to uninformed investors (Subrahmanyam, 1991). Hence, the order submission strategies observed in the OMXS 30 futures market are likely to be driven by the degree of trader patience, which motivates our focus on liquidity-based models of trader behavior when we form hypotheses regarding effects of the introduction of a closing call auction. In a recent study, Kandel et al. (2010) perform an extensive analysis of closing call auction introductions in equity markets. They form empirical predictions based on both information-based and liquidity-based theory. We extend the analysis of Kandel et al. (2010) to index futures markets. Due to the low information asymmetry among index futures traders, we are able to abstract from information-based theory and to focus on liquidity-based theory.

In the theoretical models of limit order book markets in Foucault et al. (2005) and Roşu (2009) the degree of trader patience, synonymous with competitiveness in liquidity supply, is treated as an exogenous variable with great influence on market liquidity. Trader patience is typically difficult to measure separately from liquidity, making such models hard to assess.[3] Foucault et al. (2005) argue that trader patience at the market close is relatively low as discretionary traders need to execute their orders. The introduction of a closing call auction, they argue, increases trader patience because it extends market opening hours and offers a limit order book with a high probability of execution. This natural experiment implies an exogenous change in trader patience and hence yields an opportunity to assess the liquidity-based models.[4] Foucault et al. (2005) and Roşu (2009) predict that decreasing patience at the market close should lead to decreasing liquidity. The increasing trader patience associated with the closing call auction introduction should, by the same reasoning, improve market liquidity. We investigate these relations empirically. In line with Kandel et al. (2010) we focus our analysis on the day-end trading. Kandel et al. (2010) find that closing call auction introductions at stock markets enhance last-

[3] Previous empirical work addressing the endogeneity problem includes Linnainmaa and Roşu (2009) who use weather as an instrument for trading activity and study its causal relation to market liquidity. Pascual and Veredas (2009) use a two-stage sequential ordered probit model to study how trader patience is influenced by market liquidity.

[4] Another rich theoretical model of the dynamic limit order submission choice is provided by Goettler et al. (2005). In that model trade is driven by differences in asset valuation. We base our testable hypotheses on the models by Foucault et al. (2005) and Roşu (2009) because they let trade be driven by differences in patience, which the introduction of a closing call auction is clearly related to.

minute liquidity in terms of market tightness (similar results are found by Aitken et al., 2005). In addition to market tightness, we also investigate market resiliency and market depth.

Roşu (2009) shows that low trader patience can lead to many limit orders posted in the depth of the order book, as patient liquidity providers see an opportunity to profit from impatient liquidity demanders. In his model, this effect is restricted to patient traders who would come to the market regardless of the patience of other traders. Both Foucault et al. (2005) and Roşu (2009) assume that the arrival processes of patient and impatient traders are independent. In contrast, we hypothesize that an increased presence of impatient traders attracts an opportunistic patient trader who strategically posts limit orders outside the prevailing spread to utilize the concurrent increased presence of impatient traders. We label this behavior *order fishing* and investigate its presence before and after the introduction of a closing call auction by studying the depth of the order book towards the end of the trading day.

Another measure that is sometimes related to liquidity is trading volume. The liquidity-based and information-based models of trading dynamics predict that we would see a transfer of volume from the continuous trading phase to the newly introduced closing call auction. Such volume migration is also observed in previous studies of closing call auctions in equity markets (e.g., Pagano and Schwartz, 2003; Hillion and Suominen, 2004; Huang and Tsai, 2008; Kandel et al., 2010). We investigate such migration in the index futures market, expecting it to be smaller than in other markets as it is partially driven by information-based trading.

Price discovery is a core incentive for policy makers to institute closing call auctions. Before the introduction of the closing call auction at the OMXS 30 index futures market, the futures settlement price was set to the last trading price from the continuous trading session. Hillion and Suominen (2004) argue that closing prices set in that way are subject to price manipulation, and that a closing call auction may limit such behavior. Moreover, from the framework of Foucault et al. (2005) we can infer that the increased patience among traders should lead to less microstructure noise. We estimate the amount of noise contained in futures prices towards the end of the trading session before and after the introduction of the closing call auction at the futures market. We expect the introduction of the closing call auction to lead to lower futures volatility towards the end of the continuous trading session, and to enhance price discovery and accuracy of the futures settlement price.

Overall, our analysis of the introduction of the closing call auction in the OMXS 30 index futures market contributes to the literature in four important ways. Firstly, to our knowledge, this study is the first to analyze the impact of a closing call auction on the quality of a futures market. Such mechanisms in stock markets are by now well studied, but no guidance on to what extent the same effects can be expected in other markets is available.[5] Secondly, our analysis emphasizes trader behavior, which determines aggregate market quality measures such as liquidity and price discovery. In doing so, we investigate whether the closing mechanism has an influence on trader patience, which has never been done empirically before. We also introduce the concept of order fishing and analyze how this behavior is influenced when a closing call auction is introduced. To the best of our knowledge, this trader behavior is not accounted for in current theoretical or empirical research.

Thirdly, whereas previous work focus on bid-ask spreads, we also study limit order book liquidity effects in terms of depth and resiliency. The analysis of the effects of the closing call auction regarding different dimensions of liquidity improves our understanding of the closing call auction influence on trader behavior. Finally, our ability to observe trader patience allows us to link trader behavior to liquidity and price discovery in order to form testable hypotheses founded in

[5] Lee et al. (2007) and Lee et al. (2009) study the futures market impact of stock market closing call auction introductions, both using data from the Taiwan market. The former studies price reactions whereas the latter focus on hedging efficiency before and after the closing call introduction.

theoretical work. Thus, our methodology forms a framework for empirical assessment of liquidity-based models that is relevant beyond the analysis of closing call auctions.

Section 2 presents details of the OMXS 30 index futures market along with information on the data set applied in this study. After that, we present our theoretical framework and our empirical hypotheses in section 3. Section 4 outlines our empirical methodology for analyzing impacts of the introduction of the closing call auction at the futures market, whereas section 5 contains our results and discussion. Section 6 concludes.

2. THE OMXS 30 INDEX FUTURES MARKETS

This section describes the structure of the OMXS 30 index futures market. It also presents the data used for the subsequent empirical analysis.

2.1 Futures market structure

The Swedish exchange for options and other derivatives (OM) introduced the OMXS 30 index in September 1986 as an underlying asset for trading in standardized European options and futures. The OMXS 30 is a value-weighted market index which consists of the 30 most actively traded stocks on the Stockholm Stock Exchange (acquired by OM in 1998). In 2003, the Helsinki Stock Exchange (HEX) merged with OM, and the joint company name was changed to OMX in 2004. After a series of acquisitions (e.g., the Copenhagen Stock Exchange and the Iceland Stock Exchange), OMX became the leading exchange for trading stocks, futures, options and other derivatives in the Nordic countries. In 2007, NASDAQ acquired OMX, and the newly merged company was renamed the NASDAQ-OMX Group upon completion of the deal in early 2008. At present, the NASDAQ-OMX options and futures exchange is the third largest derivatives exchange in Europe, with a trading activity of nearly 600,000 contracts per day.

The trading environment for OMXS 30 index futures constitutes a combination of an electronic limit order book, a market making system, and an upstairs market (block trades). Incoming orders are automatically matched against orders already in the limit order book if matching orders can be found; otherwise incoming orders are added to the limit order book. Only members of the exchange, either ordinary dealers or market makers, can trade directly through NASDAQ-OMX. Market makers supply liquidity to the market by posting bid-ask spreads on a continuous basis. Continuous trading through the limit order book is possible during normal trading hours; between 9:00 a.m. and 5:20 p.m.

On June 8, 2009, NASDAQ-OMX introduced a closing call auction for OMXS 30 futures.[6] As of then, futures trading ends with a call auction after the normal trading hours. The call auction procedure consists of two phases; call interaction and uncross. After the end of the continuous trading session at 5:20 p.m., the futures limit order book directly shifts to the call interaction phase, which lasts for at least 60 and at the most 90 seconds, and ends when the uncross is carried out. The interaction phase allows for the same type of order book management and transparency as during the continuous trading session, but without market orders. For the duration of the interaction phase an indicative equilibrium price and a cumulative volume eligible for matching at this price is shown in the order book. Uncross is carried out randomly between 5:21:00 and 5:21:30 p.m., when the closing auction price is determined and the call auction trading volume is allocated.

The OMXS 30 index futures market consists of contracts with different maturities. Throughout a calendar year, trading is possible in at least three futures contract series, with up to one, two, and three months left to expiration, respectively. On the fourth Friday of the expiration month, if it is a Swedish bank day, one contract series expires. If the day in question is not a Swedish bank day

[6] The trading day at the futures market starts directly with the continuous trading session, without a dedicated opening auction, that is common in stock markets (see e.g., Kandel et al., 2010).

or is declared to be a half trading day, the contract series expires on the preceding bank day. A new expiration month series is listed four Swedish bank days prior to the expiration of the previous futures series. For example, towards the end of June, the June contracts expire and are replaced with newly issued September contracts. At that time, the July contracts (with one month left to expiration) and the August contracts (with two months left to expiration) are also listed. In addition to this basic maturity cycle, futures with maturity up to two years exist. These long contracts always expire in January and are included in the basic maturity cycle when they have less than three months left to expiration. All OMXS 30 index futures are cash settled at maturity.

2.2 Data

We use a data set that consists of information on all trades and quotes for all OMXS 30 index futures between June 9, 2008, and February 5, 2010. The data are obtained from the Thomson Reuters Tick History database, maintained by the Securities Research Centre of Asia-Pacific (SIRCA) and include information of prices (transactions prices and settlement prices), trading volume (the number of traded contracts), open interest, and order book depth (the five best bid and ask quotes and corresponding sizes) for each futures contract. The records show the timing of each futures trade and quote with an accuracy down to the millisecond.

In our empirical analysis we focus on the futures contracts that are closest to maturity (the nearby futures contracts). Each month, at the end of the day before the final trading day of the expiring contract, we "roll over" to the next nearby contract. The empirical analysis is conducted during two different sub-periods: Pre-period is between June 9, 2008, and June 5, 2009; and Post-period is between June 8, 2009, and February 5, 2010. The breaking-point between Pre- and Post-period is motivated by the introduction of the closing call auction procedure at the futures market on June 8, 2009. In addition, on February 8, 2010, the continuous trading session at the OMXS 30 index futures market was extended with five minutes. Following the extension, continuous trading ends at 5:25 p.m. and is followed by the two phases of the closing call auction. Hence, the Post-period ends on February 5, 2010, in order to facilitate a robust analysis with respect to the five-minute extension of the continuous trading session at the futures market.[7]

Table 1 shows summary statistics for daily futures market trading activity for each of the two different sub-periods. The statistics are presented for the "rolled over" futures contract and for each of the three contracts closest to maturity. We note that futures trading volume and open interest are highly concentrated to the nearby contract, which motivates our subsequent focus on the "rolled over" futures contract in the empirical analysis. For the "rolled over" futures contract, we observe that the closing call auction accounts for around 2% of the daily total trading volume during the Post-period. This is in line with the results from Aitken et al. (2005), who find that almost 2.5% of the daily trading volume is executed at the closing call auction at the Australian Stock Exchange. However, Kandel et al. (2010) find the closing call auction to be slightly more popular at both the Milan Stock exchange and the Paris Bourse at around 3% immediately following the call introduction, and around 4% roughly one year after the introduction. Potential origins of these volume differences across exchanges include differences in the type of asset traded (stocks and futures) and differences in the closing call auction design (e.g., the length of the closing call batching period, which is longer in the Milan and Paris cases).

3. EMPIRICAL HYPOTHESES

Several theoretical market microstructure models offer predictions on the effects of a closing call auction introduction. Kandel et al. (2010) provide an overview of such models, categorizing them as information-based models and liquidity-based models. In information-based models, such as Admati and Pfleiderer (1988) and Kaniel and Liu (2006), asymmetric information is the main

[7] The pre-period is one year long and the post-period is eight months long. As all reported metrics are daily averages, this period length assymmetry is not expected to influence the results. For robustness, we repeat our investigation with both periods being six months long (Dec 5, 2008 – June 5, 2009, and June 8, 2009 – Dec 8, 2009, respectively). The results (that are not reported) are qualitatively the same.

determinant of trading strategies. In liquidity-based models, such as Foucault et al. (2005) and Roşu (2009), it is assumed that all traders have access to the same information. Instead, trading strategies are based on traders' waiting costs and probabilities of execution. For our stock index futures market setting, we argue that the liquidity-based models offer the most appropriate description of the trading dynamics.

According to the theory of Subrahmanyam (1991), in markets for baskets of securities, such as stock index futures, adverse selection costs are diversified away, mitigating the risk of trading with privately informed counterparties. This makes such markets attractive to uninformed (discretionary) traders, and asymmetries in information less influential on market dynamics. Berkman et al. (2005) provide empirical support for this hypothesis by showing that the permanent price impact of large purchases (sales) in stock index futures are more than 95% (80%) smaller than corresponding price impacts of trades in the underlying securities. Following this evidence, we base our empirical hypotheses on liquidity-based models, where private information does not influence trading strategies.

In the models by Foucault et al. (2005) and Roşu (2009) there are two types of traders; patient and impatient. As the models assume no information asymmetries, the heterogeneity in trading horizon (patience) is the main driver of market dynamics. A trader's patience determines his waiting cost, which he trades off with the execution cost. In equilibrium of each model this trade-off induces impatient traders to submit market orders, whereas patient traders tend to submit limit orders. Accordingly, market liquidity depends on the ratio of patient to impatient traders, denoted ρ by Foucault et al. (2005), which is exogenous in the model.[8] When ρ is high, competition between patient traders causes the market bid-ask spreads to be tight. On the other hand, when ρ is low, patient traders do not need to post aggressive limit orders to achieve order execution, which leads to wider bid-ask spreads.

[8] Roşu (2009) denotes this ratio *c*, calling it a measure of competition in the supply of liquidity.

What are the implications of the liquidity-based models for the closing of the stock index futures market? Foucault et al. (2005) offer some insights on this issue. In reference to stock markets, they postulate that the lack of overnight trading and institutional benchmarking to the closing price make many investors eager to trade towards the end of the trading day. In the market for stock index futures, such impatient traders are likely to include arbitrageurs who typically do not hold any positions overnight, and portfolio hedgers who benchmark their performance to the reference price. This increase of impatient traders, and corresponding decrease in ρ, is likely to have implications for market quality towards the end of the trading day. The introduction of a closing call auction extends market opening hours and offers a limit order book with a high probability of execution. Foucault et al. (2005) argue that the introduction would decrease the impatience towards the end of the continuous trading. As we are able to estimate patient and impatient behavior in the futures limit order book, we formulate two testable hypotheses, based on the predictions from Foucault et al. (2005):

H1a: In the absence of a closing call auction at the futures market, the ratio of patient to impatient traders (ρ) decreases as the end of the trading day is approaching.

H1b: With the introduction of a closing call auction at the futures market, the decrease of ρ at the end of the trading day is mitigated.

In order for their model to converge to its equilibrium, Foucault et al. (2005) make some simplifying, yet clearly unrealistic, assumptions. They also discuss how these assumptions can be relaxed, but not in the particular setting of the market closing. One of their assumptions is that limit orders must be posted inside the prevailing spread, i.e., they have to be price-improving. Hence, when patient traders want to exploit the increasing impatience towards the end of the trading day, their most passive choice available in the model is to improve the current spread by one tick. Furthermore, traders are by assumption not allowed to modify or cancel limit orders, and as ρ is exogenously given, the number of patient traders is independent of the number of impatient traders.

We think that these assumptions rule out important aspects of patient trader behavior towards the end of the trading day. Firstly, we argue that as the current best prices are likely to be absorbed by impatient traders, strategic patient traders will post limit orders outside the best prevailing spread. Secondly, traders are typically reluctant to have limit orders positioned deep into the order book, as they constitute free options if fundamental prices move in that direction (Copeland and Galai, 1983). We argue that near the close of the trading day, such traders will tend not to withdraw their limit orders due to the potential of execution with an impatient trader as counterparty. Thirdly, we reason that the high probability of impatient trading at the close of the trading day will attract patient traders that would otherwise not have come to the market (or would otherwise have behaved impatiently). We refer to these three features of opportunistic patient trader behavior as *order fishing*. Once the closing call auction is introduced we expect a decreasing trader impatience to reduce such order fishing behavior.

The dynamics of order fishing behavior is partially supported by Roşu (2009). In his model, limit orders do not have to be price-improving and they can be modified or cancelled at no cost. Accordingly, he predicts that when large market orders are expected, patient traders post limit orders away from the best price, creating a hump-shaped limit order book depth. The third part of the order fishing story above, that a high presence of impatient traders in a market would attract patient traders who would otherwise not come to the market, is not captured in Roşu's (2009) model. Similar to Foucault et al. (2005), he assumes that the arrival rates of patient and impatient traders are independent Poisson processes. Realizing that order fishing is a combination of increasing incoming limit orders beyond the best prices and decreasing cancellations of such orders, we measure *net order fishing* (NOF) as the ratio of these two. Accordingly, a NOF ratio higher than one indicates the presence of order fishing, and a NOF ratio lower than one implies that the free option disincentive is stronger than the order fishing incentive.

The strategy to post limit orders in the depth of the order book has earlier been analyzed in equity market settings. Using data from the New York Stock Exchange SuperDOT system, Harris and Hasbrouck (1996) find that limit orders beyond the best prices have low execution rate and hence incur high opportunity costs. Ahn et al. (2001) find that the depth beyond best prices increases with intraday volatility (at the Hong Kong Stock Exchange). To our knowledge, however, no one has studied order fishing strategies in response to trader patience before.

We set up the following hypotheses regarding order fishing behavior towards the close of the futures market:

H2a: In the absence of a closing call auction at the futures market, net order fishing activity increases as the end of the trading day approaches.

H2b: With the introduction of a closing call auction at the futures market, the tendency of increasing net order fishing towards the end of the trading day is mitigated.

These hypotheses are supported by Roşu (2009), though we believe that an actual dependence between patient and impatient trader arrival processes makes the tendency even stronger than he predicts.

The behavior of patient and impatient traders is important for several aspects of market quality. As such aspects are likely inputs in the decision of introducing a closing call auction it is interesting to investigate if the effects predicted by theoretical models realize at implementation. Hence, in the next two subsections we discuss implications of the above hypotheses in terms of market liquidity and price discovery.

3.1 Predictions of futures market liquidity

As pointed out by Kyle (1985), market liquidity has three dimensions: tightness, depth, and resiliency. Below, we discuss the expected impact of the closing call auction introduction on each of these dimensions, but first we turn to trading volume.

As trading volume is easily observable in most markets, it is an important measure for benchmarking our results to previous studies of closing call auctions on stock markets. For policy-makers, however, the importance of volume is secondary to measures of market quality. The expected impatience of traders in the absence of a closing call auction leads to a prediction of high day-end trading volume in the models by Foucault et al. (2005) and Roşu (2009). Information-based models make the same prediction, but based on the notion that informed traders prefer to trade when uninformed traders trade, as this minimizes their price impact costs. Thus, before the introduction of the closing call auction at the futures market, we form the following hypothesis regarding futures trading volume towards the end of the continuous trading session:

H3a: In the absence of a closing call auction at the futures market, trading volume increases as the end of the trading day approaches.

According to both the liquidity-based models and the information-based models, an introduction of a closing call will cause trading volume to migrate from the end of the continuous trading session to the call auction. In stock market settings (such as those described by Pagano and Schwartz, 2003, and Kandel et al., 2010), both patience and information will drive trading volume migration from the continuous trading to the call auction. In our stock index futures market setting, we expect no (or weak) information-driven migration. Hence, we predict that migration observed in futures markets is positive but smaller in magnitude than what is observed in stock markets.

H3b: The introduction of a closing call auction at the futures market induces migration of trading volume from the end of the continuous trading session to the call auction.

Turning to market liquidity, Foucault et al. (2005) and Roşu (2009) make clear predictions on how ρ is related to liquidity in terms of tightness and resiliency. Market tightness describes the cost of a roundtrip trade of a quantity of securities without price impact. This is usually measured in terms of the bid-ask spread. Resiliency is the ability of a market to recover after a liquidity shock. Foucault et al. (2005) measure this as the probability that, from a liquidity shock to the next transaction, the spread reverts to its competitive level. Both Foucault et al. (2005) and Roşu (2009) show that low competition among liquidity suppliers (low ρ) results in larger spreads and lower resiliency. Provided that we find support for hypothesis *H1a*, i.e., the notion that ρ falls towards the end of the futures market trading day, we hence expect to see a concurrent widening of the futures spread and a fall in resiliency before the closing call auction is introduced:

H4a: In the absence of a closing call auction at the futures market, the bid-ask spread widens as the end of the trading day approaches.

H5a: In the absence of a closing call auction at the futures market, the resiliency decreases as the end of the trading day approaches.

Moreover, the introduction of the closing call auction is expected to mitigate the fall in ρ towards the end of the trading day (according to hypothesis *H1b*). As a result, we expect to see tighter bid-ask spreads and higher resiliency following the introduction of the closing call auction:

H4b: The introduction of a closing call auction at the futures market leads to a smaller bid-ask spread at the end of the continuous trading session.

H5b: The introduction of a closing call auction at the futures market leads to higher resiliency at the end of the continuous trading session.

The third dimension of liquidity, depth, describes how much a trade of given quantity is influencing the market prices. The assumptions of Foucault et al. (2005) do not allow them to analyze depth, but Roşu (2009) shows that when the competition in liquidity supply is high, depth is high too. In line with this prediction, if ρ is low at the close of the market (as hypothesized in *H1a*) then depth should also be low. However, this prediction is dependent on the assumption of independent order arrival processes. If order fishing behavior is strong, the prediction of low depth at the close may be reversed by the arrival of patient traders who want to take advantage of potentially large market orders. This reasoning leads us to present two conflicting hypotheses:

H6aI: In the absence of a closing call auction at the futures market, the depth decreases as the end of the trading day approaches (in line with Roşu, 2009).

H6aII: In the absence of a closing call auction at the futures market, the depth increases as the end of the trading day approaches (if net order fishing is high).

These hypotheses highlight that depth is influenced by both liquidity supply competition and order arrival dependency. Our empirical investigation may show which of these factors is most influential. The closing call introduction is expected to mitigate the influence of both factors, leading to the hypothesis:

H6b: The introduction of a closing call auction at the futures market leads to a mitigated depth effect at the end of the continuous trading session.

3.2 Predictions of futures volatility and price discovery

Foucault et al. (2005) and Roşu (2009) do not emphasize volatility in their models. However, it is straightforward to assume that if a closing call auction introduction increases patience at the close of the continuous trading phase, it also mitigates volatility. Information-based models also predict lower day-end volatility in the presence of a call auction, as informed traders migrate to the call auction. Similar to our above prediction on trading volume, as we argue that information-based effects are weak in the stock index futures market, we expect that the fall in volatility is smaller in the futures market than what is observed in equity markets. Nevertheless, we formulate the following hypothesis:

H7: The introduction of a closing call auction at the futures market leads to lower volatility at the end of the continuous trading session.

The futures closing price is often used as the reference price for settlement of other derivatives, portfolio manager performance evaluations, and mutual fund net asset valuations. Due to its importance, the futures closing price is also subject to market price manipulation (see Hillion and Suominen, 2004). Hence, ensuring accuracy of the closing price is an important task for policy-makers, and a strong incentive for the introduction of a closing call auction. As the closing call auction at the futures market is likely to assemble large volumes for a final trade, it is believed to mitigate price manipulation and to make futures prices more stable for traders with incentives to trade at the reference price. In the absence of such a mechanism, the race to trade before closing can induce large futures price movements that do not reflect changes in fundamental value. Hence, we predict an improved futures price discovery and a more accurate futures settlement price after the introduction of the closing call auction:

H8: The introduction of a closing call auction at the futures market leads to an improved accuracy of the closing (settlement) price.

4. EMPIRICAL FRAMEWORK

Our empirical analysis is structured into three parts. In this section we introduce the empirical measures used for each part. Firstly, we introduce how we use limit order book data to observe patient, impatient, and order fishing behavior at the futures market. The resulting measures allow us to test hypotheses regarding trader behavior. Secondly, we present our measures of trading volume and futures market liquidity in different dimensions. Finally, we show our measure of futures volatility and techniques for measuring futures price discovery and price accuracy.

4.1 Observing trader behavior in the limit order book

We observe exactly the same order book information as traders at the OMXS 30 index futures market observe in real time. This includes information on prevailing limit orders of up to five levels on both the ask side and the bid side. The data set is limited in the sense that we do not know about any conditions attached to orders. Trades that are executed at several price levels are observed separately; we have no information of what trades belong together in that sense. Furthermore, trades resulting from crosses within the limit order book are reported together with trades that are executed outside the exchange and trades that are crossed with hidden liquidity. The data set also does not explicitly discriminate between limit order book updates that are due to trades and updates that are due to withdrawn limit orders. Finally, we have no information on the identities of traders. In spite of these limitations, we are able to distinguish different levels of aggressiveness of orders at the futures market.

We record volume changes at each price level in the order book during the time period studied. Negative volume changes can be due to either withdrawn limit orders or the execution of market orders. We match each observed trade to the last limit order book observation time-stamped before the trade occurs and the ten subsequent updates of the limit order book data. The first negative change in order volume at the price level of the trade that equals or exceeds the trade volume is concluded to be due to the trade. If this volume change is on the ask-side (bid-side) of the limit order book, the trade is concluded to be buyer-initiated (seller-initiated). This trade-matching algorithm matches 93.5% of all trades to changes in the limit order book. Trades that are not matched to a change in the order book are assumed to be block trades executed at the upstairs market or crossed at hidden liquidity. Following Coppejans et al. (2004), block trades are excluded from further analysis, on the basis that they may bias measurement of trading costs and liquidity. Trades crossed at hidden liquidity are excluded as we neither can distinguish them from block trades, nor can we observe hidden liquidity in the order book. Negative volume changes in the limit order book that are not matched to any trades are taken to represent withdrawn limit orders.

Positive volume changes in the futures limit order book can be either inside the spread, at the spread, or beyond the spread.[9] The assumption in Foucault et al. (2005) that limit orders must be price-improving implies that orders inside the spread should be classified as *patient* and that market orders should be classified as *impatient* (other order types are not allowed). In a real-world setting such as the one we study, we argue that limit orders inside the spread may well be regarded as impatient, whereas orders at the spread may be seen as the option suitable for patient traders. Hence, for our application, we include both market orders and price-improving orders in the category of impatient orders. Orders posted at the current spread are classified as patient. Orders posted beyond the spread, in the depth of the limit order book, are classified as *passive orders*.[10]

Throughout our analysis we consider order volumes rather than the number of orders, due to our inability to observe whether two separate trading volumes belong to each other. Foucault et al. (2005) assume that all orders represent the same volume and hence focus on the number of patient and the number of impatient traders arriving at the market. In our analogy, it seems

[9] In the classification system applied in Degryse et al. (2005) these types of orders correspond to aggressiveness level 4, 5, and 6. For market orders, we are able to distinguish trades that do not change the prevailing spread from trades that have a price impact (level 3 in Degryse et al.). Level 1 represents trades that walk the book. As trades at different price levels are reported separately in our data set, we cannot distinguish such trades from trades that absorb all depth at the best price level (level 2).

[10] As price-improving limit orders can be argued not to be impatient, we repeat our subsequent investigations excluding such orders. The results of these robustness tests are qualitatively the same, but somewhat weaker. These results are available from the authors upon request.

sensible to focus on the volumes the traders represent rather than the number of orders they submit to the futures market.

Using these classifications of order types, we are able to calculate an empirical measure of the degree of patience, denoted ρ by Foucault et al. (2005) and c by Roşu (2009). We denote this empirical approximation of the degree of patience r_i, and define it as:

(1) $$r_i = \frac{1}{T}\sum_{t=1}^{T}\left(\frac{Volume\ of\ \ patient\ orders_{i,t}}{Volume\ of\ \ impatient\ orders_{i,t}}\right)$$

where i denotes a time interval during which orders are observed on each trading day t, and T is the number of trading days in our sample. We calculate sample averages of r for each minute in the periods before and after the introduction of the closing call auction.

4.2 Measuring market liquidity in different dimensions

In the second part of our analysis, we document trading volume and liquidity on a minute-by-minute basis. Futures trading volume is available directly in the transaction data. Futures market tightness and market depth measures are based on limit order book data, whereas the measure of market resiliency utilizes observations on both transactions and limit order book updates.

Futures market tightness is represented by the relative bid-ask spread, which is the difference between the best bid and offer prices prevailing in the order book at the end of each minute as a percentage of the spread midpoint at the same time. Our overall measure of futures market depth is the average of depth observed on the bid side and the ask side, and is obtained as the number of contracts available within k ticks away from the spread midpoint (following Coppejans et al., 2004). Hence, the depth measure describes the quantity that changes the market price by k ticks. The tick size at the futures market throughout our sample is SEK 0.25 and we use $k = 4$. With this setting of k we are never restricted by our data set, since order book data are observed to a depth of five different levels. Market depth can also be measured individually for the bid-side and the ask-side of the order book. We find however that the two tend to be similar and hence report their average.

Our market resiliency measure mirrors the definition given in Foucault et al. (2005), the probability that after a liquidity shock, the spread returns to its previous value before the next transaction occurs. We let market orders that changes the prevailing spread represent liquidity shocks. We record the spread prevailing just before each such liquidity shock (S_{shock}) and compare it to the spread prevailing just before the next trade observation that is preceded by an order book update (S_{update}). We define futures market resiliency in a given time period *i* as the observed probability that S_{update} is smaller than or equal to S_{shock} according to:

(2) $$Resiliency_i = \frac{1}{J_i} \sum_{j=1}^{J_i} I_{i,j} (S_{shock,i,j} - S_{update,i,j} \le 0)$$

where J_i is the number of liquidity shocks during minute *i*, and $I_{i,j}$ is an indicator variable that equals one when the statement within the parenthesis is true, and zero otherwise.

4.3 Futures price discovery and volatility

Realized volatility is calculated on a minute-by-minute basis as 100 times the midpoint return squared (following Hillion and Suominen, 2004).

In our price discovery analysis, we investigate whether the introduction of the closing call auction at the futures market makes futures prices towards the end of the trading day, including the closing call auction price itself, more or less noisy. In their stock market analysis, Kandel et al. (2010) compute the serial correlation between open-to-close returns and subsequent close-to-open returns, and compare correlation levels before and after the introduction of the closing call auction. The idea is to investigate if transaction prices towards the end of the continuous trading session contain more or less noise after the closing call introduction, given the assumption that price discovery at the open is the same before as well as after the introduction. Accordingly, we define the open-to-close futures return on day *t* as $R_{oc,t}$ and the corresponding close-to-open futures return from day *t* to the next day as $R_{co,t+1}$ according to:

(3) $$R_{oc,t} = \ln(P_{c,t}) - \ln(P_{o,t})$$

(4) $$R_{co,t+1} = \ln(P_{o,t+1}) - \ln(P_{c,t})$$

where $P_{o,t}$ ($P_{c,t}$) is the opening (closing) futures price on day *t*.

Instead of just calculating the correlation coefficient between $R_{co,t+1}$ and $R_{oc,t}$, as in Kandel et al. (2010), we regress the former on the latter in the following dummy variable regression model:

(5) $$R_{co,t+1} = \alpha_1 Q_{1,t+1} + \alpha_2 Q_{2,t+1} + \alpha_3 Q_{1,t+1} R_{oc,t} + \alpha_4 Q_{2,t+1} R_{oc,t} + u_{co,t+1}$$

where α_1, α_2, α_3, and α_4 are regression coefficients, $u_{co,t}$ is a close-to-open futures return shock at time *t*, and $Q_{1,t}$ ($Q_{2,t}$) is a dummy variable that equals one during the Pre-period (Post-period) and zero otherwise. In the regression setup, α_3 (α_4) measures the dependence of close-to-open returns on preceding open-to-close returns during the Pre- (Post-) period. Thus, if futures closing prices are noisy during the Pre- (Post-) period, we expect close-to-open returns to be dependent on preceding open-to-close returns, and the coefficient α_3 (α_4) to be significantly different from zero. Moreover, if the introduction of the closing call indeed reduces the noise in futures prices towards the futures market closing, we expect $|\alpha_4|$ to be lower than $|\alpha_3|$.

The futures returns are calculated using different definitions of the closing price. In specification A, we use the last trading price in the continuous trading session during the Pre-period, and the closing call auction price during the Post-period, enabling us to evaluate whether the introduction of the closing call auction facilitates a less noisy futures closing price, and thus futures settlement price. Moreover, to investigate whether the introduction of the closing call alters the amount of noise in the futures prices towards the end of the continuous trading session, we use the last trading price in the continuous trading session, both during the Pre- and the Post-period, as the closing price in specification B. Finally, for robustness, specification C replaces the last trading price in specification B with the average trading price during the last five minutes of the continuous trading session.

The coefficients in each regression model are estimated with maximum likelihood, where standard errors are corrected for heteroskedasticity and autocorrelation in the residuals (20 lags) according to White (1980), and Newey and West (1987). Moreover, since close-to-open and open-to-close returns, at least on the stock market, often are found to be well described by a generalized autoregressive conditional heteroscedasticity (GARCH) process (see e.g., Masulis and Ng, 1995), we add the following equations to the regression model in equation (5):

(6) $$u_{co,t+1} = \sqrt{h_{co,t+1}}\,\varepsilon_{co,t+1}$$

(7) $$h_{co,t+1} = \beta_0 + \beta_1 \varepsilon_{co,t}^2 + \beta_2 h_{co,t}$$

where β_0, β_1, and β_2 are regression coefficients, $\varepsilon_{co,t+1}|\Im_t \sim N(0,1)$, $\Im_t$ denotes the information set available at time *t*, $N(0,1)$ is the standard normal distribution, and $h_{co,t}$ is the conditional variance of close-to-open futures return shocks at time *t*.

5. RESULTS AND ANALYSIS

We begin our analysis of the closing call auction introduction by controlling for differences between the time period before and after the introduction that are not likely to be connected to the event in question. As the sample studied in this paper (by necessity) spans parts of the financial turmoil of 2008, including the Lehman Brothers crisis and its aftermath, we expect our measures of trader patience, net order fishing, futures volatility, trading activity, and liquidity to vary substantially over the days and months of our sample period. Table 2 displays averages of these measures for the two sub-periods considered in our study, calculated for the hour 11:00-12:00 each day. The state of the limit order book at this time of the day is assumed to be independent of the closing mechanism of the market. As expected, the Pre-period that contains the lion share of the financial turmoil has substantially higher volatility and illiquidity than the following Post-period.[11] The Pre-period also shows a lower degree of trader patience and net order fishing. Furthermore, Table 1 shows that the Pre-period has a much higher futures trading activity than the Post-period, possibly reflecting traders' needs for hedging in times of uncertainty. All the across-period differences are statistically significant and reflect an increasing quality of the OMXS 30 futures market over the time interval studied. To control for this, in our subsequent analysis, we follow Kandel et al. (2010) and report each day-end measure of trading activity and liquidity relative to the average of the same measure at noon on the same day (11:00-12:00 a.m.). In this way we retain inter-temporal effects specific to the end of the day, whereas general inter-temporal effects are cancelled out.

5.1 Futures market trader patience and order fishing

Our measures of the degree of patience and net order fishing are presented in Figures 1 and 2. Following Kandel et al. (2010), we focus on the last ten minutes of the continuous trading session

[11] Note that market tightness is a measure of illiquidity, whereas market depth is a measure of liquidity.

of the futures market in our analysis. Figure 1 illustrates a trend of falling relative patience (falling *r*) as the closing of the futures market approaches. In the last minute of continuous trading, the degree of patience among traders is more than 40% lower than between 11:00 and 12:00 in the same day (henceforth referred to as noon). This is in line with hypothesis *H1a*. Furthermore, we observe a pattern of higher trader patience after the introduction of the closing call auction, across all ten minutes before the closing time at the futures market. This implies that the trend is mitigated, which supports our hypothesis *H1b*. Our results lend support to the predictions by Foucault et al. (2005) that the extra trading opportunity after the continuous trading session decreases trader impatience.

To statistically test these observations we run pooled panel regressions of *r* with nine minute dummy variables as regressors. We then perform an *F*-test to test whether the regression coefficients are jointly different from zero. This test is carried out for each of the Pre- and Post-period samples, with *p*-values reported in the right-most column of Table 3. For each separate minute, we employ a *t*-test to investigate each null hypothesis that the values before and after the introduction of the closing call auction in the futures market are the same. The *p*-values of these tests are reported for each variable and each minute in Table 3. The *F*-test shows that there is a statistically significant decrease in patience at the close of the futures market during the pre-period. This trend persists in the post-period, but there is statistical evidence that it is mitigated, at least in the last minute of the continuous trading session (at the 5% significance level). This indicates that the introduction of the closing call auction increases the patience of traders towards the close of the continuous session. The concentration of this effect to the last minute of continuous futures trading corresponds to the equity market findings of Kandel et al. (2010), showing that hypothesized effects of closing call auctions are concentrated to the last minute. Overall, our test results constitute support for our hypotheses *H1a* and *H1b*.

We assess the order fishing hypotheses in a similar way as for the degree of patience. For each minute, before and after the introduction of the closing call auction, average ratios of net order fishing (NOF) are calculated. These averages are tested for differences across minutes and sub-samples using *F*-tests and *t*-tests, with results presented in Table 3. During the Pre-period, we observe a trend of increasing NOF, and the *F*-test indicates that this trend is statistically significant. This constitutes support for hypothesis *H2a*. The trend of increasing NOF is particularly strong in the very last minute of continuous futures trading, where the ratio is more than 50% higher than at noon and also higher than the value ten minutes earlier. After the introduction of the closing call auction, the sharp last-minute increase in NOF is vanishing. The last-minute NOF is only marginally higher than ten minutes earlier. The *t*-tests show that the difference between the pre- and the post-periods are statistically significant for the last two minutes of the continuous trading session. This constitutes support for hypothesis *H2b*, and is in line with predictions by Roşu (2009). To our knowledge, the evidence presented here is the first empirical evidence of order fishing behavior.

5.2 Futures market liquidity

From the previous stock market studies, we expect the introduction of a closing call auction at the futures market to cause a reallocation of trading volume from the last minutes of the continuous trading phase to the auction. This behavior is mainly driven by discretionary traders seeking to trade at the reference price, which in the case of OMXS 30 index futures is set equal to the closing call auction price. Figure 3 and Table 4 (with *F*-tests and *t*-tests of the same type as in Table 3) display the average trading activity in the last ten minutes of the daily continuous trading session during each of our two sub-periods, relative to noon, before and after the call auction introduction. The Pre-period volumes show the expected pattern of a sharply increasing volume in the last minute of the trading day. In addition, the *F*-test for difference among minute-by-minute trading volumes during the final ten minutes of the continuous trading session is rejected at any reasonable significance level. The increasing trading volume towards the end of the continuous trading session during the Pre-period is consistent with hypothesis *H3a*.

Unexpectedly, the increasing trading volume pattern persists after the closing call auction introduction, as the Post-period exhibits a corresponding substantial last-minute volume increase, which is supported by the corresponding *F*-test result in Table 4. Relative to noon, the last-minute trading volume before the introduction is 28.35, as compared to 24.31 after the introduction. Thus, we only find weak support for our hypothesis *H3b* during the final minute of the continuous trading session, that trading migrates to the closing call auction; the *t*-test indicates a difference between the normalized last-minute Pre- and Post-period trading volumes only at the 10% significance level. Moreover, each *t*-test for corresponding across-period difference of trading volume for each other minute during the last ten minutes of the continuous trading session in fact indicates an increase in trading volume from the Pre-period to the Post-period.

Our trading volume results imply a smaller trading activity impact of the closing call auction in the OMXS 30 futures market than what has been reported for stock markets. Kandel et al. (2010) show that the pre-introduction last-minute trading volume relative the preceding minute is more than 150% higher in Milan (MIB 30) and more than 100% higher in Paris (CAC 40). The corresponding post-introduction numbers are reported at less than 15% higher in both indexes. For comparison, the OMXS 30 index futures pre-introduction last-minute trading volume relative the preceding minute is more than 150% (from 11.09 to 28.35 in Table 4), while the corresponding post-introduction figure amounts to roughly 66% (from 14.64 to 24.31). Hence, the decrease in last-minute trading volume is much smaller in the index futures market than in the equity market. This may be due to that stock markets have more information-driven traders, who according to theory will migrate to the closing call auction. As we document in Table 1 that the closing call auction in OMXS 30 index futures does attract about 2% of the daily trading volume, we conclude that there is a migration of trading activity to the closing call auction, but that this migration does not only originate from the last few minutes of the continuous trading phase.

Figures 4, 5 and 6 display futures market liquidity (tightness, depth and resiliency respectively) in the last ten minutes of the continuous trading, and Table 4 reports associated *F*-tests and *t*-tests. The measures reported are again related to noon measures to control for time effects within our sample. We find that end-of-day market spreads are on average tighter than at noon, indicating higher liquidity. In the very last minute of continuous trading, however, market tightness is decreasing (the spread is widening). This is consistent with hypothesis *H4a*, and in line with the prediction that decreasing competition leads to wider spreads. The same pattern is found for the stock markets investigated by Kandel et al. (2010), but they observe a much stronger increase before the introduction of a closing call auction than we do for the futures market. Furthermore, we find no evidence in favor of our hypothesis *H4b*. The introduction of the closing call auction at the futures market appears not to affect the relative bid-ask spread.

Our results for market resiliency resemble those for market tightness. We do observe a statistically significant last-minute decrease in resiliency, which is predicted following the increase in trader patience. However, the decrease in resiliency persists after the closing call auction is introduced. We hence have evidence in support for hypothesis *H5a*, but not for *H5b*. Even though trader patience is higher at the close of the market when a closing call auction is instituted, this does not seem to influence liquidity in terms of tightness and resiliency.

From the results in Figure 5 and Table 4, we observe a clear and highly significant increase in futures market depth towards the end of the continuous trading session, in particular for the last minute of the Pre-period. This result is in accordance with hypothesis *H6aII*, and not *H6aI*, and suggests that the assumption of independent order arrival processes in Roşu (2009) should be relaxed in future theoretical work. Moreover, we find a highly significant difference in Pre-period and Post-period depth during the last minute of the continuous trading session. The sharp last-minute increase in futures market depth observed before the introduction of the closing call auction is reversed into a corresponding decrease in depth after the introduction, which is consistent with hypothesis *H6b*. Note that previous stock market studies do not consider the depth dimension of liquidity, making this particular result novel to the research on the effects of the introduction of a closing call auction in general.

The support for our hypotheses *H6aII* and *H6b* provides indirect evidence in favor of our order fishing hypothesis at the futures market. The Pre-period observation of an increasing last-minute depth may be seen as an indication of less trading aggressiveness. Liquidity providers may regard the last minute as an opportunity to profit from an expected increase in the intensity of discretionary market orders by entering limit orders (and/or refraining from removing limit orders) at prices deviating more from the midpoint than otherwise. After the introduction of the closing call auction in the futures market, this opportunity disappears as discretionary traders are likely to prefer trading in the call auction. Hence, the decreasing depth may reflect that last-minute order fishing is no longer profitable at the futures market.

5.3 Futures market price discovery and volatility

Figure 7 displays futures realized volatility towards the closing of the continuous trading session calculated as a ratio of realized volatility at noon. In addition, results from corresponding F-tests and t-tests are displayed in Table 4. We see that before the introduction of the closing call, the last ten minutes of futures trading exhibit volatilities twice as large as at noon. Such volatility differences are in line with the well-known intraday U-shape in volatility (see e.g., Hillion and Suominen, 2004). The ratio between the last minutes and noon observed here for the OMXS 30 futures market is on par with that observed for the CAC 40 stock market in Paris, but slightly lower than that of MIB 30 stock market in Milan (Kandel et al., 2010).

Focusing on the last minute of trading in the period before the introduction of the call auction, we observe more than eight times higher futures volatility than at noon. Again, this is somewhat smaller than what Kandel et al. (2010) find for the stock market in Milan (11 times higher volatility), but larger relative to what they find for Paris (four times higher). According to Hillion and Suominen (2004), this last minute volatility increase may be due to manipulation related to the reference price of the market.

After the introduction of the closing call auction, the end-of-day volatility is lower (relative to noon) in our sample, consistent with the results in Kandel et al. (2010). Still, futures volatility is increasing in the last minute, up to 5.5 in our Post-period, which is higher than the findings for European stock markets, where Kandel et al. (2010) find a corresponding Post-period normalized day-end volatility of two to three times larger than the noon level. From the associated *t*-test in Table 4, we conclude that there is a significant difference between Pre-period and Post-period volatility during the final minute of the continuous trading session, at least at the 10% significance level. Thus, we find some support for our hypothesis *H7*; the last-minute futures volatility effect appears to be mitigated by the introduction of a closing call auction at the futures market, in line with previous results from stock markets. This may be due to decreasing opportunities for reference price manipulation.

Table 5 contains results from the regressions of futures close-to-open returns on preceding open-to-close returns. Starting with the results for specification A, where we use the last trading price in the continuous trading session during the Pre-period, and the closing call auction price during the Post-period when computing futures returns, we note that the coefficient α_3 is significantly negative at any reasonable significance level, whereas the coefficient α_4 clearly is not significantly different from zero. Evidently, the futures close-to-open returns are significantly negatively related to preceding open-to-close returns during the Pre-period, but not during the

Post-period. This result is consistent with the notion that the Pre-period closing price is noisier than the corresponding Post-period closing call auction price, and implies that the introduction of the closing call auction has reduced the noise in the futures settlement price. Thus, we find support for our hypothesis *H8*; closing the futures market with a call auction improves price discovery at the end of the trading session, and results in a more efficient futures settlement price.

For specification B, in which we let the last trading price in the continuous trading session during both the Pre- and the Post-period represent the closing price in the futures return calculations, the regression results in Table 5 show that the coefficient α_3 (α_4) is (not) significantly negative at any reasonable significance level. The evidence indicates that the introduction of the closing call auction reduces the noise, and therefore improves price discovery, at the very last instant of the continuous trading session. Even when we in specification C consider the average trading price during the final five minutes of the continuous trading session as the proxy for the futures closing price, we can observe a significantly negative Pre-period α_3 and a Post-period α_4 that is not significantly different from zero. However, the specification C level of the estimated α_3 is only roughly -0.02 while the corresponding estimated coefficient is less than -0.07 for each of the specifications A and B. Hence, for the Pre-period, the evidence show that the average futures trading price during the final five minutes of the continuous trading session is less noisy than the corresponding last trading price. This would indicate that in the absence of a closing call auction, calculating the daily futures settlement price using an average trading price is a more efficient choice than simply using the price from the very last transaction of the day.

6 CONCLUDING REMARKS

This paper is the first to investigate how the introduction of a closing call auction in a futures market influences market quality and price accuracy at the end of the trading day. The closing mechanism at the futures market is important to both policy-makers and market participants as it determines the daily futures settlement price, which is widely used as a reference price for valuation of other index derivative products and investment portfolios. Our results show that the closing call auction reduces end-of-day volatility and improves the closing price accuracy. The introduction of a closing call auction at the OMXS 30 index futures market can hence be regarded as successful.

The index futures market is also interesting from a theoretical perspective, as it is a market primarily characterized by traders without private information (Subrahmanyam, 1991; Berkman et al., 2005). This makes the market suitable as a test-ground for theoretical models where orders submission strategies are determined by trader patience rather than private information (such as Foucault et al., 2005, and Roşu, 2009). Using high-frequency data, we are able to infer from limit order book entries that trader patience decreases at the close of the market, and that this effect is reduced when a closing call auction is introduced. The theoretical models by Foucault et al. (2005) and Roşu (2009) predict that decreasing trader patience leads to wider bid-ask spreads and lower market resiliency, and our empirical investigation confirms both these effects. As the introduction of a closing call auction increases trader patience, liquidity should, according to the models, improve. Such improvements are, however, not documented in our study.

Roşu (2009) also predicts that the low competition in liquidity supply seen at the close of the market would lead patient traders to post limit orders outside the current spread and to refrain from withdrawing orders that have ended up deep inside the order book. We label these patient trading strategies order fishing, and document a sharp (statistically significant) increase in such behavior in the very last minute of the trading day. The order fishing behavior vanishes when the closing call auction is introduced. Roşu also predicts that the decreasing patience at the close of the market leads to decreasing market depth, but our investigation documents the opposite. We believe that the potential of large market orders associated with low trader patience attracts opportunistic patient traders who would otherwise not have come to the market. This trader type is ruled out by Roşu's assumption of independent arrival processes of patient and impatient traders. Our results suggest that this assumption should be relaxed in future theoretical work.

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Table 1: Summary statistics for futures trading activity

	Daily total volume	*Daily call volume*	*Relative daily call volume*	*Daily number of trades*	*Daily open interest*
Panel A: Pre-period					
Nearby contract	90 981	NA	NA	13 024	463 541
Second contract	22 389	NA	NA	1 692	94 471
Third contract	182	NA	NA	4	7 665
Rollover	94 866	NA	NA	13 566	476 031
Panel B: Post-period					
Nearby contract	63 935	1 335	0.0209	11 083	404 650
Second contract	14 626	181	0.0123	1 327	63 914
Third contract	147	0	0.0000	1	9 559
Rollover	66 532	1 422	0.0214	11 592	415 716

Table 1 contains daily summary statistics (averages) for futures trading volume (number of traded contracts), number of transactions, and open interest. Pre-period is between June 9, 2008, and June 5, 2009, and Post-period is between June 8, 2009, and February 5, 2010. Relative daily call volume is the daily call volume divided by daily total volume. Trading volume and number of trades are measured during the official exchange opening hours, and exclude off-exchange trades. Days with involuntary trading interruptions at the futures market and half trading days (days before holidays) are excluded.

Table 2: Measures of patience, net order fishing, volatility and liquidity at the futures market

	Degree of patience	*Net order fishing*	*Realized volatility*	*Market tightness*	*Market depth*	*Market resiliency*
Pre-period	0.5678	0.9761	0.0045	0.0007	143.59	0.6847
Post-period	0.8233	1.0214	0.0013	0.0004	228.07	0.7283
Test (*p-value*)	0.0000	0.0000	0.0000	0.0014	0.0000	0.0000

Table 2 reports measures of the ratio of patient to impatient traders (*r*), net order fishing (*NOF*), realized volatility, limit order book tightness, depth and resiliency at the futures market. All measures are reported for the hour 11:00-12:00 each day, averaged across all trading days in each period. Realized volatility, market tightness, and market depth are calculated for each minute in the interval 11:00-12:00 each day, and then averaged. *r* is measured as the volume placed by the use of patient orders during the interval, i.e., orders at the best bid-ask spread, relative the volume placed by the use of impatient orders during the interval, i.e., market orders and orders within the best bid-ask spread. Net order fishing is measured as the ratio of passive order submissions during the interval to cancelled orders beyond the best bid-ask quotes during the interval. Passive order submission is measured as the limit order volume placed outside the best bid-ask spread. Cancelled order activity is measured as the volume withdrawn from the order book outside the best bid-ask spread. Realized volatility is the square of 100 times the minute return. Futures market tightness is the relative bid-ask spread, calculated as the difference between best bid and offer prices prevailing in the order book at the end of each minute as a percentage of the spread midpoint at the same time. Futures market depth is measured at the end of each minute as the number of contracts within four ticks away from the spread midpoint in each direction, divided by two. The tick size throughout our sample is SEK 0.25. Futures market resiliency is the probability that after a liquidity shock, the spread returns to its previous value (or smaller) before the next transaction occurs. Liquidity shocks are defined as market orders that change the prevailing spread. Pre-period is between June 9, 2008, and June 5, 2009, and Post-period is between June 8, 2009, and February 5, 2010. Days with involuntary trading interruptions at the futures market and half trading days (days before holidays) are excluded.

Table 3: Normalized measures of degree of patience and net order fishing towards the end of the continuous trading phase

		Minutes before closing of continuous trading										
Variable	*Period*	5:10	5:11	5:12	5:13	5:14	5:15	5:16	5:17	5:18	5:19	*Test* (*p-value*)
Degree of patience (r)	*Pre-*	1.051	1.073	1.066	1.114	0.991	0.976	0.926	0.791	0.792	0.585	0.000
	Post-	1.150	1.234	1.225	1.166	1.166	1.016	0.964	0.903	0.880	0.692	0.000
	Test (*p-value*)	0.245	0.069	0.106	0.627	0.046	0.561	0.578	0.037	0.180	0.020	
Net order fishing	*Pre-*	1.106	1.120	1.137	1.075	1.124	1.115	1.125	1.186	1.233	1.523	0.000
	Post-	1.068	1.071	1.087	1.070	1.133	1.239	1.112	1.135	1.133	1.080	0.005
	Test (*p-value*)	0.396	0.165	0.295	0.899	0.833	0.094	0.704	0.356	0.011	0.000	

Table 3 reports measures of the ratio of patient to impatient traders (*r*) and net order fishing (NOF) for each minute in the interval 5:10-5.20 pm, relative to the value of the ratio for the hour 11:00-12:00 each day. Reported numbers are averages across all trading days in each period. *r* is measured as the volume placed by the use of patient orders, i.e., orders at the best bid-ask spread, relative the volume placed by the use of impatient orders, i.e., market orders and orders within the best bid-ask spread. Net order fishing is measured as the ratio of passive order submissions to cancelled orders beyond the best bid-ask quotes, at the futures market for the last ten minutes during the trading day. Passive order submission is measured as the limit order volume placed outside the best bid-ask spread. Cancelled order activity is measured as the volume withdrawn from the order book outside the best bid-ask spread. Pre-period is between June 9, 2008, and June 5, 2009, and Post-period is between June 8, 2009, and February 5, 2010. Days with involuntary trading interruptions at the futures market and half trading days (days before holidays) are excluded. A pooled panel regression with dummy variables for nine minutes is run for each sub-period and each variable. F-tests are performed for each of these regressions to test the null hypothesis that all the regression coefficients are zero, i.e. that there is on average no significant change in the variable in question over the interval 5.10-5.20 pm. The p-values of these tests are presented in the rightmost column of the table. For each separate minute, a t-test is employed to investigate each null hypothesis that the values before and after the introduction of the closing call auction in the futures market are the same. The p-values of these tests are reported in the table.

Table 4: Normalized average futures trading volume, liquidity and volatility towards the end of the continuous trading phase

		Minutes before closing of continuous trading										
Variable	*Period*	5:10	5:11	5:12	5:13	5:14	5:15	5:16	5:17	5:18	5:19	*Test* (*p-value*)
Trading volume	*Pre-*	4.461	4.487	4.585	4.751	5.253	6.104	7.702	9.868	11.09	28.35	0.000
	Post-	5.257	5.492	6.244	8.417	8.197	9.500	10.64	13.83	14.64	24.31	0.000
	Test (*p-value*)	0.081	0.025	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.053	
Market tightness	*Pre-*	0.834	0.875	0.858	0.820	0.892	0.822	0.764	0.819	0.789	1.093	0.000
	Post-	0.792	0.815	0.826	0.837	0.844	0.845	0.872	0.847	0.857	1.007	0.000
	Test (*p-value*)	0.238	0.166	0.405	0.651	0.253	0.566	0.003	0.464	0.101	0.288	
Market depth	*Pre-*	1.846	1.909	2.082	2.116	2.184	2.435	2.652	2.799	3.271	5.007	0.000
	Post-	1.878	2.000	2.081	2.241	2.496	2.559	2.703	2.838	2.965	2.482	0.000
	Test (*p-value*)	0.789	0.478	0.993	0.401	0.032	0.468	0.776	0.823	0.133	0.000	
Market resiliency	*Pre-*	0.991	0.979	0.972	0.980	0.983	0.992	0.990	0.987	0.990	0.908	0.097
	Post-	1.107	1.095	1.091	0.966	0.944	1.033	0.947	0.941	0.903	0.904	0.000
	Test (*p-value*)	0.000	0.001	0.000	0.678	0.281	0.197	0.178	0.138	0.004	0.858	
Realized volatility	*Pre-*	2.846	2.906	2.486	2.652	2.335	3.516	3.127	4.095	3.981	8.740	0.000
	Post-	2.318	2.258	3.111	4.355	2.482	3.906	3.466	2.977	3.712	5.543	0.001
	Test (*p-value*)	0.310	0.226	0.184	0.004	0.710	0.563	0.631	0.167	0.700	0.083	

Table 4 reports measures of trading volume, bid-ask spread, depth, resiliency, and realized volatility, for each minute in the interval 5:10-5.20 pm, relative to the value of the ratio for the hour 11:00-12:00 each day. Reported numbers are averages across all trading days in each period. Futures market tightness is the relative bid-ask spread, calculated as the difference between best bid and offer prices prevailing in the order book at the end of each minute as a percentage of the spread midpoint at the same time. Futures market depth is measured at the end of each minute as the number of contracts within four ticks away from the spread midpoint in each direction, divided by two. The tick size throughout our sample is SEK 0.25. Futures market resiliency is the probability that after a liquidity shock, the spread returns to its previous value (or smaller) before the next transaction occurs. Liquidity shocks are defined as market orders that change the prevailing spread. Realized volatility is the square of 100 times the minute return. Pre-period is between June 9, 2008, and June 5, 2009, and Post-period is between June 8, 2009, and February 5, 2010. Days with involuntary trading interruptions at the futures market and half trading days (days before holidays) are excluded. A pooled panel regression with dummy variables for nine minutes is run for each sub-period and each variable. F-tests are performed for each of these regressions to test the null hypothesis that all the regression coefficients are zero, i.e. that there is on average no significant change in the variable in question over the interval 5.10-5.20 pm. The p-values of these tests are presented in the rightmost column of the table. For each separate minute, a t-test is employed to investigate each null hypothesis that the values before and after the introduction of the closing call auction in the futures market are the same. The p-values of these tests are reported in the table.

Table 5: Regression results for futures close-to-open returns on futures open-to-close returns

Specification	*Computation of futures closing price*	α_1	α_2	α_3	α_4	β_0	β_1	β_2
A	*Pre-period: Last trading price in continuous session*	2.64e-4	9.94e-4	-0.0745	-0.0213	1.71e-6	0.1016	0.8887
	Post-period: Closing call auction price	(0.5733)	(0.0168)	(0.0001)	(0.7940)	(0.0000)	(0.0008)	(0.0000)
B	*Pre-period: Last trading price in continuous session*	2.39e-4	9.28e-4	-0.0731	-5.80e-3	1.60e-6	0.0939	0.8963
	Post-period: Last trading price in continuous session	(0.6013)	(0.0340)	(0.0000)	(0.9370)	(0.0000)	(0.0007)	(0.0000)
C	*Pre-period: Average trading price in continuous session* (*5 min.*)	7.98e-4	1.02e-3	-0.0192	-5.30e-3	1.27e-6	0.0889	0.9028
	Post-period: Average trading price in continuous session (*5 min.*)	(0.0327)	(0.0073)	(0.0000)	(0.9395)	(0.0000)	(0.0012)	(0.0000)

Table 5 contains estimation results from GARCH regression models of futures close-to-open returns (R_{co}) on preceding futures open-to-close returns (R_{oc}).The coefficients for each model are estimated with maximum likelihood using data from the period between June 9, 2008, and February 5, 2010, where standard errors are corrected for heteroskedasticity and autocorrelation in the residuals (20 lags) according to White (1980), and Newey and West (1987). The model equations are:

$$R_{co,t+1} = \alpha_1 Q_{1,t+1} + \alpha_2 Q_{2,t+1} + \alpha_3 Q_{1,t+1} R_{oc,t} + \alpha_4 Q_{2,t+1} R_{oc,t} + u_{co,t+1},\ u_{co,t+1} = \sqrt{h_{co,t+1}}\varepsilon_{co,t+1},\ h_{co,t+1} = \beta_0 + \beta_1 \varepsilon^2_{co,t} + \beta_2 h_{co,t}$$

where $u_{co,t}$ is a close-to-open futures return shock at time *t*, $\varepsilon_{co,t+1}|\Im_t \sim N(0,1)$, $\Im_t$ denotes the information set available at time *t*, $N(0,1)$ is the standard normal distribution, $h_{co,t}$ is the conditional variance of close-to-open futures return shocks at time *t*, and $Q_{1,t}$ ($Q_{2,t}$) is a dummy variable that equals one during the Pre-period (Post-period) and zero otherwise. Pre-period is between June 9, 2008, and June 5, 2009, and Post-period is between June 8, 2009, and February 5, 2010. Days with involuntary trading interruptions at the futures market and half trading days (days before holidays) are excluded. As closing price, Specification A uses the last trading price in the continuous trading session during the Pre-period and the closing call auction price during the Post-period, Specification B uses the last trading price in the continuous trading session during both the Pre-period and the Post-period, and Specification C uses the average trading price during the last five minutes of the continuous trading session during both the Pre-period and the Post-period.

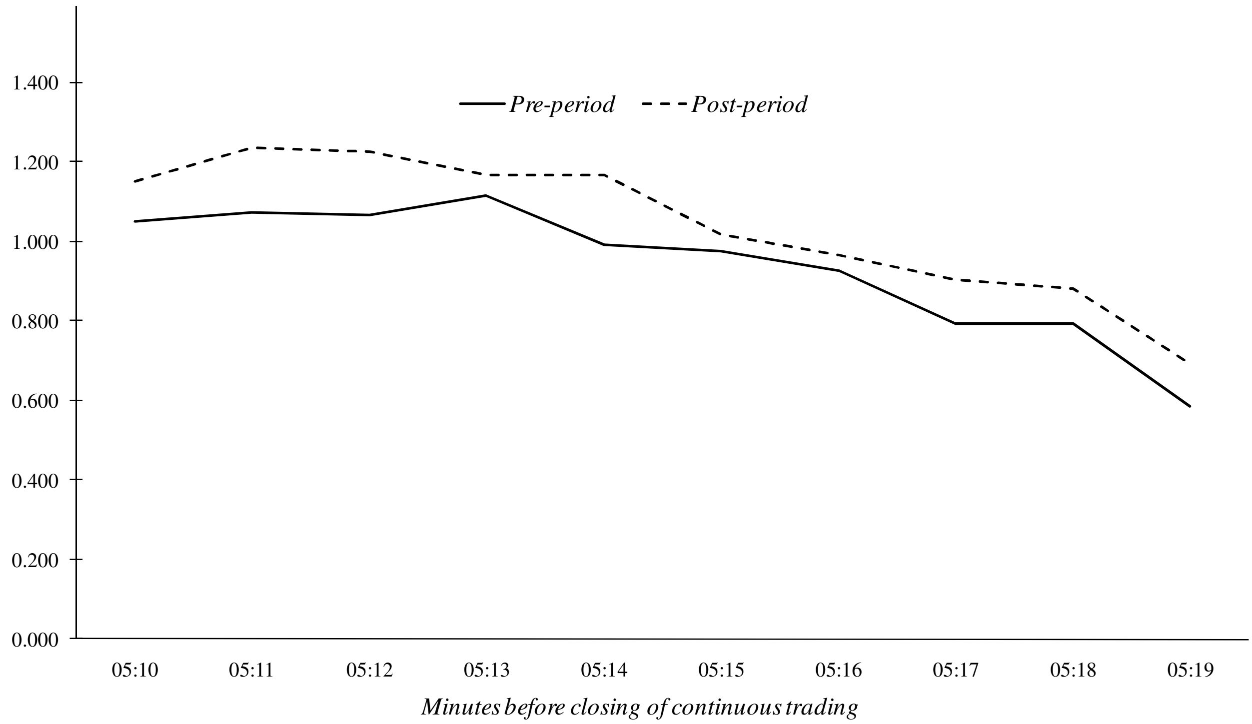

Figure 1: Degree of patience (*r*) towards the end of the continuous trading phase

The figure displays the ratio of patient to impatient traders (*r*) at the futures market for the last ten minutes during the trading day. *r* is measured as the volume placed by the use of patient orders, i.e., orders at the best bid-ask spread, relative the volume placed by the use of impatient orders, i.e., market orders and orders within the best bid-ask spread. For intertemporal comparability, the *r* for each minute each day is divided by the average minute-by-minute noon *r* on the same day (11:00-12:00). Averages of such ratios across all days are reported for each period. Pre-period is between June 9, 2008, and June 5, 2009, and Post-period is between June 8, 2009, and February 5, 2010. Days with involuntary trading interruptions at the futures market and half trading days (days before holidays) are excluded.

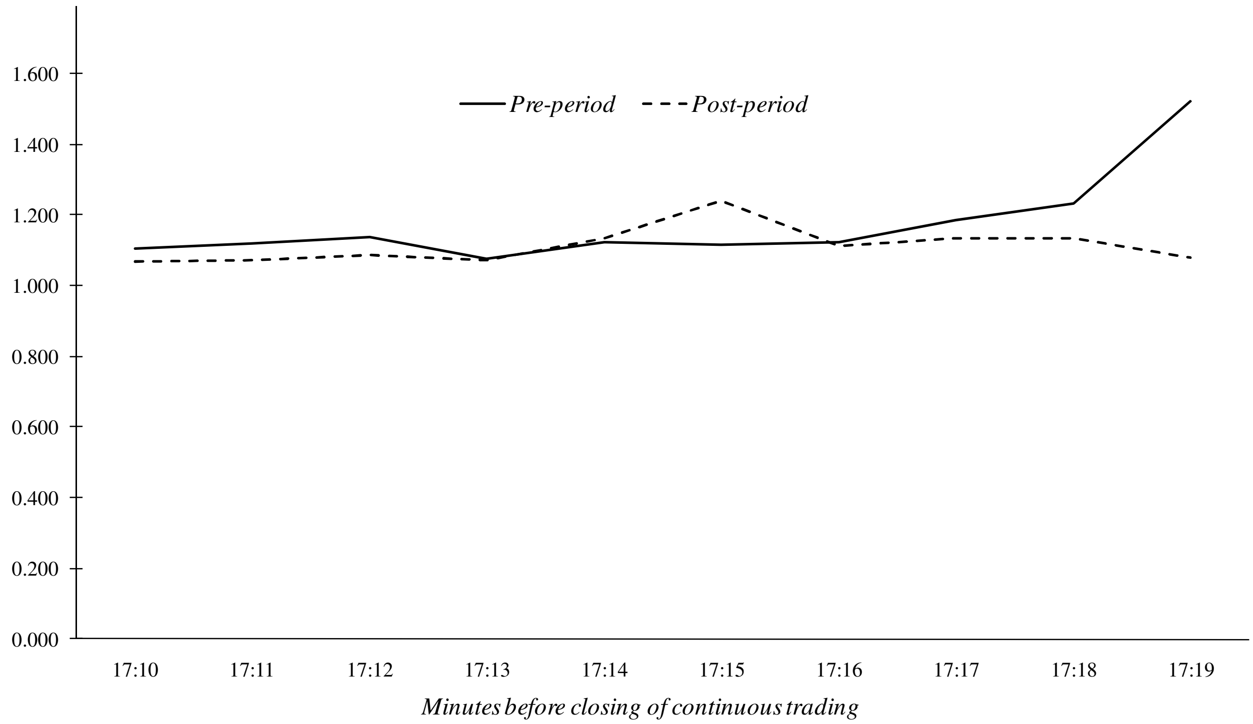

Figure 2: Net order fishing towards the end of the continuous trading phase

The figure displays net order fishing, measured as the ratio of passive order submissions to cancelled orders beyond the best bid-ask quotes, at the futures market for the last ten minutes during the trading day. Passive order submission is measured as the limit order volume placed outside the best bid-ask spread. Cancelled order activity is measured as the volume withdrawn from the order book outside the best bid-ask spread. For intertemporal comparability, net order fishing for each minute each day is divided by the average minute-by-minute noon net order fishing on the same day (11:00-12:00). Averages of such ratios across all days are reported for each period. Pre-period is between June 9, 2008, and June 5, 2009, and Post-period is between June 8, 2009, and February 5, 2010. Days with involuntary trading interruptions at the futures market and half trading days (days before holidays) are excluded.

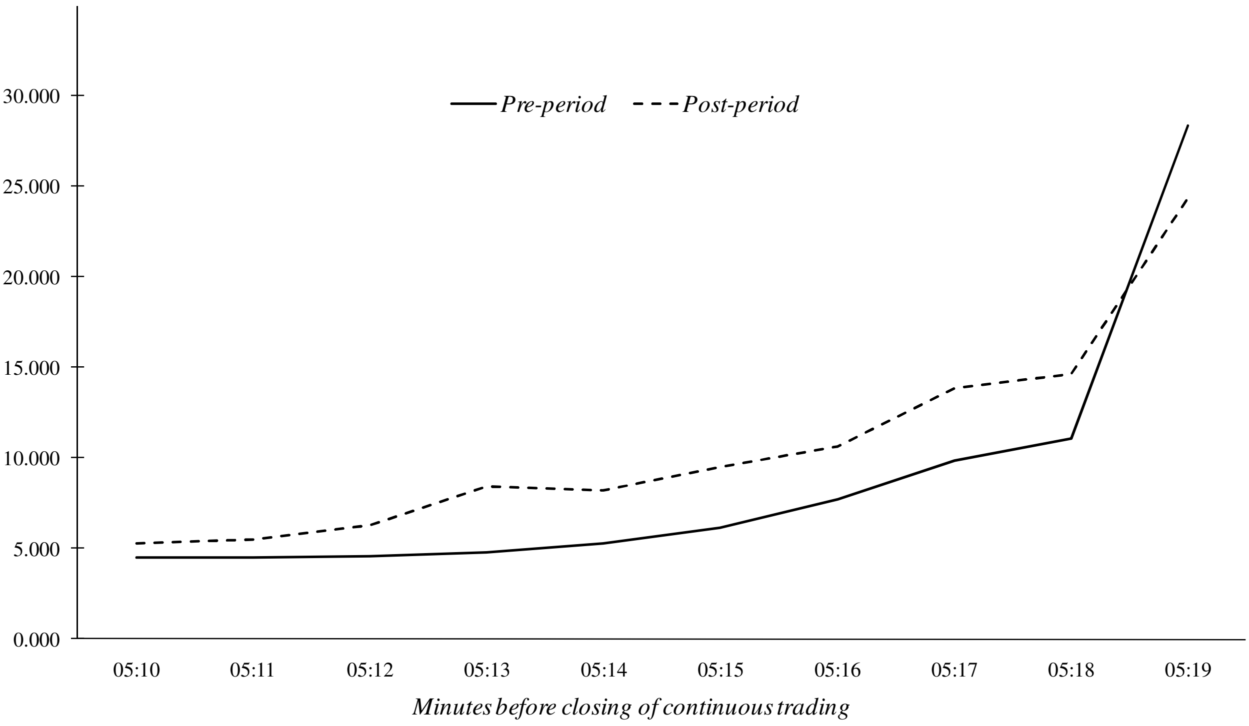

Figure 3: Trading volume towards the end of the continuous trading phase

The figure displays futures trading volume for the last ten minutes during the trading day. For intertemporal comparability, the trading volume of each minute each day is divided by the average minute-by-minute noon trading volume on the same day (11:00-12:00). Averages of such ratios across all days are reported for each period. Pre-period is between June 9, 2008, and June 5, 2009, Post-period is between June 8, 2009, and February 5, 2010. Days with involuntary trading interruptions at the futures market and half trading days (days before holidays) are excluded.

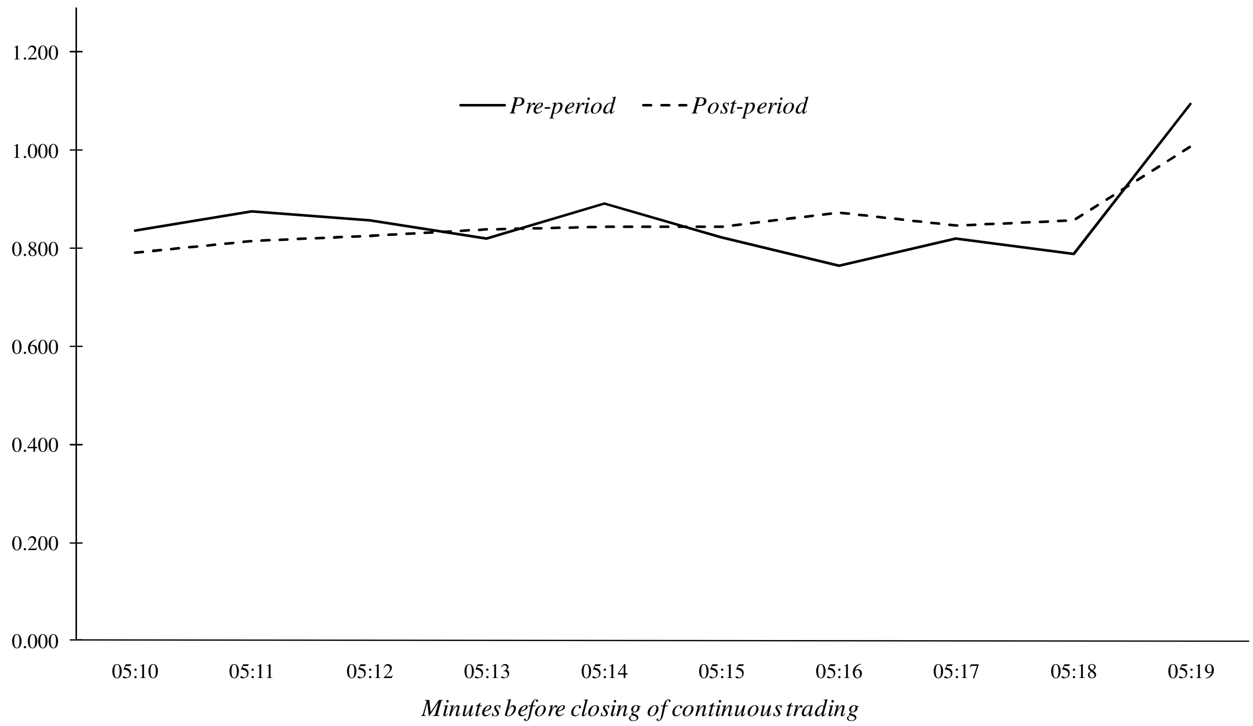

Figure 4: Market tightness towards the end of the continuous trading phase

The figure displays the relative bid-ask spread for the last ten minutes during the trading day. The relative bid-ask spread is the difference between best bid and offer prices prevailing in the order book at the end of each minute as a percentage of the spread midpoint at the same time. For intertemporal comparability, the spread of each minute each day is divided by the average minute-by-minute noon spread on the same day (11:00-12:00). Averages of such ratios across all days are reported for each period. Pre-period is between June 9, 2008, and June 5, 2009, Post-period is between June 8, 2009, and February 5, 2010. Days with involuntary trading interruptions at the futures market and half trading days (days before holidays) are excluded.

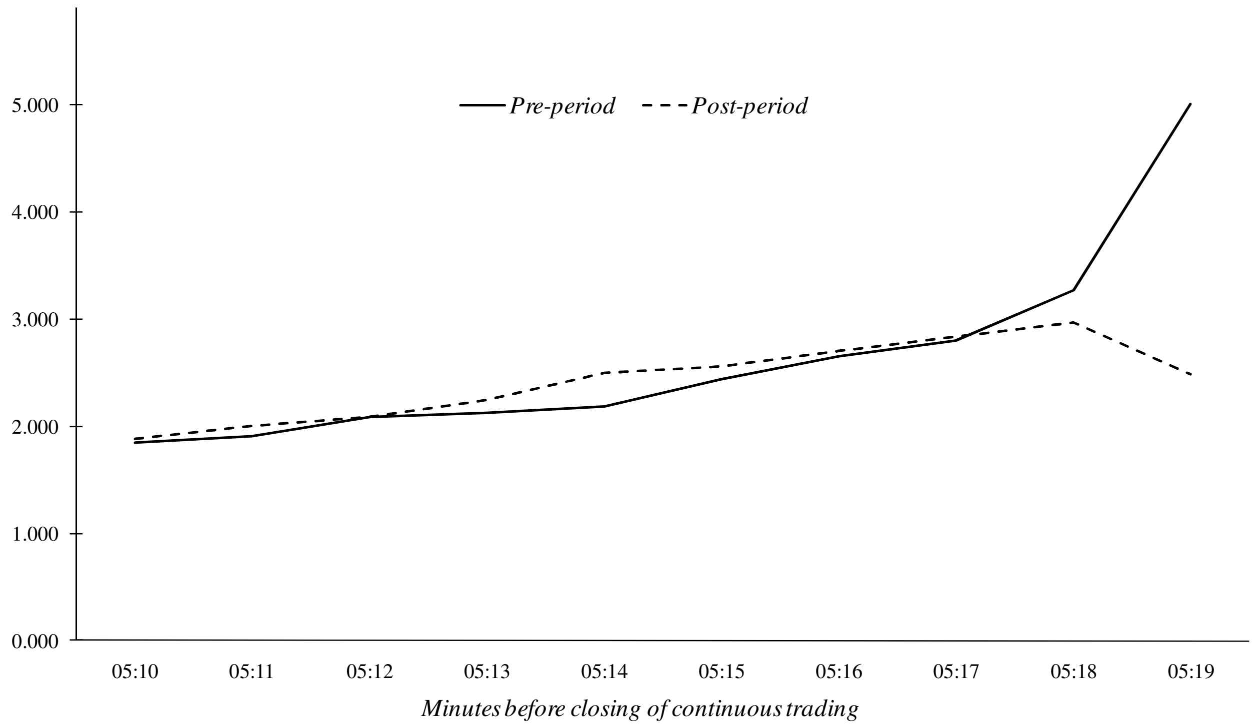

Figure 5: Market depth towards the end of the continuous trading phase

The figure displays the order book market depth for the last ten minutes during the trading day. Market depth is measured as the number of contracts within four ticks away from the spread midpoint in each direction, divided by two. The tick size throughout our sample is SEK 0.25. For intertemporal comparability, the depth of each minute each day is divided by the average minute-by-minute noon market depth on the same day (11:00-12:00). Averages of such ratios across all days are reported for each period. Pre-period is between June 9, 2008, and June 5, 2009, Post-period is between June 8, 2009, and February 5, 2010. Days with involuntary trading interruptions at the futures market and half trading days (days before holidays) are excluded.

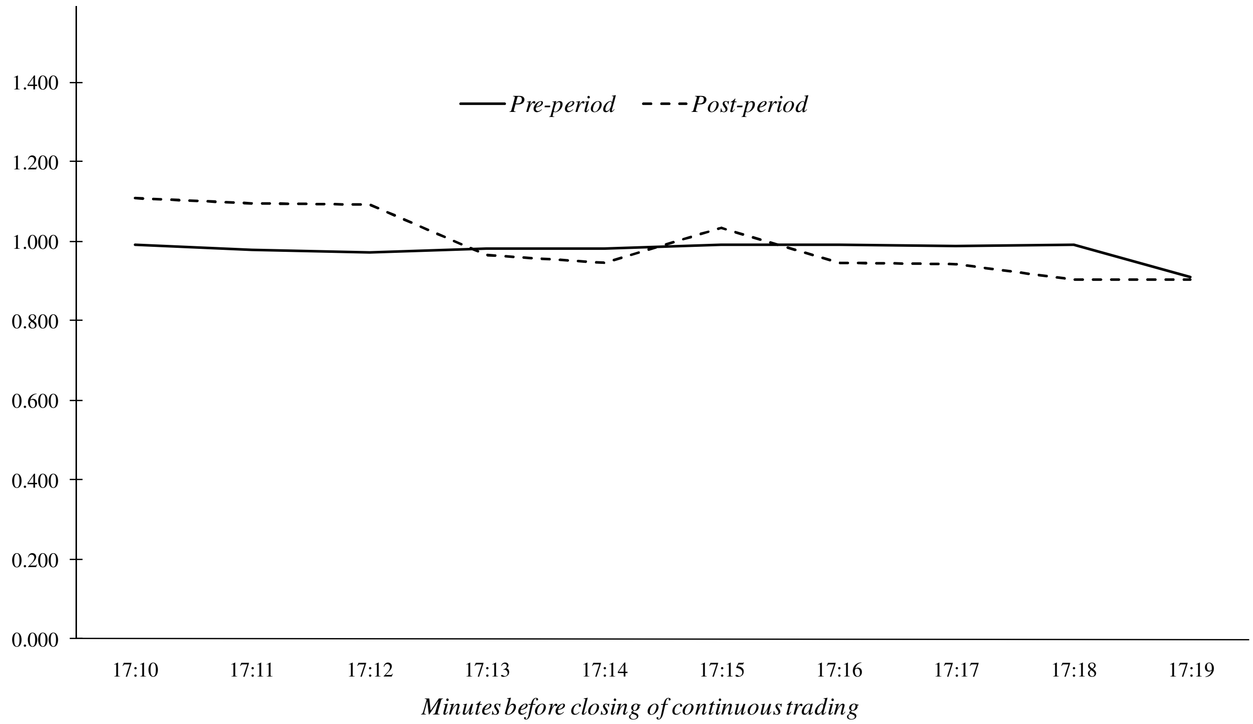

Figure 6: Market resiliency towards the end of the continuous trading phase

The figure displays futures resiliency at the futures market for the last ten minutes during the trading day. Resiliency is measured as the probability that after a liquidity shock, the spread returns to its previous (or smaller) value before the next transaction occurs. Liquidity shocks are defined as market orders that change the prevailing spread. For intertemporal comparability, futures resiliency for each minute each day is divided by the average minute-by-minute noon resiliency on the same day (11:00-12:00). Averages of such ratios across all days are reported for each period. Pre-period is between June 9, 2008, and June 5, 2009, and Post-period is between June 8, 2009 and Feb 5, 2010. Days with involuntary trading interruptions at the futures market and half trading days (days before holidays) are excluded.

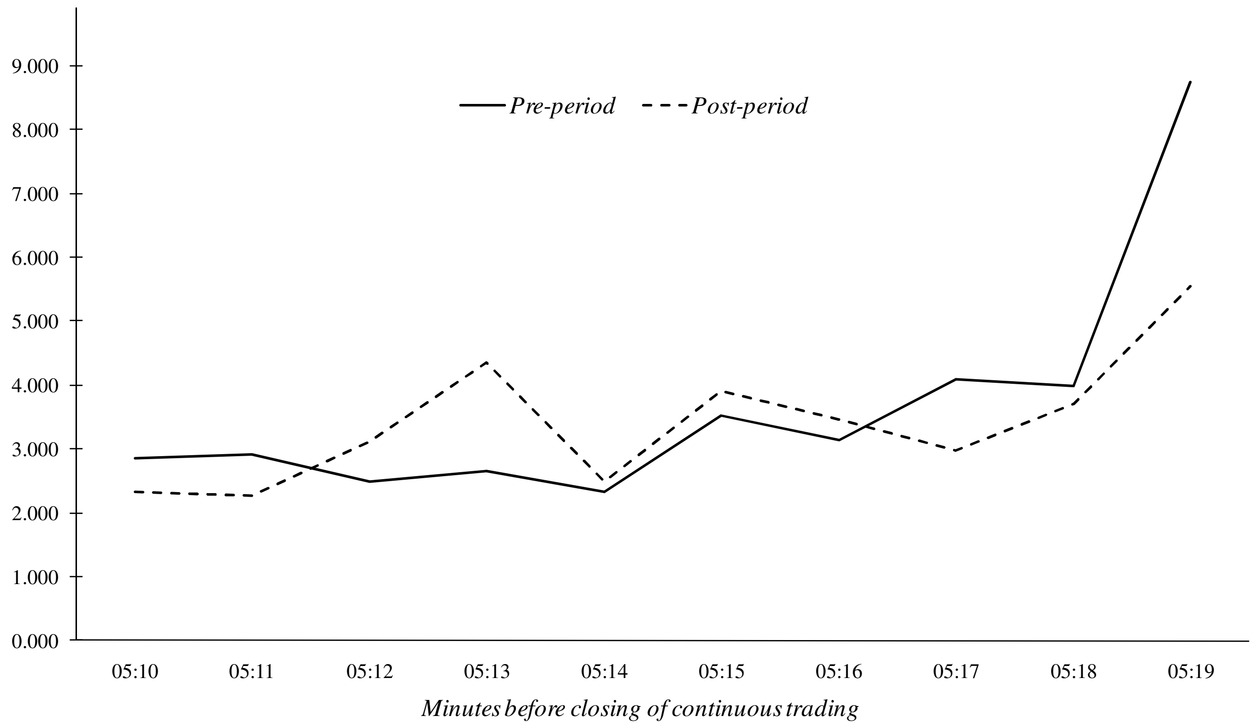

Figure 7: Realized volatility towards the end of the continuous trading phase

The figure displays the realized volatilities for the last ten minutes during the trading day. Realized volatility is defined as the 100 times the midpoint return squared. For intertemporal comparability, the realized volatilities of each minute each day is divided by the average minute-by-minute noon realized volatility on the same day (11:00-12:00). Averages of such ratios across all days are reported for each period. Pre-period is between June 9, 2008, and June 5, 2009, Post-period is between June 8, 2009, and February 5, 2010. Days with involuntary trading interruptions at the futures market and half trading days (days before holidays) are excluded.