Trading Aggressiveness and its Implications For Market Efficiency*

Olga Lebedeva†

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Abstract

This paper investigates the empirical relationship between an increase in trading aggressiveness following earnings announcements of a firm and the speed of its stock's price adjustment to the new equilibrium level. An increase in trading aggressiveness can contribute to the quicker price convergence in the initial stage of price reaction, since it allows for quicker price changes over short time intervals. However, it can also slow down the subsequent stabilization process by increasing the probability of price overshooting and making abnormal volatility of a stock more persistent. Overall, my findings suggest that abnormal trading aggressiveness after earnings announcements is especially harmful for illiquid stocks. Convergence time of these stocks has even increased as compared to the period, when intermarket sweep orders were not available on the market.

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†University of Mannheim, 68131 Mannheim, Germany. E-mail: lebedeva@corporate-finance-mannheim.de. Tel: +49 621 181 2278.

1 Introduction

This paper analyzes the empirical relationship between abnormal trading aggressiveness after earnings announcement releases and the speed of stock's price adjustment to its new equilibrium level. An investor is trading aggressively, if she prefers a quicker execution of her order over the best quoted price. Such a situation is most likely to arise, when investors expect immediate changes in the value of a stock and the speed of order execution is of primary importance. Two recent examples of abnormal trading aggressiveness on the market are the Flash Crash day (May 6, 2010), when the Dow Jones Industrial Average index (DJIA) dropped by more than 1,000 points in less than one hour, and the release of erroneous information about United Airlines bankruptcy on Bloomberg terminals on September 8, 2008. In both of these events, traders switch to the most aggressive orders on the market as soon as they realize that it is better for them to have their (sell) order executed immediately, even at an inferior price.[1] Waiting for the best quoted price in such moments is costly, since the average price may be much lower in the next second.

Periods immediately after corporate information releases also belong to the category of events, when it pays off to act quickly. New information about a firm makes investors revise their beliefs, which leads to an expected change in the fundamental value of a stock. Subsequently, investors with quicker rates of information processing will trade more aggressively to exploit their advantage. Chakravarty et al (2011a) indicate that even uninformed investors may increase their trading aggressiveness around earnings announcements, as a result of reduced liquidity supply.

Distinguishing an aggressive orders from non-aggressive ones is hard without knowing investor preferences at the time of order submission. Fortunately, with the implementation of the Regulation National Market System (Reg NMS) by the Securities and Exchange Commission (SEC) in October 2007, the most aggressive trading instrument on U.S. equity markets, an Intermarket Sweep Order, has to be marked as such at the time of its submission.[2] The "Order Protection Rule" of the Reg NMS legally requires an execution of any limit order at the best quoted prices across all trading venues on US financial markets. An Intermarket Sweep Order (ISO) represents an exemption to this rule, introduced to allow institutional investors to trade large blocks quickly. If

[1] As documented by Chakravarty et al (2011b) for the Flash Crash day and Lei and Li (2010) for the false announcement of United Airlines bankruptcy.

[2] The Regulation National Market System (Reg NMS) is a set of rules for U.S. equity financial markets, adopted by the Securities and Exchange Commission (SEC) in August 2005. Section 2 discusses the Reg NMS in more detail.

an order is marked as Intermarket Sweep, a trading venue has to give this order an immediate execution, even if this leads to a trade-through of the best quoted price.[3] Thus, a degree of trading aggressiveness can be measured as a proportion of the total volume, executed through aggressive orders within a particular interval of time.

Which implications does abnormal trading aggressiveness have on the speed of price adjustment after a corporate information release? Higher execution speed of an aggressive order ensures that a larger portion of this order, as compared to a usual limit order, is executed per one time interval. Thus, aggressive trading enables quicker price changes over relatively short time intervals. They are beneficial in the initial stage of price reaction, when the price moves in the direction of its new equilibrium level. As soon as the price is close to this new level, it enters the subsequent stabilization stage.[4] Excessively high aggressive trading may actually slow down the stabilization process, since quicker price changes increase the probability of price overshooting and the intraday volatility of a stock. Overall, these effects should be more pronounced for the stocks with low liquidity levels, since it is even easier to move prices of these stocks. Illiquid stocks have a thin order book with a lower number of shares quoted at each price. Therefore, an aggressive order will be going faster through a thinner order book, producing even larger price changes per one time interval.

The objective of this paper is to empirically examine whether the price adjustment process can benefit from increases in trading aggressiveness after an earnings announcement release. Earnings announcements belong to a very small group of announcements, which happen regularly for the broad cross-section of firms in the market. They represent a natural choice for this study, because only few years of trading data is available since the final implementation of the Reg NMS in October 2007. I restrict the sample only to those announcements, which happen within trading hours, to investigate the immediate price reaction and trading process after an information release.[5]

[3] Chakravarty et al (2010) provides an excellent overview of ISO characteristics and their use on current financial markets.

[4] Fleming and Remolona (1999) analyze the two-stage adjustment process in the U.S. Treasury market upon arrival of macroeconomic announcement releases. They identify the first stage as an almost immediate price reaction with a reduction in the trading volume. The second stage lasts for more than an hour with abnormal price volatility, trading volume and bid-ask spreads. Patell and Wolfson (1984) and Jennings and Starks (1985) find that abnormal stock returns dissipate within five to fifteen minutes after earnings and dividend announcements. However, intraday volatility and serial correlation in returns persist for several hours. Brooks, Patel, and Su (2003) examine the price adjustment process in U.S. equity markets after unanticipated events. They find that the initial price reaction lasts around 20 minutes after the release and that the prices experience some reverse changes over the following two hours.

[5] Even though earnings announcements outside trading hours are more common, the length of the

This paper contributes to two strands of the finance literature. Following the pioneering work of Chakravarty et al (2010) and Chakravarty et al (2011a), it sheds light upon the use and characteristics of intermarket sweep orders (ISOs) on the current financial markets. Further, this paper addresses the on-going debate on the efficiency of financial markets. Since the Efficient Market Hypothesis of Fama (1965), theoretical papers, e.g. French and Roll (1986), treat public information as such that is already incorporated into prices, before any investor can trade on it. In contrast with the theory, prior empirical studies document abnormal trading volumes and volatility in several hours after corporate information releases, indicating that price adjustment does not happen immediately.[6] The main reason for the prolonged price adjustment process is that investors have heterogeneous beliefs and different rates of information processing, upon which they trade until they reach the consensus. Recent theoretical studies by He and Wang (1995) and Hong and Stein (1999) incorporate heterogeneity of investors in their models of stock trading by allowing investors to observe different subsets of information at different times.[7]

The speed of price adjustment to public information is important not only for investors and market regulators, but also for trading exchanges, which have to remain competitive by attracting order flow from uninformed investors. This is only possible if a trading exchange promotes accurate and transparent prices. Therefore, understanding how changes in the regulation of financial markets and introduction of new aggressive order type affect the price adjustment process is of high importance to broad categories of market agents.

Major findings of this paper are as follows. In the first step, I show that intraday volatility during normal trading periods is higher in time intervals with the higher proportion of volume traded through intermarket sweep orders, especially for stocks

price adjustment period might be biased for these announcements due to sufficient time provided to investors to process new information. I also exclude extremely illiquid stocks, for which announcements happen exclusively within trading hours, from my sample.

[6]Patell and Wolfson (1984), Jennings and Starks (1985), Woodruff and Senchack (1988) and Greene and Watts (1996) examine the speed of price adjustment after earnings and dividend announcements. Masulis and Shivakumar (2002) analyze differences in the price convergence process between NYSE and NASDAQ around announcements of seasonal equity offerings (SEO). The recent study by Coleman (2011) investigates price movements after fatal industrial disasters and CEO deaths.

[7]He and Wang (1995) develop a multiperiod model, in which differentially informed investors repeatedly trade with each other. They show that volume and volatility will persist upon arrival of private or public information. Hong and Stein (1999) differentiate between two types of boundedly rational agents in their model: "newswatchers", who can observe private information, and "momentum traders", who condition their trades on past prices. The authors show that under the assumption of gradual diffusion of information across the population prices will underreact in the short run and will overreact in the long run.

with low liquidity levels. Further, I investigate intraday changes in trading aggressiveness on an earnings announcement day and document a significant 14% increase in the proportion of ISO volume in the half-hour immediately following an announcement. Afterward, it steadily decreases, but deviations remain significant till the end of an announcement day. My findings are consistent with Chakravarty et al (2011a), who report an overall increase of 5.5% in the proportion of ISO volume on an announcement day. They attribute this increase in trading aggressiveness to reduced market breadth and liquidity supply. However, the analysis of intraday trading aggressiveness in this paper implies that there is an additional jump in aggressive trading immediately following an announcement release, which indicates the entrance of informed traders with quicker rates of information processing.

In the final step, I analyze the link between changes in trading aggressiveness and the speed of price adjustment after an earnings announcement release. The length of the price adjustment period is defined as the number of 10-minute intervals from an announcement release until the interval, in which intraday volatility of one-minute midpoint returns is no longer abnormal.[8]

The results of difference-in-differences analysis suggest that abnormal trading aggressiveness is especially harmful for illiquid stocks. Importantly, convergence time of illiquid stocks with abnormal trading aggressiveness is significantly longer than in the pre-Reg NMS period, when intermarket sweep orders were not available. Further, the relationship between changes in trading aggressiveness and the speed of price adjustment for illiquid stocks is U-shaped, with higher deviations in trading aggressiveness leading to a slower convergence process. With excessively low trading aggressiveness, price changes of illiquid stocks are not sufficiently quick, whereas excessively high trading aggressiveness rather increases persistence in abnormal volatility of these stocks. This finding suggests that only moderate increases in trading aggressiveness are optimal for illiquid stocks.

In contrast, moderate or even excessive increases in trading aggressiveness do not play a big role for liquid stocks. The speed of the price adjustment for these stocks does not differ significantly between pre- and post-Reg NMS periods. Surprisingly, the convergence process even becomes quicker if trading aggressiveness decreases on an announcement day, which suggests that only very small levels of trading aggressiveness can be optimal for liquid stocks. The reason behind is that price changes for liquid

[8] I prefer the volatility criterion over measuring abnormal returns or serial correlation in returns, since it covers both stages of the price adjustment, the initial price reaction and the subsequent stabilization period.

stocks are already very quick due to a large number of investors trading these stocks, and any additional increases in aggressive trading only lead to price overshooting and unnecessarily high volatility levels.

The remaining part of the paper is organized as follows. Section 2 provides details of the relevant institutional framework and develops main hypotheses of this study. The construction of the data set is described in Section 3. Section 4 analyzes the determinants of ISO volume and intraday volatility in the base period. Section 5 examines trading aggressiveness within an announcement day and its influence on the speed of price adjustment for stocks with different liquidity levels. Section 6 briefly concludes.

2 Institutional Background and Hypothesis Development

2.1 Overview of Reg NMS and Intermarket Sweep Orders

On August 29, 2005, the Securities and Exchange Commission (SEC) adopted a new set of rules to modernize US equity markets and to promote their efficiency. This set of rules is known as the Regulation National Market System (the Reg NMS) and aims to improve competition not only among individual trading venues, but also among individual orders sent to different markets. Due to technical difficulties in implementation of several changes required by this new regulation the full compliance with the Reg NMS was only achieved in October 2007.[9]

The most important change, introduced by the Reg NMS, was the adoption of the "Order Protection rule" (Rule 611).[10] This rule guarantees protection of limit orders against possible execution at inferior prices ("trade-throughs").[11] Such a protection is needed in the current markets with a high speed in quotation changes. The best bid and offer quotes may change over very short time intervals between the submission of

[9] See Regulation NMS, SEC Release No. 34-51808.

[10] Among other important changes is the so-called "Access Rule", which requires transparent access to price quotations on all trading venues and regulates maximum amount of fees for every quotation access. "Subpenny Rule" requires the minimum tick size of $0.01, unless a stock price is below $1. A major change to Market Data Rules and Plans is introducing the opportunity for individual markets to distribute their market data independently (in addition to providing it to Plans, such as, for example, Consolidated Tape).

[11] A trade-through occurs when the best available bid or offer quotation on a market is ignored, that is "traded-through". According to the Trade-Through Study of the SEC, around 7.9% of the total volume of traded shares on NASDAQ and around 7.2% on NYSE was traded through before the adoption of the Reg NMS.

an order and its execution. Thus, it is almost impossible to control *ex-post* whether an order was executed at the deteriorated best quoted price, or if an order was simply traded-through. The "Order Protection Rule" requires execution of any limit order at the best available price, defined as the lowest ask or the highest bid price quoted over the previous one second among all equity trading venues in the US. If a venue, to which a limit order is sent, does not currently quote the best price, it has to re-route the order to a venue with the best price.

The Order Protection Rule cares mainly for interests of retail investors. The best-price execution guarantee increases investor confidence and decreases retail investor's search costs for the market with the best available price. Further, protection of the best-priced limit orders minimizes investor transaction costs, since the number of trade-throughs automatically declines. The reduction of investor transaction costs is also beneficial for listed firms. With smaller transaction costs, investors will demand a lower expected return on equity and the cost of capital for these firms will decrease.

Although appealing to retail traders with a long-term investment horizon, for whom the speed of order execution is not of the highest priority, the "Order Protection Rule" is less attractive for short-term traders and institutional traders with large blocks. Imagine an institutional investor, or a dealer representing this investor, who would like to sell 3,500 shares. For simplicity, suppose there are three trading venues: A, B and C. Figure 1 shows current bid prices and a number of shares available at each price for all three venues. Trading venue A currently quotes the highest bid price at \$10.75, so let an investor submit his order to A. However, depth at the best available quote is too small to get this order fully executed. In this example, only 500 shares can be sold at the best price. Without the presence of trading venues B and C on the market, the next 2,000 shares of the order would get executed at \$10.70 and the remaining 1,000 shares at \$10.67. However, it is quite seldom that a stock is traded on a single trading venue or that a single trading venue continuously quotes the best price. In the current example, B and C both quote the next best bid price at \$10.73. Under the "Order Protection Rule" the outstanding part of the order (3,000 shares) has to be re-routed by A to B or C. Unfortunately, the re-routing takes time and the best bid offer may change while the order is re-routed. Thus, the execution of large-sized orders under the "Order Protection Rule" takes longer time and might end up executing at an inferior average price, as compared to the case, when the whole order had been executed at a single venue.

To avoid such situations, the "Order Protection Rule" makes an exemption for a

Figure 1: **Bid Side of Limit Order Book**

Venue A		Venue B		Venue C	
Price	Shares	Price	Shares	Price	Shares
$10.75	500	$10.73	1,000	$10.73	800
$10.70	2,000	$10.69	2,000	$10.71	2,000
$10.67	3,500	$10.66	3,000	$10.68	2,000

specific order type, an intermarket sweep order (ISO).[12] This order type provides an opportunity for institutional investors to trade large block positions quickly. Specifically, when an intermarket sweep order arrives at a particular trading venue, it has to be executed immediately, even if it would require a trade-through. To comply with the principles of the "Order Protection Rule", an investor sending an ISO order has additionally to take out all liquidity at the better prices, available at the time of submission of an ISO order, from other venues quoting the stock. Therefore, an ISO order represents not a single order, but rather a series of marketable limit orders (Immediate-or-Cancel) with the same limit price sent across all trading venues quoting the stock.[13]

To give an example, suppose that an institutional investor would like to sell 2,000 shares at the limit price of $10.71 at the trading venue C and he makes use of an ISO order. According to the regulation, in addition to the limit order routed to C, he has to submit additional ISOs with the same limit price for 500 shares at Venue A and for 1,000 shares at Venue B. Thus, he attempts to extract all available liquidity at the superior prices from venues B and C. Since trading venues can recognize these orders as intermarket sweep, they instantaneously execute them against outstanding limit orders up to a limit price of $10.71. If the current bid quotes do not change, an investor will sell 3,500 shares instantly across all markets and the new best price will drop to $10.71 on the trading venue C. If some better priced quotations are no longer available by the time of the order execution, then these orders (or their remaining parts) get automatically canceled, and an investor has still fulfilled his obligations with respect to the "Order Protection Rule".

In this paper I measure trading aggressiveness of a stock as the proportion of vol-

[12]Paragraphs (b) 5 and (b) 6 of Rule 611, Regulation NMS, SEC Release No. 34-51808.

[13]Paragraph (b)(30) of Rule 600 gives a formal definition of an intermarket sweep order as a limit order, which satisfies the following requirements: (1) when routed to a trading venue, the limit order is identified as an intermarket sweep order; and (2) simultaneously with the routing of the limit order identified as an intermarket sweep order, one or more additional limit orders, as necessary, are routed to execute against the full displayed size of all protected quotations with a superior price.

ume traded with ISO orders over a particular time interval. With their ability to sweep liquidity almost instantly up to a particular price level, ISOs represent the most aggressive orders available on the current markets. Chakravarty et al (2010) find that the use of ISO orders in the post-Reg NMS world is non-trivial and amounts up to 46% of all trades or 41% of trading volume in their sample.

2.2 Hypothesis Development

Trading and price process. I consider a sequential trade framework similar to that of Glosten and Milgrom (1985), Kyle (1985) and Easley and O'Hara (1992). The trading day consists of a finite number of discrete time intervals $t = 1, 2, \dots$. Each time period t one trader arrives at the market. Let V_t be the value of a stock at time t and let P_t be its current midpoint price, calculated as an average of the best bid quote and the best ask quote.[14] Trader's beliefs are distributed as follows:

- with probability q_1 a trader believes that a stock is undervalued ($V_t > P_t$),
- with probability q_2 he believes that a stock is priced correctly ($V_t = P_t$) and
- with probability q_3 he believes that a stock is overvalued ($V_t < P_t$).[15]

Distribution of beliefs will change over time, with higher q_2 during periods of normal trading and lower q_2 in periods around information releases concerning the fundamental value of a stock.

Each trader has a possibility to submit an order of size 1. If a trader believes that a stock is undervalued, he will submit an immediately executable buy order.[16] The buy order will exercise against outstanding limit orders with the lowest ask prices and the midpoint price will subsequently increase. By contrast, if a trader believes that a stock is overvalued, he will submit a sell order and the midpoint price will drop. I assume that buy and sell orders contribute by the same amount σ to the price change per one

[14] I assume that the bid and ask are set competitively by the incoming limit orders of liquidity traders or by market makers of the stock. I do not explicitly model the supply side of the market, since the basic intuition would remain unchanged and the inclusion of the supply side would unnecessarily complicate the setup.

[15] In contrast to standard sequential trade models, e.g., Glosten and Milgrom (1985), Kyle (1985) and Easley and O'Hara (1992), I do not differentiate between informed and uninformed traders. If uninformed have to trade for liquidity reasons, q_1 can be interpreted as the probability that a trader has to buy a stock and q_3 as the probability that he has to sell a stock.

[16] Examples of immediately executable orders in the current trading systems are market orders and marketable limit orders, with the limit price above the lowest ask price.

time period: $\frac{\Delta P}{\Delta t} = \sigma$. If a trader believes that a current price is fair, he will abstain himself from trading and the price will stay on the previous level. Figure 2 shows the tree diagram with possible price outcomes.

The expected price in the next time period will then be:

$$E\left[P_{t+1}\right] = q_1 \cdot (P_t + \sigma) + q_2 \cdot P_t + q_3 \cdot (P_t - \sigma) = P_t + \sigma(q_1 - q_3) \tag{1}$$

and the expected price change will equal $E\left[P_{t+1} - P_t\right] = \sigma(q_1 - q_3)$.

Note that if $q_1 = q_3$, then the expected price change equals zero. A nonzero expected price change can only occur in the case when $q_1 > q_3$ or $q_3 > q_1$, that is, when traders with certain type of beliefs dominate. In these cases, midpoint returns will be positively serially correlated over time as the price is driven in a particular direction by the dominating trader type.

The expected variance over one time period is proportional to σ^2:

$$\begin{aligned} Var\left[P_{t+1}\right] &= E\left[P_{t+1} - E\left[P_{t+1}\right]\right]^2 = q_1 \cdot \left[\sigma - \sigma(q_1 - q_3)\right]^2 + \\ &+ q_2 \cdot \left[0 - \sigma(q_1 - q_3)\right]^2 + q_3 \cdot \left[-\sigma - \sigma(q_1 - q_3)\right]^2 = \\ &= \sigma^2 \left[q_1 + q_3 - (q_3 - q_1)^2\right]. \end{aligned} \tag{2}$$

The detailed derivation is in appendix. The expected variance will be the highest if $q_1 = q_3$ and will equal $\sigma^2(q_1 + q_3)$. This observation is intuitive since if one trader type dominates ($q_1 > q_3$ or $q_3 > q_1$), the price will move in one direction more frequently than in the other and, therefore, overall price fluctuations will decrease. This effect will be more pronounced the higher the difference between q_1 and q_3 is. In the extreme case, for example, if $q_1 = 1$, the price will increase by σ each period and the expected variance will be zero. Also, returns will be perfectly correlated over time.

Note that in a particular case when $q_2 = 0$ and $q_1 = q_3 = 0.5$ the price process above will follow a random walk with $E\left[P_{t+1}\right] = P_t$ and $Var\left[P_{t+1}\right] = \sigma^2$. Whereas a random walk process is widely accepted for modeling of stock prices on a weekly or monthly basis, it might not be as appropriate for modeling of intraday (and even daily) price changes.[17] Most importantly, intraday price process violates assumptions

[17] Niederhoffer and Osborne (1966) were among the first to document dependence properties of intraday transaction prices. Mucklow (1994) provides a good survey of market microstructure effects on the price process.

of continuous trading and normality of returns. Normally, there are several periods of non-trading during a day, especially for illiquid stocks. The price process above incorporates this result by allowing q_2 to be different from zero. Further, whereas a random walk process assumes constant volatility, numerous empirical findings show that it varies considerably over time.[18] This observation is also incorporated in the price process above since volatility will be changing with variations in the distribution of trader beliefs.[19]

Trading with aggressive orders. Suppose that in addition to "normal" market orders or immediately executable limit orders there exist aggressive orders that are overall quicker executed in the following sense: if both a normal order and an aggressive order of an identical size are submitted in t, then the whole size of the aggressive order, but only a portion of the normal order will be executed in $t+1$. Thus, an aggressive order will move the price by a larger amount per one time period than a normal order. Assume that, as before, a price will change by σ following a normal order, but will change by $y \cdot \sigma$ following an aggressive order, with $y > 1$. Further assume that the probability that a trader submits an aggressive order equals ψ and, consequently, the probability of a normal order is $1 - \psi$. Figure 3 shows the tree diagram with possible price outcomes.

The expected price change is then increasing in ψ and y.[20]

$$E\left[P_{t+1} - P_t\right] = \sigma(q_1 - q_3) \cdot \left[1 + \psi(y-1)\right]. \tag{3}$$

The expected variance is proportional to σ^2 , as before, and increasing in ψ and y:

$$Var\left[P_{t+1}\right] = \sigma^2 \cdot \left[1 - \psi(1 - y^2)\right] \cdot \left[q_1 + q_3 - (q_1 - q_3)^2\right]. \tag{4}$$

Note that the expected variance with aggressive trading will be always higher since $\psi > 0$ and $y > 1$. Obviously, the expected variance will be increasing due to both, ψ and y. However, empirically it is only possible to measure ψ as a proportion of

[18]For a recent survey, see Andersen et al (2001).

[19]One more "stylized" fact concerning an intraday price process is a negative serial correlation in consecutive transaction prices, since a price is continuously bouncing between the bid and the ask. Since the price process above considers only changes in the midpoint price, this issue does not play a big role here.

[20]The detailed derivation is in appendix.

aggressive orders within a particular time period. Therefore, in the following I assume that y is constant over time.

Implications for price convergence. Prior empirical studies document an increase in trading aggressiveness following company's information releases.[21] Which implications does it have on the speed of price adjustment towards its new fundamental value? Overall, it can have two countervailing effects. A higher proportion of aggressive orders causes prices to move quicker within a given time interval.[22] Thus, an increase in trading aggressiveness may speed up price convergence due to a quick movement of the price towards its new level. However, if aggressive orders are used excessively, the price changes per one time interval may become too large, which increases the probability of price overshooting and slows down the convergence process.

Further, an increased use of aggressive orders produces an additional negative effect on the intraday volatility of a stock. Note that the expected volatility, equal to $\sqrt{Var(P_{t+1})}$, is an increasing function of $\sqrt{\psi}$. Thus, the expected volatility will be overall higher for the higher proportion of aggressive orders, making it harder for a price to stabilize on its new level. However, it is important to note that since the slope of this function is decreasing in ψ, the intraday volatility will be increasing at a diminishing rate.

To sum up, for moderate changes in trading aggressiveness, the positive effect of quicker price movements is countervailed by the negative effect of higher increases in intraday volatility. Overall, it is not clear, which of two effects dominates. For an excessive increase in use of aggressive orders, the negative effect of an increased probability of price overshooting is further strengthened by the negative effect of higher intraday volatility. Therefore, an excessive increase in trading aggressiveness after an information release should lead to the slower speed of price adjustment towards the new fundamental value of the stock.

Liquid vs Illiquid stocks. The influence of an increase in trading aggressiveness can be different for stocks with different liquidity levels. Since illiquid stocks have lower depth of the limit order book at each price level, price impact per share traded is overall higher for these stocks. Assume that the price impact of a liquid stock equals σ per share traded and the price impact of an illiquid stock equals $x \cdot \sigma$, with $x > 1$.

[21] Chakravarty et al (2011a) report an increase in the proportion and volume of ISO orders after earnings announcements; Lei and Li (2010) document an increased use of ISO orders after an erroneous information on bankruptcy announcement of United Airlines on September 8, 2008.

[22] From (3) it is clear that the expected price change is a linear function of ψ.

Importantly, the problem of the higher price impact of an illiquid stock will be much more pronounced with the use of aggressive orders. Again, suppose that two orders, a normal order and an aggressive order, which are of an identical size, are submitted at t for an illiquid stock. Assume that the aggressive order is executed completely already in $t+1$, due to its faster execution. However, only a portion of the normal order is executed until this time point. Overall, more shares of the aggressive order will be traded in one time interval and, additionally, a price will change by a larger amount per each share traded. Basically, an aggressive order is "going faster through a thinner book". The effect of a "thinner book" for illiquid stocks is, thus, additionally multiplied with the effect of "faster trading" with aggressive orders, so that the price impact per one time interval equals $\frac{\Delta P}{\Delta t} = y \cdot x \cdot \sigma$. The following table summarizes different levels of the price impact per time interval for liquid and illiquid stocks:

Price impact per time interval

	Liquid	Illiquid
Normal order	σ	$x \cdot \sigma$
Aggressive order	$y \cdot \sigma$	$y \cdot x \cdot \sigma$

The expected price change and the expected variance of an illiquid stock will be higher than those of a liquid stock and will be increasing in x, y and ψ.[23]

$$E\left[P_{t+1} - P_t\right] = x \cdot \sigma(q_1 - q_3) \cdot \left[1 + \psi(y-1)\right] \tag{5}$$

$$Var\left[P_{t+1}\right] = x^2 \cdot \sigma^2 \left[1 - \psi(1-y^2)\right] \cdot \left[q_1 + q_3 - (q_1 - q_3)^2\right]. \tag{6}$$

Thus, positive and negative effects of changes in aggressive trading after an information release on the convergence time will be more pronounced for illiquid stocks.

3 Data and Sample Construction

3.1 Earnings Announcements Sample

Investigating immediate price reaction and trading process after an information release is only possible if an announcement happened within trading hours. For this

[23]The detailed derivation is in appendix.

reason, it is necessary to know exact time stamps of announcement releases. Since the full compliance with the Reg NMS was achieved in October 2007, there are only few years of trading data available. Thus, only information releases that happen regularly can provide a large enough sample to analyze a broad cross-section of firms in this short time period. Earnings announcements is the most natural choice for this study, since this is the most common type of information release for any stock. Each time unexpected news about earnings comes to the market, a stock price will experience an adjustment to its new equilibrium level. Therefore, examining the speed of price convergence around these regular announcements is of higher importance than examining the speed of price convergence around a one-time event, such as a tender offer announcement or a merger announcement.

[Insert Table 2 approximately here]

The data source for earnings announcements is the Institutional Brokers Estimate System (I/B/E/S) database. I collect announcements starting from January 2006 and ending in December 2009 that happened within trading hours of US equity trading exchanges (9:30 a.m. to 16:00 p.m. EST). Each record has an exact date and a time stamp (up to a minute). Further, each firm is required to exist in the intersection set of I/B/E/S and CRSP. Table 2 provides details of the sample construction. An initial sample comprises 10,334 announcements of 3,361 firms. I omit 647 announcements when a stock is not traded on an announcement day, out of which 148 announcements are made on the weekend and the remaining announcements are either for the stocks that stopped trading or for which trading is halted on an announcement day. Intraday transaction data is not available for 265 firms, which excludes another 967 announcements. I further eliminate very illiquid stocks of companies that make their announcements exclusively within trading hours (58 firms with 308 announcements) and the stocks, for which the closing price is less than $5 on an announcement day.[24] Excluding the days with multiple announcements and the announcements, for which there was not at least 40 days of trading data available before an announcement, leaves 5,944 announcements and 2,307 firms. Finally, to ensure that differences in results between the pre-Reg NMS period and the post-Reg NMS period are not driven by differences in the samples of underlying stocks, I require that each stock in the sample has at least one announcement in each of regulation periods. The final sample consists of 3,613 announcements

[24]Panel B of Table 3 shows that firms announcing only within trading hours are relatively small with the median of $130 mln in market capitalization. They also have small turnover and low liquidity, as measured by the relative spread and the Amihud measure.

and 675 firms, out of which 1,818 announcements happened prior to the adoption of the Reg NMS and 1,795 afterward.

[Insert Table 3 approximately here]

The most crucial requirement in the construction of the data set is that an announcement should happen within trading hours. Out of 6,536 firms, for which I/B/E/S reports earnings announcement releases over 2006-2009, 3,175 firms never announce within trading hours. Out of the remaining 3,361 firms, 58 firms release their earnings information exclusively within trading hours and 3,303 announce both within and outside the trading hours. Table 3 displays summary of main firm characteristics in each of three groups. Panel A additionally reports summary statistics of firms in the final sample, which is a subsample of the group of firms with earnings announcements both within and outside trading hours. All variable definitions are given in Table 1. Overall, firms announcing both within and outside trading hours (Panel A, columns 4-6) are smaller than firms announcing only outside trading hours (Panel B, columns 4-6), with the median market capitalization of $239 mln and $482 mln, correspondingly. In addition, they have a lower ROA and are less liquid (as measured by the relative spread and the Amihud daily price impact measure). However, they are not as small and as illiquid as the firms that announce exclusively within trading hours (Panel B, columns 1-3). Even though there is a small bias towards smaller firms, the initial sample still covers more than 50% of all firms with earnings announcement releases. The final sample (Panel A, columns 1-3) does not differ significantly from the initial sample (Panel A, columns 4-6). Since the most illiquid stocks with closing prices below $5 are excluded from the final sample, the firms in this sample have slightly larger market capitalization ($256 mln) and are more liquid as compared to the initial sample.

3.2 Intraday Transaction and Quote Data

Two major variables of interest in this study, trading aggressiveness and price changes within a day, require the use of intraday transaction data. The source for these data is the NYSE Transaction and Quote database (TAQ). In the first step, I extract data on the number and the volume of ISO and non-ISO trades on an announcement day as well as 40 trading days preceding an announcement. The base period consists of 38 trading days preceding an announcement day, starting on day -40 and ending on day -2. I collapse transaction-by-transaction data over 15-minute intervals and extract the number of trades and the traded volume in each 15-minute interval separately for ISO and non-ISO orders. ISO orders are marked with the code F in the condition field of the TAQ database.

To identify the direction of a trade, I use Lee and Ready's (1991) algorithm. For each trade I assign the bid (B_t) and the ask quote (A_t) prevailing one second before the trade took place.[25] The midpoint price (Q_t) is calculated as the average of the prevailing bid and ask quotes ($Q_t = \frac{A_t+B_t}{2}$). Trades with the transaction price (P_t) above the midpoint price ($P_t > Q_t$) are identified as buyer-initiated transactions and those with the transaction price below the midpoint price ($P_t < Q_t$) as seller-initiated transactions. If the transaction price is equal to the midpoint price, the current transaction price is compared with the previous transaction price. If $P_t < P_{t-1}$, I consider a trade to be seller-initiated; if $P_t > P_{t-1}$, I consider it to be buyer-initiated. Should the two prices be equal, the trade is left as unclassified.

In addition, I calculate the average 5-minute price impact and the average relative spread over 15-minute intervals separately for ISO and non-ISO orders. The relative spread for a transaction is defined as the difference between the corresponding ask and the corresponding bid, scaled by the midpoint price ($RelSpr_t = (A_t - B_t)/Q_t$). I set observations with $RelSpr > 0.5$ to missing values. The price impact of each trade after 5 minutes is defined as $PrcImp_t = 2\left|Q_{t+5} - Q_t\right|/(Q_t)$, where Q_{t+5} represents the midpoint price for a stock after five minutes (300 seconds).

Intraday one-minute returns are computed from the closing midpoint price for each minute from the TAQ Quotes database. Closing midpoints serve better the purposes of the price adjustment analysis, since they exclude the bid-ask bounce, which is present in transaction prices.

4 Trading Aggressiveness and Intraday Volatility in the Base Period

Definition of Trading Aggressiveness. Trading aggressiveness is defined as the proportion of total volume, traded with aggressive intermarket sweep orders within a particular time interval (the proportion of ISO volume). Daily trading aggressiveness is, therefore, the proportion of daily volume, executed through ISO orders. Intraday trading aggressiveness is measured as the proportion of the traded volume over the

[25]Henker and Wang (2006) consider this procedure to be more appropriate compared to the classical Lee and Ready (1991) five-second rule. Bessembinder (2003) tries zero- to thirty-second delays in increments of five seconds and does not find any differences in the results.

respective time interval within a day, for example 10 minutes, 15 minutes, 1 hour etc.[26] In the following, the terms "trading aggressiveness" and "trading with aggressive orders" are used interchangeably.

The median proportion of ISO volume in my sample is 36%. However, the variation is quite significant with 22% of volume traded through ISOs for the firms in the lowest decile and 56% in the highest decile.

4.1 Determinants of ISO volume

Intermarket sweep orders provide an opportunity for large traders, such as institutional investors, to trade large blocks quickly. Thus, trading with aggressive orders should be especially intensive in large firms, which usually have a higher percentage of institutional ownership. Panel A of Table 4 examines size and trading characteristics of stocks with different levels of trading aggressiveness in the Post-Reg NMS period. Columns 3 and 4 report trading characteristics of firms with low trading aggressiveness (the proportion of ISO volume is below the median) and Columns 5 and 6 of those with high trading aggressiveness (the proportion of ISO volume is above the median). Panel B reports the characteristics of the same subsamples of stocks before the Reg NMS.[27]

[Insert Table 4 approximately here]

According to the expectations, stocks with higher trading aggressiveness (high TA) belong on average to larger firms. The mean market capitalization is $3,017 mln as compared to $2,374 mln in the sample with low trading aggressiveness (low TA). However, the median firm in the high TA group does not differ significantly in size from the median firm in the low TA group, as reported by the Mann-Whitney test on the equality of the medians in the last column of Table 4. They also do not differ significantly in their turnover, although it has overall increased for both groups after the Reg NMS. The relative spreads and the intraday volatility, calculated as the standard deviation of one-minute closing midpoint returns, have also increased in the post-Reg NMS period. This increase can be largely attributed to the financial crisis of 2008. Importantly, the

[26] The proportion of the total number of trades, executed through ISOs, is highly correlated with the proportion of ISO volume (the correlation coefficient of 93%). Main insights of the paper do not change, if the proportion of ISO trades is used to measure trading aggressiveness.

[27] Note that ISOs were first introduced with the adoption of the Reg NMS. Thus, the division of stocks in different trading aggressiveness categories is only possible in the post-Reg NMS period. The samples of stocks before the Reg NMS remain exactly the same as the samples after the Reg NMS. This provisional division is just done to compare how trading characteristics of stocks in two subsamples change with the adoption of the new regulation.

spreads of firms with high trading aggressiveness have more than doubled, whereas the increase for the group with low trading aggressiveness constitutes moderate 25% (from 1.18% to 1.47%). This is intuitive, since intermarket sweep orders quickly take out liquidity at the best quotes, so that the closing bid and ask quotes for each minute are wider than for stocks with the lower ISO use. Additionally, if investors know that aggressive trading is high in a particular stock, their limit orders are more likely to be "cream skimmed" by the aggressive informed traders and they will adjust the quotes accordingly. Larger increase in intraday volatility of stocks in the high TA group provides indirect evidence that intraday volatility increases as trading becomes more aggressive. The next section addresses this question in more detail.

[Insert Table 5 approximately here]

Table 5 analyzes the determinants of ISO volume in a multivariate setup. Models (1) and (2) report results of cross-sectional OLS regressions for the base period with the mean proportion of daily volume, executed through aggressive orders as the dependent variable (*%ISOvol*). Consistent with the univariate results, the larger the market capitalization of the firm, the higher will be the use of the aggressive orders during normal trading times. Further, investors trade higher proportion of their volume with ISOs in NASDAQ-listed stocks. These findings are consistent with those of Chakravarty et al (2010). Interestingly, liquidity of the stock, as measured by the average intraday relative spread and the Amihud measure, does not have any impact on the proportion of volume traded with aggressive orders in the base period.

Models (3) and (4) examine the factors that influence deviations in the proportion of ISO volume after an earnings announcement release from its base period level ($\Delta ISOvol$). Importantly, trading aggressiveness increases more for illiquid stocks, whereas the size of the firm does not play a role any longer. Further, trading with aggressive orders is less intensive if an overall volume experiences large increases on an announcement day ($\Delta Volume$). This result is intuitive since order execution becomes overall quicker with higher volume increases (as it is easier to find a counterparty for a trade). Therefore, a trader does not necessarily need to act aggressively to get his order quicker executed. Finally, in line with the expectations, trading aggressiveness is higher after larger earnings surprises, as proxied by an absolute stock return in 24 hours after an announcement release ($EarnSurp$).

Results from Table 5 suggest that there is an important difference between the use of ISO orders in the normal trading times and around earnings announcement releases. In the periods of normal trading ISO orders are mostly used to trade large blocks of orders in the stocks of large firms (with higher institutional ownership), which exactly justifies their introduction to equity markets. After earnings announcement releases, however, traders mostly use ISO orders to grab all available liquidity in the already illiquid stocks. Since ISO orders can only be used by large traders, one possible reason for an increased use of these orders after announcement releases might be different rates of information processing by institutional investors. The investors with quicker processing rates will largely use aggressive orders to get their (informed) orders executed quickly, especially in the stocks with scarce liquidity supply.

4.2 Intraday volatility

Summary statistics from Table 4 indicate that intraday volatility has experienced larger increases in the Post-Reg NMS period for the sample of stocks with the higher proportion of volume traded with intermarket sweep orders. Since the effects of aggressive trading should be more pronounced for illiquid stocks, I examine intraday volatility separately for the subsamples of stocks with different liquidity levels. Figure 4 displays variations of one-minute return volatility (in %) throughout a normal trading day. Panel A shows the mean intraday volatility for the subsample of liquid stocks (with the relative spread below the median of all sample stocks) and Panel B presents the similar graph for the subsample of illiquid stocks (with the relative spread above the median of all sample stocks). The dashed line represents the mean intraday volatility in the period prior to the adoption of the Reg NMS, the solid line represents the subsample of stocks with low trading aggressiveness (low TA) in the post-Reg NMS period and the dash-dotted line represents the subsample of stocks with high trading aggressiveness (high TA) in the post-Reg NMS period.

[Insert Figure 4 approximately here]

Intraday volatility displays a U-shaped pattern for all stocks, which is a stylized fact in the literature.[28] Volatility is the highest at the opening of the trading day (9:30-10:00 a.m. EST). It takes its lowest values between 12:00 p.m. and 14:00 p.m and increases again during the last trading hour (15:00-16:00 p.m. EST). The most striking result

[28]Wood et al (1985) and Harris (1986) were among the first to document unusually high returns and their standard deviations at the beginning and at the end of the trading day. Lockwood and Linn (1990) find similar patterns for returns of the Dow Jones Industrial Average (DJIA) over a long time horizon (January 1964-February 1989). Admati and Pfleiderer (1988) provide theoretical justification for this phenomena.

is that intraday volatility has almost tripled for the illiquid stocks after the adoption of the new regulation, from 0.42% to 1.22% (at 12:00 p.m.) Definitely, a large part of this increase comes from turbulent financial markets amidst financial crisis. Still, an increase in the volatility of liquid stocks is much lower, from 0.31% to 0.35% (at 12:00 p.m.) In line with prior expectations, intraday volatility for more aggressively traded stocks is on average higher in both subsamples. However, the difference between the high TA and the low TA group is larger for illiquid stocks (0.22%) than for liquid stocks (0.04%). Importantly, the ratio of two differences (0.22%/0.04%=5.50) is around 1.5 times larger than the ratio of average volatilities across liquid and illiquid stocks (1.22%/0.35%=3.48).

Table 6 confirms prior findings concerning intraday volatility in a multivariate setup. It presents results of panel OLS regressions with intraday volatility as the dependent variable, controlling for year- and hour-fixed effects. One observation represents a 10-minute trading interval for a stock in the base period (days -40 to -2 before an announcement release). Standard errors are clustered on the firm level. P-values of the two-tailed t-test with the null-hypothesis of a coefficient equaling zero are reported in form of asterisks to the right of each coefficient.

[Insert Table 6 approximately here]

Models (1) and (2) use a continuous variable, *%ISOvol,* the proportion of total volume traded with ISOs in a 10-min interval, as the main explanatory variable. It is statistically significant for the total sample (Model 1), after controlling for the total volume traded within a 10-minute interval (*IntrVolume)* and for an overall higher volatility of small and illiquid stocks (captured by the corresponding indicator variables). However, its economic significance is only marginal. An increase in the ISO use from 0% to 100% results in an increase of intraday volatility by 0.04%. Model (2) examines the influence of aggressive orders separately for samples of liquid and illiquid stocks. In addition to the indicator variable for illiquid stocks, *Illiquid,* it also includes the interaction term of this variable with *%ISOvol* ($Illiquid \cdot \%ISOvol$), which captures an additional effect that intermarket sweep orders have on intraday volatility of illiquid stocks. Since trading with aggressive orders does not significantly alter volatility of liquid stocks (the coefficient on *%ISOvol* is no longer significant), the whole effect for illiquid stocks is captured by this interaction term. The coefficient is statistically and economically significant. An increase in the ISO use from 0% to 100% results in an increase of intraday volatility for illiquid stocks by 0.16%, which represents a 13% increase from its average level of 1.22%. Interestingly, size controls do not yield any significant results (as captured by the coefficient on the interaction term of $Small \cdot \%ISOvol$). Results do not change if I substitute the continuous variable *%ISOvol* with the indicator variable, *High TA*, which is equal one for the stocks with high trading aggressiveness (the proportion of ISO volume is above the median) and zero otherwise (Model 3). The difference-in-differences analysis in Model (4), which also includes observations from the pre-Reg NMS period, shows that volatility has significantly increased for illiquid stocks in the Post-Reg NMS period, and even more so for illiquid stocks with high trading aggressiveness.

5 Trading Aggressiveness and The Speed of Price Convergence After Earnings Announcements

5.1 Intraday Trading Aggressiveness

This section documents a significant increase in trading aggressiveness in the hours immediately following earnings announcement releases. The reasons for this increase are twofold. First, investors have different rates of information processing. Those investors who are able to quicker process new information will try to exploit their advantage and will largely use aggressive orders for these purposes. Consequently, informed investors trade more aggressively after larger earnings surprises. Second, trading by uninformed investors might also become more aggressive due to scarce liquidity supply and reduced breadth of the markets around earnings announcements. Chakravarty et al (2011a) provide empirical evidence in support of the second explanation. Their findings suggest that trading aggressiveness increases significantly on an announcement day as a result of reduced liquidity supply. In addition to the daily trading aggressiveness, as analyzed by Chakravarty et al (2011a), I examine changes in the use of aggressive orders on the intraday level, in the trading hours immediately before and immediately after earnings announcement releases. I find that trading aggressiveness experiences a jump in hours following an announcement release and continues to deviate significantly till the end of the trading day.

Table 7 summarizes differences in use and trading characteristics between ISO (Panel A) and non-ISO orders (Panel B). First three columns report the cross-sectional mean of respective variables in half an hour following an information release. The last column displays the mean of the bootstrapped distribution from the base period. Since the base period is rather short (38 days) and proportions of the number of trades and of their volume are not normally distributed, I create an empirical distribution for each variable with a bootstrapping procedure. I do this by repeatedly drawing with replacement one observation from the base period that happened exactly in the half-hour following an announcement for each stock and repeatedly calculating the mean across all stocks in this bootstrapped sample. The empirical distribution for each variable is based on 1,000 bootstrapped samples.

[Insert Table 7 approximately here]

Overall, summary statistics show that the proportion of volume, traded through ISO orders, increases in half an hour after an announcement release from 36% to 42%. It is slightly higher for stocks with large positive earnings surprises.[29] The proportion of ISO trades also increases from 40% to 45%. Importantly, the relative spread and the 5-minute price impact of ISO orders after an information release are higher than those of non-ISO orders, in contrast to the base period. It suggests that ISO orders are mostly used by uninformed investors during normal trading times and are increasingly used by informed investors after information releases. This finding also provides evidence that aggressive ISO orders have primary impact on the permanent price changes after earnings announcements and can directly influence the price adjustment process.

Table 8 investigates deviations in trading aggressiveness in half an hour following an announcement (Panel A) and in half an hour preceding an announcement (Panel B). All coefficients represent percentage changes from the mean of the bootstrapped distribution. The first column shows results for all earnings announcements, whereas the second and the third columns present findings for large positive and large negative earnings surprises, correspondingly.

[Insert Table 8 approximately here]

Consistent with previous results from Table 7, the proportion of ISO trades and of ISO volume significantly increases after an announcement release by 12% and 14%, correspondingly. The number of ISO trades increases by 139%, mostly due to an increase in an overall number of trades and volume immediately after an earnings announcement

[29]Earnings surprises are measured as an absolute value of the 24-hour return. They are classified as "large" if an absolute value of the 24-hour return exceeds 2%. Results are robust to different definitions of earnings surprise (e.g., an absolute 24-hour return exceeds 3%, 4% or 5%) (not tabulated).

(not tabulated). Interestingly, the number of purchase transactions and their proportion significantly increase both for positive and for negative earnings surprises, which shows that a significant amount of investors believes in undervaluation of a stock after negative earnings releases. Also, investors mostly use ISO orders for fire-sale transactions when bad news is released, as suggested by an increase of 214% in the proportion of ISO sell orders after large negative surprises (as compared to 15% increase in the proportion of ISO buy orders after positive news releases). Panel B of Table 8 examines deviations in trading aggressiveness in half an hour prior to an announcement release. Although all deviations are still significant, their absolute values are almost two times lower than the corresponding deviations from the period after an announcement.

[Insert Figure 5 approximately here]

Figure 5 displays mean percentage deviations in the proportion of ISO volume throughout an announcement day. Deviations from the bootstrapped means are measured in 15-minute intervals relative to the 15-minute interval with an earnings announcement release (interval 0). The dashed line shows the 1% significance level for the mean percentage change in the proportion of ISO volume, equal to 4.8%. Overall, it is evident that trading aggressiveness experiences a jump of up to 15% in the first fifteen minutes after an information release. Afterward, it steadily decreases, but never drops below the 1% cutoff value till the end of the trading day. In the periods prior to an announcement release, deviations are significant in 60% of all cases and rarely drop below zero. These findings are consistent with Chakravarty et al (2011a), suggesting that uninformed investors increase their trading aggressiveness as liquidity supply decreases. The 15% jump immediately after the release, however, indicates that there is an additional pressure from traders with quicker rates of information processing immediately after an information release.

5.2 Trading Aggressiveness and the Speed of Price Adjustment

Definition of the end of the price adjustment process. I consider that price adjustment ends in the period, in which volatility of one-minute closing midpoint returns is no longer abnormal. The volatility criterion is more appropriate for this study than, for example, measuring abnormal returns or abnormal serial correlations in price changes, since this is the only criterion that captures two stages of price adjustment, the initial price reaction as well as the subsequent period of price stabilization. Remember that trading with aggressive orders results in quicker price movements, which potentially makes the first stage shorter, but at the same time it increases volatility of the stock and the probability of price overshooting, which makes it harder for a price to stabilize on its new level.

Prior studies by Patell and Wolfson (1984) and Jennings and Starks (1985) find that the initial price reaction is rather short, since abnormal returns dissipate in five to fifteen minutes after an earnings announcement release. However, abnormal volatility of intraday returns persists for several hours and can even extend in the following trading day. The recent study by Brooks, Patel and Su (2003) provides similar evidence for unanticipated events with abnormal returns lasting for 15 minutes and abnormal variance for at least three hours after an event.

The exact procedure of determining the end of the price adjustment process is as follows. First, I calculate volatility of one-minute closing midpoint returns within each 10-minute interval for an event window, which includes event days 0 to 3, and for the base period with event days -40 to -2. I numerate all intervals in the event window relative to the first 10-minute interval immediately after an announcement (interval 0). The numeration is consecutive for all days in the event window. For example, if an announcement time was 3 p.m., then a period from 9:30 a.m. till 9:40 a.m. on the next day is numerated as period 7.

I use a non-parametric test, proposed by Smith et al (1997), to define whether volatility is abnormal in each of 10-minute periods after an information release. If volatility is normal, it should on average exceed volatility on non-event days roughly half of times simply by chance. Thus, volatility is considered to be abnormal if it exceeds the volatility in the same 10-minute period calculated over days $[-40; -2]$ in more than 50% of all cases.[30]

The period, in which the price ends its adjustment, is defined as the first 10-minute period, for which:

- the volatility is no longer abnormal

- the volatility in the preceding hour is abnormal (more precisely: the volatility in the preceding six 10-minute intervals is abnormal in more than 50% of all cases)

- the volatility in the following hour continues to stay on a normal level (more

[30]To increase the power of the test, I compare volatility in each of 10-minute intervals in the event window to six 10-minute intervals that lie within the same hour over all non-event days. Thus, if a stock was traded over all 10-minute intervals in the base period, one 10-minute interval in the event window is compared to 6*38=228 ten-minute periods on non-event days.

precisely: the volatility in the following six 10-min intervals is normal in more than 50% of all cases).

Univariate tests. Panel A of Table 9 displays the distribution of the length of price adjustment periods across liquid and illiquid stocks across pre- and post-Reg NMS periods. One unit corresponds to a ten-minute interval. Thus, the median length of price adjustment for a liquid stock before the Reg NMS is 16*10=160 minutes or 2 hours and 40 minutes after an announcement release. After the Reg NMS the median convergence time for liquid stocks has significantly decreased by thirty minutes, as reported by a non-parametric Mann-Whitney test. The median length of the price adjustment period for illiquid stocks has also decreased in the post-Reg NMS period from 4 hours and 10 minutes to 3 hours and 50 minutes, however, this 20-minute change is not statistically significant. Given a significant increase in an overall electronic trading in recent years, it is even more surprising that the length of the convergence period did not decrease significantly for illiquid stocks. Further, the standard deviation has even increased for these stocks in the post-Reg NMS period, implying that the adjustment process has become quicker for some illiquid stocks and slower for the other ones.

[Insert Table 9 approximately here]

To investigate this issue, I break all stocks into terciles of trading aggressiveness (TA1 - TA3) in the post-Reg NMS period. Trading aggressiveness is measured as the change in the proportion of ISO volume traded after an announcement release relative to its mean in the base period ($\Delta ISOvol$). TA3 includes stocks with the highest increases in trading aggressiveness on an announcement day, whereas TA1 includes stocks with the lowest increases.[31] Panel B of Table 9 summarizes the results. Whereas changes in trading aggressiveness on an announcement day barely have any influence on the median speed of price adjustment of liquid stocks, there is a striking U-shaped relationship for stocks with low liquidity levels. Illiquid stocks with moderate changes in trading aggressiveness (TA2) experience a significant decline in their median convergence time by 1 hour and 20 minutes, as compared to the pre-Reg NMS period. The median convergence time for stocks in the TA1 group declines by only 40 minutes. Surprisingly,

[31] Although on average trading aggressiveness increases in hours after the release, changes in the proportion of ISO volume can take negative values for some stocks in the TA1 sample.

the price adjustment process even slows down for illiquid stocks with the highest increase in their trading aggressiveness (the TA3 group).

[Insert Figure 6 approximately here]

Figure 6 depicts the relationship between the mean length of the price adjustment period, measured as the number of ten-minute time intervals until the price stabilizes on its new level, and the mean change in the proportion of ISO volume after an information release. Overall, the patterns are consistent with those reported in Table 9. For liquid stocks, the relationship is rather weak, with slightly quicker price adjustment for stocks with higher negative deviations in the proportion of ISO volume on an announcement day. For illiquid stocks, the relationship has a U-shape, with the slower adjustment process for stocks with higher absolute deviations in the proportion of ISO volume. The adjustment period is the longest for stocks with excessive increases in their trading aggressiveness on an announcement day (above 50%).[32]

Regression analysis. To control for other factors that might influence the length of the adjustment period, I estimate negative binomial regressions with the number of 10-minute intervals required for the price adjustment as the dependent variable. The main regression specification is as follows:

$$\#Intervals_i = \alpha_i \cdot \Delta ISOvol_i + \theta_i \cdot \mathbf{X_i} + \varepsilon_i,$$

where $\mathbf{X_i}$ is the vector of control variables, which includes a dummy variable *BigSurp,* indicating whether the earnings surprise is large (an absolute 24-hour return is above 2%); total volume traded within three days after an announcement release (*EventVolume*, in shares); average intraday volatility of one-minute returns in the base period (*Intr Volat),* and an average size of a firm, proxied by the log of its market capitalization at the beginning of the base period (*LnMCap).* I expect the coefficient to be positive for large earnings surprises, which cause disagreement between investors, making it harder for a price to adjust to its new level. The coefficient for total volume traded after an information release should also be positive, since larger abnormal volume may also temporarily destabilize the price. The higher intraday volatility of a stock in the base period, the easier it is for a price to converge to this "normal"

[32]Stocks with excessive increases in their trading aggressiveness ($\Delta ISOvol > 0.5$) are not just outliers in the sample, since 222 stocks out of 839 illiquid stocks belong to this group. Only the group of stocks with large negative decreases in their trading aggressiveness ($\Delta ISOvol < -0.5$) has slightly less than 200 observations.

volatility level, thus, I expect a negative coefficient for this variable. Finally, I do not have priors for *LnMCap,* since it can have two countervailing effects on the length of the price adjustment period. A price might converge quicker since stocks of large firms are normally traded by a larger number of investors. However, if those investors have largely heterogeneous beliefs about the new value of the stock, price adjustment might be slower. I also include year-fixed effects, dummies for different days of the week (Monday to Friday) and different times within a day (Morning, Noon and Afternoon) to control for possible day- and time-specific effects.

[Insert Table 10 approximately here]

Table 10 presents the results for liquid stocks in the Post-Reg NMS period. The coefficient on $\Delta ISOvol$ is significant at the 5% level. This result suggests that there exists a linear relationship between increases in trading aggressiveness and the length of the price adjustment period in the sample of liquid stocks. A 100% increase in the proportion of volume traded with ISOs increases the number of 10-minute periods until the price fully adjusts by 21%.[33] Thus, the length of an adjustment period on average increases by 40 minutes if $\Delta ISOvol$ changes its value from 0 to 1.[34] However, the results of the univariate analysis suggest that the relationship may not be just linear and can depend on the absolute value of the deviation in the proportion of ISO volume as well as on its sign. For this reason, I replace the main variable of interest, $\Delta ISOvol$, by its absolute value (Model 2) and separately examine an influence of positive and negative deviations in ISO volume on the length of the adjustment period (Model 3). Only the coefficient on the absolute value of negative deviations in ISO volume ($|\Delta ISOvol|_{if\,\Delta ISOvol<0}$) is statistically significant at the 10% level. The economic significance of this coefficient is rather large: a 100% decrease in the proportion of volume traded with ISOs decreases convergence time by 37% (ca. 1 hour and 10 minutes).

As expected, price adjustment is significantly longer for stocks with large earnings surprises. Intraday volatility in the base period has also the expected negative sign, but its coefficient is not statistically significant. Coefficients on the total volume traded after an information release and on the size are close to zero and are largely insignificant.

[33] General interpretation of any coefficient β in negative binomial regressions is as follows: for one unit change in an explanatory variable, the difference in logs of expected counts of the response variable is expected to change by β.

[34] The mean number of 10-minute periods until adjustment equals 20 if $\Delta ISOvol$ is 0. The expected 21% change increases this number to 24 for $\Delta ISOvol = 1$.

[Insert Table 11 approximately here]

Table 11 conducts the similar analysis in the sample of illiquid stocks in the post-Reg NMS period. Overall results confirm the U-shaped relationship between changes in trading aggressiveness and the length of the adjustment period after an announcement release. The higher the absolute value of a deviation in the proportion of ISO volume, the longer it takes for a stock to converge to its new level (Model 2). A 100% change in the proportion of ISO volume slows down the adjustment process by almost 20% or approximately 1 hour from its mean value of 5 hours if $\Delta ISOvol = 0$, which is statistically and economically significant. Importantly, positive deviations in ISO volume have higher statistical significance (5%) than negative deviations (10%), although the latter have a larger coefficient value (Model 3). From control variables, only size plays a significant role in the adjustment process of illiquid stocks. Stocks of relatively larger firms converge quicker, which suggests that the larger number of investors trading has a positive overall effect for stocks with low liquidity levels.

[Insert Table 12 approximately here]

To prove causality in the relationship between the use of aggressive orders and the length of the convergence period, I conduct a difference-in-differences analysis by additionally including earnings announcements from the pre-Reg NMS period. Since each stock in the final sample has at least one announcement in each of the regulation periods, the results are not influenced by differences in the underlying stock samples. Table 12 displays findings separately for subsamples of liquid and illiquid stocks (Models 1 and 2) and for the total sample (Model 3), controlling for differences in liquidity with a dummy variable *Illiquid*. All coefficients can be interpreted as the relative changes in convergence time from the mean value in the pre-Reg NMS period. In the sample of liquid stocks, only firms with negative deviations in ISO volume display significantly quicker price adjustment in the post-Reg NMS period (by 37%). The length of the convergence time for an average illiquid stock has decreased by 20% in the post-Reg NMS period. However, it is significantly higher by 16% (17%) for the stocks with larger increases (decreases) in their trading aggressiveness on an announcement day. I obtain similar results for the total sample, as reported by Model 3, except that statistical significance of the coefficients now becomes higher due to a larger number of observations.

Overall, the difference-in-differences analysis confirms previous results from Tables 10 and 11. As compared to the pre-Reg NMS period, convergence time is the shortest for liquid stocks with negative deviations in the proportion of ISO volume on an announcement day. Since liquid stocks are traded by a large number of investors, there is no need for quicker price movements of these stocks. Therefore, only very small proportions of ISO volume can positively influence the adjustment process. Large increases in trading aggressiveness for liquid stocks only destabilize the price by increasing the probability of price overshooting and abnormal volatility on an announcement day.

Importantly, the results differ significantly for stocks with low liquidity levels. After the adoption of the new regulation, convergence time has overall decreased for these stocks. However, the relationship between the use of ISO orders after the adoption of the Reg NMS and the length of the price adjustment period has a U-shaped pattern. Thus, illiquid stocks with moderate increases in trading aggressiveness have the shortest convergence time, as compared to the pre-Reg NMS period. Illiquid stocks with excessively high and excessively low proportions of ISO volume take significantly longer time to converge. These findings imply that moderate increases in the use of ISO orders on an announcement day benefit the convergence process the most. Since illiquid stocks are infrequently traded, they can profit from quicker price movements in the initial stage of price reaction, however, only if trading aggressiveness is not very high. As soon as the proportion of ISO volume increases by more than 50% on an announcement day, the negative effect on volatility dominates the positive effect of quicker price movements and may even lead to a longer convergence time than in the period, when no ISO orders were available.

6 Conclusions

This paper analyzes how abnormal trading aggressiveness after earnings announcement releases influences the speed of price adjustment of stocks in U.S. financial markets. Trading aggressiveness is measured as the proportion of volume, traded with the most aggressive limit orders, intermarket sweep orders, over a particular time interval. These orders represent an exemption to the "Order Protection Rule" of the Regulation National Market System and are executed more quickly than other limit orders, but possibly at an inferior price.

Initially, intermarket sweep orders were introduced to allow institutional investors to trade large blocks quickly, without waiting for the execution at the best quoted price. The findings in this paper indicate that even though during normal trading times intermarket sweep orders are indeed used by larger firms, which normally have higher institutional ownership rates, the reasons for their use may be largely different after information releases. Specifically, a 14%-jump in the proportion of ISO volume in the half-hour immediately following an announcement release can be attributed to the entrance of informed traders with quicker information processing rates. Importantly, abnormal trading aggressiveness after earnings announcements is even higher for stocks with already scarce liquidity supply, which makes these stocks even more illiquid at the times when liquidity is needed the most. One more adverse effect of intermarket sweep orders is that they largely increase intraday volatility of stocks, even during normal trading times. Intraday volatility of stocks with overall higher trading aggressiveness experiences significantly larger increases, as compared to the pre-Reg NMS period.

The major result of this study is that excessive trading aggressiveness after earnings announcements is especially harmful for the speed of price adjustment of illiquid stocks. As compared to the pre-Reg NMS period, the convergence time has even increased for illiquid stocks with deviations in the proportion of ISO volume above 50%. Only moderate increases in trading aggressiveness positively contribute to the convergence process of these stocks. For liquid stocks, the effects of abnormally high trading aggressiveness on an announcement day are not as adverse as for illiquid stocks. However, as compared to the pre-Reg NMS period, the convergence time has decreased for liquid stocks with an overall lower use of ISOs on an announcement day.

The findings in this paper suggest that excessive use of intermarket sweep orders produces adverse effects on intraday volatility and the convergence process of illiquid stocks after information releases. Thus, market efficiency for illiquid stocks can be even further reduced in situations when traders become too aggressive - something, that needs to be taken into account by the market regulators if they are interested in the promotion of accurate and transparent prices.

References

Admati, Anat R., and Paul Pfleiderer, 1988, A theory of intraday patterns: Volume and price variability, *Review of Financial Studies* 1, 3–40.

Andersen, Torben G., Tim Bollerslev, Francis X. Diebold, and Heiko Ebens, 2001, The distribution of realized stock return volatility, *Journal of Financial Economics* 61, 43–76.

Bessembinder, Hendrik, 2003, Issues in assessing trade execution costs, *Journal of Financial Markets* 6, 233–257.

Brooks, Raymond, M., Ajay Patel, and Tie Su, 2003, How the equity market responds to unanticipated events, *Journal of Business* 76, 109–133.

Chakravarty, Sugato, Pankaj Jain, Thomas McInish, and James Upson, 2011a, Trading aggressiveness and market breadth around earnings announcements, *Working Paper, SSRN eLibrary.*

Chakravarty, Sugato, Pankaj Jain, James Upson, and Robert Wood, 2010, Clean sweep: Informed trading through intermarket sweep orders, *Working Paper, SSRN eLibrary.*

Chakravarty, Sugato, James Upson, and Robert Wood, 2011b, The flash crash: Trading aggressiveness, liquidity supply, and the impact of intermarket sweep orders, *Working Paper, SSRN eLibrary.*

Coleman, Les, 2011, An exploratory analysis of factors influencing initial market response and media reports following shock corporate events, *Financial Review* 46, 313–336.

Easley, David, and Maureen O'Hara, 1992, Time and the process of security price adjustment, *Journal of Finance* 47, 577–605.

Fama, Eugene F., 1965, The behavior of stock-market prices, *Journal of Business* 38, 34–105.

Fleming, Michael J., and Eli M. Remolona, 1999, Price formation and liquidity in the U.S. treasury market: The response to public information, *Journal of Finance* 54, 1901–1915.

French, Kenneth R., and Richard Roll, 1986, Stock return variances: The arrival of information and the reaction of traders, *Journal of Financial Economics* 17, 5–26.

Glosten, Lawrence R., and Paul R.. Milgrom, 1985, Bid, ask and transactions prices in a specialist market with insider trading, *Journal of Financial Economics* 14, 71–100.

Greene, Jason T., and Susan G. Watts, 1996, Price discovery on the NYSE and the NASDAQ: The case of overnight and daytime news releases, *Financial Management* 25, 19–42.

Harris, Lawrence, 1986, A transaction data study of weekly and intradaily patterns in stock returns, *Journal of Financial Economics* 16, 99–117.

He, Hua, and Jiang Wang, 1995, Differential information and dynamic behavior of stock trading volume, *Review of Financial Studies* 8, 919–972.

Henker, Thomas, and Jian-Xin Wang, 2006, On the importance of timing specifications in market microstructure research, *Journal of Financial Markets* 9, 162–179.

Hong, Harrison, and Jeremy C. Stein, 1999, A unified theory of underreaction, momentum trading, and overreaction in asset markets, *Journal of Finance* 54, 2143–2184.

Jennings, Robert, and Laura Starks, 1985, Information content and the speed of stock price adjustment, *Journal of Accounting Research* 23, 336–350.

Kyle, Albert S., 1985, Continuous auctions and insider trading, *Econometrica* 53, 1315–1335.

Lee, Charles M. C., and Mark. J. Ready, 1991, Inferring trade direction from intraday data, *Journal of Finance* 46, 733–746.

Lei, Adam Y.C., and Huihua Li, 2010, Still in the air: A clinical study of order strategies in response to erroneous information, *Working Paper, SSRN eLibrary.*

Lockwood, Larry J., and Scott C. Linn, 1990, An examination of stock market return volatility during overnight and intraday periods, 1964-1989, *Journal of Finance* 45, 591–601.

Masulis, Ronald W., and Lakshmanan Shivakumar, 2002, Does market structure affect the immediacy of stock price responses to news?, *Journal of Financial and Quantitative Analysis* 37, 617–648.

Mucklow, Belinda, 1994, Market microstnicture: An examination of the effects on intraday event studies, *Contemporary Accounting Research* 10, 355–382.

Niederhoffer, Victor, and M. F. M. Osborne, 1966, Market making and reversal on the stock exchange, *Journal of the American Statistical Association* 61, 897–916.

Patell, James M., and Mark A. Wolfson, 1984, The intraday speed of adjustment of stock prices to earnings and dividend announcements, *Journal of Financial Economics* 13, 223–252.

Smith, Brian F., Robert White, Michael Robinson, and Nason Richard, 1997, Intraday volatility and trading volume after takeover announcements, *Journal of Banking and Finance* 21, 337–368.

Wood, Robert A., Thomas H. McInish, and J. Keith Ord, 1985, An investigation of transactions data for NYSE stocks, *Journal of Finance* 40, 723–739.

Woodruff, Catherine S., and A. J. Jr. Senchack, 1988, Intradaily price-volume adjustments of NYSE stocks to unexpected earnings, *Journal of Finance* 43, 467–491.

Appendix: Detailed Derivations

Trading with non-aggressive orders.

Expected price change:

$$E\left[P_{t+1} - P_t\right] = q_1 \cdot \sigma + q_3 \cdot (-\sigma) = \sigma(q_1 - q_3)$$

Expected price variance:

$$\begin{aligned} Var\left[P_{t+1}\right] &= E\left[P_{t+1} - E\left[P_{t+1}\right]\right]^2 = q_1 \cdot \left[\sigma - \sigma(q_1 - q_3)\right]^2 + \\ &+ q_2 \cdot \left[0 - \sigma(q_1 - q_3)\right]^2 + q_3 \cdot \left[-\sigma - \sigma(q_1 - q_3)\right]^2 = \\ &= \sigma^2 \cdot \left[q_1 \cdot (1 - q_1 + q_3)^2 + q_2 \cdot (q_3 - q_1)^2 + q_3 \cdot (q_3 - q_1 - 1)^2\right]. \end{aligned}$$

Let $q_3 = q_1 + \varepsilon$. Then $q_2 = 1 - q_1 - q_3 = 1 - 2q_1 - \varepsilon$. Replacing q_2 and q_3 in the expression above, we obtain:

$$\begin{aligned} Var\left[P_{t+1}\right] &= \sigma^2 \cdot \left[q_1 \cdot (1 + \varepsilon)^2 + (1 - 2q_1 - \varepsilon) \cdot \varepsilon^2 + (q_1 + \varepsilon) \cdot (\varepsilon - 1)^2\right] = \\ &= \sigma^2 \cdot \left[2q_1 + \varepsilon - \varepsilon^2\right] = \sigma^2 \cdot \left[q_1 + q_3 - (q_3 - q_1)^2\right]. \end{aligned}$$

Trading with aggressive orders.

Expected price change:

$$\begin{aligned} E\left[P_{t+1} - P_t\right] &= [1 - \psi] \cdot (q_1 \cdot \sigma - q_3 \cdot \sigma) + \psi \cdot (q_1 \cdot y\sigma - q_3 \cdot y\sigma) = \\ &= [1 - \psi] \cdot \sigma \cdot (q_1 - q_3) + \psi \cdot y\sigma \cdot (q_1 - q_3) = \\ &= \sigma \cdot (q_1 - q_3) \cdot \left[1 + \psi \cdot (y - 1)\right]. \end{aligned}$$

Expected price variance:

$$\begin{aligned} Var\left[P_{t+1}\right] &= [1 - \psi] \cdot \sigma^2 \cdot \left[q_1 + q_3 - (q_1 - q_3)^2\right] + \psi \cdot y^2\sigma^2 \cdot \left[q_1 + q_3 - (q_1 - q_3)^2\right] = \\ &= \sigma^2 \cdot \left[q_1 + q_3 - (q_1 - q_3)^2\right] \cdot \left[1 - \psi \cdot (1 - y^2)\right]. \end{aligned}$$

Illiquid stocks.

Expected price change:

$$
\begin{aligned}
E\left[P_{t+1}-P_t\right] &= [1-\psi]\cdot(q_1\cdot x\sigma - q_3\cdot x\sigma)+\psi\cdot(q_1\cdot yx\sigma - q_3\cdot yx\sigma) = \\
&= [1-\psi]\cdot x\sigma\cdot(q_1-q_3)+\psi\cdot yx\sigma\cdot(q_1-q_3) = \\
&= x\sigma\cdot(q_1-q_3)\cdot[1+\psi\cdot(y-1)]\,.
\end{aligned}
$$

Expected price variance:

$$
\begin{aligned}
Var\left[P_{t+1}\right] &= [1-\psi]\cdot x^2\sigma^2\cdot\left[q_1+q_3-(q_1-q_3)^2\right]+\psi\cdot y^2x^2\sigma^2\cdot\left[q_1+q_3-(q_1-q_3)^2\right] = \\
&= x^2\sigma^2\cdot\left[q_1+q_3-(q_1-q_3)^2\right]\cdot\left[1-\psi\cdot(1-y^2)\right].
\end{aligned}
$$

Figure 2: Price Changes with Normal Orders

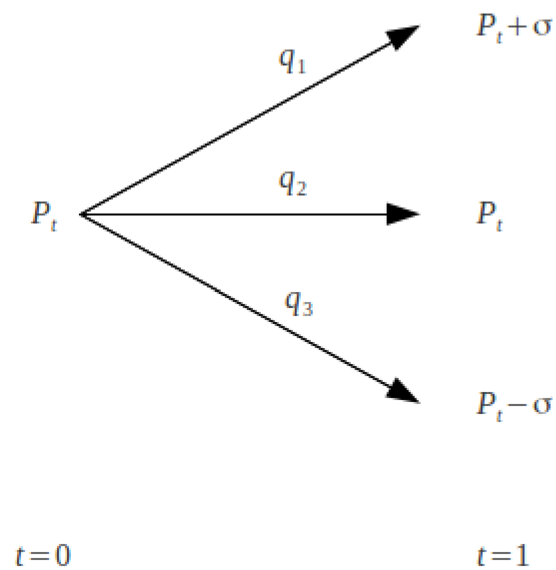


Figure 3: Price Changes in the Presence of Aggressive Orders

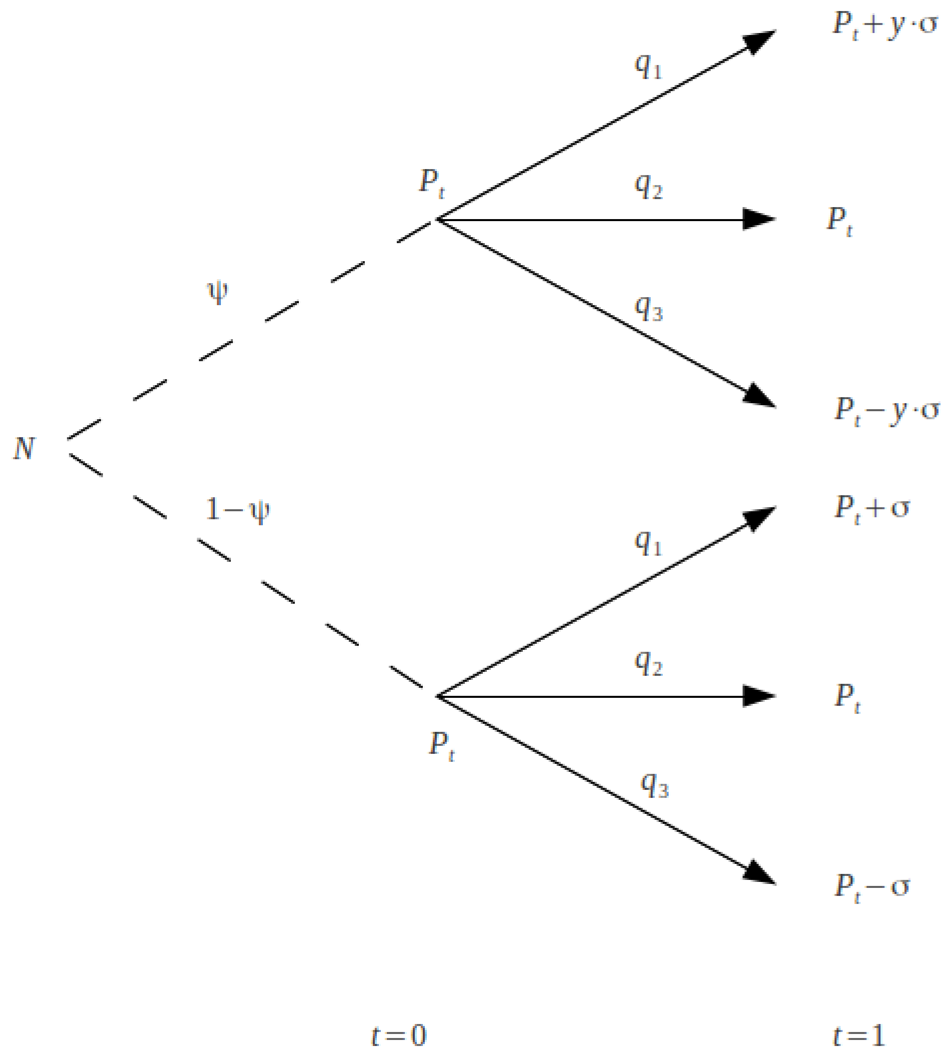
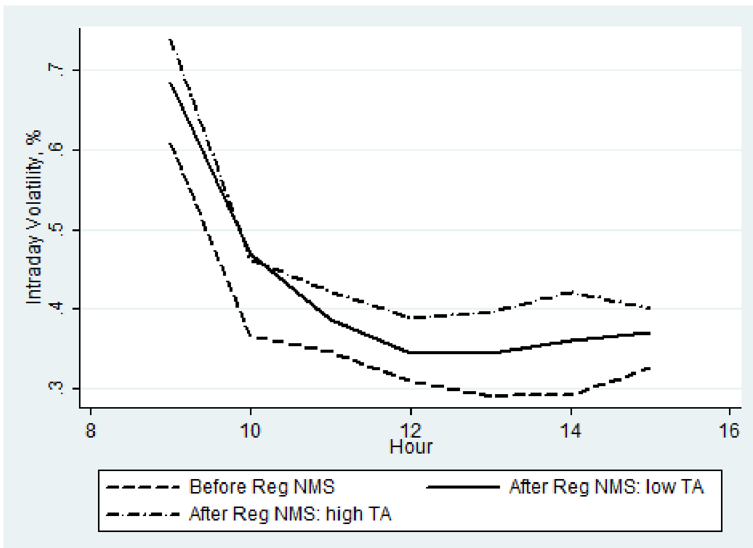


Figure 4: **Intraday Volatility in the Pre- and Post-Reg NMS Period.** The figure displays variations of the intraday volatility (in %), measured as the standard deviation of one-minute closing midpoint returns, throughout a normal trading day. Panel A shows the mean intraday volatility for the subsample of liquid stocks (the relative spread is below the median). Panel B presents the mean intraday volatility for the subsample of illiquid stocks (the relative spread is above the median).

A. Liquid Stocks.



B. Illiquid Stocks.

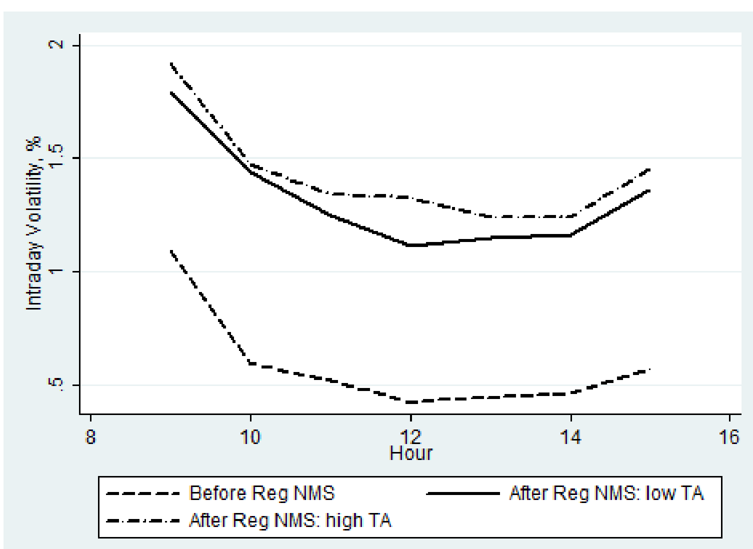


Figure 5: **Changes in Proportion of ISO volume on an Announcement Day**. This figure displays mean percentage deviations in the proportion of ISO volume throughout an announcement day. Deviations from the bootstrapped means are measured in 15-minute intervals relative to the 15-minute interval with an earnings announcement release (interval 0). The dashed line shows the 1% significance level for the mean percentage change in the proportion of ISO volume, equal to 4.8%.

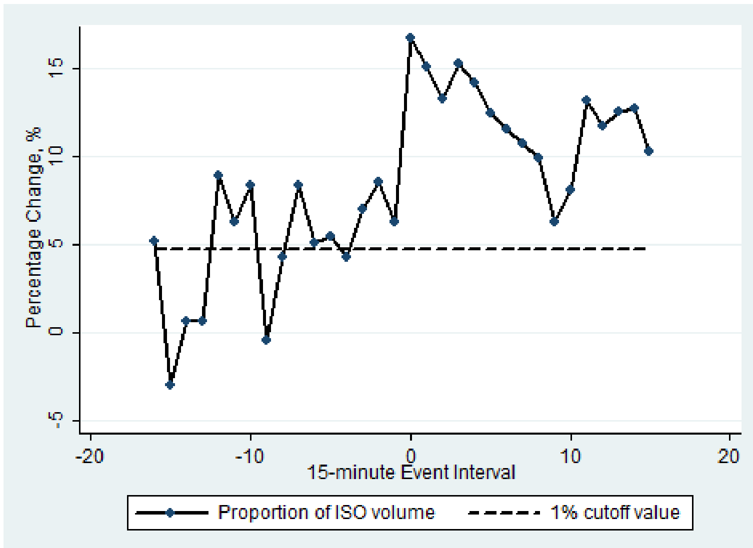


Figure 6: **Convergence Time and Trading Aggressiveness.** This figure depicts the relationship between the mean length of the price adjustment period and the mean change in the proportion of ISO volume after an information release, separately for the samples of liquid and illiquid stocks. The length of the price adjustment period is measured as the number of ten-minute time intervals until volatility of one-minute midpoint returns is no longer abnormal.

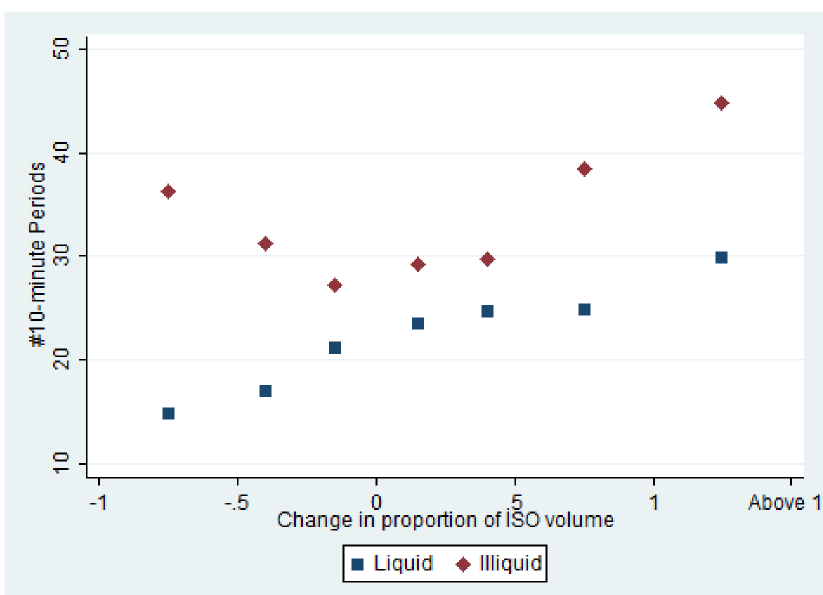


Table 1: **Variable Definitions.** This table defines all variables in this paper and indicates databases, used for their construction.

Variable	**Description**	Source
%ISOvol	Proportion of daily volume, executed through aggressive intermarket sweep orders (ISO)	TAQ
$\Delta ISOvol$	Change in the proportion of daily volume, executed through aggressive intermarket sweep orders (ISO), after an announcement release relative to its mean in the base period	TAQ
Afternoon	1, if an announcement is released between 2 p.m. and 4 p.m., and zero otherwise.	I/B/E/S
Amihud	Amihud's measure of illiquidity, defined as the ratio of the daily absolute return to the dollar trading volume on that day (Amihud, 2002).	CRSP
BigSurp	1, if an absolute value of the 24-hour return after an announcement exceeds 2%, and zero otherwise.	TAQ
EarnSurp	An absolute value of a stock return in 24 hours after an announcement release	TAQ
EventVolume	Total volume traded within three days after an announcement release (in thousands of shares)	TAQ
HighTA	1 for stocks with the proportion of ISO volume above its median value of all stocks in the sample (in the base period), and zero otherwise	TAQ
Illiquid	1, if the relative spread of a stock is above its median value of all stocks in the sample.	TAQ
Intr Volat	Intraday volatility, measured as the standard deviation of one-minute closing midpoint returns (in %)	TAQ
Intr Volume	Total volume traded within a 10-minute interval (in shares)	TAQ
Leverage	Market leverage, defined as the ratio of total liabilities to the sum of total liabilities and market capitalization of the company.	Compustat
Liquid	1, if the relative spread of a stock is below its median value of all stocks in the sample.	TAQ
LnMCap	Natural logarithm of market capitalization	CRSP
MCap	Market value of equity (in million $)	CRSP

Variable	Description	Source
Morning	1, if an announcement is released between 9:30 a.m. and 12 p.m. EST, and zero otherwise.	I/B/E/S
Nasdaq	1, if a stock is listed on Nasdaq, and zero otherwise.	TAQ
Noon	1, if an announcement is released between 12 p.m. and 2 p.m. EST, and zero otherwise.	I/B/E/S
Number of ISO trades	Total number of executed intermarket sweep orders in a particular time interval	TAQ
Number of ISO buys	Total number of executed purchase transactions through intermarket sweep orders in a particular time interval	TAQ
Number of ISO sells	Total number of executed sale transactions through intermarket sweep orders in a particular time interval	TAQ
Post-Reg NMS	1 after the final implementation of the Regulation NMS (October 2007), and zero otherwise	
Pre-Reg NMS	1 before the final implementation of the Regulation NMS (October 2007), and zero otherwise	
Prc	Stock price (in $)	CRSP
Price Impact	The measure of price impact of each trade after 5 minutes, defined as $PrcImp_t = 2\left\|Q_{t+5} - Q_t\right\|/(Q_t)$, where Q_{t+5} is the midpoint price of a stock after five minutes.	TAQ
Proportion of ISO trades	The ratio of the number of intermarket sweep orders to the total number of orders executed in a particular time interval	TAQ
Proportion of ISO volume	The ratio of the volume, executed through intermarket sweep orders, to the total volume traded in a particular time interval	TAQ
Proportion of ISO buys	The ratio of the number of purchase transactions executed through intermarket sweep orders to the total number of purchase transactions in a particular time interval	TAQ
Proportion of ISO sells	The ratio of the number of sale transactions executed through intermarket sweep orders to the total number of sale transactions in a particular time interval	TAQ
RelSpr	Intraday relative spread, defined as the difference between the ask and the bid, scaled by their average; observations with *RelSpr>0.5* are set to missing values.	TAQ

Variable	**Description**	Source
RelSpr (daily)	Daily relative spread, defined as the difference between the closing ask and the closing bid, scaled by their average; observations with *RelSpr (daily)*>*0.5* are set to missing values.	CRSP
ROA	Return on assets, defined as the ratio of operating income after depreciation to average total assets of the current year and the previous year.	Compustat
Small	1, if the market capitalization of a stock is below its median value of all stocks in the sample.	CRSP
TA_i	ith tercile of trading aggressiveness (TA1 - the lowest tercile of trading aggressiveness and TA3 - the highest tercile of trading aggressiveness)	Own calculations
Time to Convergence	The number of 10-minute intervals from an announcement time until the interval, in which intraday volatility of 1-minute returns (*Intr Volat)* is no longer abnormal	Own calculations
Total Assets	Total assets (in mln $)	Compustat
Total Liabilities	Total liabilities (in mln $)	Compustat
Turnover	Average daily traded volume, divided by the number of shares outstanding	CRSP
Volatility	Annualized standard deviation of daily stock returns over the calendar month	CRSP
Volume	Average daily traded volume (in thousands of shares)	CRSP

Table 2: **Sample Construction.** This table shows the sample selection of earnings announcements in US firms that happened within trading hours (from 9:30 a.m. till 16:00 p.m. EST) over the years 2006-2009. Data source for dates and times of earnings announcements is the Institutional Brokers Estimate System (I/B/E/S) database. Each firm is required to exist in the intersection set of I/B/E/S and CRSP.

Criteria	**Announcements**	**Firms**
Initial sample	10,334	3,361
Stock was traded on an announcement day	9,687	3,273
Intraday transaction data available on TAQ	8,720	3,008
Exclude companies that announce only within trading hours (very illiquid)	8,414	2,950
Closing price not less than $5	6,126	2,334
Not more than one announcement per day	6,040	2,322
Trading data exists for previous 2 months	5,944	2,307
At least one announcement before and one announcement after Reg NMS, out of which:	3,613	675
- Before Reg NMS	1,818	675
- After Reg NMS	1,795	675

Table 3: **Sample Distributions.** This table displays distributions of firm characteristics for three groups of firms: 1) firms that make earnings announcements both within and outside of trading hours, used also as the initial sample (Panel A, Columns 4-6); 2) firms that make earnings announcements only within trading hours (Panel B, Columns 1-3); 3) firms that make earnings announcements only outside trading hours (Panel B, Columns 4-6). Summary characteristics of firms in the final sample are presented in Columns 1-3 of Panel A. See Table 1 for the exact definition of all variables.

Panel A: Firms announcing within and outside trading hours

	Final			Initial		
	N	Mean	50%	N	Mean	50%
Total Assets (in mln $)	666	8672	686	3246	6220	477
Total Liabilities (in mln $)	666	5990	507	3245	4309	274
MCap (in mln $)	675	2670	256	3304	2254	239
Prc (in $)	675	26	21	3304	20	14
ROA	654	0.07	0.05	3029	-0.01	0.04
Leverage	666	0.54	0.55	3241	0.46	0.41
RelSpr (daily)	675	0.01	0.00	3304	0.01	0.01
Amihud	675	0.95	0.04	3304	1.93	0.06
Volatility	675	0.44	0.41	3304	0.59	0.53
Turnover	675	0.006	0.003	3304	0.007	0.005

Panel B: Firms announcing only within or only outside trading hours

	Within			Outside		
	N	Mean	50%	N	Mean	50%
Total Assets (in mln $)	54	3791	251	3100	4375	584
Total Liabilities (in mln $)	54	2668	175	3096	3067	278
MCap (in mln $)	57	433	130	3175	2448	482
Prc (in $)	57	22	17	3175	21	16
ROA	25	0.07	0.06	2689	0.02	0.06
Leverage	49	0.53	0.64	3075	0.38	0.32
RelSpr (daily)	57	0.02	0.01	3175	0.01	0.00
Amihud	57	2.43	0.11	3175	0.79	0.01
Volatility	57	0.47	0.40	3175	0.55	0.52
Turnover	57	0.005	0.003	3175	0.009	0.007

Table 4: **Trading Characteristics before Reg NMS and after Reg NMS.** This table displays differences in trading characteristics of stocks in the final sample in two regulatory periods. Panel A presents firm characteristics after the achievement of full compliance with the Reg NMS (October 2007 - December 2009). Panel B displays firm characteristics in the pre-Reg NMS period (January 2006 - September 2007). See Table 1 for the exact definition of all variables. Columns 1-2 report trading characteristics of the total sample. Columns 3-4 report trading characteristics of firms with low trading aggressiveness (the proportion of ISO volume is below its median value of all stocks in the sample). Columns 5-6 report trading characteristics of firms with high trading aggressiveness (the proportion of ISO volume is above its median value of all stocks in the sample). P-values of the Mann-Whitney test with the null-hypothesis of the difference in medians equaling zero are reported in form of asterisks in the last column. * denotes statistical significance at the 10% level, ** denotes statistical significance at the 5% level, *** denotes statistical significance at the 1% level.

	Total		Low TA		High TA		MW-test
	Mean	50%	Mean	50%	Mean	50%	
Panel A: Post-Reg NMS							
MCap (in mln $)	2695	254	2374	291	3017	208	
Turnover (in %)	0.63	0.36	0.63	0.40	0.63	0.29	
RelSpr (in %)	3.40	1.91	3.16	1.47	3.63	2.26	**
Intr Volat (in %)	0.95	0.73	0.94	0.65	0.97	0.80	
Panel B: Pre-Reg NMS							
MCap (in mln $)	2570	267	2208	292	2934	236	
Turnover (in %)	0.51	0.25	0.47	0.29	0.55	0.22	
RelSpr (in %)	1.75	1.09	1.87	1.18	1.63	1.02	
Intr Volat (in %)	0.47	0.33	0.56	0.40	0.38	0.30	***

Table 5: **Determinants of ISO trading volume.** This table examines the determinants of ISO volume in the base period and after earnings announcement releases. Models (1) and (2) report results of cross-sectional OLS regressions with the mean proportion of daily volume traded with aggressive orders as the dependent variable (*%ISOvol*). The dependent variable in Models (3) and (4) is the percentage deviation in the proportion of ISO volume on an announcement day from its value in the base period ($\Delta ISOvol$). See Table 1 for the exact definition of all variables. P-values of the two-tailed t-test with the null-hypothesis of a coefficient equaling zero are reported in form of asterisks to the right of each coefficient. * denotes statistical significance at the 10% level, ** denotes statistical significance at the 5% level, *** denotes statistical significance at the 1% level. I also report the number of observations (N) and R^2 for each regression.

	(1) %ISOvol	(2) %ISOvol	(3) $\Delta ISOvol$	(4) $\Delta ISOvol$
LnMCap	0.022 ***	0.022 ***	0.002	-0.007
RelSpr	-0.0001		0.0175 **	
Amihud		-0.0002		0.0190 **
Volume	-0.0000	-0.0000		
Δ Volume			-0.0001 **	-0.0001 ***
EarnSurp			0.56 **	0.58 ***
Nasdaq	0.138 ***	0.138 ***	-0.005	-0.000
Monday			0.06	0.05
Tuesday			0.09 *	0.08
Wednesday			0.11 **	0.10 **
Thursday			0.10 *	0.08 *
Friday			.	.
Morning			-0.00	-0.00
Noon			.	.
Afternoon			0.05	0.05
Year 2007	0.01	0.01	0.12 **	0.10 *
Year 2008	0.02 ***	0.02 ***	0.02	0.01
Year 2009	.	.	.	.
Constant	0.18 ***	0.18 ***	-0.12	-0.01
N	1771	1771	1768	1768
R-squared	0.24	0.24	0.02	0.02

Table 6: **Regression Analysis of the Intraday Volatility in the Base Period.** This table presents results of panel OLS regressions with intraday volatility as the dependent variable, controlling for year- and hour-fixed effects. One observation represents a 10-minute trading interval for a stock in the base period (days -40 to -2 before an announcement release). Standard errors are clustered on the firm level. See Table 1 for the exact definition of all variables. P-values of the two-tailed t-test with the null-hypothesis of a coefficient equaling zero are reported in form of asterisks to the right of each coefficient. * denotes statistical significance at the 10% level, ** denotes statistical significance at the 5% level, *** denotes statistical significance at the 1% level. I also report the number of observations (N) and R^2 for each regression.

	(1) IntrVolat	(2) IntrVolat	(3) IntrVolat	(4) IntrVolat
%ISOvol	0.039 ***	0.004		
High TA			-0.014	-0.010
Small	0.43 ***	0.45 ***	0.44 ***	0.24 ***
Illiquid	0.82 ***	0.76 ***	0.76 ***	0.35 ***
Small · %ISOvol		-0.03		
Illiquid · %ISOvol		0.16 ***		
Small · High TA			-0.02	-0.02
Illiquid · High TA			0.11 ***	0.07 **
Post-Reg NMS				-0.04
Small · Post-Reg NMS				0.13 **
Illiquid · Post-Reg NMS				0.40 ***
IntrVolume	-0.00	-0.00	-0.00	-0.00
N	1689221	1689221	1689221	3298146
R-squared	0.14	0.14	0.14	0.13

Table 7: **Differences in Characteristics of ISO and non-ISO Orders.** This table summarizes differences in use and trading characteristics between ISO (Panel A) and non-ISO orders (Panel B). First three columns report the cross-sectional mean of respective variables in half an hour following an information release. The last column displays the mean of the bootstrapped distribution from the base period, constructed from observations in the corresponding half-hour intervals. Earnings surprises are measured as an absolute value of the 24-hour return. They are classified as "large" if an absolute value of the 24-hour return exceeds 2%. See Table 1 for the exact definition of all variables. All variables are calculated from the intraday transaction data in the NYSE TAQ database.

Panel A: ISO orders

	Event			Mean
	Total	Big Pos Surp	Big Neg Surp	
Proportion of Trades	0.45	0.46	0.46	0.40
Proportion of Volume	0.42	0.43	0.42	0.36
Relative Spread (in %)	2.30	2.55	2.27	1.90
Price Impact (in %)	2.21	2.56	2.59	1.48

Panel B: Non-ISO orders

	Event			Mean
	Total	Big Pos Surp	Big Neg Surp	
Proportion of Trades	0.55	0.54	0.54	0.60
Proportion of Volume	0.58	0.57	0.58	0.64
Relative Spread (in %)	2.26	2.33	2.50	2.04
Price Impact (in %)	2.16	2.43	2.53	1.55

Table 8: **Trading Aggressiveness Half an Hour Before and After an Announcement.** This table displays deviations in the number and the proportion of ISO trades and ISO volume in half an hour immediately following an announcement (Panel A) and in half an hour immediately preceding it (Panel B). All numbers are percentage deviations from the corresponding mean of the bootstrapped empirical distribution. Earnings surprises are measured as an absolute value of the 24-hour return. They are classified as "large" if an absolute value of the 24-hour return exceeds 2%. See Table 1 for the exact definition of all variables. All variables are calculated from the intraday transaction data in the NYSE TAQ database. Significance levels are reported in form of asterisks to the right of each coefficient. * denotes statistical significance at the 10% level, ** denotes statistical significance at the 5% level, *** denotes statistical significance at the 1% level.

Panel A: Half an Hour After an Announcement

	All		Big Pos Surp		Big Neg Surp	
Δ Number of ISO trades	1.39	***	1.75	***	2.05	***
Δ Proportion of ISO trades	0.12	***	0.15	***	0.15	***
Δ Proportion of ISO volume	0.14	***	0.17	***	0.17	***
Δ Number of ISO buys	1.41	***	1.90	***	1.95	***
Δ Number of ISO sells	0.11	***	0.14	***	0.12	***
Δ Proportion of ISO buys	0.12	***	0.15	***	0.15	***
Δ Proportion of ISO sells	1.36	***	1.61	***	2.14	***

Panel B: Half an Hour Before an Announcement

	All		Big Pos Surp		Big Neg Surp	
Δ Number of ISO trades	0.44	***	0.24	***	1.04	***
Δ Proportion of ISO trades	0.07	***	0.07	***	0.11	***
Δ Proportion of ISO volume	0.07	***	0.04	**	0.11	***
Δ Number of ISO buys	0.42	***	0.26	***	1.00	***
Δ Number of ISO sells	0.08	***	0.11	***	0.13	***
Δ Proportion of ISO buys	0.05	***	0.03	**	0.08	***
Δ Proportion of ISO sells	0.45	***	0.23	***	1.09	***

Table 9: **The Length of the Price Adjustment Period: Summary Statistics and Univariate Analysis.** Panel A of this table presents distributions of the length of the price adjustment period, separately for samples of liquid and illiquid stocks, in the pre- and the post-Reg NMS periods. See Table 1 for the exact definition of all variables. 1 unit corresponds to a 10-minute interval. The significance level of the non-parametric Mann-Whitney test on the equality of medians of pre- and post-Reg NMS distributions is reported in row 3. Panel B displays the median convergence time across different terciles of trading aggressiveness (TA1 - TA3) in the post-Reg NMS period. Trading aggressiveness is measured as the change in the proportion of ISO volume traded after an announcement release relative to its mean in the base period ($\Delta ISOvol$). TA1 includes stocks with the lowest increases in trading aggressiveness on an announcement day and TA3 includes stocks with the highest increases. The significance level of the non-parametric Mann-Whitney test on the equality of medians between liquid and illiquid stocks is reported in the last column. The last two rows report the significance level of the Mann-Whitney test on the equality of medians across different terciles of trading aggressiveness. * denotes statistical significance at the 10% level, ** denotes statistical significance at the 5% level, *** denotes statistical significance at the 1% level.

Panel A: Before Reg NMS vs After Reg NMS

	Liquid			Illiquid		
	Before	After	MW-test	Before	After	MW-test
5%	0	0		1	0	
25%	5	5		9	7	
50%	16	13	**	25	23	
75%	38	30		61	63	
95%	81	76		91	91	
Mean	25.30	21.73		35.41	34.58	
Std	25.39	23.17		30.37	31.55	

Panel B: Liquidity and Aggressiveness Terciles

	Liquid	Illiquid	MW-test
Pre-Reg NMS	16	25	***
Post-Reg NMS	13	23	***
TA1	12	21	***
TA2	13	17	*
TA3	13	27	***
MW (TA1 vs TA3)		*	
MW (TA2 vs TA3)		***	

Table 10: **The Length of the Price Adjustment Period after the Reg NMS: Liquid Stocks.** This table presents results of negative binomial regressions in the sample of liquid stocks, for which the relative spread is below the median relative spread of all stocks in the final sample. The dependent variable in each model is a number of 10-minute periods until a price adjusts to its new equilibrium level. See Table 1 for the exact definition of all variables. P-values of the two-tailed t-test with the null-hypothesis of a coefficient equaling zero are reported in form of asterisks to the right of each coefficient. * denotes statistical significance at the 10% level, ** denotes statistical significance at the 5% level, *** denotes statistical significance at the 1% level.

# 10-min Periods	(1)	(2)	(3)
Δ ISOvol	0.19 **		
$\|\Delta ISOvol\|$		0.05	
$\|\Delta ISOvol\|_{if\ \Delta ISOvol>0}$			0.08
$\|\Delta ISOvol\|_{if\ \Delta ISOvol<0}$			-0.45 *
BigSurp	0.20 **	0.21 **	0.20 **
Volume	0.00	0.00	0.00
Intr Volat	-0.12	-0.14	-0.12
LnMCap	0.04	0.04	0.04
Monday	0.11	0.11	0.11
Tuesday	0.24 *	0.25 *	0.23 *
Wednesday	0.15	0.17	0.16
Thursday	0.15	0.17	0.15
Morning	-0.05	-0.06	-0.06
Noon	0.11	0.10	0.10
N	783	783	783
P(Chi-Squared)	0.002	0.007	0.002

Table 11: **The Length of the Price Adjustment Period after the Reg NMS: Illiquid Stocks.** This table presents results of negative binomial regressions in the sample of illiquid stocks, for which the relative spread is above the median relative spread of all stocks in the final sample. The dependent variable in each model is a number of 10-minute periods until a price adjusts to its new equilibrium level. See Table 1 for the exact definition of all variables. P-values of the two-tailed t-test with the null-hypothesis of a coefficient equaling zero are reported in form of asterisks to the right of each coefficient. * denotes statistical significance at the 10% level, ** denotes statistical significance at the 5% level, *** denotes statistical significance at the 1% level.

# 10-min Periods	(1)	(2)	(3)
Δ ISOvol	0.05		
$\|\Delta ISOvol\|$		0.18 **	
$\|\Delta ISOvol\|_{if\ \Delta ISOvol>0}$			0.18 **
$\|\Delta ISOvol\|_{if\ \Delta ISOvol<0}$			0.23 *
BigSurp	0.03	0.05	0.05
Volume	0.00	0.00	0.00
Intr Volat	0.05	0.05	0.05
LnMCap	-0.26 ***	-0.23 ***	-0.23 ***
Monday	0.10	0.11	0.11
Tuesday	0.12	0.13	0.13
Wednesday	0.18	0.19	0.19
Thursday	0.13	0.14	0.14
Morning	-0.43 ***	-0.42 ***	-0.41 ***
Noon	0.02	0.02	0.02
N	839	839	839
P(Chi-Squared)	0.000	0.000	0.000

Table 12: **The Length of the Price Adjustment Period: the Difference-in-Differences Analysis.** This table presents results of negative binomial regressions, including observations from the pre- and the post-Reg NMS periods. Model 1 reports the results for the sample of liquid stocks, Model 2 presents the results for the sample of illiquid stocks and Model 3 displays the results for the total sample. The dependent variable in each model is a number of 10-minute periods until a price adjusts to its new equilibrium level. See Table 1 for the exact definition of all variables. P-values of the two-tailed t-test with the null-hypothesis of a coefficient equaling zero are reported in form of asterisks to the right of each coefficient. * denotes statistical significance at the 10% level, ** denotes statistical significance at the 5% level, *** denotes statistical significance at the 1% level.

# 10-min Periods	(1)	(2)	(3)
$\lvert\Delta ISOvol\rvert_{if\ \Delta ISOvol>0}$	0.08	0.15 **	
$\lvert\Delta ISOvol\rvert_{if\ \Delta ISOvol<0}$	-0.45 *	0.16	
Illiquid			0.30 ***
Post Reg NMS	-0.01	-0.23 *	-0.10
Illiquid · Post-Reg NMS			-0.10
Liquid· $\lvert\Delta ISOvol\rvert_{if\ \Delta ISOvol>0}$			0.06
Liquid· $\lvert\Delta ISOvol\rvert_{if\ \Delta ISOvol<0}$			-0.53 **
Illiquid· $\lvert\Delta ISOvol\rvert_{if\ \Delta ISOvol>0}$			0.23 ***
Illiquid· $\lvert\Delta ISOvol\rvert_{if\ \Delta ISOvol<0}$			0.27 **
BigSurp	0.23 ***	0.00	0.09 **
EventVolume	0.00 ***	-0.00	0.00 ***
Intr Volat	-0.22 **	0.05	0.05
LnMCap	0.02	-0.21 ***	-0.03 *
N	1728	1595	3323
P(Chi-Squared)	0.000	0.000	0.000