Quote Stuffing and Market Quality

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Abstract

Quote stuffing is the practice of placing a large number of orders and cancelling them quickly. We identify numerous events of this kind in the period since Reg. NMS has been in place, with a peak average of 1,026 episodes per day in 318 symbols in 2010. We find that quote stuffing is harmful to market quality, widening spreads and raising volatility. This occurs not only on the Nasdaq where we observe the quote stuffing, but also on the NYSE, Archipelago and Amex. Trading rises though, and the median market share of high frequency trading rises an average of 7.5% during these episodes. We estimate that each 1,000 cancellations during the quote stuffing are associated with 805 shares of high frequency trading volume. Institutional participants migrate off exchange, with a median increase in the TRF market share that averages 15%. Aggregate message volume on Nasdaq appears to have plateaued, but peaks in one minute message bursts continue to rise.

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1. Introduction

High frequency trading (HFT) represents the majority of equity market trading volume since the final passage of Reg. NMS in August 2007. There is an active academic debate as to whether HFT is harmful to market quality.

Some papers suggest that HFT improves market quality. Hasbrouck and Saar (2013) analyze the ITCH data feed from Nasdaq. They identify HFT activity by orders linked closely in time. From these matched orders, they suggest that HFT activity lowers short-term volatility and bid-ask spreads, and increases displayed depth. Brogaard, Hendershott and Riordan (BHR, 2014) analyze a data set from Nasdaq that identifies HFT firms. They find that HFT increases price efficiency through their marketable orders. Carrion (2013) studies the same data set as BHR and concludes that HFT participants supply liquidity when it is low and take liquidity when it is high. Menkveld (2013) analyzes the arrival of the Chi-X high frequency platform in Europe, the most active European trading network, and concludes that HFT firms act as market makers in the new market. Brogaard, Hagströmer, Norden and Riordan (2014) find that fast and colocated traders improve market liquidity at Nasdaq OMX Stockholm by relaxing their inventory management constraints.

On the contrary, other papers find pernicious effects of HFT on market quality. Gai, Yao and Ye (2014) find that exogenous latency reduction at Nasdaq that lead to more HFT activities do not improve market liquidity but generate externatilities. Menkveld and Zoican (2014) have a similar finding that adverse selection cost and effective spread rise after an improvement in speed at Nasdaq OMX Nordic. Three studies have re-examined the BHR data set and reached different conclusions. Brogaard, Hendershott and Riordan (2013) use the 2008 short sale ban as an exogenous shock and find that HFT firms decrease liquidity and increase volatility. Gao and Mizrach (2013) find that HFT firms decrease their market making activity and increase their aggressive trades during Federal Reserve Treasury purchases. Hirschey (2013) notes that HFT firms anticipate the order flow from non-HFT investors and their aggressive trades are highly correlated with future returns. Breckenfelder (2013) studies the competition among HFT firms at Nasdaq OMX Stockholm and finds that it leads to a decline in liquidity and a rise in short-term volatility.

Judging HFT as solely "good" or "bad" is too general given the fact that it covers a variety of strategies that may impact the market differently. Hagströmer and Norden (2013) divide HFT

into market making and opportunistic specializations, and find that the majority of HFT volume comes from market making activities. Biais and Foucault (2014) discuss the HFT heterogeneity and classify HFT strategies in five categories ranging from market making to manipulation. On one hand, high frequency market makers are generally deemed as beneficial to the market, as shown theoretically by Jovanovic and Menkveld (2012) and empirically by Menkveld (2013) and others. On the other hand, Menkveld and Zoican (2014) find that market quality deteriorates when high frequency speculators are also taken into account. The diversity of HFT strategies suggests that analyzing the average effect of HFT may provide a misleading conclusion on its impact on market quality.

Although HFT market making constitutes a large share of HFT activities, HFT firms are more profitable from aggressive trading. Baron, Brogaard and Kirilenko (2012) analyze data from the Commodity Futures Trading Commission that identifies the HFT participants. They study the profitability of HFT in the E-mini futures contract and find that aggressive HFT firms make higher profits than mixed or passive HFT firms. BHR (2014) find that HFT firms earn high profits in liquidity demanding trades and suffer losses in liquidity supplying trades without fee rebates.

HFT enables the fastest traders to gain the largest profits as they can process news quickly. Several studies provide theoretical models in which HFT firms have speed advantage upon news arrivals. Biais, Foucault and Moinas (2013) and Hoffmann (2014) suggest that differences in speed increase adverse selection costs and thus HFT generates negative externalities and reduces social welfare. Foucault, Hombert, and Roşu (2013) argue that the ability of HFT firms to receive news faster creates additional information asymmetry and thus reduce liquidity. Martinez and Roşu (2013) model HFT participants as informed traders who observe news stream and trade quickly. They find that HFT generates trading volume and volatility and decreases liquidity.

HFT participation has also dramatically increased the number of orders entering the equity market. We document a rise in the cancellation to execution ratio in ITCH from 28 in 2008 to 84 in 2013. Apart from this rising trend, stocks frequently exhibit bursts in quoting and cancellation activity that do not appear to be related to fundamentals. In this paper we analyze these "quote stuffing" episodes that often occurred in the absence of news.

Quote stuffing has been documented in ITCH data by Gai, Yao and Ye (2014) at the level of individual Nasdaq servers. They find the evidence that message flows of stocks on the same server tend to move together. Hasbrouck (2013) also suggests that high frequency oscillations in quoting

contribute to the short-term volatility after Reg. NMS. Eggington, Van Ness and Van Ness (2013) analyze these episodes across exchanges and find hundreds of cases per day. The theoretical model by Baruch and Glosten (2013) suggests that fleeting orders are an outcome of a benign equilibrium where strategic liquidity suppliers manage their risk. While it provides a possible explanation for fleeting quotes, their model is based on the assumption that the short lived orders are used solely by liquidity providers. However, HFT aggressive firms may create fake news events by submitting and quickly cancelling a large amount of quotes as a way to make profits.

We identify numerous episodes of high frequency cancellations since Reg. NMS has been implemented. The number of occurrence peaks in 2010 with an average of 930 episodes per day in 257 symbols. We find that quote stuffing has detrimental impact on market quality. Volatility increases and bid-ask spreads widen persistently following quote stuffing. We observe the effects not only on Nasdaq where quote stuffing occurs, but also on NYSE, Arca, and Amex.

An important issue on quote stuffing is whether it generates negative externalities to other market participants. Gai, Yao and Ye (2014) argue that the message flow of a stock could block trading of stocks on the same Nasdaq server. However, we find that trading activity of the same stock rises on Nasdaq and other exchanges during quote stuffing events. We observe that the share of high frequency trading increases during these episodes. We estimate that each $1,000$ cancellations are associated with 805 shares of high frequency trading volume during the quote stuffing minute. Another externality from high frequency cancellations is that institutional traders appear to go off exchange when quote stuffing is happening.

The paper is organized as follows. Section 2 describes the ITCH data set at the message level and presents our definition of HFT activity. Section 3 describes annual trends in quote stuffing events. Section 4 describes the effects on market quality on Nasdaq where our quote stuffing events originate. Section 5 reports the same market quality metrics for other exchanges. Section 6 looks at trading activity which rises on both Nasdaq and other exchanges. On Nasdaq, we document that HFT firms grab a larger market share of the higher trading activity. Dark pools also grab a larger market share. Section 7 looks at quote stuffing externalities. Section 8 concludes.

2. ITCH

Identifying the effects of high frequency trading requires data at the messaging level. ITCH is the underlying message feed for the Nasdaq Totalview, the most comprehensive order book that Nasdaq

provides to market participants. We list the messages, in Table 1, analyzed in this manuscript, all of which change the status of the order book in some way.

[INSERT Table 1 HERE: Description of ITCH Messages]

Market makers can enter multiple quotes at different price tiers in the book, and they can also choose to display their market participant ID (MPID) or to trade anonymously. An F message indicates an addition to the order book with the MPID, and an A message is anonymous. Each message enters with an order number. The link between the orders enables us to determine the time between when an order enters and leaves the book.

Messages can leave in five ways. We can see an execution against that quote with the message E. This determines the aggressive side in the trade, so there is no ambiguity about trade direction. Trades occasionally execute at a different price than quoted, and these trades are designated with the message symbol C. Orders can be deleted in their entirety, and these messages are designated with a D. An order can be partially deleted, which is a X message. Order can also be cancelled and replaced, and these are designated with an U.

Time stamps are in nanoseconds. We define a high frequency message as any order chain with 50 millisecond link or less. This is the same definition used in Hasbrouck and Saar (2012), Hasbrouck (2013), and Ye, Yao and Gai (2013). Only HFT firms are able to operate with this latency which requires extensive infrastructure investments.

Our analysis proceeds with a definition of quote stuffing events. We then turn to the effects on market quality of quote stuffing.

3. Quote Stuffing Trends

We have ITCH data going back to August 2003, but we analyze the data following Reg. NMS, 2008-2013.

3.1 Definition

We analyze the data in one-minute intervals. This appears to be long enough to capture quote stuffing in both large and small capitalization stocks. We analyze the 380 minutes from 09:35 to 15:55. This helps us to avoid problems at the open and close which may distort our measures.

We take the intersection of stocks listed in ITCH with those in Compustat. There are approx-

imately 7,000 ticker symbols that we analyze on a given trading day.

For C, D, E, U and X messages, we count the number of occurrences of both HFT and non-HFT messages, $\#D^{HFT}, \#D^{nHFT}$, etc.

We define our quote stuffing events using three criteria. We first identify a 30-standard deviation increase in HFT cancellation frequency compared to the moving average of the preceding 22 days during that minute

$$zD^{HFT}_{i,t,n} = \frac{\#D^{HFT}_{i,t,n} - \overline{D}^{HFT}_{i,t,n-1}}{\sigma(D^{HFT}_{i,t,n-1})} \tag{1}$$

where

$$\overline{D}^{HFT}_{i,t,n-1} = \sum_{j=1}^{22} \#D^{HFT}_{i,t,n-j}/22$$

and

$$\sigma(D^{HFT}_{i,t,n-1}) = \sum_{j=1}^{22} (\#D^{HFT}_{i,t,n-j} - \overline{D}^{HFT}_{i,t,n-1})$$

This is our measure of volatility. To avoid very illiquid stocks, we also require at least 500 HFT cancellations in the minute, $\#D^{HFT}_{i,t,n} \geq 500$.

Finally, since news is likely to generate additional quoting activity, we filter out any stocks that have Reuters news stories on the day before, the day of, and the day after the quote stuffing occurs.

3.2 Frequency of events

Even at the 30 standard deviation threshold, there are a surprisingly large number of quote stuffing events. An event is an occurrence in any symbol at the one-minute time frame on one side of the book. If quote stuffing occurs on both the bid side and the ask, this counts as two events in our sample.

[INSERT Figure 1 HERE: Average Daily Quote Stuffing Events 2008-13]

Quote stuffing becomes more frequent in the first three years of our sample. There are an average of 676 episodes per day in 2008, 776 in 2009, and 930 in 2010.

The number of events has been falling since 2010 though, and the frequency in 2013 is only 35% of the 2008 level. This is consistent with industry reports[1] that the share of high frequency trading volume has been falling recently.

[1] See the estimates by the Tabb Group and Rosenthal Securities, http://www.nytimes.com/ interactive/2012/10/15/ business/Declining-US-High-Frequency -Trading.html?_r=1&. Profits also appear to have fallen as well.

3.3 Characteristics

We next graph the average number of different listings that are impacted each day. These follow a similar trend to the number of events

[INSERT Figure 2 HERE: Average Daily Symbols Impacted by Quote Stuffing 2008-13]

164 stocks per day are impacted in 2008. The number of effected symbols rises steadily, peaking at 263 in 2011. There is a slowdown in 2012, followed by a substantial decline last year, to a low of only 88 symbols per day in 2013.

We report summary statistics on the symbols impacted by quote stuffing in Table 2. The data are drawn from CRSP and represent the volume and market capitalization at the start of the trading month.

[INSERT Table 2 HERE: Stock Characteristics]

The average market capitalization of the effected symbols is the largest in 2013 at over $3.1 billion. The size of the stocks appears relatively stable with market cap averages rising and falling with the market as a whole.

The average volume is highest in 2009 at just over two million shares. Volume in the quote stuffing symbols rises in 2012 and 2013 even though market volumes were down in those years.

The ten largest stocks are also impacted, but these episodes appear to be news related. AAPL, for example, has an average of more than 100 quote burst episodes from 2008 to 2012, but all of these are removed by our news filter. After news filtering, only Berkshire Hatheway remains in our news filtered sample. It has events in each year from 2009 to 2013, with 124 events in 2010.

Since our message traffic is from Nasdaq's ITCH feed, it is perhaps not surprising that more than 40% of the events are in Nasdaq listed stocks. This percentage peaks in 2011, when it exceeds 47%. The NYSE has fallen steadily from nearly 42% to less than 25%.

About 50% of our events are in common shares, 30% in ETFs, and 20% in other types (non-U.S. listings, preferred shares, REITs, etc.)

4. Market Quality on Nasdaq

Because the quote stuffing we document is occurring on Nasdaq, we first examine market quality

metrics on Nasdaq itself.

We first look at volatility, measured as the high-low range in a one-minute interval on the bid side[2] of the order book, $HL_{i,t+1,n}$,

$$HL_{i,t,n} = \frac{p^{high}_{i,t,n} - p^{low}_{i,t,n}}{0.5 \times (p^{high}_{i,t,n} + p^{low}_{i,t,n})}. \tag{2}$$

We compare the volatility for stocks experiencing quote stuffing in the minute after the burst ensues to the volatility of the same security in the same minute on the prior day. Given the heterogeneity of stocks in the quote stuffing sample, a large frequency of extreme observations result in a non-normal distribution of volatility difference. Therefore, it is inappropriate to test the mean difference. Instead, we conduct a non-parametric Wilcoxon signed rank test

$$W = \left|\Sigma_i \left[sign(HL_{i,t+1,n} - HL_{i,t+1,n-1}) \cdot R_i\right]\right|, \tag{3}$$

where R_i is the rank of the absolute difference $|HL_{i,t+1,n} - HL_{i,t+1,n-1}|$ for stock i, and $sign(x)$ equals 1 if $x > 0$, 0 if $x = 0$, and -1 if $x < 0$. The test has greater efficiency than paired t-test on non-normal distributions. The null hypothesis is that the median difference between volatility on day n at time $t + 1$ and that at the same minute on the prior day $n - 1$ is zero. We use the one-sided test and the alternative is that volatility rises during quote stuffing. In Table 3, we show that this is overwhelmingly the case.

[INSERT Table 3 HERE: Bid Volatility]

We reject for all years, 2008-13, that volatility is constant. Volatility more than doubles from 0.373% to 0.852% at the 90th percentile during the minute after a quote stuffing event.

The next measure is the bid-ask spread. We use the inside spread from the NYSE Trade and Quote Database (TAQ) and report the average bid-ask spread within a one-minute interval in Table 4.

[INSERT Table 4 HERE: Percentage Bid-Ask Spread]

The quoted spread is measured in percent in the minute after the quote burst,

$$S_{i,t+1,n} = \frac{p^{a}_{i,t+1,n} - p^{b}_{i,t+1,n}}{0.5 \times (p^{a}_{i,t+1,n} + p^{b}_{i,t+1,n})}. \tag{4}$$

The median inside spread on Nasdaq rises by 2 basis points, from 0.164% to 0.184%. Looking

[2] The results for ask-side volatility are qualitatively similar to the bid side.

at the 90th percentile, the rise in spreads is even more dramatic, a 12 basis point increase from 1.067% to 1.178%. The Wilcoxon signed rank test rejects at the 33 standard deviation level or greater in each year of the sample.

Our final two measures of market quality relate to the number of messages required to execute a trade. The first measure, which we have just for Nasdaq, is the cancellation to execution ratio. Using the message symbols from Section 2, we define the HFT cancellation to execution ratio as

$$CR_{i,t,n}^{HFT} = \frac{\#D_{i,t,n}^{HFT} + \#U_{i.t,n}^{HFT} + \#X_{i.t,n}^{HFT}}{\#C_{i,t,n}^{HFT} + \#E_{i,t,n}^{HFT}}. \tag{5}$$

We narrow the cancellation ratio to restrict it to high frequency activity using the 50 millisecond rule. We contrast the HFT cancellation ratio for a symbol with its cancellation ratio on the previous day at the same minute. We then test formally for differences in the median using the Wilcoxon signed rank test. To better visualize the changes, we graph the 90th percentile of the distributions in Figure 3.

[INSERT Figure 3 HERE: Cancellation to Execution Ratio]

In the upper tails of the distribution, we can easily see the effect of the bursts. They reach as high as $4,549$ cancellations per execution in 2009. This ratio has trended down though, along with the overall number of quote stuffing episodes.

The Securities and Exchange Commission (SEC) estimates an average of 17.61 cancellations per trade for all stocks traded on Nasdaq in 2012 and 19.49 in 2013.[3] These indicate the extreme stress than quote stuffing places on the order book.

A broader measure is the number of inside quote updates required to execute a trade. We compute this from TAQ for all exchanges, including Nasdaq for common stocks

[INSERT Table 5 HERE: Inside Quote to Trade Ratio - Common Stocks]

Inside quotes on TAQ show a similar pattern to Nasdaq total message activity. On Nasdaq, there are an average of 36 times more inside quotes per trade in a 90th percentile stock.

It has been widely documented that ETFs have a higher quote to trade ratio. We report the ratio separately in Table 6 for ETFs.

[INSERT Table 6 HERE: Inside Quote to Trade Ratio - ETFs]

[3] Cancellation to execution ratios are much higher on ETFs, 71.54 in 2012 and 68.70 in 2013.

On Nasdaq, inside quotes per trade for ETFs are 2,048 for 90th percentile stocks, this is 12 times higher than for ETFs not experiencing quote stuffing.

5. Market Quality on Other Exchanges

Given the intense competition among exchanges, one might expect that quote stuffing on Nasdaq would simply lead to activity migrating to other exchanges. We find that market quality measures are effected on all the listing exchanges. We rely on TAQ data here which is not as comprehensive as ITCH. It provides only inside quotes and trades, and we don't know how quotes leave the book.

In Table 3, we also report the high-low range on the bid side[4] in the minute after the quote burst on other listing exchanges, Amex, NYSE, and Arca. Compared to the same minute on the prior day, the 90th percentile volatility rises from 0.92% to 1.45% on Amex, from 0.31% to 0.43% on NYSE, and from 0.38% to 0.84% on Arca during the sample period from 2008-2013. The Wilcoxon signed rank test rejects the null hypothesis of equal volatility at the 4.92 standard deviation level or greater in each year for any of the three exchanges.

The average bid-ask spreads on other listing exchanges are presented in Table 4 as well. During the minute after a quote stuffing event the inside spread at the 90th percentile increases from 0.505% to 0.546% on NYSE and from 1.320% to 1.637% on Arca. Because we find spreads fall in 2013, the average on Amex falls from 2.359% to 2.150%. The Wilcoxon tests reject at the 7 standard deviation level or higher.

We also compute the number of inside quote updates required to execute a trade on Amex, NYSE, and Arca, as shown in Table 5. The ratio of inside quote to trade rises dramatically in the minute after quote burst. For example, in 2010 it is as 152 times higher as the same minute on the prior day on Amex, 13 times higher on NYSE, and 18 times greater on Arca.

6. Trading Activity

We analyze trading volume in this section, measured both as the number of trades and also trading volume. Despite the high rate of cancellations during the quote stuffing episodes, volume actually rises on the Nasdaq and other exchanges, compared to the same time on the previous day. We

[4] The results for ask-side volatility are qualitatively similar to the bid side.

think this has a strategic motivation, and we will show that trading volume is increasing in the number of high frequency cancellations.

We first illustrate the typical pattern of volume using data from April 23, 2013, which is graphed in Figure 4.

[INSERT Figure 4 HERE: Volume per Minute]

Volume, $V_{t,n}$, spikes along with the surge in cancellations and remain elevated for around five minutes after the event. We test for this rise in volume during the minute after quote stuffing across our entire sample in Table 7.

[INSERT Table 7 HERE: Trading Volume Per Minute]

We find that trading volume, $V_{i,t,n}$, spikes as well during quote stuffing episodes, and the pattern is consistent with trades. The Wilcoxon tests reject the null hypothesis of no volume difference at the *six* standard deviation level or greater for all the exchanges in each year from 2008-2013. Volume on Nasdaq and Arca rises the most at the 90th percentile. It averages nearly five times higher on both Nasdaq and Arca.

Our finding contrast with the conjecture that a large number of cancellations would block trading activity. We want to explore whether our conclusion would change if there are extremely more cancellations on a stock. We run a screen for quote stuffing episodes with more than $100,000$ cancellations in one minute and list the cases in Table 8.

[INSERT Table 8 HERE: 100,000 and More Cancellations Per Minute]

We find 98 events that occurred on 42 stocks in April, June and August from 2010-2012. The most striking incident is Google (GOOG) on August 11, 2010 with $five$ occurrences and more than $330,000$ cancellations in each minute. The stock that experienced the highest number of episodes in the sample period is White Mountains Insurance (WTM) which experienced 28 bursts on April 19, 2010.

For each event, we compare the trading volume in the minute of a huge number of cancellations to the same minute on the prior day. Consistent with the conclusion for the quote stuffing sample, trading activity also rises during these episodes with an extremely high number of cancellations. The 90th percentile of volume increases from $3,060$ to $5,535$ on Nasdaq, from $2,500$ to $5,500$ on

NYSE, and from $1,600$ to $3,454$ on Arca. The result for Amex is ambiguous because there are only two observations among these episodes. The Wilcoxon tests reject the null of no change at the *three* standard deviation level or higher for Nasdaq, NYSE, and Amex.

6.1 HFT volume

Our next step is to see whether we can attribute the increase in trading activity to high frequency trading firms. The first step is to examine whether HFT volume, $VC_{i,t,n}^{HFT} + VE_{i,t,n}^{HFT}$, rises during quote stuffing.

[INSERT Table 9 HERE: HFT Volume]

Volume rises on average more than 16 times during quote stuffing, with the largest increases during events in 2013.

We then compare changes in aggregate HFT market share $V_{t,n}^{HFT}\%$

$$V_{t,n}^{HFT}\% = \frac{VC_{i,t,n}^{HFT} + VE_{i,t,n}^{HFT}}{VC_{i,t,n}^{HFT} + VE_{i,t,n}^{HFT} + VC_{i,t,n}^{nHFT} + VE_{i,t,n}^{nHFT}}. \tag{6}$$

in the minute after the quote stuffing to the same minute in the same securities on the prior day, $V^{HFT}\%_{t,n-1}$. 90th percentiles of these ratios are reported in Table 10.

[INSERT Table 10 HERE: HFT Market Share of Volume]

The HFT share of trades, at the 90th percentile, rises on average by 17.07%, with the largest increases of 30% in 2011. The Wilcoxon test reject equality of the distributions at the 18 standard deviation level or higher. It appears that HFT traders are driving non-HFT participants from the order book and capturing a larger market share of trades.

6.2 Zero volume hurdle

Many stocks have no volume and we use a hurdle model to describe these. The hurdle model consists of two parts: a zero model that separate the high occurrence of zeros from observed trades, and a linear model that predicts the non-zero volume. We use the HFT volume in the same minute on the prior day as a explanatory variable in the zero model. In the linear model we predict the volume of HFT executions in the minute of quote bursts using the number of cancellations. We report the model estimation for each year from 2008-2013 in Table 11.

[INSERT Table 11 HERE: HFT Hurdle Model]

On average, 100 shares of HFT volume in the minute of quote stuffing, but on the prior day, $V^{HFT}_{t,n-1} = VC^{HFT}_{t,n-1} + VE^{HFT}_{t,n-1}$, results in a 29.8% probability of observing positive trading volume,

$$\Pr(V^{HFT}_{t+1,n} > 0 | V^{HFT}_{t+1,n-1} = 100) = 29.8\%. \tag{7}$$

The marginal effect is that each additional $1,000$ cancellations, $\#CN_{t,n} = \#D_{t,n} + \#U_{t,n} + \#X_{t,n}$, are associated with 805 shares of HFT volume in the quote burst minute,

$$\mathrm{E}(V^{HFT}_{t,n} | V^{HFT}_{t,n-1} > 0, \#CN_{t,n} = \#CN^0_{t,n} + 1,000) - \mathrm{E}(V^{HFT}_{t,n} | V^{HFT}_{t,n-1} > 0, \#CN_{t,n} = \#CN^0_{t,n}) = 805. \tag{8}$$

The probability that HFT firms trade following a quote stuffing event has remained steady since 2008. In 2008, there is positive volume during quote stuffing in 40.2% of the events where at least 100 shares were transacted on the prior day. In 2013, this probability is 40.4%.

6.3 Profits

We estimate profits in the six years of our sample in Table 12.

[INSERT Table 12 HERE: HFT Profits]

We consider all trades under 50 milliseconds in the minute after quote stuffing, and close out the trades at the end of the minute. Profits per trade rise through 2011, peaking at $23.41.

There is an additional externality from the active quoting of the HFT firms on the non-HFT participants. We study the choices of non-HFT firms in the next section.

6.4 Institutional trading

Institutional participants appear to go off exchange when quote stuffing is occurring. We calculate the market share of volume going to the Trade Reporting Facility (TRF) in Table 13.

[INSERT Table 13 HERE: TRF Market Share of Volume]

These trades are recorded in TAQ and include both dark pool and internalized trades. The TRF share rises an average of 15% at both the median and the 90th percentile.

7. Market Wide Message Flows

We first tabulate the aggregate number of messages of all kinds in ITCH. Daily averages are plotted in Figure 5.

[INSERT Figure 5 HERE: Estimates of Market Wide Message Traffic]

Message traffic appears to have peaked in 2011 with an average of 398 million messages per day on ITCH. Daily averages have fallen in 2013 back to 2007 levels.

We produce a rough estimate of message activity on other exchanges from the TAQ database. We tabulate all the inside quote changes and trades, but miss quotes away from the inside and odd lot trades. The daily message totals are 68% correlated with ITCH.

The TAQ data display the same overall pattern, peaking in 2011. While 2012 and 2013 are both lower than 2011, the message activity is more than double 2007. The rise of BATS and Direct Edge, which have now merged and are challenging Nasdaq and NYSE, explains much of the change.

Despite a slowdown in average activity, the market continues to experience new highs, as shown in Figure 6, in one-minute message frequency.

[INSERT Figure 6 HERE: Aggregate ITCH Message Peaks]

The all time high for our sample from 2008-13 occurs on April 23, 2013 at 13:10, when more than 8.2 million messages are transmitted.

8. Conclusion

Rapid submission and cancellation strategies by high-frequency trading (HFT) firms are a common occurrence, effecting hundreds of ticker symbols every day. We find that quote stuffing is harmful to market quality: prices become more volatile and bid-ask spreads rise. This occurs not only on the Nasdaq where we observe the quote stuffing, but also on the NYSE, Archipelago and Amex. HFT quote stuffing raises their market share of trading activity. We estimate that $1,000$ high frequency cancellations generate an average of $five$ high frequency trades in the next minute. Rapid cancellations drive institutional trades to non-exchange trading venues, with the median TRF market share rising 19% on average. Aggregate message activity in the equity markets has

stabilized, but there are still sporadic episodes of message bursts that pose operational risks for the markets.

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Table 1: ITCH Message Description

Messages that Add Liquidity	
A	Add w/o MPID
F	Add w/ MPID
Delete, Cancel, or Replace	
D	Deletion
U	Cancel and replace
X	Partial cancellation
Executions	
C	At different price
E	At linked order price

For a more complete description, please read the documentation with the releases of the Nasdaq ITCH Total View data set, versions 3.0, 3.1, 4.0 and the current 4.1, available at http://www.nasdaqtrader.com/Trader.aspx?id=itch.

Table 2: Characteristics of Stocks Experiencing Quote Stuffing

	Average		Listing Exchange				Share Types		
Year	**Volume**	**Mkt cap $bn**	**NYSE**	**Nasdaq**	**Amex**	**Arca**	**Common**	**ETFs**	**Other**
2008	1,650,149	2.734	41.64%	23.81%	4.02%	30.54%	49.01%	30.01%	20.98%
2009	2,042,369	1.751	28.25%	41.07%	3.56%	27.12%	54.16%	29.14%	16.69%
2010	1,369,771	1.644	27.32%	40.46%	3.08%	29.14%	51.93%	28.69%	19.38%
2011	1,102,990	1.859	22.55%	47.07%	2.89%	27.49%	55.78%	27.23%	17.00%
2012	1,358,948	2.637	29.97%	46.48%	2.40%	21.15%	58.29%	20.97%	20.75%
2013	1,701,716	3.187	23.40%	44.16%	2.83%	29.61%	48.28%	29.80%	21.92%

The table reports characteristics of stocks experiencing quote stuffing events in the Nasdaq Totalview ITCH data. The volume, market capitalization, listing exchange data and share types are from CRSP on the first day of the month.

Table 3: Bid Price Range During Quote Stuffing Events
90th Percentile

	Nasdaq $P90(.)$		Amex $P90(.)$		NYSE $P90(.)$		Arca $P90(.)$	
Year	$HL_{t+1,n}$	$HL_{t+1,n-1}$	$HL_{t+1,n}$	$HL_{t+1,n-1}$	$HL_{t+1,n}$	$HL_{t+1,n-1}$	$HL_{t+1,n}$	$HL_{t+1,n-1}$
2008	0.638%	0.497%	0.326%	0.209%	0.433%	0.400%	0.601%	0.486%
2009	0.729%	0.490%	1.682%	1.240%	0.491%	0.441%	0.618%	0.464%
2010	1.197%	0.436%	0.885%	0.817%	0.528%	0.318%	1.365%	0.504%
2011	0.680%	0.340%	1.068%	0.725%	0.321%	0.223%	0.697%	0.323%
2012	0.693%	0.273%	1.633%	0.521%	0.318%	0.217%	0.645%	0.295%
2013	1.176%	0.199%	3.105%	2.021%	0.498%	0.269%	1.089%	0.213%

The table reports the 90th percentile of the high-low bid range, $HL_{t+1,n}$ during the minute after the quote stuffing event at time $t+1$ on day n, compared to the same security at time $t+1$ on the prior day, $n-1$. We perform Wilcoxon signed rank tests for equality of the distributions. Test statistics are normally distributed, and all the tests reject at the 4.92 standard deviation level or higher.

Table 4: Percentage Bid-Ask Spread During Quote Stuffing Events
90th Percentile

	Nasdaq $P90(.)$		Amex $P90(.)$		NYSE $P90(.)$		Arca $P90(.)$	
	$S_{t+1,n}$	$S_{t+1,n-1}$	$S_{t+1,n}$	$S_{t+1,n-1}$	$S_{t+1,n}$	$S_{t+1,n-1}$	$S_{t+1,n}$	$S_{t+1,n-1}$
2008	0.681%	0.541%	2.025%	2.245%	0.451%	0.358%	0.611%	0.520%
2009	0.834%	0.948%	1.952%	1.424%	0.517%	0.522%	0.846%	0.776%
2010	2.001%	1.732%	1.846%	1.724%	0.951%	0.867%	2.408%	2.042%
2011	1.167%	0.977%	1.945%	1.798%	0.551%	0.470%	1.264%	0.979%
2012	1.667%	1.373%	1.854%	1.833%	0.338%	0.318%	3.198%	2.498%
2013	0.716%	0.834%	3.279%	5.128%	0.468%	0.492%	1.496%	1.104%

The inside bid-ask spreads are from the NYSE Trade and Quote Database. The table reports the 90th percentile of the percentage bid-ask spread, $S_{t+1,n}$ during the minute after the quote stuffing event at time $t+1$ on day n, compared to the same security at time $t+1$ on the prior day, $n-1$.We perform Wilcoxon signed rank tests for equality of the distributions. Test statistics are normally distributed, and all the tests reject at the 7.12 standard deviation level or higher.

Table 5: Inside Quotes Per Trade During Quote Stuffing Events
90th Percentile for Common Stocks

	Nasdaq $P90(.)$		Amex $P90(.)$		NYSE $P90(.)$		Arca $P90(.)$	
	$QT_{t+1,n}$	$QT_{t+1,n-1}$	$QT_{t+1,n}$	$QT_{t+1,n-1}$	$QT_{t+1,n}$	$QT_{t+1,n-1}$	$QT_{t+1,n}$	$QT_{t+1,n-1}$
2008	637	38	40	15	40	26	321	51
2009	1,120	46	90	11	49	34	141	44
2010	2,957	46	1,372	9	642	51	917	50
2011	2,047	51	56	27	211	75	664	42
2012	1,374	50	44	26	98	81	47	28
2013	2,408	59	1,034	24	327	110	239	52

The source is the NYSE Trade and Quote Database using share codes from CRSP. The table reports the 90th percentile of the ratio of inside quotes per trade, $QT_{t+1,n}$ during the minute after the quote stuffing event at time $t+1$ on day n, compared to the same security at time $t+1$ on the prior day, $n-1$.We perform Wilcoxon signed rank tests for equality of the distributions. Test statistics are normally distributed, and all the tests reject at the 11.66 standard deviation level or higher.

Table 6: Inside Quotes Per Trade During Quote Stuffing Events
90th Percentile for Exchanged Traded Funds

	Nasdaq $P90(.)$		Arca $P90(.)$	
	$QT_{t+1,n}$	$QT_{t+1,n-1}$	$QT_{t+1,n}$	$QT_{t+1,n-1}$
2008	1,895	157	579	144
2009	2,258	187	433	125
2010	1,920	141	1,594	193
2011	1,546	147	1,159	158
2012	1,564	209	339	148
2013	3,102	187	531	161

The source is the NYSE Trade and Quote Database using share codes from CRSP. The table reports the 90th percentile of the ratio of inside quotes per trade, $QT_{t+1,n}$ during the minute after the quote stuffing event at time $t+1$ on day n, compared to the same security at time $t+1$ on the prior day, $n-1$. Only Nasdaq and Archipelago are reported since they contain the vast majority of ETF trading. We perform Wilcoxon signed rank tests for equality of the distributions. Test statistics are normally distributed, and all the tests reject at the 11.66 standard deviation level or higher.

Table 7: Trading Volume Per Minute During Quote Stuffing Events
90th Percentile

	Nasdaq $P90(.)$		Amex $P90(.)$		NYSE $P90(.)$		Arca $P90(.)$	
	$V_{t+1,n}$	$V_{t+1,n-1}$	$V_{t+1,n}$	$V_{t+1,n-1}$	$V_{t+1,n}$	$V_{t+1,n-1}$	$V_{t+1,n}$	$V_{t+1,n-1}$
2008	3,400	3,300	1,800	1,400	2,700	2,700	2,200	2,054
2009	3,202	2,907	1,280	1,360	3,200	3,000	2,990	2,900
2010	3,100	2,200	800	600	2,500	2,100	2,400	1,600
2011	2,500	1,900	400	363	2,200	2,220	2,062	1,700
2012	4,765	2,000	1,470	570	4,112	1,900	4,051	1,600
2013	56,893	2,620	1,838	1,000	5,080	1,200	42,493	2,200

The source is the NYSE Trade and Quote Database. The table reports the 90th percentile of trading volume $V_{t+1,n}$ during the minute after the quote stuffing event at time $t+1$ on day n, compared to the same security at time $t+1$ on the prior day, $n-1$.We perform Wilcoxon signed rank tests for equality of the distributions. Test statistics are normally distributed, and all the tests reject at the 3.044 standard deviation level or higher.

Table 8: Stocks with 100,000 or More Cancellations Per Minute

Date	Time	Symbol	$\#CN_{t,n}$	Date	Time	Symbol	$\#CN_{t,n}$	Date	Time	Symbol	$\#CN_{t,n}$
08/11/2010	14:30	GOOG	363,813	04/19/2010	10:15	WTM	139,171	06/09/2010	10:28	DHI	116,559
08/11/2010	14:53	GOOG	363,709	08/20/2010	14:52	SMI	138,664	06/28/2011	11:39	LPNT	116,316
08/11/2010	14:21	GOOG	343,929	04/19/2010	10:47	WTM	138,118	08/20/2010	14:50	SMI	114,813
08/11/2010	14:22	GOOG	343,637	04/19/2010	10:13	WTM	137,648	06/04/2010	12:32	HCBK	113,845
08/11/2010	15:06	GOOG	333,098	04/19/2010	10:46	WTM	137,306	06/30/2011	9:50	DVA	113,438
06/09/2010	10:29	DHI	283,161	04/19/2010	10:45	WTM	134,366	06/18/2010	14:51	WFC	112,867
08/20/2010	14:17	SMI	273,749	04/19/2010	10:07	WTM	134,289	06/22/2011	9:40	OILZ	111,017
06/15/2011	10:18	CEPH	253,093	04/19/2010	10:12	WTM	133,906	08/19/2010	12:50	DRAD	110,799
04/30/2012	15:50	IBB	236,913	04/19/2010	10:10	WTM	133,458	06/17/2010	10:02	AUTH	110,653
06/09/2010	10:33	DHI	204,991	08/08/2011	10:11	KRG	133,043	06/09/2011	9:50	ENZN	110,410
06/09/2010	10:15	ALL	201,690	08/08/2011	10:13	KRG	131,668	06/09/2010	10:09	LUV	110,293
08/20/2010	14:51	SMI	191,946	04/19/2010	10:08	WTM	131,623	08/11/2010	11:15	GBNK	109,928
06/25/2010	9:43	VLO	189,410	04/19/2010	10:09	WTM	131,335	08/11/2010	10:56	GBNK	109,852
06/09/2010	10:05	MO	173,397	04/19/2010	10:11	WTM	131,219	06/22/2011	9:41	OILZ	109,456
06/04/2010	12:32	LINTA	166,419	04/19/2010	10:14	WTM	130,817	04/19/2010	10:02	WTM	109,437
06/04/2010	12:34	T	165,869	08/08/2011	10:14	KRG	129,718	08/11/2010	11:01	GBNK	108,627
04/24/2012	15:51	PSSI	159,752	06/17/2011	12:15	ARQL	129,089	06/17/2011	14:25	LGND	108,587
04/19/2010	10:18	WTM	159,210	06/04/2010	12:32	T	128,715	08/11/2010	10:57	GBNK	107,131
06/30/2011	10:12	PRE	154,919	04/19/2010	10:06	WTM	127,789	08/03/2010	11:35	MPET	107,086
04/19/2010	10:17	WTM	154,510	06/17/2011	14:24	IDIX	127,655	06/04/2010	12:32	ACAS	105,770
06/04/2010	12:33	HCBK	151,334	08/08/2011	10:12	KRG	127,131	08/31/2010	10:00	ODP	105,679
04/19/2010	10:43	WTM	150,621	08/19/2010	12:51	DRAD	125,472	06/22/2011	10:03	FAS	105,532
04/19/2010	10:42	WTM	150,067	08/08/2011	10:15	KRG	125,418	04/21/2011	14:30	LPLA	104,533
04/19/2010	10:39	WTM	149,647	06/17/2010	10:03	AUTH	124,705	06/29/2010	13:39	SSL	103,317
04/19/2010	10:41	WTM	148,965	06/09/2010	10:30	DHI	124,661	08/20/2010	12:03	ACHN	103,219
06/04/2010	12:33	AES	148,712	04/26/2011	13:34	AGN	123,450	04/27/2010	9:52	APOL	102,736
08/23/2010	10:45	GA	148,625	06/15/2011	9:41	PTIE	122,316	06/25/2010	9:42	VLO	102,201
04/19/2010	10:38	WTM	147,242	04/27/2011	13:05	VRX	121,621	08/24/2010	10:13	AUTH	102,036
04/19/2010	10:16	WTM	146,840	06/04/2010	12:31	LINTA	119,997	04/27/2010	11:38	APOL	101,618
06/09/2010	10:34	DHI	146,302	04/19/2010	10:03	WTM	119,765	06/21/2010	12:28	SMI	100,662
04/19/2010	10:40	WTM	144,602	04/19/2010	10:05	WTM	118,162	06/09/2010	10:04	F	100,362
04/19/2010	10:19	WTM	144,189	04/19/2010	10:04	WTM	117,822	08/19/2010	15:21	DRAD	100,083
04/19/2010	10:44	WTM	139,961	08/31/2012	12:11	UHAL	116,962				

The table presents the quote stuffing episodes with $100,000$ or more cancellations, $\#CN_{t,n} = \#D_{t,n} + \#U_{t,n} + \#X_{t,n}$, in one minute from April, June, and August 2010-2012. The cases are ranked in descending order of the number of cancellations.

Table 9: High Frequency Trading Volume
90th Percentile

	$P90(.)$	
	$V_{t,n}^{HFT}$	$V_{t,n-1}^{HFT}$
2008	600	400
2009	400	300
2010	200	95
2011	235	100
2012	1,192	100
2013	15,814	100

The source is the Nasdaq Totalview ITCH data. The table reports the 90th percentile of HFT trading volume $V_{t,n}^{HFT}$ during the minute after the quote stuffing event at time t on day n, compared to the same security at time t on the prior day, $n-1$.We perform Wilcoxon signed rank tests for equality of the distributions. Test statistics are normally distributed, and all the tests reject at the 29.89 standard deviation level or higher.

Table 10: High Frequency Market Share of Volume
90th Percentile

	$P90(.)$	
	$V_{t,n}^{HFT}\%$	$V_{t,n-1}^{HFT}\%$
2008	50.000%	38.084%
2009	50.000%	41.800%
2010	72.200%	48.604%
2011	80.370%	50.147%
2012	54.268%	45.455%
2013	85.714%	66.042%

The source is the Nasdaq ITCH Totalview Database. The table reports the 90th percentile of HFT market share of volume $V_{t,n}^{HFT}\%$ during the minute after the quote stuffing event at time t on day n, compared to the same security at time t on the prior day, $n-1$.We perform Wilcoxon signed rank tests for equality of the distributions. Test statistics are normally distributed, and all the tests reject at the 18.75 standard deviation level or higher.

Table 11: Regression Model for Effect of Cancellations on Trades

	Logit		OLS		
	Intercept	$V_{t,n-1}^{HFT}$ ($\times 10^{-3}$)	Intercept	$\#CN_{t,n}$	R^2
2008	-0.4684	0.7309	-117.0000	0.2477	0.1657
	(0.0218)	(0.0610)	(45.7000)	(0.0086)	
2009	-0.8746	0.8965	263.9279	0.1194	0.0314
	(0.0207)	(0.0638)	(87.0611)	(0.0106)	
2010	-1.5050	1.1500	1,154.0000	0.1603	0.0137
	(0.0190)	(0.0689)	(188.9000)	(0.0221)	
2011	-1.3870	0.5267	1,103.0000	0.1442	0.0451
	(0.0268)	(0.0617)	(152.5000)	(0.0154)	
2012	-0.6249	1.4494	-4,084.0562	4.5137	0.2019
	(0.0187)	(0.1012)	(379.2383)	(0.1275)	
2013	-0.4259	0.3564	-26,470.0000	10.8300	0.4393
	(0.0334)	(0.0654)	(1,920.0000)	(0.3068)	
All	-0.9472	0.9249	677.4124	0.8047	0.0386
	(0.0088)	(0.0301)	(192.8301)	(0.0282)	

The table reports the estimates and t-statistics of the hurdle model for each year from 2008-2013. There are two parts in a hurdle model: a logit model and a linear regression model. The dependent variable is the HFT volume in the minute during quote bursts, $V_{t,n}^{HFT} = VC_{t,n}^{HFT} + VE_{t,n}^{HFT}$. In the logit model, we use high frequency trading volume in the previous day $V_{t,n-1}^{HFT}$ as a explanatory variable. The independent variable in the linear model is the number of cancellations in the minute of quote stuffing, $\#CN_{t,n} = \#D_{t,n} + \#U_{t,n} + \#X_{t,n}$. Numbers in parenthesis are the standard error of coefficient estimates.

Table 12: HFT Profit Estimates

	$\pi_{t+1,n}/T$	$\pi_{t+1,n}/V$
2008	4.28	0.0032
2009	0.59	0.0043
2010	9.02	0.0226
2011	23.41	0.0250
2012	-3.49	-0.0017
2013	2.38	0.0052

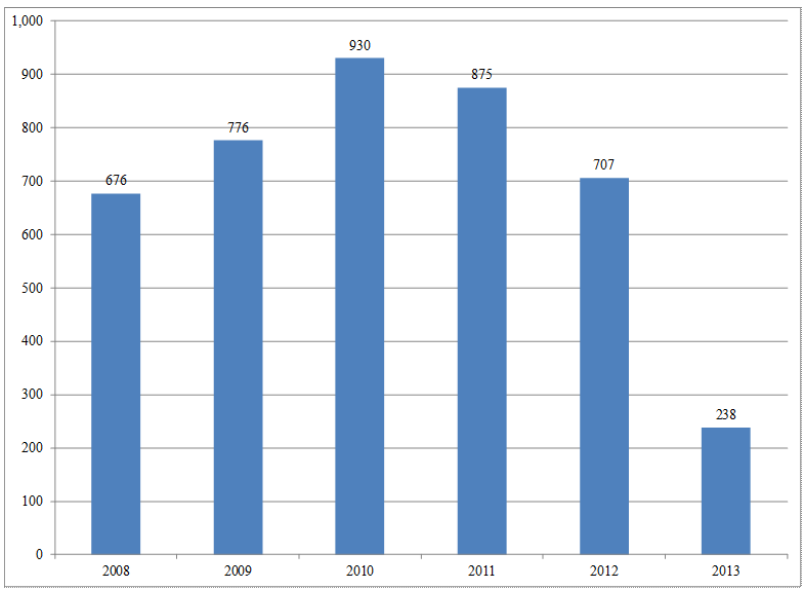
The table reports 1-minute profit estimates for HFT aggressive trades.

Table 13: Market Share of Dark Pools During Quote Stuffing Events
90th Percentile

	$P90(.)$	
	$TRF\%_{t,n}$	$TRF\%_{t,n-1}$
2008	71.154%	66.667%
2009	77.343%	66.667%
2010	100.000%	71.429%
2011	96.823%	63.887%
2012	83.333%	75.000%
2013	85.524%	82.829%

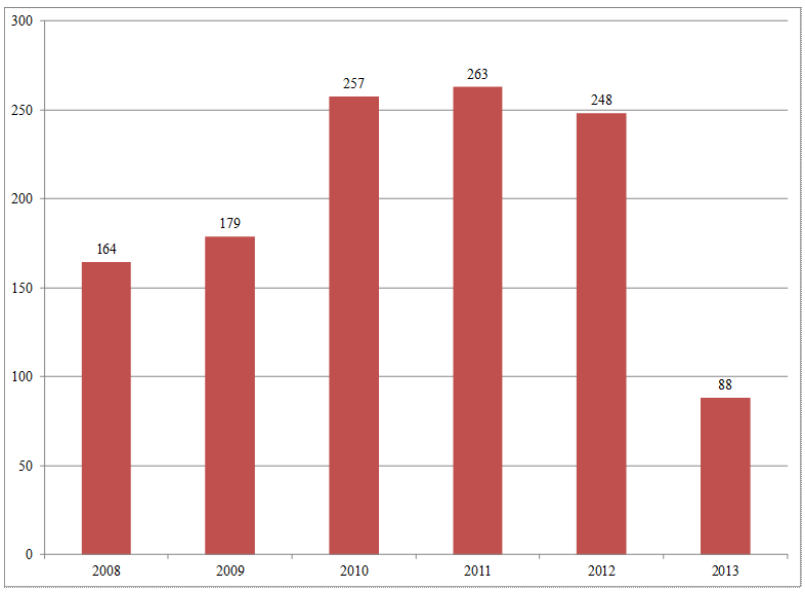
The table reports the 90th percentile of the market share of volume recorded in the trade reporting facility (TRF) from NYSE TAQ data during the minute after the quote stuffing event at time t on day n, compared to the same security at time t on the prior day, $n-1$. We perform Wilcoxon signed rank tests for equality of the distributions. Test statistics are normally distributed, and all the tests reject at the 23.26 standard deviation level or higher.

Figure 1: Quote Stuffing Events
Daily Averages



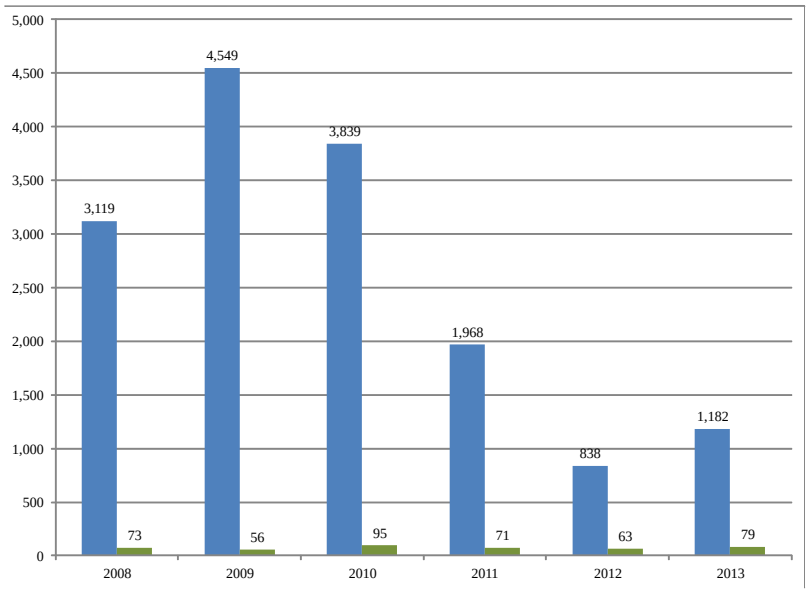
A quote stuffing event occurs when there is a 30-standard deviation increase in the high frequency cancellation rate compared to the rate for that symbol on the prior day. A stock can experience multiple events during the day, and there can be quote stuffing on both the bid and ask. Cancellations are computed using order level data from Nasdaq Totalview ITCH.

Figure 2: Symbols Experiencing Quote Stuffing
Daily Averages



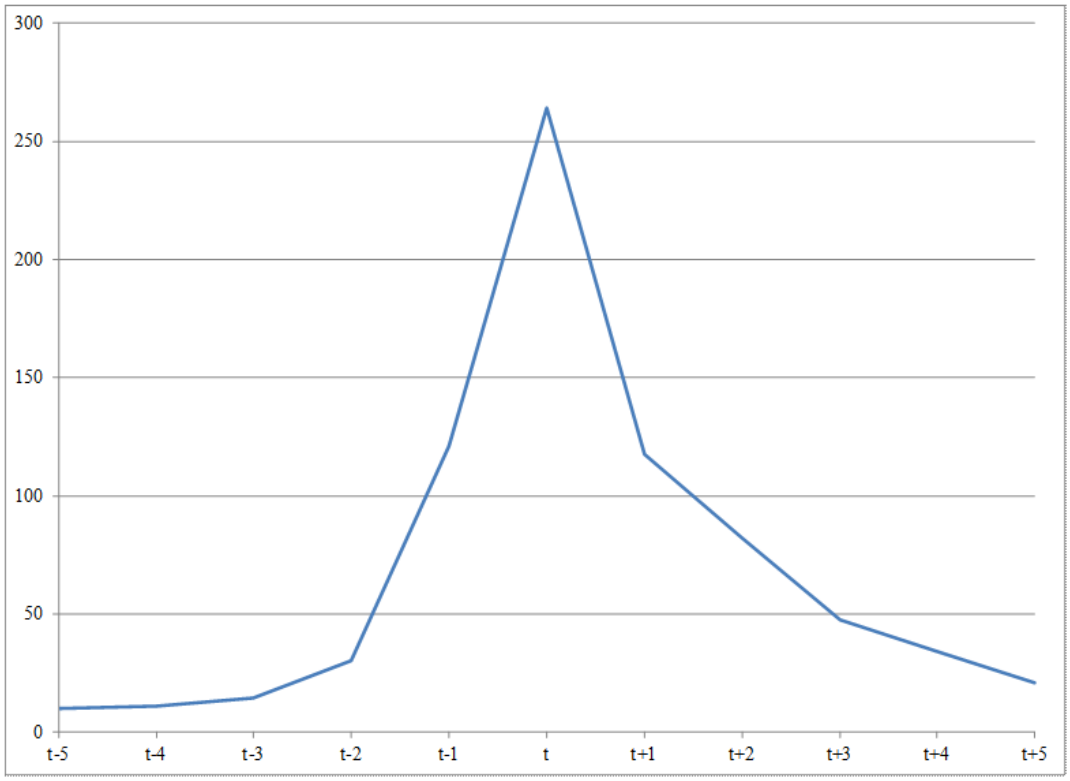
A quote stuffing event occurs when there is a 30-standard deviation increase in the high frequency cancellation rate compared to the rate for that symbol on the prior day. Cancellations are computed using order level data from Nasdaq Totalview ITCH.

Figure 3: Cancellation to Execution Ratio During Quote Stuffing Events
90th Percentile



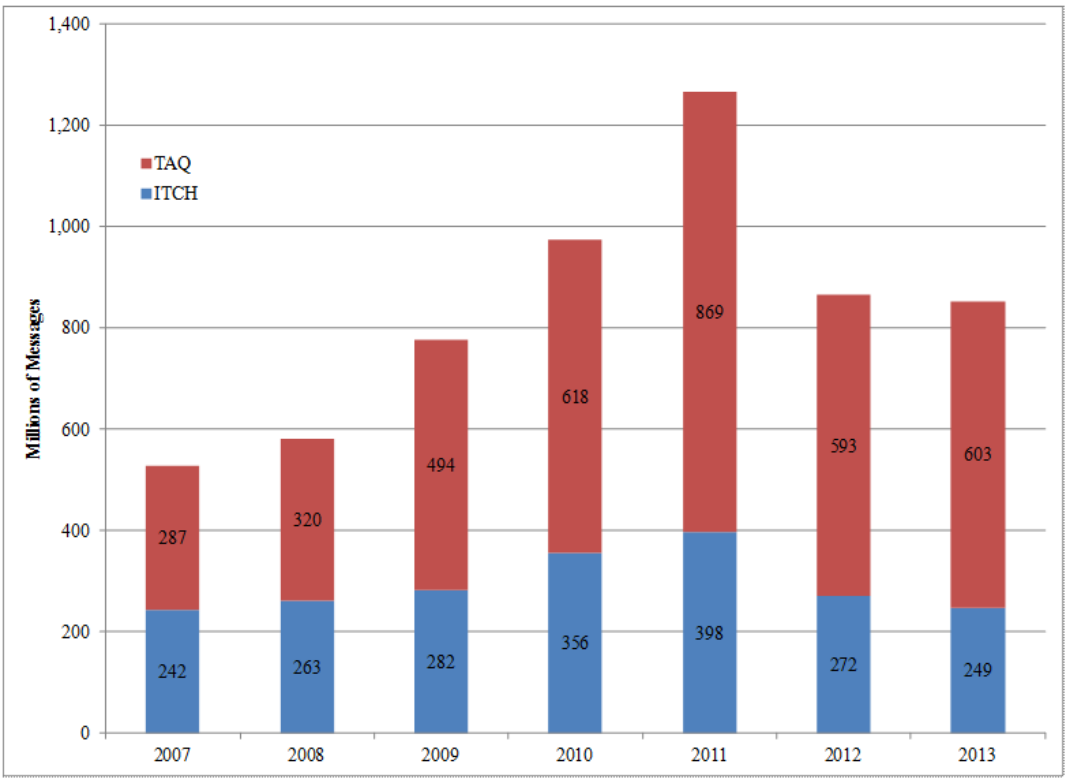
A quote stuffing event occurs when there is a 30-standard deviation increase in the high frequency cancellation rate compared to the rate for that symbol on the prior day. Cancellations are computed using order level data from Nasdaq Totalview ITCH. This chart reports the 90th percentile of cancellation to execution ratio $CR_{i,t,n}^{HFT} = \#D_{i,t,n}^{HFT} + \#U_{i.t,n}^{HFT} + \#X_{i.t,n}^{HFT}/(\#C_{i,t,n}^{HFT} + \#E_{i,t,n}^{HFT})$, of all trades, in the minute after the quote stuffing, $CR_{t,n}$ against the prior day's ratio for those same securities, $CR_{t,n-1}$. The Wilcoxon test for median differences rejects at the 12.73 standard deviation level or higher.

Figure 4: Trades per Minute During Quote Stuffing Events
90th Percentile



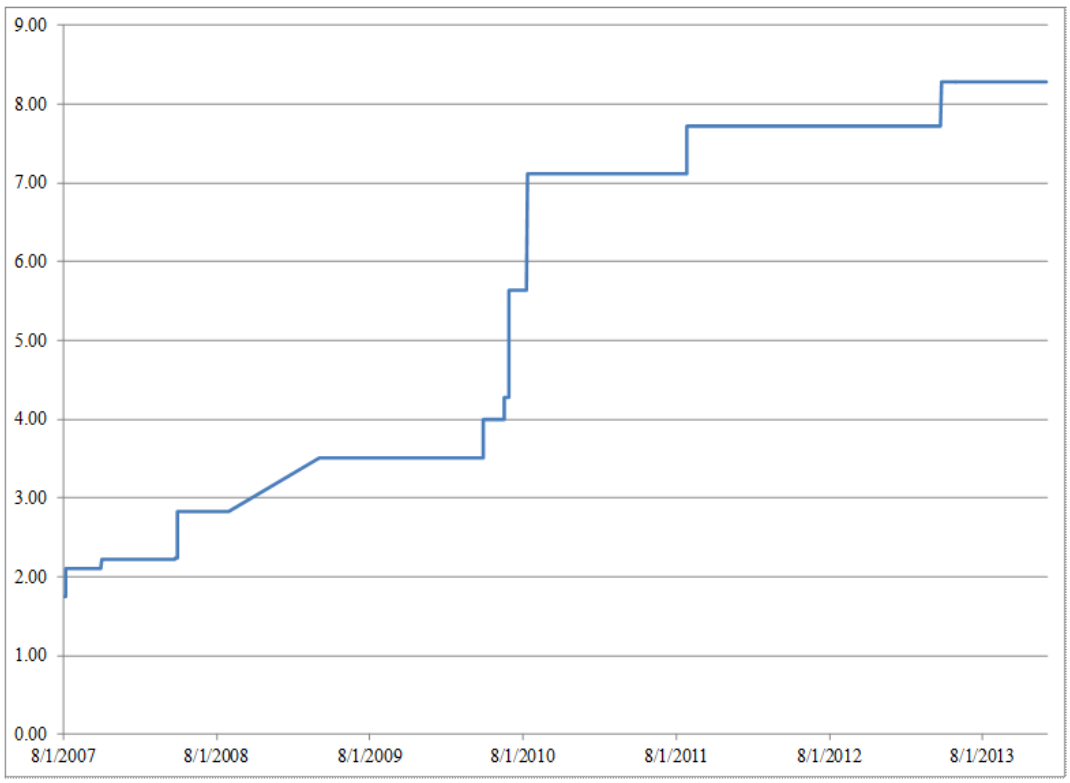
The chart depicts trading activity for the day of April 23, 2013 during quote stuffing events at time t and for five periods before and after. We examine the 10% most actively traded stocks.

Figure 5: Estimates of Market Wide Message Traffic
Daily Averages



The chart reports averages of aggregate daily ITCH and TAQ message traffic.

Figure 6: Growth in Message Traffic on Nasdaq
One-Minute Peaks



The chart reports local maxima of one minute aggregate daily ITCH message traffic.