Competition and Exchange Data Fees

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Abstract

We investigate whether the introduction of market data fees on three exchanges induces market participants to change their trading behavior and whether this affects exchange and market-wide market quality. The introduction of data fees leads to an economically significant fall in that exchange's market volume. The impacted exchange experiences a decline in its time with competitive quotes and in participants routing their orders to it. The informativeness of trading on the impacted exchange declines. Market-wide the fee introduction decreases liquidity and increases volatility. At least part of the data feed value comes from the order book depth. We show that some market participants appear to have elastic demand for data, and that their response to the introduction of data fees on one exchange can reverberate throughout the stock market.

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1 Introduction

Recently, a spat has erupted between the SEC (and many investors) and the exchanges over whether data fees are too high. The data that exchanges sell is to some degree a public good (Alan and Schwartz, 2013) and plays an important role in the price discovery process. Investors argue that exchanges are exclusive processors of essential information and therefore high data fees are a way to extract economic rents from a captured audience.[1] Exchanges argue that competition amongst the exchanges means investors choose to not subscribe to their data feeds and focus on trading on other venues. In competitive markets rents should diminish and any exchange charging too high data fees would be competed out of business. The concerns therefore boil down to the question whether the equity market exchange structure is competitive (Spatt, 2020). This article tests whether investors change their behavior due to fee changes, indicating that exchanges face competition, and how the changes impact market quality.

Exchanges are monopolist suppliers of their own order book data. A major source of revenue for exchanges is the sale of their data. For example, in recent years Nasdaq sells over 90 data products contributing to almost 20% of their total revenue.[2] Exchanges sell faster access to their core data—such as best bid and ask or last trade prices—and proprietary non-core data—such as bid and ask quotes worse than the best ones. For example NASDAQ in the 4th quarter of 2018 generated $97 million in revenues from selling its data.[3]

[1]The Managed Funds Association and The Alternative Investment Management Association filled a petition regarding the SEC ruling on August 22, 2018 that sums up the concern: "The Associations are concerned that exchanges as exclusive processors are charging unreasonable fees for market data products, and as a consequence, restricting trade and harming competition." (MFA and AIMA, 2018).

[2]SEC (2016, p.11). The exchange data environment and fee structure is complex. For example, see `https://www.nasdaqtrader.com/Trader.aspx?id=Global_Market_Data` or `https://www.nyse.com/market-data` for a list of the products offered by NASDAQ and NYSE, respectively. In addition to the data itself other services, such as colocation, are also available from many of the exchanges.

[3]`http://ir.nasdaq.com/news-releases/news-release-details/nasdaq-reports-fourth-quarter-`

We study three discrete data fee events in the U.S. equity markets that occurred on ARCA, Direct Edge, and BATS. We use a difference-in-differences identification design, examining the one month prior to the data fee announcement and the three months following its implementation for the exchange that introduced the fee versus other exchanges. We find that when a trading venue increases its data fees, it loses market share. The decline is due to the impacted exchange having less competitive quotes, and fewer trades being directed to the venue. At the impacted venue, liquidity providers' revenues increase, and trades become less informative. For stocks that heavily traded on the impacted venue before the fee introduction, the effect of data fee even has market-wide implications. Liquidity decreases and price efficiency declines. Finally we show that at least part of the effect of data fees is due to some traders losing access to the order book depth information.

It is challenging to establish causality between a drop in market-share and the introduction of the fee. For example, exchanges can have higher market-share in specific segments of the market and their market share is therefore likely subject to fads. The dot-com boom in 2001 disproportionately affected technology companies listed on Nasdaq. Unobserved heterogeneity can lead to an omitted-variable bias and preclude causal inference. We pursue a difference-in-difference methodology where the treated stock is the stock trading on the exchange introducing the fee and the control group is the same stock traded on all other exchanges. Instead of controlling for potentially endogenous control variables, which may preclude causal inference (Lewbel, 2019, p.853), we address omitted variables using many fixed effects (following Gormley and Matsa, 2014).

We begin by examining whether the impacted exchange's market share reacts to data fee changes. When a fee is introduced, traders must decide whether or not the expected

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benefit of having order book information outweighs the explicit costs of purchasing it. If the data are valuable to all participants, we expect no change in trading volume at the impacted exchange. If some participants choose not to subscribe to the data, we expect that at the margin they will be less active on the impacted exchange, resulting in that exchange's volume declining. Using the difference-in-differences design we find that an increase in fees corresponding to a decrease in market share is evidence that exchanges are, to some degree, subject to price sensitive traders.

The results are consistent with investors being able to pick and choose their data needs and being able to vote with their wallets. Besides trading volume, the fee introducing exchange decreases the amount of time it has quotes at the NBBO. Finally, we also observe a decline in ISOs on the fee introducing exchange. Consistent with these results we also find from detailed FINRA Rule 606 data that brokers are routing less market and less limit orders to the exchange introducing the fee.

We next ask whether the decline in market participant trading activity alters the impacted venue's market quality. We focus on two types of market quality, liquidity and price discovery. We capture liquidity using the venue's effective spread, and find essentially no effect. However, when we decompose the measure into the price impact (information) component and the realized spread (intermediary revenue) component we observe that both are changing, and netting each other out to result in the overall liquidity null effect. The price impact component decreases while the realized spread component increases.

The second dimension of venue market quality we examine is price discovery. We calculate the information share coming from the fee-introducing exchanges versus the other exchanges. The information share estimates from which exchange price innovations materialize. The results indicate that impacted venue experiences a decline in its information share.

While we cannot directly observe the behavior of different types of investors, we can infer whose behavior changed based on changes in volume and venue market quality. Our results help us understand who, at the margin, is changing their trading behavior. Three key results suggests it is informed traders who change their behavior.

First, while informed and uniformed traders use passive limit orders to enter trades, the use of ISOs tends to be by informed traders (Chakravarty, Jain, Upson, and Wood, 2012). We show that ISO trades decline even more than non-ISO trades, consistent with informed investors being the ones disproportionately changing their behavior. Second, the price impact of trades declines. Price impact is a proxy for the information embedded in a trade. A lower price impact suggests less informed trades occurring on the fee introducing exchange. Third, the information share analysis is a direct measure of price discovery and therefore informed trading. The information share decreasing on the exchange introducing the fee is the final piece of evidence suggesting informed traders drive the decline in market volume.

While the fee introductions have an affect on the impacted exchange, we next ask whether they have a market-wide effect. If the fee introduction does not translate to wider implications the argument for regulatory oversight is less obvious. Unlike the analysis so far, our difference-in-differences framework using stock-day-venue observations will not work as our dependent variable is observed at the stock-day level, and all stocks are impacted at the same dates. We adjust the specification to accommodate the focus on market wide outcomes. Specifically, we divide the sample of stocks into two categories based on its market share on the treated exchange in the pre-announcement period. Arguably, access to an exchange's data should be more important for stocks that trade relatively heavily on that exchange. Thus, the stocks with above median market share are "treated" and those with below median market share as the "control" group. We continue with a difference-in-differences framework but with this alternative measure of treatment that allows for a market-wide evaluation.

We focus again on liquidity and price discovery, but this time at the market-wide level. As a validity check on our treatment versus control categorization we first show that the fee introduction has a greater impact on trading for stocks with higher pre-announcement market share. We find that market-wide price impact is unaffected, suggesting that the informed traders who left the impacted venue migrated to other exchanges. We also find that liquidity decreased through an increase in the realized spread. In addition we find that noise in the price process increased, as measured by high-frequency volatility and the Hasbrouck pricing error. The results suggest that one exchange's data fee introductions can detrimentally impact market-wide liquidity and price discovery.

Finally, we take advantage of the market-wide setup to tease out whether the findings due to the fee introduction are driven by subscribers having faster access to core data, subscribers having access to non-core data, or both. Empirical and theoretical work mainly focuses on speed. There is less empirical evidence showing that traders care about non-core data (Boehmer, Saar, and Yu, 2005). As such, we test whether market quality is impacted in a setting where speed is irrelevant, and so the impact must be driven by the availability of non-core data. We examine the opening and closing auctions. Non-core data on exchanges away from where the auction occurs might be relevant for the auction as it provides information about pending trading interests, which is especially relevant if the exchange has a large market-share. We look at price deviations in the opening and closing auctions on the exchange the stock is listed. We find the deviations worsen, consistent with lower market quality, after the fee introductions. The results suggest that the non-core data itself is at least partially driving the results.

Our paper adds to the literature on exchange data fees. Brannon and Jennings (2019) shows that exchanges increasing data fees results in higher revenues. A broader literature examines other dimensions of exchange competition. Overall, Foucault and Menkveld (2008) find that competition can improve liquidity. More specifically, Ramos and von Thadden (2008) focuses on how transaction costs impacts exchange competition and Pagnotta and Philippon (2018) studies the role of speed among exchanges. Budish, Lee, and Shim (2019) models exchange competition's effect on trading fees and speed technology costs. Hendershott and Jones (2005) study the removal of market data for three ETFs trading on Island ECN. Like us, they document a large and significant drop in volume traded for these ETFs on Island ECN after the venue ceases to display order book data to any traders for these securities. An important difference between this event and our study is that, in their case, order book information is unavailable at any price to any trader. In our study, market data is available for a price, and so both access to market data and subsequent order routing decisions are strategic decisions. In other words, in our study pre-trade transparency does not change, which has its own effect on trader behaviour and market quality (Boehmer et al., 2005). Hendershott and Jones (2005) find that liquidity traders are less likely to route their orders to Island ECN after market data is removed, while we find that informed traders are more sensitive to the existence of fees.

A nascent literature on exchange competition over data is evolving. Cespa and Foucault (2014) examine the joint pricing decisions of an exchange's data products and trading fees. They argue that an increase in data fees reduces price discovery and increases the transfer from liquidity traders to liquidity providers. We find that information share falls and realized spreads per trade increase after exchanges introduce fees for market data. Easley, O'Hara, and Yang (2016) similarly predict that "price-informed" traders benefit at the expense of "price-uninformed" when prices for market data are sufficiently high as to induce differential access. Easley et al. (2016) further argue that restriction of market data can increase volatility and cost of capital and decrease incentives to produce fundamental information.

Jones (2018) argues that though market data is valuable to market participants, market data fees are a small cost to the industry overall and the market for data is characterized by "robust competition." Glosten (2020) explores the compliments of data across exchanges and argues it limits the ability of competition to contain data fee prices. Spatt (2020) studies how the cross-subsidization and tiered pricing of exchanges products reduces exchange competitiveness. Hendershott, Rysman, and Schwabe (2020) shows that the NYSE gains market share after the introduction of new market data products, the NYSE Integrated Feed, demonstrating that this information is valuable to traders. They further demonstrate the existence of a positive externality for market data: traders who do not subscribe also increase their trading on the NYSE after the Integrated Feed begins.

We contribute to this literature by documenting the effects of a exchange data fee. We show traders are sensitive to data fees, as demonstrated by their decrease in market share following the fee introduction. The fee introduction leads to venue and market-wide market quality implications. The findings in this article suggest data access, even when self-selected, have important market implications.

2 Data Fee Introductions, Data, and Methodology

This section describes the three data fee introductions, the data and construction of variables, and the methodology we use.

2.1 Three Data Fee Introductions

Fees for order book information are complex and frequently changing. Due to the complexity of fees, different market participants face different total costs for market data and it is difficult to summarize the average cost of market data in a simple way. We study three events where exchanges introduce fees for the first time. These events are advantageous because we can clearly identify instances where the cost of market data unambiguously increase for all market participants.

The first event is the introduction of market data fees by ARCA on January 1, 2009 (SEC, 2015, p.6). Prior to this date, order book information from ARCA was provided free of charge. Already in 2006, the exchange filed with the SEC to establish fees for its market data (SEC, 2008). The filing was subsequently approved in December 2008 and fees were introduced in 2009. These initial fees included a $750 per month access fee, a monthly fee of $15 per device for professional subscribers for ETFs and equities data as governed by the CTA Plan and $15 per device and month for data covering other equities securities governed by the Nasdaq UTP plan. For non-professional subscribers, the monthly fees per device were $5 for both categories. While these fees might appear to be small, "[t]he reasonably projected revenues from the proposed fees for NYSE Arca's non-core data are $8 million per year." (SEC, 2008, p.5) Given the uncertainty involved whether ARCA will be allowed to charge fees and given the late approval in December 2008, for ARCA, we consider the announcement date to be the same as the implementation date of the fee, i.e., January 1, 2009.

The second event is the introduction of fees for order book data on the Direct Edge EDGX exchange. This data contains information on all displayed orders, executions and order modifications and was initially provided free-of-charge to all Member firms. On February

22, 2012, Direct Edge announced the introduction of monthly fees of $500 for internal use of the feed and $2,500 for users who wish to distribute the feed externally (CBOE, 2012). Implementation of the fees took place on May 1, 2012 (SEC, 2012, p.3).

The final event is the introduction of market data fees by BATS exchange on July 1, 2013 (SEC, 2013a,b, pp.1-2). BATS fee structure initially comprised of a total charge of $1,500 per month for depth of book data for internal use only, covering both the BZX and BYZ exchange (Reuters, 2013) and was announced April 2, 2013 (CBOE, 2013). For top of book and last sale data, these fees total $1,000 across both sub-exchanges. For firms that wish to distribute the data externally, the total monthly costs would be $7,500 for depth of book data and $5,000 for top of book and last sale data.

2.2 Data

Data for our analysis are obtained from the NYSE Trade and Quote (TAQ) database. The TAQ data contain trades and quotes for all securities listed on the NYSE, the American Stock Exchange (AMEX), the Nasdaq National Market System and Small Cap issues. Using the TAQ data, we calculate a set of liquidity and trading activity variables at the stock-day level separately for the exchange introducing the fee and for all other trading venues in windows either side of the fee announcement date and the fee implementation date. The sample includes all common stocks that are listed on the NYSE or Nasdaq. Our windows are defined as the one month period prior to the announcement date for the introduction of data fees and three months after the implementation of data fees.[4] We choose to focus on the periods before announcement and after implementation to ensure our analysis is not

[4]For the ARCA fee introduction, we use the implementation date as the announcement date. Substantial regulatory and legal processes occurred over the period from the initial filing in 2006 and the implementation date in 2009. The final approval occurred very close to the implementation date and so we treat this as analogous to an announcement date for this event.

affected by changes in order routing decisions by traders in anticipation of the introduction of fee introduction. We use one month pre-announcement and three month post-event sample periods so as to exclude the most severe months of the Global Financial Crisis around the bankruptcy of Lehman Brothers in September of 2008, while retaining roughly equal sample sizes for each event.[5]

The set of variables we analyse are the log dollar volume traded, the log dollar volume traded via intermarket sweep orders (ISOs), the time at NBBO, the information share of the treated exchange, the dollar average trade size, the average percent effective spread, percent realized spread, and percent price impact across trades. For all variables we estimate one on the trading venue introducing the market fee (the "treated" venue) and one across all other trading venues.[6]

Log dollar volume is defined as the log of the total dollar value traded across the N_{ijt} trades in stock i on venue j and date t:

$$Log\,Dollar\,Volume_{ijt} = \ln \sum_{n=1}^{N_{ijt}} s_n \times P_n, \tag{1}$$

where s_n and P_n are the number of shares and share price for the n^{th} trade in stock i, venue day j, and day t, respectively. Similarly, we compute the dollar volume traded via ISOs, but in this case we only sum over all ISO trades, i.e., trades with a condition containing "F" in the TAQ database.

To estimate the time each venue quotes prices at the NBBO, we estimate the NBBO following Holden and Jacobsen (2014) and compare the NBBO each second to the quotes of

[5]In untabulated results we find that the main results are robust to using equally-sized windows prior to the announcement date and after the implementation date.
[6]Refer to Appendix Table 1 for detailed descriptions of all variables.

the exchange. If the bid and the ask are equal to the national best bid and ask prices, this variable takes the value of one. We sum up the time at NBBO over whole continuous trading session.[7] Note, that when using the time at NBBO we only have one observations per stock-day for the treated exchange. The time at NBBO for the other exchanges is automatically given by 6.5 hours minus the seconds the treated exchange quotes at NBBO prices.

The effective spread, realized spread and price impact for the n^{th} trade in stock i on venue j and date t are respectively defined as:

$$Effective\ Spread_n = 100 \times \frac{D_n\left(P_n - M_n\right)}{M_n}, \tag{2}$$

$$Realized\ Spread_n = 100 \times \frac{D_n\left(P_n - M_{n+5}\right)}{M_n}, \tag{3}$$

$$Price\ Impact_n = 100 \times \frac{D_n\left(M_{n+5} - M_n\right)}{M_n}, \tag{4}$$

where D_n is an indicator variable equal to one if the n^{th} trade in stock i on venue j and date t is a customer buy and negative one if the trade is a customer sell, P_n is the trade price, M_n is the prevailing NBBO midquote at the time of the trade and M_{n+5} is the prevailing exchange midquote five minutes after the trade time. Customer trade directions are assigned according to the Lee and Ready (1991) algorithm. For each trade-level variable defined in Equations (2), (3) and (4), our stock-day-venue value is the average across all trades in that stock-day-venue.[8] All variables are winsorized to limit the effect of outliers on our results. Specifically, we split our sample into categories based on whether or not the trade takes place in the pre or post event window, and whether trades take place on treated or control venues.

[7]We exclude stock-days where the continuous trading session is less than 6.5 hours.

[8]We gratefully use the code provided by Craig Holden and Stacey Jacobsen to calculate each of our variables, as described in Holden and Jacobsen (2014), with slight modifications to separate estimation into different venues.

For each of the four categories, we winsorize each sample at the 1% and 99% level.

We also estimate the information share of the treated exchange from midpoint prices prevailing trades. We estimate the information share of the treated exchange as the contribution of that exchange to the total variance of the common (random-walk) component, following Hasbrouck (1995). As in Hasbrouck (1995) we derive a lower and an upper bound of the information share, because when prices at different venues move at the same time the movement cannot be uniquely attributed to any venue. In the regression we use the upper and lower bounds, the average of the lower and upper bounds, and also estimate a modified information share following Lien and Shrestha (2009).

To illustrate how we define our variables, BATS first announced the introduction of data fees on April 2, 2013 that would be implemented on July 1, 2013. For every stock in our sample and every trading date in the month before the announcement date and three months after the implementation date, we calculate each activity or liquidity variable for all trades and quotes on BATS and also for all trades and quotes on all other trading venues excluding BATS. We then use the stock-day trading activity or simple average of liquidity variables using all trades and quotes on BATS as our treated group and stock-day trading activity or average liquidity using all trades and quotes from other venues as the control group. We do this for each of our three events corresponding to announcement and implementation of data fees for ARCA, Direct Edge and BATS respectively. Our final sample consists of 3,646 stocks that record trades in stocks on ARCA, BATS and Direct Edge and the control venues, over the three four month periods around each fee announcement and implementation event (249 trading days in total).[9]

[9]Stocks without sufficient trading data to calculate our trading activity and liquidity variables over our sample are excluded from the final sample.

2.3 Summary Statistics

Table 1 presents stock-day summary statistics for our sample for trades on the exchange introducing the fee (treated) and all other venues (control). Panel A contains averages across stock-days for trading on the treated exchanges while Panel B contains averages across stock-days on the controls venues.

Table 1 about here

Trading activity on the treated venue represents approximately 11% of total volume traded across all stock-venue-days in our sample with $3.4m worth of stock traded on the treated exchange on average compared with $28.1m on other venues. Average natural log dollar volume traded is 12.4 on treated exchanges and 14.6 on control venues. Examining log volume before the pre-announcement and post-implementation periods, we note that exchanges introducing fees appear to lose market share relative to the control venues. Log dollar volume declines by approximately 0.12 for treated venues from the pre-announcement to post-implementation periods. For control venues, this variable increases by 0.06.

There are also notable differences in average effective spreads, realized spreads or price impact between the treated and control exchanges. The average effective spread for trades taking place on the treated exchange is around 49bps while for a trade on all other venues, this average is 67bps. This may reflect that treated venues tend to attract more order flow when overall liquidity is better. Decomposing effective spreads into price impact and realized spreads demonstrates that similar fractions of trading costs are accounted for by adverse selection and dealer revenue. The average price impact for trades on treated exchanges is 21.2bps, or approximately 43% of the average effective spread. For trades on control venues, the average price impact is 25.5bps, or approximately 42% of the average effective spreads.

Trading costs trended lower across our sample periods on both venues, with effective spreads approximately 5-7bps lower in the post-fee implementation period than the pre-fee announcement period on both venue categories. Decomposing the effective spread highlights important differences in the reason behind these changes. On treated exchanges, both average price impact and realized spreads fall by around 3-4bps. On control venues, realized spreads fall by around 4bps while price impact falls by 1.6bps. Trades on treated exchanges are, on average, less informative as to future midpoint price movements after fees are introduced, both in absolute terms and relative to the change on control venues.

Figure 1 plots the average trading activity for each of the three fee introductions in the pre- and post-event periods.

Figure 1 about here

The y-axis depicts the average of log dollar value traded by venue type while the x-axis depicts the number of days before announcement date and after the implementation date. The "treated" line is the daily simple average of log dollar volume on the treated exchange across all stock-days in the sample. The "control" line is the equivalent average across the same stocks, but traded on all other venues. To ensure comparability, each series is normalized by subtracting the log of dollar volume observed at the beginning of the pre-announcement month. In-line with Table 1, there is a significant relative drop in volume on treated exchanges that does not occur on the control venues.

2.4 Methodology

We use a difference-in-differences approach to identify the effect of fees for order book information on trading volumes. Our strategy treats the introduction of fees as natural experiments that exogenously raise the price for order book information on one exchange but not others. For each of our three events, we construct a sample of stock-day observations of log dollar volume (total and split into ISO and non-ISO volume), average trade size and time at NBBO for the venue introducing the fee and a sample of stock-day observations for all other venues where the stock is traded. We assign stock-days on the venue introducing fees as the treated group and stock-days on all other venues as the control group. We then pool the sample together across all three events and estimate the effect of fee introduction using difference-in-difference estimators. We use two different key specifications.

The first specification is:

$$y_{ijt} = \beta \, Treat_j \times Post_t + \psi \, Treat_j + \theta_{it} + \varepsilon_{ijt}, \tag{5}$$

where y_{ijt} is the trading activity or market quality variable for stock i on venue j (either the treated or control exchange) and date t. $Treat_j$ is an indicator variable taking the value one for trades taking place on the treated exchanges and zero otherwise.[10] $Post_t$ is an indicator variable taking the value one if the date is within three months after the fee introduction for venue j and zero otherwise. θ_{jt} fixed effect for each stock-day. The parameter β identifies the effect of the fee introduction.

Of importance is that in Equation (5) each stock-day pair has a fixed effect for each stock-day. These fixed effects capture stock-day shocks that impact all venues. Consequently, this specification is robust to any unobserved effects at the stock-day level. $Treat_j$ captures any time invariant differences between the venues. Therefore, the β coefficient captures

[10] Note that a venue is only takes the value $Treat_j = 1$ during the window around the announcement and implementation of its fee introduction. For example, Direct Edge will have $Treat_j = 1$ starting one month prior to the fee announcement date, February 22, 2012, until three months after its implementation on May 1, 2012. All other dates, the Direct Edge data would be part of the group making up $Treat_j = 0$.

time-varying venue specific changes, while controlling for stock-day variation.

The second specification includes fixed effects for stock-venue and for day. This model is given by:

$$y_{ijt} = \beta\, Treat_j \times Post_t + \theta_{ij} + \gamma_t + \varepsilon_{ijt}, \tag{6}$$

where and $Treat_j$ and $Post_t$ are defined as per Equation (5). θ_{ij} is a stock-venue fixed effect, γ_t is a daily fixed effect The key parameter of interest is again β, which again captures the effect of the fee introduction on the trading activity or market quality variable for trading on the treated exchange relative to the control venues.

In Equation (6) our fixed effect approach captures the stock-venue invariant effect. That is we control for the variation that exists across stock-venues. The day fixed effects capture market-wide differences that affect all stock-venue pairs. Recall that the unit of observation is at the stock-day-venue level. Thus, this specification corresponds to the typical finance difference-in-differences regression fixed effects structure, where our unit dimension is the stock-venue (instead of the more standard, firm) and our time dimension is day. Note that the $Treat_j$ indicator is excluded from Equation (6) as it is co-linear with the stock-venue fixed effects.

The two econometric specifications in Equations (5) and (6) are similar insofar as they both use the introduction of market data fees on an exchange as treatments that affect trading on that exchange while trading on other venues act as the control group. The key difference between the specification relates to what kind of variation is controlled for by the fixed effects.

In all the regression specifications we pool data across the three events and estimate a single treatment effect corresponding to their average effect of fee introduction on trading activity and market quality. Examining three events limit the likelihood that the results are driven by some time-varying change that occurred at the same time as the fee introduction. We estimate all regressions using standard errors clustered at the stock level.

3 Market Participants' Response to Data Fees

Traders faced with fees for order book information must decide whether or not the expected benefit of having this information outweighs the explicit costs of purchasing it. It may be that order book information from venues introducing fees is so important that practically all market participants are forced to subscribe to the data after fees are introduced. If so, we hypothesize there will be no change in an exchange's trading volume. If the demand for data is inelastic and participants simply incur the new few, then nothing has changed. Order submission strategies that were optimal in the absence of fees would remain optimal when fees are introduced. In this case, the venue introducing fees suffers no loss of market share and fees are just a mechanism to transfer surplus from the trading process from traders to the exchange.

If instead, at least some traders are sensitive to the introduction of fees at the extensive margin (i.e. they choose not to subscribe to order book data), then we argue that they should become less likely to submit orders to that venue and the venue introducing fees will lose market share. This leads to the first testable hypothesis regarding data fees and trading outcomes: at least some traders are sensitive to the cost of order book information and choose to route their orders elsewhere after data fees are introduced, leading to lower market share.

We show that trading volume on the impacted exchange decreases following the data fee introduction. The decline comes from both changes in passive limit orders and aggressive intermarket sweep orders. In addition, we observe at the broker level a shift away from trading on the impacted exchanged.

To ensure that trading volume does not change because of changes in maker-taker fees, we look through all SEC filings from ARCA, Direct Edge, and Bats during our event window that mention "maker", "taker", or "rebate". Of the 41 filings only one filing is linked to a change in the maker-taker fees, on March 5, 2009, ARCA increases both maker rebates and taker fees by 0.01 cents. Most other filings are relevant for options only, other examples are an introduction of a new investor tier and a restriction of rebates by the message-to-trade ratio.

3.1 Trading Volume

Estimates from our differences-in-differences regressions for log dollar value traded are presented in columns (1) and (2) of Table 2. These regressions test whether venues that introduce fees for order book information suffer a fall in market share relative to other venues. Our empirical approach is designed to identify the effect of fees on market share and execution quality. A change in market share reflects that at least some traders do not subscribe to the fees and prefer to route some of their orders to other exchanges, relative to the pre-fee environment. If instead all traders subscribe, then there is no change in the information environment for any trader and no incentive to change order routing strategies. Our log volume regressions are therefore tests of the hypothesis that some traders are sensitive to the cost of order book information and exchanges face downward sloping demand curves for order book information. Column (1) refers the treatment effect estimated using stock-day fixed effects while Column (2) refers to the model estimated using stock-venue and date fixed effects.

Table 2 about here

The point estimates for the effect of fee introduction on log volume in Table 2 are highly consistent across specifications — venues lose 14.6-18.5% of their existing volume on average after introducing fees, relative to venues that do not introduce fees.[11] The effect is highly statistically significant. In terms of dollar value, a 14.6-18.5% fall corresponds to around $494,000 to $626,000 less daily volume for the average stock on the treated venues in our sample, or $39,000 to $49,000 for the median stock. The coefficient estimates in Table 2 demonstrate that at least some market participants are sensitive to the introduction of fees and prefer to route their orders to other venues after fees are introduced.

Columns (3) and (4) perform the same tests but where the dependent variable is the log of average trade size. These regressions tell us whether or not the trades that take place on the treated exchange tend to be larger or smaller after order book fees are introduced. The point estimates for both treatment effects are economically small and statistically not significant in both specifications.

3.2 Types of Trading Volume

We next consider how fees affect different *types* of volume traded on the treated exchanges. The presence of Reg NMS means that market orders must be routed to the exchange with the best prices. However traders have full discretion over where they submit limit orders and where they submit intermarket sweep orders (ISOs), where traders with direct market access have the discretion to exclude particular exchanges. Market shares could fall because

[11] Since the dependent variable is in logs, the treatment effect parameter captures the difference-in-differences in logs and so captures percentage changes in volumes.

exchanges attract fewer limit orders after fees (and so spend less time at the NBBO and have less market orders routed to it) or because they attract fewer ISOs.

In columns (5), (6), and (7) of Table 2 we estimate potential components of trading volume that lead to the fee introduction's effect on trading activity. Columns (5) and (6) estimate the differences-in-differences regressions explaining log dollar value similar as for columns (1) and (2) but we now also distinguish between ISO and non-ISO trades using an indicator variable. In other words, instead of explaining the dollar value of the treated versus the control exchange, given by y_{ijt} in Equations (5) and (6), we explain $y_{ijt,ISO}$ with ISO equal to zero or one if $y_{ijt,ISO}$ refers to, respectively, the non-ISO or ISO dollar value of stock i in exchange j on day t.

The interaction, $Treat \times Post$, indicates a drop in the dollar value of non-ISO trades of around 12% to 14%. The triple interaction term, $Treat \times Post \times ISO$, captures the incremental effect of the treatment on ISO trades. Both specifications indicate a further drop in the dollar value of ISO trades of around 3%, which is statistical significant at the 1% level. In other words, regressions in columns (5) and (6) indicate that fees affect the market-share of ISO trades more than non-ISO trades.

Column (7) of Table 2 estimates the effect of the treatment on the time the treated exchange quotes prices at the NBBO. Because we only have one observation per stock-day we cannot include day fixed effects. Results indicate that the treatment causes a drop in the time an exchange is at NBBO of around 17%.

3.3 Brokers routing decisions

In this section we use data from Rule 606 filings in which brokers have to declare where they route incoming orders to. Rule 606 requires brokers to report the fraction of their orders that are nondirected (i.e., the customer did not choose the routing destination) and the percentage of these orders that are market orders, limit orders (with no distinction between marketable and nonmarketable), and other orders. We are not the first to use this data to investigate brokers order routing, see, for example, Battalio et al. (2016). We download filings for all 146 available brokers one quarter before the announcement and one quarter after the implementation of the market data fee from vrs.vista-one-solutions.com. We drop brokers that did not route any orders to the treated exchange in the pre-event period from our analysis.

As before, we are interested in explaining why market share of the treated exchange drops after the event. One potential reason is that brokers avoid the treated exchange, they decide to route (when allowed) market orders or limit orders to competing exchanges.[12] We therefore estimate the average percentage of market and limit orders before and after the event routed to any of the three treated venues, and calculate the difference in both. Similar as when using the time at NBBO, Rule 606 data only reports percentages of orders routed to specific venues and therefore aggregates to one when measured over all venues. Therefore, we can not estimate panel regressions with day fixed effects.

Table 3 reports the results. Panel A of Table 3 estimates the average across all brokers that routed any orders to a treated venue before the event. On average around 7.8% of market order and 9.1% of limit orders are routed to a treated venue before the event, i.e., in the last quarter of 2008 to ARCA, in the last quarter of 2011 to Direct Edge, and in the first quarter of 2013 to BATS. This average drops to 5.4% and 7.5% after the event for market and limit orders, respectively. With a *t*-statistic of -2.08, the difference for market-orders is

[12] A growing literature shows brokers may make routing decisions that are in their best interest, and not necessarily their clients. (Anand et al., 2021; Battalio et al., 2016; Cimon, 2020) Some brokers may not have been willing to pay the data fee (presumably those who decreased their volume at the impacted exchange, as they would bear the expense but the client would realize the benefit.

statistical significant.

In Panel B we estimate the average across brokers that routed limit orders to a treated venue before the event, which limits the number of available broker to 17. Using this subsection, we find that the drop in both market and limit orders is larger at around 5% (from 16% to 11% for market orders and from 19% to 14% for limit orders) and statistically significant with a t-statistic of -2.10 and -1.79, respectively.

In summary, Table 3 provides evidence that brokers that previously routed orders to the treated venue are routing less orders to this venue after the venue introduced a fee for market data. The drop in market orders could be mechanically related to the fact that we find that the treated exchange quotes less time at the NBBO (see Table 2) and given brokers obligation for best execution (Reg NMS) the percentage of orders routed to the treated exchange should fall. The drop in limit orders cannot be explained by any mechanical relation to previous results (though part of it could be due to marketable limit orders which would be affected by Reg NMS).

We further investigate the effect of data fees on broker routing decisions by splitting up the set of brokers into categories based on the types of businesses the firm is engaged in, according to FINRA broker check documents. Broker firms are obliged to report information about the firm including lists of controlling entities, firm history and firm operations to FINRA's Central Registration Depository (FINRA, 2021). These filings require each broker to specify all types of business that the firm expects to be engage that accounts for 1% or more of annual revenue.

Of the 26 possible business types in these filings, we split firms into two categories based on whether or not the broker is a participant in the over-the-counter inter-dealer market for corporate securities and whether or not the broker is a underwriter or selling group participant. Brokers that engage in these activities are, on average, larger and more sophisticated broker-dealers compared with those that do not. We estimate the change in fraction of orders routed to the treated exchange for groups of brokers split by these categories.

These results are contained in the final four columns of Table 3. We find that the effect of fees on order routing decisions is concentrated in brokers who do not participate in the interdealer market ($IDM = 0$) and those who do not participate in underwriting groups ($UW = 0$). The change in average market orders routed to the treated exchange is negative and statistically significant for these groups while it is insignificant for their sophisticated competitors, in both Panel A and B. For the limit order routing decisions, we find some evidence that the less sophisticated groups are affected, insofar as the only statistically significant reduction in limit orders is detected in the $UW = 0$ group of the brokers in Panel B. However we are unable to reject the null of no effect for the change in limit orders routed to the treated exchange. The small sample size for limit order routing decisions clearly affects our power in these tests.

We interpret these results as evidence that less sophisticated brokers are less likely to subscribe to data fees than more sophisticated brokers. Data fees can affect the routing decisions of brokers who do not subscribe both directly (because lack of data prohibits them from estimating expected execution quality) and indirectly (if in equilibrium, market quality is worse after fees are introduced). For brokers that do subscribe, only the indirect effect of fees should affect their routing decisions. Therefore, we argue a larger effect on routing decisions in one group of brokers is consistent with this group facing both the direct and indirect effects compared with another group.

4 Data fee changes and venue market quality

Having shown that there is elastic demand for the order book data from the impacted exchange, we turn to whether this impacts that exchange's market quality. If, and how, the impacted venue's market quality changes is an empirical question. It depends on the type of trader that changes their behavior the most.

We first examine how the average total trading costs for customer trades (effective spreads), informativeness of customer trades (price impact) and dealer revenue from market making (realized spreads) change around fee introduction. We run regressions analogous to those in columns (1)-(4) of Table 2 but where the dependent variables are average effective spread, price impact and realized spread for each stock-day on treated and control venues. Parameter estimates for these regressions are presented in Table 4. Columns (1) and (2) present results for average effective spread with stock-day fixed effects and stock-venue and day fixed effects respectively. Columns (3) and (4) present these results for price impact. Columns (5) and (6) present the results for realized spreads.

Table 4 about here

Table 4 provides weak evidence that average trading costs diminished after the introduction of fees. The coefficient corresponding to the treatment effect is -0.62 bps in the specification with stock-day fixed effects (t-statistic of -3.30) but is very close to zero in the specification with stock-venue and day fixed effects.

Despite this, there is substantial evidence that the components of effective spreads changed significantly after fees. In both econometric specifications, the effect of fees on average price impact is negative and highly significant (Columns (2) and (3)). The size of the parameter estimate is between -1.2 and -1.5 bps across both specifications, which corresponds to approximately 5% of the average trade price impact across all stock-days on the treated exchange in our sample. The coefficient is statistically significant at the 1% threshold in both specifications.

Columns (2) and (3) of Table 4 demonstrates that trades on treated exchange become less informative as to future price movements on average after the introduction of data fees, relative to trades on other venues with no change in data fees. A consequence of this finding is that liquidity providers face less adverse selection risk when quoting on treated venues than they do prior to fee introduction. Since we fail to find strong evidence of a comparable decrease in effective spreads, it must be that dealer revenue per trade (realized spreads) increase. Columns (5) and (6) of Table 4 confirm this point. The coefficients on average realized spread are 0.0083 and 0.0147 when using stock-day fixed effects or stock-venue and day fixed effects respectively. These effects are statistically significant at the 1% and 5% level respectively.

Together, our difference-in-difference regressions for transaction costs and transaction costs components demonstrate that the trades that are executed on treated exchanges after fees are introduced are less informative regarding future price movements, and liquidity providers make greater per-trade revenue when quoting on these venues after fees. The improvement in per-trade revenue is counterbalanced by lower trading volume, implying an ambiguous effect on total market maker revenue.

We additionally estimate the contribution of the treated exchange to the information share. Table 5 presents results for information share measured following Hasbrouck (1995) and Lien and Shrestha (2009). Similar as when using the time at NBBO, information share aggregates to one when measured over all exchanges and therefore does not allow us to estimate panel regressions with day fixed effects.

Table 5 about here

When estimating panel regressions with stock fixed effects, both specifications indicate a drop in the information share of the treated exchange of 3% to 4% with t-stats of -6.63 and -6.81, respectively. We also report the effect on the upper and lower bound of the Hasbrouck information share measure and find that both also decrease by around 3% (t-stat of -4.86) and 9% (t-stat of -12.40), respectively.

Why are trades that execute on treated exchanges less informed on average after fees are introduced? The order book information that we study contains information on depth away from the best bid and ask and also provides information on the best bid and ask at a lower latency than is available via the Securities Information Processor (SIP). Regardless of whether or not a trader has access to order book information, Reg NMS still ensures that market orders will be routed to the national best bid and offer. Order book information instead can affect decisions on where to route limit order and directed orders, where a trader specifies a particular venue for execution, such as ISOs.

Our evidence from Table 2 indicates that fees have a greater effect on ISO volume than non-ISO volume. Chakravarty et al. (2012) shows that informed traders are more likely to use ISOs than liquidity traders, and so lower average price impact likely reflects this to some degree.

It is also possible that informed traders (or their brokers) are relatively less likely to subscribe to fees than other kinds of traders, and therefore preferentially submit orders to other exchanges after fees are introduced. For example, high frequency traders (HFTs) trade via direct market access and are directly responsible for the order routing strategies. HFTs that attempt to predict and profit from future price movements at very short horizons may decide that the benefits of order book data for a particular venue are not sufficient to justify the costs and instead choose to route fewer orders to this venue in the future.

A substantial literature documents that institutional trades tend to have larger price impact than other kinds of traders such as retail (Nofsinger and Sias, 1999; Gompers and Metrick, 2001; Sias, Starks, and Titman, 2001; Yan and Zhang, 2009). Institutions that trade via direct market access may face a similar dilemma. They may choose not to subscribe and route relatively fewer orders (either limit or directed) to the treated venues.

Finally, it is also possible that some brokers themselves choose not to subscribe to order book data and limit the number of customer orders that they subsequently route to the treated exchanges. If brokers that have a greater number of informed traders as customers are disproportionately more likely to not subscribe, this may also explain the reduction in average price impact of trades on treated venues. Since institutions are more informed on average than other kinds of traders, and institutions tend to trade with larger broker-dealers, we are skeptical that the broker channel specifically can explain our results on price impact. Larger broker dealers can amortize the costs of order book data across a larger number of trades and so should be more likely to subscribe than smaller brokers, all else being equal.

While these possible explanations are not necessarily mutual exclusive, without more information about which kinds of traders subscribe or route orders across exchanges, we cannot definitively rule out one channel vs. any other and leave this for future work.

5 Data fee changes and market-wide market quality

We have so far demonstrated that the introduction of data fees on an exchange significantly reduces its market share and execution quality. We now investigate whether this translates to discernible market-wide effects for securities being traded. This is important for at least two reasons. First, from a regulatory point of view, fees for market data may simply result in orders being transferred from the exchange introducing the fee to other trading venues, but with no overall effect on liquidity or price formation. In this case, the case for regulatory intervention in the market for market data is less strong. Second, from a academic standpoint, many theoretical predictions regarding the effect of data fees relate to market-wide market quality (Easley et al., 2016; Cespa and Vives, 2018; Cespa and Foucault, 2014). Analyzing the market-wide effects of fees for market data on individual exchanges can potentially provide new evidence regarding these predictions.

A complication with analyzing market-wide effects in our setting is that the fees affect all stocks simultaneously. There is no cross-sectional variation in market data fees that permit a traditional differences-in-differences approach like we have been using so far. Instead, we split our sample of stocks for each event based on a plausible ex-ante measure of how important the introduction of data fees will be for each event: the stock's market share on the treated exchange. Specifically, we split our stocks into two sub-samples for each event based on whether or not that stock has above or below median market share on the treated exchange in the pre-announcement period. We classify stocks with above median market share as "treated" and those with below median market share as the "control" group. The intuition is relatively straightforward: market data fees on an exchange should be more important for stocks that trade relatively heavily on that exchange. This style of analysis is sometimes referred to as continuous difference-in-differences (e.g. Atanasov and Black, 2016) and is used in a number of finance settings.[13]

[13] See e.g Chetty and Saez (2005), Faccio and Parsley (2009) and Atanasov, Black, Ciccotello, and Gyoshev (2010) for examples of similar research designs that exploit cross-sectional variation in exposure to a shock to achieve identification.

Based on these sample splits, we estimate the market-wide effect of fees for market data on market quality via the following regressions:

$$y_{ijt} = \beta\, High_{ij} \times Post_t + \theta_{ij} + \gamma_t + \varepsilon_{ijt} \tag{7}$$

$$y_{ijt} = \beta\, High_{ij} \times Post_t + \psi\, High_{ij} + \gamma_t + \varepsilon_{ijt}. \tag{8}$$

In Equation (7), market quality is regressed onto stock × event fixed effects, time fixed effects and a treatment effect corresponding to stock i having above median pre-announcement market share on the treated exchange for event j ($High_{ij}$) times a post-event indicator (i.e. j in these regressions indexes events and not exchanges as it did for the difference-in-differences approach across markets).[14] Equation (8) is analogous but where the stock-event fixed effect is replaced with a single indicator variable for above and below median market-share stocks.[15]

We estimate the market-wide effect of data fees on the following variables: treated exchange market share; simple average percent effective spread price impact and realized spread; midquote volatility; and Hasbrouck (1993) pricing errors. Treated exchange market share is the daily percentage of volume traded on the exchange introducing the fee. Effective spread, price impact and realized spread are defined as per Equations (2) - (3) but using all trades on all venues. Midquote volatility is the square root of the sum of squared one second NBBO midquote returns, as recorded in the WRDS Intraday Indicator database. Results from the regressions are presented in Table 6. The pricing errors is the average difference

[14] The first fixed effect in Equation (7) and the dummy variable $High_{ij}$ is indexed by stock and event because stock i may be in the above-median market share category for one event and the below-median market share category for another event.

[15] Note that we are not able to estimate the market-wide treatment effect with stock-day fixed effects, as we do in Equation (6) as these effects are co-linear with the treatment effect.

between the midprice and the efficient price as per Hasbrouck (1993) by stock and day.

Table 6 about here

Our market-wide difference-in-differences regressions provide evidence that market data fees have a greater impact on order routing decisions for stocks with higher pre-announcement market share and that these fees have market-wide effects on market quality. After market-data fees are introduced, stocks with greater pre-announcement market share on the treated exchanges have a larger reduction in market share, indicating that the direct and indirect impact of fees on order routing decisions are greater for these stocks. This is important for our identification strategy because it demonstrates that stocks in the treated category are more exposed to the treatment than the control stocks. Treated stocks have a statistically significant increase in effective spreads and realized spreads after fees are introduced compared with stocks that have below-median pre-announcement market-shares. Similar to the effects on market quality on the treated exchange itself, we find that liquidity providers earn greater per-trade revenue in treated stocks, however this is due to wider effective spreads and not reduced price impact of trades. Since volatility and pricing errors rely on the sequence of NBBO midquotes, we cannot compute these variables on an exchange-by-exchange basis. Our results for volatility and pricing errors suggest that there is a detrimental effect of data fees on the overall price formation process.

Our analysis until now has documented that fees matter. Our results could be driven by subscribers having faster access to core data, subscribers having access to non-core data, or both. Most empirical evidence and theoretical models focus on the former (such as Easley et al., 2016) but empirically we know that non-core data also affects traders (Boehmer et al., 2005).

Following ideas elaborated by Budish et al. (2015) that batch auctions and trading in "discrete time reduces the value of tiny speed advantages," we argue that potential effects in auction quality should stem from differential access to non-core data, rather than from differential access in speed to core data. Non-core data on exchanges away from where the auction occurs might be relevant for the auction as it provides information about pending trading interests, which is especially relevant if the exchange has a large market-share.

We therefore also estimate Equations (7) and (8) for price deviations in the opening and closing auctions on the exchange the stock is listed at. Following Bogousslavsky and Muravyev (2020) and Brogaard, Ringgenberg, and Rösch (2020), market quality in these auction phases is defined as the absolute percentage difference between the auction price and the midpoint from the national best bid and offer prices in continuous trading. For the opening auction we use the midpoint after 9:30 am immediately prior to the opening auction. For the closing auction we use the midpoint from continuous trading immediately prior to the market close. Bogousslavsky and Muravyev (2020) show that these deviations are typically much larger than usual deviations recorded over equivalent time periods during continuous trading. Moreover, these deviations tend to display reversals. Therefore larger deviations are indicative of worse auction execution quality. Estimates of the effect of fees on auction execution quality are presented in Table 7.

Table 7 about here

As before, we compare stocks with above (treated stocks) and below (control stocks) median market share on the treated exchange in the pre-announcement period. After market-data fees are introduced, for treated stocks auction deviations widen by around 8 bp (t-statistic of 2.31) when only using day fixed-effects and by around 7 bp (t-statistic of 5.23) when using both day and stock fixed-effects.[16]

Overall our market-wide results indicate that the fees for market data on a single exchange can reverberate throughout the stock market and have important market-wide effects. Since speed plays no role in batch auction processes, our results for auction quality provide evidence that depth data also matters. This is an important finding since the majority of work on information and trading focuses on speed. And provides support for the proposed rule change by the SEC to extend core data to also include market depths.[17]

6 Conclusion

This paper explores the role of data fees in modern financial markets. While exchange data has properties of a public good, the exchanges control it and can, with the approval of the Securities and Exchange Commission, set a price on it. We show that when a trading venue introduces a fee on its data, it experiences a sizeable decline in trading activity. The demand for order book data is therefore not perfectly inelastic and so exchanges experience at least some trade off between losing customers and higher data fees.

By examining different measures of liquidity we infer that relatively more informed traders are most sensitive to the data fee introduction. The venue that introduces the data fee experiences a decline in price impacts and an increase in realized spreads, with a minimal net effect on effective spreads. We also find that price discovery, via the information share measure that captures from which exchange price innovations materialize, also decreases for the impacted venue. These changes are most consistent with informed traders decreasing

[16]The monthly TAQ data do not contain reliable indicators for trades corresponding to Auctions prior to 2008 so we are unable to reliably estimate these variables for our first event and exclude this from our auction analysis.

[17]Proposed Rule: Market Data Infrastructure, Securities Exchange Act Release No. 88216 (SEC, 2020).

their trading on the venue with the fee introduction.

We show that the affect is not limited to the impacted venue but leads to market-wide changes in market quality. Specifically, we find that liquidity and price discovery are harmed. Taking advantage of the institutional details of the opening and closing auctions, we are able to provide evidence that the order book depth data, not just the faster access, drive the results. The findings in this article suggest that the data fees of a single exchange can distort behavior in a way that results in market-wide changes to market quality.

A Appendix

A.1 Information share

For each stock and each day, we construct two series of 1-second midpoint quote prices from 10:00 to 15:30, one based on best bid offer prices at the treated exchange (BBO) and one estimated from national best bid offer prices excluding the treated exchange, constructed following Holden and Jacobsen (2014) ($NBBO^{-}$).We then estimate an error-correction vector autoregression (VAR) model with 60 lags using the log prices of BBO and $NBBO^{-}$ as the co-integrated VAR process and the difference in both log-prices as the co-integrated process.Given that we assume that both prices are co-integrated, both contain a single random-walk component, which is identified as the efficient price.Information share (of the BBO price) measures the proportion of the variance at the treated exchange to total variance of the efficient price. The information share can be interpreted as the fraction at which the price at the treated exchange moves first, before the $NBBO^{-}$ price.

As explained by Hasbrouck (1993, p. 1183), because price innovations across both markets are correlated, we derive an upper and a lower Information Share by either permutating the price at the treated exchange first or last.

A.2 Pricing error

We estimate Hasbrouck (1993) pricing errors as in Rösch et al. (2017, Section 1.3). For every stock-day we decompose midpoint prices into an efficient price and a pricing error using a five-lag VAR model with the following endogenous variables: (1) the logarithmic NBBO midpoint price return estimated from quotes prevailing trades; (2) the sign of the trade; (3) the sign of the trade times the number of shares traded; and (4) the sign of the trade times the square root of the number of shares traded. We then calculate the average absolute pricing error per stock-day.

Appendix Table 1: Variable definitions

Variable	Formula	Definition
Dollar Volume (mil)	$\sum_{n}^{N_{it}} s_n \times P_n$	N_{it} is the number of trades during market hours as per TAQ data for stock i on day t (split by venue where appropriate). P_n is the trade price and s_n is the number of shares of the n^{th} trade.
Trade Size ($)	$\frac{1}{N_{it}} \sum_{n}^{N_{it}} s_n \times P_n$	N_{it}, P_n, and s_n are defined as before.
ISO Dollar Volume (mil)	$\sum_{n}^{N_{it}} s_n \times P_n \times ISO_n$	N_{it}, P_n, and s_n are defined as before. ISO_n is an indicator variable equal to 1 if trade n is an Intermarket Sweep Order and 0 otherwise.
Seconds at NBBO	$\lvert\{BBO_{isj} = NBBO_{is}\}\rvert$	BBO_{isj} is the best bid and offer of stock i at second s on exchange j (during the continuous trading session) and $NBBO_{is}$ is the national best bid and offer price. BBO is equal to $NBBO$ if both the bid and the ask are equal.
Effective Spread (%)	$\frac{100}{N_{it}} \sum_{n}^{N_{it}} \left(\frac{D_n(P_n - M_n)}{M_n}\right)$	N_{it} and P_n are defined as before, D_n is the Lee-Ready signed trade direction of trade n in stock i on day t, and M_n is the midquote immediately preceding the trade.
Realized Spread (%)	$\frac{100}{N_{it}} \sum_{n}^{N_{it}} \left(\frac{D_n(P_n - M_{n+5})}{M_n}\right)$	N_{it}, P_n, D_n and M_n are defined as before. M_{n+5} is the midquote five minutes after the trade.
Price Impact (%)	$\frac{100}{N_{it}} \sum_{n}^{N_{it}} \left(\frac{D_n(M_{n+5} - M_n)}{M_n}\right)$	N_{it}, P_n, D_n and M_n and M_{n+5} are defined as before.
Midquote Volatility	$\frac{100}{T_{it}} \sum_{s}^{T_{it}} \sqrt{(r_s - \bar{r}_s)}$	T_{it} is the number of one second intervals in the trading day for stock i on day t, r_s is the one second log midquote return at the s^{th} one second interval and $\bar{r}_s$ is the average one second log midquote return in stock i and day t.
Rule 606 market orders	$mktorders_{btj}$	$mktorders_{btj}$ is the percentage of non-directed market orders received by broker b on day t for securities listed on exchange j that are routed towards the treated exchange, as reported in Rule 606 filings.
Rule 606 limit orders	$lmtorders_{btj}$	$lmtorders_{btj}$ is the percentage of non-directed limit orders received by broker b on day t for securities listed on exchange j that are routed towards the treated exchange, as reported in Rule 606 filings.
Upper/Lower Information Share	$\frac{(\psi F)^2}{\psi \Omega \psi^t}$	following Hasbrouck (1995, Eq 16). Ω is the co-variance matrix of the price innovations of the BBO price at the treated exchange and the $NBBO$ price at all the other exchanges. F is the Cholesky factorisation of Ω. We derive an upper and lower Information Share, depending on whether F contains the innovation in the price at the treated exchange first or last. For details see Appendix A.1.

Appendix Table 1 (continued): Variable definitions

Variable	Formula	Definition
Information Share	$\frac{Upper_{it}+Lower_{it}}{2}$	$Upper_{it}$ and $Lower_{ijt}$ is, respectively, the upper and the lower Hasbrouck (1995) Information Share of stock i on day t on the treated exchange.
Modified Information Share		following Lien and Shrestha (2009).
Pricing error	$\frac{1}{N_{it}} \sum_{n}^{N_{it}} \lvert M_{i,n} - \mu_{i,n} \rvert$	N_{it} is as before. $M_{i,n}$ is the log of the NBBO midpoint price prevailing trade n of stock i on day t. $\mu_{i,n}$ is the efficient price as in Hasbrouck (1993). For details see Appendix A.2.
Market Share	$\frac{DollarVolume_{ijt}}{DollarVolume_{it}}$	$DollarVolume_{ijt}$ is Dollar Volume (see above) of stock i on day t at exchange j and $DollarVolume_{it}$ is market-wide Dollar Volume.
Open Auction $\lvert Deviation \rvert$	$\left\lvert ln\left(\frac{Open_{it}}{M_{it-}}\right)\right\rvert$	$Open_{it}$ is the Open Auction Price on day t at the exchange on which stock i is listed. M_{it-} is the NBBO midpoint price during the regular trading session prevailing $Open_{it}$.
Close Auction $\lvert Deviation \rvert$	$\left\lvert ln\left(\frac{Close_{it}}{M_{it+}}\right)\right\rvert$	$Close_{it}$ is the Close Auction Price on day t at the exchange on which stock i is listed. M_{it+} is the last NBBO midpoint price during the regular trading session.

References

Alan, N. S. and R. A. Schwartz (2013). Price discovery: The economic function of a stock exchange. *Journal of Portfolio Management 40*(1), 124–132.

Anand, A., M. Samadi, J. S. Sokobin, and K. Venkataraman (2021). Institutional order handling and broker-affiliated trading venues. *Working Paper*.

Atanasov, V., B. Black, C. Ciccotello, and S. Gyoshev (2010). How does law affect finance? An examination of equity tunneling in Bulgaria. *Journal of Financial Economics 96*(1), 155–173.

Atanasov, V. A. and B. S. Black (2016). Shock-based causal inference in corporate finance and accounting research. *Critical Finance Review 5*, 207–304.

Battalio, R., S. A. Corwin, and R. Jennings (2016). Can brokers have it all? On the relation between make-take fees and limit order execution quality. *Journal of Finance 71*, 2193–2238.

Boehmer, E., G. Saar, and L. Yu (2005). Lifting the veil: An analysis of pre-trade transparency at the nyse. *Journal of Finance 60*, 783–815.

Bogousslavsky, V. and D. Muravyev (2020). Should we use closing prices? Institutional price pressure at the close. *Working Paper*.

Brannon, I. and R. H. Jennings (2019). Equity exchange fees and revenues. *Working Paper*.

Brogaard, J., M. Ringgenberg, and D. Rösch (2020). Does floor trading matter? *Working Paper*.

Budish, E., P. Cramton, and J. Shim (2015). The high-frequency trading arms race: Frequent batch auctions as a market design response. *Quarterly Journal of Economics 130*(4), 1547–1621.

Budish, E., R. S. Lee, and J. J. Shim (2019). Will the market fix the market?: A theory of stock exchange competition and innovation. *Working Paper*.

CBOE (2012). Notice of Filing and Immediate Effectiveness of Proposed Rule Change Relating to Fees Associated with Receipt of the EDGX Book Feed. `https://cdn.cboe.com/resources/regulation/rule_filings/approved/2012/SR-EDGX-2012-14-Revised.pdf`. Accessed: 2020-09-22.

CBOE (2013). CBOE Fee Schedule 2013. `https://markets.cboe.com/us/equities/notices/fee_schedule/2013/`. Accessed: 2020-09-22.

Cespa, G. and T. Foucault (2014). Sale of price information by exchanges: Does it promote price discovery? *Management Science 60*(1), 148–165.

Cespa, G. and X. Vives (2018). Exchange competition, entry, and welfare. *Working Paper*.

Chakravarty, S., P. Jain, J. Upson, and R. Wood (2012). Clean sweep: Informed trading through intermarket sweep orders. *Journal of Financial and Quantitative Analysis 47*(2), 415–435.

Chetty, R. and E. Saez (2005). Dividend taxes and corporate behavior: Evidence from the 2003 dividend tax cut. *Quarterly Journal of Economics 120*(3), 791–833.

Cimon, D. A. (2020). Broker routing decisions in limit order markets. *Journal of Financial Markets*, forthcoming.

Easley, D., M. O'Hara, and L. Yang (2016). Differential access to price information in financial markets. *Journal of Financial and Quantitative Analysis 51*(4), 1071–1110.

Faccio, M. and D. C. Parsley (2009). Sudden deaths: Taking stock of geographic ties. *Journal of Financial and Quantitative Analysis 44*(3), 683–718.

FINRA (2021). About BrokerCheck . `https://www.finra.org/investors/learn-to-invest/choosing-investment-professional/about-brokercheck`. Accessed: 2021-02-19.

Foucault, T. and A. J. Menkveld (2008). Competition for order flow and smart order routing systems. *Journal of Finance 63*(1), 119–158.

Glosten, L. R. (2020). Economics of the stock exchange business: Proprietary market data. *Working Paper*.

Gompers, P. A. and A. Metrick (2001). Institutional investors and equity prices. *Quarterly Journal of Economics 116*(1), 229–259.

Gormley, T. A. and D. A. Matsa (2014). Common errors: How to (and not to) control for unobserved heterogeneity. *Review of Financial Studies 27*, 617–661.

Hasbrouck, J. (1993). Assessing the quality of a security market: A new approach to transaction-cost measurement. *Review of Financial Studies 6*, 191–212.

Hasbrouck, J. (1995). One security, many markets: Determining the contributions to price discovery. *Journal of Finance 50*(4), 1175–1199.

Hendershott, T. and C. M. Jones (2005). Island goes dark: Transparency, fragmentation, and regulation. *Review of Financial Studies 18*(3), 743–793.

Hendershott, T., M. Rysman, and R. Schwabe (2020). Stock exchanges as platforms for data and trading. *Working Paper*.

Holden, C. W. and S. Jacobsen (2014). Liquidity measurement problems in fast, competitive markets: Expensive and cheap solutions. *Journal of Finance 69*(4), 1747–1785.

Jones, C. M. (2018). Understanding the market for U.S. equity market data. *Working Paper*.

Lee, C. M. and M. J. Ready (1991). Inferring trade direction from intraday data. *Journal of Finance 46*(2), 733–746.

Lewbel, A. (2019). The identification zoo: Meanings of identification in econometrics. *Journal of Economic Literature 57*, 835–903.

Lien, D. and K. Shrestha (2009). A new information share measure. *Journal of Futures Markets 29*(4), 377–395.

MFA and AIMA (2018). Petition for rulemaking regarding market data fees and request for guidance on market data licensing practices. `https://www.sec.gov/rules/petitions/2018/petn4-728.pdf`. Accessed: 2020-07-20.

Nofsinger, J. R. and R. W. Sias (1999). Herding and feedback trading by institutional and individual investors. *Journal of Finance 54*(6), 2263–2295.

Pagnotta, E. S. and T. Philippon (2018). Competing on speed. *Econometrica 86*(3), 1067–1115.

Ramos, S. B. and E.-L. von Thadden (2008). Stock exchange competition in a simple model of capital market equilibrium. *Journal of Financial Markets 11*(3), 284–307.

Reuters (2013). BATS exchanges to start charging for market data. `https://www.reuters.com/article/batsglobalmarkets-marketdata-fees-idUSL2N0D52AC20130418`. Accessed: 2020-09-22.

Rösch, D. M., A. Subrahmanyam, and M. A. van Dijk (2017). The dynamics of market efficiency. *Review of Financial Studies 30*, 1151–1187.

SEC (2008). Self-Regulatory Organizations; NYSE Arca, Inc.; Order Setting Aside Action by Delegated Authority and Approving Proposed Rule Change Relating to NYSE Arca Data. `https://www.sec.gov/rules/sro/nysearca/2008/34-59039.pdf`. Accessed: 2020-09-22.

SEC (2012). Self-Regulatory Organizations; EDGX Exchange, Inc.; Notice of Filing and Immediate Effectiveness of Proposed Rule Change Relating to Fees Associated with Receipt of the EDGX Book Feed. https://www.sec.gov/rules/sro/edgx/2012/34-66864.pdf. Accessed: 2020-09-22.

SEC (2013a). Self-Regulatory Organizations; BATS Exchange, Inc.; Notice of Filing and Immediate Effectiveness of a Proposed Rule Change to Impose Fees for Market Data. https://www.sec.gov/rules/sro/bats/2013/34-69936.pdf. Accessed: 2020-09-22.

SEC (2013b). Self-Regulatory Organizations; BATS Exchange, Inc.; Notice of Filing and Immediate Effectiveness of Proposed Rule Change Related to Fees for Use of BATS Exchange, Inc. https://www.sec.gov/rules/sro/bats/2013/34-69933.pdf. Accessed: 2020-09-22.

SEC (2015). Post-Hearing Briefing of NYSE ARCA. https://www.sec.gov/litigation/apdocuments/3-15350-post-hearing-brief-nyse-arca.pdf. Accessed: 2021-01-06.

SEC (2016). Initial Decisison Release No. 1015 Administrative Proceeding File No. 3-15350. https://www.sec.gov/alj/aljdec/2016/id1015bpm.pdf. Accessed: 2020-11-11.

SEC (2020). Proposed Rule: Market Data Infrastructure, Securities Exchange Act Release No. 88216. https://www.sec.gov/rules/proposed/2020/34-88216.pdf. Accessed: 2021-04-21.

Sias, R. W., L. T. Starks, and S. Titman (2001). The price impact of institutional trading. *Working Paper*.

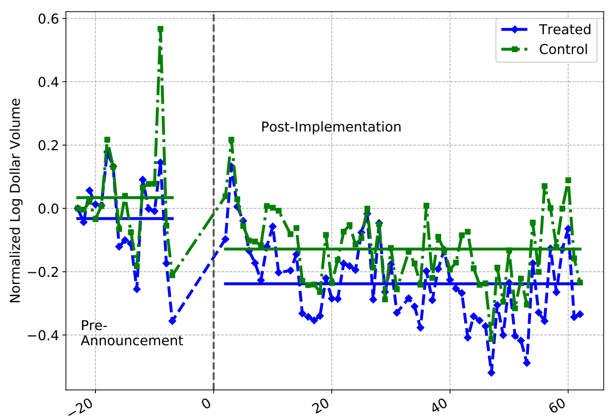
Spatt, C. S. (2020). Is equity market exchange structure anti-competitive? *Working Paper*.

Yan, X. and Z. Zhang (2009). Institutional investors and equity returns: Are short-term institutions better informed? *Review of Financial Studies 22*(2), 893–924.

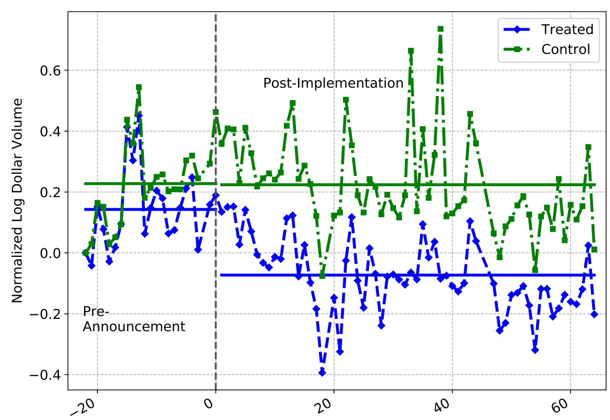
Figure 1: Trading Activity Around Fee Introduction

This figure plots the average log dollar volume traded across the stocks in our sample in windows around fee announcement and fee introduction, split by venues introducing fees and other venues. The y-axis reports the average log dollar value traded across all stocks in our sample by day, for each of three fee introduction events. The x-axis reports the number of trading days before the announcement of the fee and after the introduction of fee. Log dollar volume by day traded on the three exchanges introducing a fee is depicted in the "treated" line. Log dollar volume by day traded on all other venues not introducing fees is depicted in the "control" line. Log volume is normalized by subtracting the log of dollar volume observed at the beginning of the pre-announcement month for both treated and control series.

(a) ARCA



(b) Direct Edge



(c) BATS

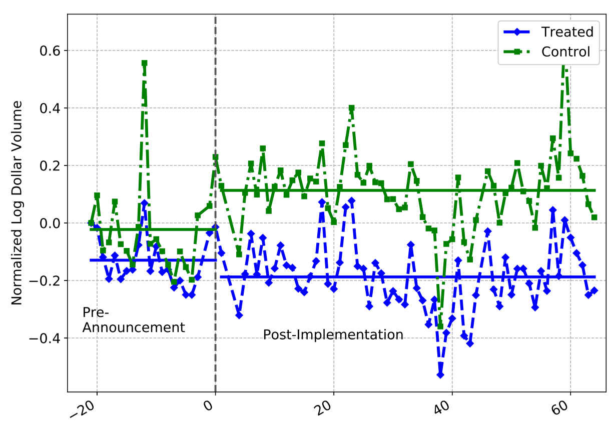


Table 1: Summary statistics

This table reports means, standard deviations, minimums, maximums and 25th, 50th and 75th quantiles for trading activity and liquidity variables for trading on treated exchanges and control venues. The sample includes trading for all stock-days on both treated exchanges and control venues in the one month prior to fee announcement and three months ("Pre-Fee") after fee implementation ("Post-Fee") for fee introductions on ARCA, Direct Edge and BATS. Dollar value traded is the total volume traded by stock-day measured in millions of dollars. Effective spread, realized spread, price impact, seconds at NBBO, and information share (Hasbrouck, 1995) are defined as per Section 2.2. All variables are Winsorized at the 1% level separately for treated exchanges in the pre-announcement and post-implementation periods and control venues in the pre-announcement and post-implementation periods.

	Mean	SD	Min	25%	50%	75%	Max	Mean Pre-Fee	Mean Post-Fee
Panel A: Trading on Treated Exchanges									
Log Dollar Volume	12.380	2.7251	4.9836	10.551	12.490	14.377	18.328	12.469	12.350
Log Trade Size	7.5189	1.0755	1.3863	6.8764	7.6295	8.2748	13.442	7.5430	7.5111
Log ISO Dollar Volume	11.713	2.6726	0.8838	9.8779	11.741	13.703	16.911	11.798	11.685
Seconds at NBBO	6,224.0	6,374.9	7.0000	1,118.0	3,844.0	9,472.0	22964	6,441.1	6,154.9
Effective Spread (%)	0.4908	1.1028	0.0128	0.0621	0.1455	0.3956	10.258	0.5459	0.4721
Realized Spread (%)	0.2881	1.0774	-2.4772	0.0008	0.0402	0.1690	10.280	0.3181	0.2779
Price Impact (%)	0.2122	0.6394	-1.9456	0.0132	0.0654	0.2042	5.9394	0.2371	0.2037
Information Share	0.2710	0.1909	0.0023	0.1003	0.2426	0.4324	0.7038	0.2757	0.2691
Panel B: Trading on Control Venues									
Log Dollar Volume	14.608	2.7103	7.1097	12.769	14.776	16.626	20.366	14.566	14.622
Log Trade Size	7.7320	1.0122	-1.6220	7.0665	7.8067	8.4523	15.395	7.7611	7.7226
Log ISO Dollar Volume	13.524	2.8226	2.0592	11.577	13.661	15.660	18.974	13.496	13.533
Effective Spread (%)	0.6700	1.4619	0.0153	0.0725	0.1736	0.5333	11.926	0.7100	0.6563
Realized Spread (%)	0.4119	1.2085	-0.8876	0.0155	0.0535	0.2304	10.427	0.4426	0.4015
Price Impact (%)	0.2545	0.6213	-1.3089	0.0305	0.0814	0.2255	5.3389	0.2661	0.2505

Table 2: Trading activity

This table reports coefficients (t-statistics) for the effect of fee introduction on log dollar volume traded, log of trade size, volume executed via intermarket sweep orders (ISOs) and otherwise, and seconds spent at NBBO. Columns (1) through (6) present difference-in-differences regressions of log dollar volume and log dollar trade size around fee introduction. The treated sample includes daily trading in all stocks in our sample on the exchange introducing order book fees. The control sample includes the daily trading in the same stocks on all other venues not introducing fees. In columns (1) through (4) each stock-day-venue combination contributes one observation to the regression. In columns (5) and (6) we further distinguish volume executed via ISOs and non-ISOs. In column (7) we only have one observation per stock-day, the number of seconds the treated exchange is at the NBBO. Observations across each of the three fee introduction events are pooled into a single regression. Standard errors are clustered at the stock level.

	Log Volume		Log Trade Size		Log Volume		Log Seconds at NBBO
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Treat × Post	-0.1853***	-0.1466***	0.0004	0.0016	-0.1321***	-0.1135***	
	(-44.3)	(-15.4)	(0.19)	(0.38)	(-30.68)	(-11.82)	
Treat × Post × ISO					-0.0285***	-0.0314***	
					(-5.27)	(-6.50)	
Post							-0.1667***
							(-22.89)
Treat	-2.3261***		-0.2504***		-2.4833***		
	(-374)		(-115)		(-405)		
Post × ISO					0.0467***	0.0465***	
					(13.66)	(15.17)	
Treat × ISO					0.4596***	0.4550***	
					(57.06)	(65.11)	
ISO					-0.6364***	-0.6311***	
					(-114)	(-129)	
# Observations	1,361,068	1,361,068	1,351,997	1,351,997	2,658,439	2,658,439	553,734
Adj. R^2	0.93	0.91	0.96	0.80	0.96	0.85	0.45
Stock × Treat FE		X		X		X	X
Day FE		X		X		X	
Stock × Day FE	X		X		X		

Table 3: Broker routing decisions

This table reports the average percent of market and limit orders that brokers route to exchanges one-quarter before announcement (*Pre*), one one-quarter after implementation (*Post*), and the change from before announcement and after implementation of market data fees ($\Delta = Post - Pre$). Each broker-market pair is one separate observation, where market is either NYSE, Nasdaq, or Amex referring to the exchange where the stock is listed. In Panel A we use all brokers that routed orders to the treated exchange before the event. In Panel B we use all brokers that routed *limit* orders to the treated exchange before the event. The difference in order routing percentages are estimated for all brokers in the sample (Δ_{All}), brokers split by whether they participate in the inter-dealer over-the-counter market for corporate securities according to FINRA broker check filings ($\Delta_{IDM=1}$ vs. $\Delta_{IDM=0}$) and brokers split by whether they participate in underwriting selling groups according to FINRA broker check filings ($\Delta_{UW=1}$ vs. $\Delta_{UW=0}$). Standard errors are clustered by market when estimating the statistical significance of the Δ terms. The data is from Rule 606 filings, available at vrs.vista-one-solutions.com.

Panel A: All brokers which routed orders to the treated exchange pre-event

	Pre	Post	Δ_{All}	$\Delta_{IDM=1}$	$\Delta_{IDM=0}$	$\Delta_{UW=1}$	$\Delta_{UW=0}$
Rule606 market orders	7.8417	5.4736	-2.3682**	-1.4087	-3.4149**	-2.1757	-2.9956***
			(-2.07)	(-0.91)	(-2.01)	(-1.47)	(-3.57)
Rule606 limit orders	9.1737	7.4710	-1.7027	-1.9690	-1.4122	-2.2303	-0.0170
			(-1.32)	(-0.89)	(-1.14)	(-1.39)	(0.01)
# Observations	115	115	115	115	115	115	115
# Brokers	27	27	27	27	27	27	27

Panel B: All brokers which routed limit orders to the treated exchange pre-event

	Pre	Post	Δ_{All}	$\Delta_{IDM=1}$	$\Delta_{IDM=0}$	$\Delta_{UW=1}$	$\Delta_{UW=0}$
Rule606 market orders	15.787	11.043	-4.7442**	-2.424	-8.1661**	-4.7865	-4.6447***
			(-2.08)	(-0.88)	(-2.11)	(-1.48)	(-4.01)
Rule606 limit orders	18.508	14.103	-4.4053*	-4.5747	-4.1548	-4.9067	-3.2253*
			(-1.77)	(-1.22)	(-1.46)	(-1.40)	(-1.95)
# Observations	57	57	57	57	57	57	57
# Brokers	17	17	17	17	17	17	17

Table 4: Liquidity and price impact

This table reports coefficients (*t*-statistics) for difference-in-differences regressions of price impact, effective spreads and realized spreads around fee introduction. The treated sample includes daily trading in all stocks in our sample on the exchange introducing order book fees. The control sample includes the daily trading in the same stocks on all other venues not introducing fees. Observations across each of the three fee introduction events are pooled into a single regression. Standard errors are clustered at the stock level.

	Effective Spread		Price Impact		Realized Spread	
	(1)	(2)	(3)	(4)	(5)	(6)
Treat × Post	-0.0062***	-0.0029	-0.0120***	-0.0148***	0.0083***	0.0147**
	(-3.30)	(-0.46)	(-5.82)	(-5.04)	(3.06)	(2.53)
Treat	-0.0373***		-0.0055***		-0.0211***	
	(-17.9)		(-2.80)		(-8.53)	
# Stocks	3,646	3,646	3,646	3,646	3,646	3,646
# Days	249	249	249	249	249	249
# Observations	1,361,068	1,361,068	1,361,068	1,361,068	1,361,068	1,361,068
Adj. R^2	0.88	0.66	0.29	0.26	0.61	0.45
Stock × Treat FE		X		X		X
Day FE		X		X		X
Stock × Day FE	X		X		X	

Table 5: Information share

This table reports changes in Hasbrouck (1995) and Modified (Lien and Shrestha, 2009) Information Share after fee introduction. We report the upper and the lower Information Share measures and the average of both. The sample includes all stocks on the venue introducing order book fees in three month windows around fee introduction. *Post* is an indicator variable equal to one after the fee introduction and zero before. Each stock-day contributes one observation to the regression. Observations across each of the three fee introduction events are pooled into a single regression. We drop one half-trading day from the analysis (24 December 2008). Standard errors are clustered at the stock level.

	Information Shares	Modified Information Shares	Upper Information Shares	Lower Information Shares
	(1)	(2)	(3)	(4)
Post	-0.0347***	-0.0408***	-0.0258***	-0.0868***
	(-6.63)	(-6.81)	(-4.86)	(-12.40)
# Stocks	3,480	3,480	3,480	3,480
# Days	248	248	248	248
# Observations	555,686	555,686	555,686	555,686
Adj. R^2	0.21	0.19	0.27	0.09
Stock FE	Yes	Yes	Yes	Yes

Table 6: Market-wide changes in market quality

This table reports coefficients (t-statistics) for market-wide difference-in-differences regressions of execution quality around fee introduction. The treated sample includes daily trading in all stocks that have above-median pre-announcement market share on the exchange introducing order book fees. The control sample includes the daily trading in the all stocks with below-median market share on the exchange introducing fees. Observations across each of the three fee introduction events are pooled into a single regression. Standard errors are clustered at the stock level.

	Market Share		Effective Spread		Price Impact		Realized Spread		Volatility		Pricing Error	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
High × Post	-0.0247***	-0.0228***	0.0274***	0.0155**	0.0040	0.0020	0.0234***	0.0133**	0.0081***	0.0044***	0.0053***	0.0030**
	(-39.5)	(-36.1)	(2.72)	(2.26)	(1.25)	(0.72)	(2.79)	(2.17)	(3.73)	(2.78)	(2.94)	(2.07)
High	0.0571***		0.0010		0.0058		-0.0061		-0.0075*		-0.0027	
	(88.6)		(0.05)		(1.16)		(-0.38)		(-1.93)		(-0.84)	
# Stocks	3,521	3,521	3,521	3,521	3,521	3,521	3,521	3,521	3,521	3,521	3,521	3,521
# Days	246	246	246	246	246	246	246	246	246	246	246	246
# Observations	676,874	676,874	676,874	676,874	676,874	676,874	676,874	676,874	676,874	676,874	676,874	676,874
Adj. R^2	0.34	0.44	0.06	0.82	0.04	0.29	0.04	0.65	0.05	0.76	0.06	0.50
Stock × Event FE		X		X		X		X		X		X
Day FE	X	X	X	X	X	X	X	X	X	X	X	X

Table 7: The role of book depth

This table reports coefficients (t-statistics) for market-wide difference-in-differences regressions of auction quality around fee introduction. Auction $|Deviation|$ is calculated as two times the absolute difference in the logarithm of the auction price and the prevailing (last) midpoint price during the continuous trading session using national best bid and ask prices. The treated sample includes daily trading in all stocks that have above-median pre-announcement market share on the exchange introducing order book fees. The control sample includes the daily trading in the all stocks with below-median market share on the exchange introducing fees. Observations across each of the three fee introduction events are pooled into a single regression. Standard errors are clustered at the stock level.

	Auction $\lvert Deviation \rvert$	
	(1)	(2)
High × Post	0.0798**	0.0697***
	(2.31)	(5.23)
High	0.0482*	
	(1.91)	
Open	0.6673***	
	(50.9)	
# Stocks	2,913	2,913
# Days	126	126
# Observations	626,608	626,608
Adj. R^2	0.12	0.40
Stock × Event FE		X
Day FE	X	X