FLORIDA INTERNATIONAL UNIVERSITY

Miami, Florida

EXAMINATION OF ORDER ROUTING CHOICES AND MARKET QUALITY UNDER ZERO COMMISSION AND FIRM-LEVEL EVENTS

A dissertation submitted in partial fulfillment of

the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

BUSINESS ADMINISTRATION

by

Le Zhao

2022

To: Dean William Hardin
College of Business

This dissertation, written by Le Zhao, and entitled Examination of Order Routing Choices and Market Quality under Zero Commission and Firm-Level Events, having been approved in respect to style and intellectual content, is referred to you for judgment.

We have read this dissertation and recommend that it be approved.

____
Qiang Kang

____
Ozde Oztekin

____
Dallin Alldredge

____
Clark Wheatley

____
Suchismita Mishra, Major Professor

Date of Defense: June 7, 2022

The dissertation of Le Zhao is approved.

____
Dean William Hardin
College of Business

____
Andrés G. Gil
Vice President for Research and Economic Development
and Dean of the University Graduate School

Florida International University, 2022

DEDICATION

To my husband Gary and my two lovely cats Miumiu and Taotao.

ACKNOWLEDGMENTS

First and foremost, I want to thank my dissertation chair Dr. Suchismita Mishra and my co-author Dr. PK Jain for their support and mentorship. I appreciate everything they have taught me. They are the ones who continually encourage me, support me, and inspire me to be a good scholar and a good person. In addition, I would like to thank two members of my cohort: Marcos Velasquez and Xiaomeng Lu, who have given me constant support in various ways. I feel so blessed to have such wonderful friends like them to study, research, and share those ups and downs together.

Finally, I am grateful to my co-authors Dr. Vinh Huy Nguyen, Dr. Douglas Cumming, Dr. Shawn O'Donoghue, and my dissertation committee members. I am grateful for their many simulating conversations, helpful suggestions, and tremendous patience.

ABSTRACT OF THE DISSERTATION

EXAMINATION OF ORDER ROUTING CHOICES AND MARKET QUALITY UNDER ZERO COMMISSION AND FIRM-LEVEL EVENTS

by

Le Zhao

Florida International University, 2022

Miami, Florida

Professor Suchismita Mishra, Major Professor

This dissertation is comprised of three essays that focus on the topics related to order routing choices in the U.S. equity market. This research provides insights into the effect of the routing order choice to dark and lit venues on the market quality under the multiple types of the event. The empirical results are significant and robust.

There are three chapters included: the first chapter discusses the dynamic fragmentation of dark and lit venues and market quality pre-and post-zero brokerage commission events. Major retail brokers that eliminate commissions dramatically increase their market share of client assets. They increasingly routed orders to off-exchange wholesale market makers instead of exchanges to potentially gain more payment for order flow to compensate for commission losses. Given the retail brokers' routing trade-off, retail investors receive less price improvement per share. Zero commission traders increase the share of odd lots and smaller order size buckets. Overall, market liquidity improves surprisingly. Effective spreads decline with retail orders placed inside the bid-ask spread. Realized spreads are unchanged, but intraday volatility increases, suggesting that new orders are relatively uninformed.

The second chapter analyzes the difference in routing order choice under a firm's scheduled vs. unscheduled event. Using earnings announcements as the reoccurring, scheduled event and share repurchase announcements as the non-reoccurring, unscheduled event, we find that traders strategically choose off-exchange venues around scheduled events. We study and confirm that the scheduled events have higher information asymmetry, which appears to cause traders to route their orders to off-exchange venues.

The last chapter explores the role of retail trading in dynamic trading fragmentation around market manipulation. We merge manipulation data from SMARTS/NASD with trading volume by exchange from TAQ. We find novel evidence that continuous trading manipulation does not equally impact the trading volume in each exchange. Changes in off-exchange trading volume share due to manipulation are positively associated with retail trading activities. Our findings suggest that manipulation increases the illiquidity curve while the retail trading flow dampens illiquidity.

TABLE OF CONTENTS

CHAPTER PAGE

LIST OF TABLES

TABLE PAGE

LIST OF FIGURES

TABLE PAGE

CHAPTER 1: TRADING VOLUME SHARES AND MARKET QUALITY: PRE- AND POST-ZERO COMMISSIONS

1.1 Introduction

The bitterness of poor quality remains long after the sweetness of low price is forgotten.

-Benjamin Franklin

The role of secondary market brokerage commissions in equities has been transformed from being the lifeblood of brokerage business (Jennings 1965) to dropping to zero under competitive pressures in 2019. The restricted and fixed nature of past brokerage commissions had important implications for secondary market information production (Brennan and Hughes 1991; Brennan and Chordia 1993). More recently, Goldstein et al. (2009) find that commissions affect institutional trading patterns, and we conjecture that the trade-off between direct commission costs and indirect costs can affect investor's asset choice.

The deregulation of brokerage commissions, in combination with the SEC's rules related to the disclosure of order execution and order routing practices have reduced commissions and improved order execution quality (Battalio and Loughran 2008; Boehmer, Jennings, and Wei 2007; Adams, Kasten, and Kelley 2021). However, recent theoretical developments point out that there may actually be a trade-off between commissions and order execution quality due to potential conflict of interest between brokers and their clients arising from the payment of order flow received by the brokers from wholesale market makers. Cimon's (2021) model of brokers' order routing decisions has not yet been tested and the recent adoption of zero commission by major retail brokers provides us with an opportunity to test its implications regarding the connection between brokerage commissions and order routing. Broker's routing decision is important because it directly affects order execution quality along many dimensions as shown by Battalio, Corwin, and Jennings (2016).

Discount brokers emerged to challenge full-service brokers in the mid-1970s, and more recent technological advancements have further intensified price competition (Bakos et al. 2005).[1] Newer firms, such as Robinhood and Webull, offered app-based trades with low or zero commissions. We track the entire time series of the proportion of retail zero commission brokers. A sharper test window also became available after Interactive Brokers launched commission-free stock trades through its IBKR Lite pricing program in October 2019 to some retail clients.[2] This action led other major brokers, such as Charles Schwab, TD Ameritrade, E*Trade, and Fidelity to quickly eliminate commissions as well, even though this disruptive strategy meant that many brokerage firms had to eventually merge with others for survival.[3] With zero commissions, retail traders can now quote prices at or within the NBBO and attempt to earn half the spread by placing limit prices that can reduce the width of the NBBO to a penny, which could not be profitably done in the presence of round-trip commissions larger than $0.01 per share.

---

[1] Brokerage commissions have declined from May 1, 1975 through present. For details see https://blog.trade.it/2017/02/06/price-wars-online-brokerage-edition/ and https://www.businessinsider.com/historical-trading-commissions-2014-3.

[2] See https://www.interactivebrokers.com/en/index.php?f=45393. Interactive Brokers did not automatically reduce commissions to zero for all retail clients. Therefore, we exclude Interactive Brokers in the main empirical analysis but include it in the robustness tests, where the proportion of retail brokers that offer zero commission encompasses Interactive Brokers. The results are similar whether or not Interactive Brokers is accounted for.

[3] The acquiring firms could offset or subsidize the loss of commission revenue through other sources such as interest on the uninvested cash in client accounts or banking services. See https://www.washingtonpost.com/business/2019/11/25/charles-schwab-will-acquire-td-ameritrade-creating-wealth-management-goliath-with-trillion-assets/.

Some critical questions in this context a few of which were highlighted in Royal (2019) are: Can brokers afford to drop a source of revenue (i.e., commissions) to zero? Did zero-commission retail brokers capture the market share of client assets from commission-charging brokers, given the trade-off between direct versus indirect trading costs, and the potential perception that cost-free trading may be associated with poorer customer service? Do firms compensate for lost commissions by leaning more on a controversial practice called payment for order flow? If so, does this reduce the ability of wholesale market makers to provide price improvement to retail investors, given higher payments paid for order flow? Payment for order flow may create a conflict of interest for brokers who must balance their need for profit with "best execution" duties to their clients. Do retail investors prefer brokers that do not charge a commission, even though the loss of commission revenue could potentially exacerbate this conflict of interest? These questions have gained significance due to the remarkable increase in retail trading in 2020 as more investors find time to trade stocks from home and replace sports gambling with stock trading during the pandemic. Notably, Congress's GameStop hearing (US House, Committee on House Financial Services, 2021) focused attention on retail traders and their brokers. SEC Chairman Gary Gensler suggests that payment for order flow (i.e., PFOF) paid by wholesalers to brokers represents a conflict of interest between retail brokers and their clients and is considering the prohibition of this practice.[4]

Therefore, it is essential to examine whether the retail broker order routing practices change after commissions dropped to zero, given the potential trade-off between payment for order flow received by the retail brokers versus price improvement offered to retail

[4] The interview for Gary Gensler can be found in https://www.barrons.com/articles/sec-chairman-says-banning-payment-for-order-is-on-the-table-51630350595.

investors for a subset of their marketable orders.

Using publicly available data sources, we extend the literature on the role of brokerage commissions to examine changes in volume along three dimensions: between commission versus commission-free brokers, exchanges versus wholesale market makers, and retail odd lot and smaller trades versus larger trades. We examine important theories related to customer attraction to zero commission brokers, broker market share, cost competition, and cream skimming of retail orders, in addition to the impact of zero commission on market quality.

Our first hypothesis focuses on market share of client assets. On one hand, commissions, which are direct costs, may allow brokers to offer larger product offerings, better customer service, and larger new brokerage account promotions. On the other hand, zero commission may be associated with an increase in indirect costs, such as less price improvement received by retail investors.[5] Thus, the impact of zero commission on investors' choice of direct (i.e., paying commissions) versus indirect costs of commission-free trading is important to explore. In fact, we find that investors may prefer to pay trading costs indirectly: Zero (positive) commission brokers dramatically increase (decrease) their market share of client assets. Increased Internet searches for the keyword "free stock trading" in Google Trends indicates that retail investors sought out information on zero commission brokers. Furthermore, we also observe that an increase in the number of smaller order size buckets and retail orders and an increase in their dollar volume is associated with the adoption of zero commissions by major brokers. Retail traders can now

[5] Zero commissions may also potentially increase indirect costs associated with trading such as lower interest paid to cash balances and higher margin interest rates charged.

trade smaller order sizes at lower transaction costs with the commission-free trading.[6]

Our second novel hypothesis focuses on order routing by brokers to non-exchange venues. In the absence of commissions, brokers are not able to directly profit from these newly acquired retail investors' accounts or trades because they are effectively providing nearly free execution services.[7] If retail brokers simply send traders' marketable orders to an exchange, the costs due to the transaction fee paid to the make-take fee exchange could imply negative net profits, unless brokers earn other revenue from clients. As a natural response, brokers may alter their order routing strategy, whereby they can derive some profit by selling the order to wholesale market makers, who compete by making payments for order flow (PFOF) to retail brokers and typically offering retail orders better prices than available from quotes posted on exchanges by providing price improvement.[8] Wholesale market makers also compete for order flow on the dimension of execution quality. Wholesale market makers earn profits from internalizing retail orders because retail orders do not typically have a relative informational advantage and are small relative to the average daily volume of a given stock. In addition, wholesale market makers may extract valuable information about sentiment from retail order flow. Formally, we test the

---

[6] For example, a passive trader wishing to purchase 100 shares currently quoting at $10.10 may previously submit a single buy order at $10 to minimize commissions. She can now achieve better execution and the same average price result with a 50-share order at $10.10 and another 50-share order at $9.90 without extra commission costs from two trades.

[7] Brokerages also earn revenue from net interest on funds held in accounts, rehypothecation of stocks held by the firm, borrowing charges for short selling, various account fees (e.g., inactivity fees, account minimum fees etc.), inter-exchange fees from credit and debit cards, payments for money sweeps to banks, and payment for order flow.

[8] According to Citadel Securities quarter 1 2019 retail execution quality statistics reported to the Financial Information Forum, 99.93% of their odd lot market orders executed at the NBBO or better and 96.03% of their market orders received price improvement for S&P 500 stocks. For details see: https://s3.amazonaws.com/citadel-wordpress-prd102/wp-content/uploads/sites/2/2016/09/09175131/FIF-Rule-605-606-WG-CitadelSecurities_Retail-Execution-Quality-Stats_Q1_2019.pdf.

hypothesis that under zero commissions, a greater proportion of trading volume is captured by wholesale market makers, because zero commission brokers concentrate on routing orders to wholesale market makers instead of to exchanges.

To test this second hypothesis, we use a difference-in-difference methodology and multivariate regressions to assess the significance of any changes in the execution venue chosen by retail brokers comparing those brokers who drop commissions to zero to those that do not. For multivariate regressions, we include broker fixed effects to control for cross-sectional differences in broker characteristics that do not change with commission rates but may have gained increased importance after adoption of zero commissions. For instance, brokers' holding companies with other financial services such as banking may not weigh PFOF the same as those who do not have other financial services.[9] Our results suggest that retail brokers who eliminated commissions changed their order routing behavior — their trading volume, which is a function of their routing decisions, shifts from exchanges to wholesale market makers.

Our third hypothesis tests the impact of commissions on several dimensions of market quality from an increase in retail trading volume where we have some expected and unexpected findings. To begin, we examine the impact of zero commissions on the amount of price improvement per share received by retail investors. Zero commissions eliminate a major source of revenue, so retail brokers may increasingly earn revenue from payment for order flow received from wholesale market makers. Wholesale market makers, in contrast, may be indifferent to the split between payment for order flow and price improvement as both represent costs, and retail brokers may prefer to receive more

[9] For details see: https://www.wsj.com/articles/the-race-to-zero-commissions-11570267802.

payment for order flow versus providing more price improvement to clients. In equilibrium, wholesale market makers, who pay increased payments for order flow, may widen effective spreads or offer less price improvement per share to maintain their gross profits. Thus, it is possible that the amount of price improvement per share offered to retail marketable orders may decline if wholesale market makers make larger payments to retail brokers. Our univariate results are consistent with this hypothesis, which suggests a statistically significant decrease in the amount of price improvement per share for stocks that are popular among retail investors. In other words, it appears that retail investors receive less price improvement per share after zero brokerage commissions are implemented.

We proceed further to examine the impact of zero commissions on additional dimensions of market quality beyond the price improvement aspect above. Mackintosh (2021) reports that retail daily dollar volume increased as early as December 2019 when most retail brokers reduced commissions to zero. We note that with zero commissions, new and existing retail investors can quote limit orders at the bid and ask price or inside the spread more frequently because the order placement strategy is no longer constrained by non-zero commission costs. In addition, market makers can offer narrower quotes because retail orders become smaller permitting market makers to adjust quotes with greater frequency. These strategies unexpectedly result in narrower quoted and effective spreads.[10] As retail investors are typically uninformed (Kumar and Lee 2006; Foucault, Sraer, and Thesmar 2011; Barber and Odean 2013), the direction of the stock's trade does not permanently affect the stock's price. As the movement of the quote mid-point is unaffected,

[10] Larrymore and Murphy (2009) find a rising internalization rates are associated with a decline in the bid-ask spread and variance of the pricing error.

realized spreads increase or remain unchanged, and consequently, price impact may fall. Even if the retail order flow is potentially informed (Kaniel, Saar, and Titman 2008; Kelley and Tetlock 2013; Barrot, Kaniel, and Sraer 2016), the impact of adverse selection is mitigated because wholesale market makers can adjust quotes more frequently as order size decreases. Alternatively, an increase in uninformed retail order flow could magnify fluctuations in price, which may cause market makers to reduce liquidity due to changes in the value of their inventory (Ho and Stoll 1981).

Formally, we test our third hypothesis that zero brokerage commissions affect the overall market quality by using the DTAQ data. We conjecture that quoted spread, effective spread and price impact decrease while realized spread increases or remains constant and market microstructure noise increases after the brokerage industry eliminated commissions. We find a significant decrease in percent effective spreads and price impact after zero brokerage commissions came into effect, while realized spread remains unaffected. The decline in effective spread is inconsistent with cream skimming, whereby an increase in uninformed retail orders internalized by wholesale market makers may increase the proportion of informed order that execute on exchange (Easley, Kiefer, and O'Hara 1996), and is consistent with wholesale market makers serving as cost competitors (Battalio 1997).

Our study complements contemporary research papers on the enhanced role of the retail investors. For instance, Ozik, Sadka, and Shen (2021) focus on the pandemic lockdown period and show that the increased retail trading flattens the illiquidity curve. Eaton et al. (2021) study retail brokerage platform outages and find the level of retail sophistication matters for market quality. In addition, Adams, Kasten, and Kelley (2021) examine the retail execution costs and find that off-exchange retail trades have lower effective spreads than comparable on-exchange trades after commissions drop to zero. Our study is distinct from the above complementary papers in several dimensions. First, in terms of the research question, we focus on the changes in retail broker's order routing destination (exchanges versus wholesalers) as the driving force behind changes trading volume shares and execution quality. Second, instead of focusing on Robinhood alone, we include all major brokers in our analysis and also track the entire time series of the proportion of zero commission brokers in the brokerage industry as a whole. Third, besides DTAQ data, we additionally use SEC Rule 605 reports to examine aggregated order execution quality and SEC Rule 606 reports from retail brokers to examine previously untested hypotheses on broker order routing changes.

To the best of our knowledge, we are the first to examine the distribution of volume between commission versus commission-free brokers, exchanges versus wholesale market makers, and retail odd lot and smaller trades versus larger trades. This empirical analysis tests important theories related to market share as well as whether wholesale market makers behave either as cost competitors or cream skimmers of retail orders. We use multiple datasets to examine the impact of zero commissions as each dataset has its own unique advantages. The 605 reports provide execution quality metrics for each security by execution venue at monthly frequency. The 606 reports disclose order routing practices by brokers, at monthly frequency. The reports are released each quarter. DTAQ provides trade level data inclusive of odd-lots at the individual security level. Robintrack statistics allow us to focus on stocks heavily traded by retail investors. FINRA's transparency data allows us to examine volume by wholesaler market maker. Thus, the combination of datasets helps us to fully understand the impact of zero commissions on retail participation, broker routing, and market quality.

The remainder of the Chapter 1 is organized as follows. Section 1.2 develops our hypotheses on the relationship between zero- commissions, order routing choices, and market quality. Section 1.3 describes data sources. Section 1.4 reports our main empirical results and robustness tests, and Section 1.5 concludes the paper. Additional information is provided in Appendices.

1.2 Literature Review and Hypothesis Development

We test three main hypotheses related to how zero commissions affect broker order routing decisions and market quality. The most important impact of the elimination of commissions may be on a broker's market share of retail clients. We empirically test whether retail brokers that eliminate commissions attract client assets in accordance with Bell, Keeney, and Little (1975) market share theorem. If some retail brokers adopt zero commissions, while other brokers maintain positive commissions, there may be a considerable shift in the market share of the retail investors' assets from the positive to zero commission brokers or vice versa. The shift may occur in either direction because non-zero commissions may allow brokers to offer larger product offerings, better customer service, larger new account promotions, higher cash balance interest, and more price improvement. Alternatively, eliminating commissions may be preferred by retail investors as it reduces the direct cost of trading. However, should the indirect costs of zero price products be high, then demand for zero price products may be lower than that for the non-zero price product (Fan, Cai, and Bodenhausen 2022). In this scenario, how do retail customers choose a broker considering this trade-off between direct and indirect costs and the potential perception that cost-free trading may be associated with worse customer service, less price improvement received, and may exacerbate brokers' conflict of interest because commissions are no longer available as a source of revenue? Some brokers advertise that they do not accept PFOF for equity trades[11] and others have paid fines for not providing customer trades with best prices[12].Decision-making may follow referent thinking where people compare the benefits and costs for each option and choose the option that should provide the highest benefit for any level of cost.[13] However, Shampanier, Mazar, and Ariely (2007) suggest a "zero-price" effect in decision making, which is the human cognitive bias to overvalue the "free" component in the products. In other words, a product or service with a "free" promotion is extraordinarily attractive to individuals.

Therefore, we conjecture that retail investors may use referent thinking or act under zero-price psychological influences (Shampanier, Mazar, and Ariely 2007) in choosing a brokerage. With positive commissions the referent thinking effect dominates the decision in choosing the broker. Retail investors evaluate brokers by comparing the estimated benefits they may receive along with costs. However, after most retail brokers implemented zero-commissions in October 2019, advertising it as "free-trading", the zero-price effects dominate the retail investor's decision-making process. We conjecture that retail investors overvalue the "free-trading" component and ignore the potential costs, not realizing that with free pricing customers' orders become the product when sold for PFOF.

---

[11] See https://www.spglobal.com/marketintelligence/en/news-insights/trending/IiJL9zOpAk76f_BrDunluA2.

[12] See https://www.wsj.com/articles/robinhood-settles-claims-it-didnt-ensure-best-prices-for-customer-trades-11576776167.

[13] See Payne et al. (1991) and Simonson and Tversky (1991). Referent thinking, such as the comparison between risk and return, are widely applied in portfolio optimization in finance.

Brokers that charge zero-commissions may also increasingly compete for customers based on the digital experience provided by their trading platforms. In addition, retail investors who made frequent trades due to flexible work schedules during the COVID pandemic and are now accustomed to zero commissions may find brokers charging zero commissions more attractive than the positive commission brokers.

In addition, orders submitted by retail investors are typically uninformed (Kumar and Lee 2006; Foucault, Sraer, and Thesmar 2011; Barber and Odean 2013), and generally have smaller size than orders submitted by institutional investors (Barber, Odean, and Zhu 2008). As retail investors no longer need to consolidate their trades to save on commissions, the size of retail orders may decline. Therefore, brokers may receive more uninformed orders that are of smaller size after eliminating commissions.

Hypothesis 1: Zero-commission brokers gain more retail clients; and the volume from small retail-sized orders increases.

One consequence of zero commissions is that brokers are no longer able to directly earn revenue from a retail investor's commission and are effectively providing nearly free execution services.[14] If retail brokers simply send investors' marketable orders to a traditional make-take exchange, the costs due to the transaction fee paid to the exchange could imply negative net revenue (O'Donoghue 2022).

Battalio, Jennings, and Selway (2001), Parlour and Rajan (2003) and Fox, Glosten, and Rauterberg (2019)) suggest that selling orders for payment for order flow (PFOF) helps broker achieve lower commissions. A theoretical model in Cimon (2021) also predicts that

[14] Brokerages also earn revenue from net interest on funds held in accounts, rehypothecation of stocks held by the firm, borrowing charges for short selling, various account fees (e.g., inactivity fees, account minimum fees etc.), inter-exchange fees from credit and debit cards, payments for money sweeps to banks, and payment for order flow.

the size of commissions drives broker routing behavior. Thus, to offset revenue losses associated with zero commissions, brokers may alter their order routing strategy, where they may derive some revenue by selling more orders to wholesale market makers in exchange for PFOF. Thus, wholesaler market maker, who offer PFOF, may become the preferred destination for retail brokers after commissions drop to zero instead of exchanges, who do not offer PFOF.[15]

Why is payment for order flow profitable? For retail brokers, payment for order flow is revenue as a function of the number of shares sold to a wholesale market maker. Retail investors are generally considered to be uninformed and do not have a relative informational advantage relative to institutional investors (Chung, Chuwonganant, and McCormick 2006; Kumar and Lee 2006; Foucault, Sraer, and Thesmar 2011; Barber and Odean 2013). Wholesale market makers pay for retail order flow to minimize adverse selection costs, because it is uniformed. Orders from retail investors are also smaller relative to institutional orders. Thus, the risk from being a counterparty to retail orders is much smaller due to their relatively smaller order size and limited information content.

Easley, Kiefer, and O'Hara (1996) argue that wholesale market makers cream skim uninformed retail orders to earn the half bid-ask spread less their nominal cost of paying for the flow and any price improvement. As more uninformed order flow is routed off-exchange, the proportion of informed orders executed on exchange increases causing bid-ask spreads to increase. Battalio (1997), however, argues that an increase in orders executed by wholesale market makers can lead to narrower bid-ask spreads when wholesale market makers serve as cost competitors to those posting quotes on exchange.

[15] Retail brokers have reduced incentive to route marketable orders to those exchanges which pay high make rebates subsidized by high take fees as suggested by Battalio, Corwin, and Jennings (2016).

Wholesale market makers also trade against retail orders to enter or exit their market making positions, which, in turn, increases liquidity. Furthermore, these wholesale market makers may use retail order flow as part of hedging strategies across different asset classes. Once the wholesale market maker purchases uninformed retail order flow, they internalize 100% of it instead of sending these orders to exchanges. This choice has direct implications for the market share captured by trading venues. Formally, we test the hypothesis that total trading volume increases for off-exchange wholesale market makers.

Hypothesis 2: After the adoption of zero commission by leading retail brokers, order routing to off-exchange venues increases and trading volume subsequently increases off-exchange.

The third important impact of commissions are the changes in market quality emanating from the trade-off between the first two hypotheses. Several welfare implications of relative ease of retail trading are highlighted by Heimer and Simsek (2019) in the context of leveraged retail forex trading including the specific concern that excessive trading volume that does not necessarily benefit market participants, enriches institutions and intermediaries. Zero commissions are hypothesized to increase retail trading volume but they eliminate a major source of broker revenues, thereby, adversely affecting their profits. So retail brokers may increasingly earn revenue from payment for order flow received from wholesale market makers. Wholesale market makers, in contrast, may be indifferent to the split between payment for order flow and price improvement as both represent costs, and retail brokers may prefer to receive more payment for order flow versus providing more price improvement to clients. In equilibrium, wholesale market makers, who pay increased PFOF, may offer less price improvement per share to maintain their gross profits. The conflict of interests arising from PFOF have not been examined in the fragmented equity markets.[16] Thus, it is possible that the amount of price improvement per share offered to retail marketable orders may decline if wholesale market makers make larger payments to retail brokers. A decline in price improvement represents an increase in indirect costs to retail investors.

We further proceed to examine other dimensions of market quality such as effective spread, realized spread and price impact. On the one hand, the decline in the direct commission revenue may indirectly cause effective spreads to widen, should wholesale market makers offset a loss of revenue if payment of order flow increases. On the other hand, under zero commissions retail investors can more easily place orders at or within the bid and ask prices more frequently, because a non-zero commission no longer constrains the price of quotes.[17] In addition, market makers can adjust quoted prices more frequently when retail trade sizes decline. This strategy results in a narrower effective spread as suggested by Bartlett, McCrary, and O'Hara (2022).

Retail investors are assumed to be uninformed in many theoretical models and many empirical studies find that orders placed by retail investors introduce more noise to the market.[18] Hence, stock intraday volatility (noise) may increase after a sharp increase

[16] Ernst and Spatt (2021) study PFOF in the options market but do not address on-versus off-exchange order routing.

[17] For example, if an investor saves \$50 a day and commissions are \$8. Previously the investor will likely wait to accumulate \$5,000 to buy 100 shares of stock quoting at a current bid of \$50.00 and an ask of \$50.05 by posting a limit buy at \$50.01. With non-zero commissions they provide liquidity only once in 3 months because buying 1 share per day deeply cuts into returns. In contrast, with zero commissions, the investor can place a 1 share order every single day inside the bid-ask spread. In addition, after the initial purchase, the investor may post a limit sell at \$50.04 with the hope of buying it back at \$50.01 again. Such an investor may do this multiple times each day. This is strategy is profitable with a commission-free trades but not with a \$8 commission per trade.

[18] See Black (1986); Shleifer and Summers (1990); De Long et al. (1990); Stambaugh (2014); Kumar and Lee (2006); Kurov (2008); Foucault, Sraer, and Thesmar (2011).

in uninformed retail trading associated with zero commissions. Furthermore, because retail investors are typically uninformed, the direction of a stock's trade does not increase the informativeness of that stock's price. As more retail orders enter the market after zero commissions are adopted and retail order size declines, price impact should fall because the overall flow is less informed and market makers can adjust their quotes more often. Thus, the realized spreads should increase or remain unchanged.

Hypothesis 3: Under zero commissions and increased uninformed retail participation, market quality changes. Price improvement per share offered to retail investors is less. Quoted spread, effective spread, and price impact decrease while volatility (noise) and realized spread increase or remain constant.

1.3 Data and Methodology

Zero commission adoption announcements are collected from brokerage websites and the timestamps for such announcements are from their official twitter accounts. The data for the quarterly net change in client assets are collected and calculated from retail brokers' 10-Q reports. FINRA's transparency data allows us to examine volume by wholesaler market maker. We also use the NYSE Daily Trade and Quote (DTAQ) database, SEC Rules 605 and 606 public disclosure reports of order execution and routing practices, CRSP, and VIX volatility index from CBOE. We also download Short Interest from Compustat's supplemental files, because the media has reported that retail investor trading may have been involved in a possible short squeeze in GameStop.

The DTAQ trade file contains detailed information about every trade, such as the stock symbol, time stamp, trade price, share volume, execution venue (including exchanges and off-exchange), and trade condition. The DTAQ quote file and NBBO file contains detailed information about each quote such as the time stamp, stock symbol, or exchange(s) where quotes are posted, bid and ask price, size, best bid or offer indicators and various other quote conditions. Holden and Jacobsen (2014) provide the institutional details that go behind the creation of the DTAQ dataset and its relative advantages over other datasets.

We use the SEC Rule 605 to analyze changes in order execution for market makers. Rule 605 requires market centers to make publicly available standardized, monthly reports of statistical information concerning their order executions categorized by security, order type, and order size. Information includes number of covered orders, shares, execution speed, realized spreads, effective spreads, and price improvement.

We use the SEC Rule 606 reports to evaluate changes in order routing behavior for brokers who introduced zero commission versus those who continue to charge positive commissions. The data in the SEC Rule 606 reports are provided on a quarterly frequency. Each broker or dealer disclosures its routing in NMS stocks by the percentage of their orders that are non-directed and are market, limit, or other order types. It also requires brokers to provide the percentage of each order type that is routed to each of their top ten routing destinations and any other venue receiving at least five percent of their non-directed orders. The reports also contain a discussion of some aspects of a broker's relationship with each venue, including payment for order flow. We manually collect the Q3-2019 and Q4-2019 Rule 606 reports for retail brokers and calculate the changes in broker's routing to each venue by order type. Additional information on Rules 605 and 606 can be found on the SEC website. Control variables, such as the Amihud illiquidity measure (Amihud 2002), daily volume, price and volatility are derived from CRSP, and VIX volatility index is sourced from CBOE.

We use two sample periods for this study: the immediate-post-event sample period and matched-month-post-event sample period. For the sharpest test of the impact of zero commissions, we use the immediate-post-event sample period from June 2019 to February 2020 surrounds the adoption of zero commission by major retail brokers, such as Ally Invest, Charles Schwab, E*Trade, Fidelity, Raymond James, and TD Ameritrade between October 3, 2019, and October 21, 2019. For robustness test, we use matched-month-post-event sample period which treats June to September 2019 as pre-sample period and June to September 2020 as post-sample period to control for the month and quarter seasonality effects emanating from periodicity in earnings announcements and other corporate events. The results from the matched-month-post-event sample period are available in Appendix B. Separately, we also analyze the impact of zero commissions by constructing a continuous time series variable tracking the proportion zero commission brokers in the retail trading services industry.

Our sample includes all stocks with average of daily closing price above $2.00 during regular trading hours (9:30am-4:00pm). From Robintrack data (https://robintrack.net) we create a list of the top 100 most popular stocks among retail investors by counting the average number of Robinhood users that hold a particular stock on a given day.

We identified the wholesale market makers and exchanges to which retail brokers route orders using the SEC Rule 606 reports that retail brokers make publicly available. Table 1.1 Panel A lists the wholesale market makers and their payments for receiving orders. Table 1.1 Panel B lists the retail brokers that charge and do not charge commissions. The payments paid by wholesale market makers are collected from the publicly available

SEC Rule 606 reports, and the commissions are from each broker's public website. We follow Boehmer et al. (2021) to identify transactions as retail buys if the transaction price is just below the round penny and sells if the transaction is just above the round penny. This approach separates retail investors' marketable orders from those of institutions because institutional trades generally do not receive this type of sub-penny price improvement.

1.4 Empirical Results

1.4.1 New Client Acquisition by Zero Brokerage Commission Brokerages

First, we use retail brokers' 10Q reports from Q4-2018 to Q1-2021 to examine the change in market share of retail investors' assets. In each quarter, we calculate the net percent change in the broker's client assets. The results are presented in Figure 1.1. Figure 1.1(a) presents the net change in client assets in each quarter for retail brokers. The blue solid line represents the net change in client assets for retail brokers that announced zero commissions, and the red dashed line is for retail brokers that charge non-zero commissions. The grey vertical line is the October 2019 event time when the major retail brokers announced zero commissions. The retail brokers that announced zero commissions in October 2019 used in our analysis are Ally Invest, Charles Schwab, E*Trade, Fidelity, Raymond James, and TD Ameritrade. The retail brokers with non-zero commissions as of April 1, 2020 for whom we could locate order routing information are BB&T Securities LLC, Citi Group, Edward Jones, LPL Financial, Morgan Stanley, Muriel Siebert, Stifel, and Zacks Trade. As the trends are similar before the zero-commission event, we infer that the two categories of brokers are similar. Brokers that reduced commissions to zero and those that continued to charge commissions, both lost clients, were nearly flat, and then gained client assets, respectively, in the three quarters leading up to the announcement. Thus, the choice of zero commission is an exogenous shock with respect to market share of client assets. The non-zero commission brokers can be used as a good control group. After the fourth quarter of 2019, when the major retail brokers introduced zero-commission trades, the net change in client assets changed dramatically in the following quarter. Despite the increase in retail stock trading activity,[19] retail brokers who continued to charge non-zero commissions reported a 9% loss in client assets. In contrast, zero commission brokers saw the net new investor asset acquisitions grow by 7%, for a net difference between brokers charging zero and non-zero commissions of 16%. The large difference in the net change in client assets suggests that commissions are an important factor for retail investors when choosing a broker. Media also reported an immediate surge in retail customer accounts at zero commission brokers.[20] Additionally, zero-commission brokers may have attracted first-time retail investors in the first quarter of 2020 during the COVID-19 quarantine, and existing retail investors may have moved assets from brokers that charge a non-zero commission to those that charge no commission. Additionally, we exploit the variation in commission reduction across brokers in our sample. Figure 1.1(b) compares the percentage reduction in commissions with the percentage change in their client assets after the zero-commission event. The bars represent the absolute reduction in the commission per trade by each broker and the line represents the average client assets growth rate by broker after zero commission event. Figure 1.1(b) suggests a positive

[19] Bloomberg reports an increase in retail trader volume: https://www.bloomberg.com/news/articles/2020-02-21/free-stock-trades-are-stirring-an-epic-mom-and-pop-buying-frenzy.

[20] https://www.barrons.com/articles/tda-raymond-james-and-zero-commissions-51571852744.

relation between the magnitudes of commission reduction and increases in client assets.

To confirm that commission-free trading is an important factor in driving the growth of client assets of zero commission brokers, we next examine search interest for "free stock trading" in Google Trends. Figure 1.2 shows the weekly nationwide search popularity of keywords "Free Stock Trading" from 06/2019 - 06/2020 in Google Trends. At the beginning of October 2019, when several major retail brokers announced the implementation of zero commissions, the search volume of keywords "Free Stock Trading" increased. Furthermore, the popularity of "Free Stock Trading" reaches its peak at the end of March 2020, when the nationwide lockdown policies started, and search volume increased again in the mid-April 2020, when stimulus checks from the IRS are deposited. The changes in "Free Stock Trading" searches suggest that brokerage commissions are an important factor for retail investors in searching and choosing online brokers. Overall, Figure 1.2 along with findings in Figure 1.1 are consistent with Hypothesis 1. We show that investors are attracted by “free” trading and retail brokers who adopt zero commission policy gain client market share, suggesting the zero-price effects dominate the investor’s decision-making procedure when choosing a broker.

Next, we examine changes in retail orders from trade sizes. Table 1.2 reports the difference-in-difference results for the average change in the number of shares executed by order size bucket and order type from SEC Rule 605 reports, which allows us to examine changes in order sizes routed to wholesale market maker. As predicted, the number of shares executed increased across all size buckets for wholesale market makers after zero-commissions are implemented. Moreover, the percentage difference between the smallest order size bucket (100-1,999) and largest order size bucket (2,000-5000+) is positive and statistically significant. This increase is consistent with the hypothesis that retail investors may have submitted more orders of smaller size after the zero-commission event. Consequently, the wholesale market makers may receive more shares of covered orders in the 100-1,999 share small size bucket relative to larger share size buckets.

While our difference-in-difference test in Table 1.2 supports our hypothesis that number of smaller orders executed increases after zero commissions are adopted, we now focus on a multivariate analysis to control for other explanatory variables. Table 1.3 presents results from the following OLS regression:

$$VolumeShare_{i,t} = \alpha + \beta_1 ZCEvent\ Dummy + \beta_2 RetailPop_i + \beta_3 ZeroCommission \times RetailPop_i + \beta_4 Volatility_{i,t} + \beta_5 VIX_t + \beta_6 \log(MktCap)_{i,t} + \beta_7 InvPrice_{i,t} + \beta_7 Effective\ Spread_{i,t} + \epsilon_{i,t} \quad (1.1)$$

To address the potential endogeneity concern, we also test the following regression with lagged controls:

$$VolumeShare_{i,t} = \alpha + \beta_1 ZCEvent\ Dummy + \beta_2 RetailPop_i + \beta_3 ZeroCommission \times RetailPop_i + \beta_4 Volatility_{i,t-1} + \beta_5 VIX_{t-1} + \beta_6\ log(MktCap)_{i,t-1} + \beta_7 InvPrice_{i,t-1} + \beta_8 Effective\ Spread_{i,t-1} + \epsilon_{i,t} \quad (1.2)$$

The dependent variable, $VolumeShare_{i,t}$, is the proportion of shares executed for stock *i* in month *t* in the smaller order size buckets of less than 1,999 shares divided by the total shares executed in all order size buckets, and *ZCEvent Dummy* is a dummy variable that equals one if the observation is after the zero commission event month and zero otherwise. $RetailPop_{i,t}$ is a dummy variable equal to 1 if the stock *i* is one of the top 100 stocks held by Robinhood users in month *t*. In addition, we control for market volatility, using *VIX* (Comerton-Forde, Malinova, and Park 2018). At the stock level we control for firm size using the natural log of market capitalization, *log(MktCap*), stock's return variance, *Volatility,* mean closing price, *Price*, and mean effective spread, *EffectiveSpread* (Hendershott and Moulton 2011; Malinova and Park 2015; Stoll 2000). The dataset is an unbalanced panel as it contains eight months and 6,767 stocks. Therefore, we cluster by time to minimize the number of uncorrelated observations (Petersen 2009; Thompson 2011). Each regression includes time fixed effects, which absorbs common shocks that are stock invariant.

Equation (1.1) in Table 1.3 reports coefficients under contemporaneous control variables, and equation (1.2) reports the lagged control variables. The coefficient on *ZCEvent Dummy* is positively and statistically significant at the 1% level. This result suggests that the implementation of the zero commission relatively increases volume for order size buckets containing 100 – 1,999 shares relatively more than other larger order size buckets. Moreover, the interaction of the ZCEvent Dummy and retail popular stock dummy is positive and statistically significant, which suggests that the proportion of smaller orders may increase more for stocks that are popular among retail investors. The coefficient on the retail popular stock dummy is negative, suggesting that retail popular stocks are also popular among institutional traders and in general have relatively more executed orders in size buckets greater than 1,999 shares. Overall, we find that retail investors may submit smaller size orders, as more shares are executed in the smaller order size buckets when commissions fall to zero.

In addition, we examine the odd-lot volume executed off-exchange from DTAQ data to test whether our results in Table 1.3 are robust. DTAQ dataset provides more frequent intra-day data at security level, and it contains the trading size and price for each transaction. In today's market, nearly half of all trades are in odd lots size.[21] The intuition is that, before commissions drop to zero, retail traders may sub-optimally combine orders into a single large order when they pay a fixed commission per trade. As commissions fall to zero, retail traders may place many more odd-lot sized orders to execute their optimal trading strategy. The findings are presented in Table 1.4. Panel A shows overall changes in volume by trade size bucket as reported by all off-exchange venues. Panel B shows changes in retail trading volume by size bucket in off-exchange venues where we identified marketable retail orders that received price improvement based on method proposed by Boehmer et al. (2021). As we hypothesized, odd lot trade size executions increased relative to larger trade sizes by more than 60% for all off-exchange venues (in Panel A) and marketable retail order executions that received price improvement (in Panel B) after commissions dropped to zero. The percentage difference between the smaller (1-1,999 shares) and larger (2,000-5000+ shares) trade size buckets (2,000-5000+ shares) is positive and statistically significant in both Panel A and Panel B. Overall results from DTAQ data are consistent with our hypothesis that retail investors placed more smaller size orders after commissions drop to zero.

To further understand the economic significance of the change in the odd lot and small trade sizes, we divide the trading volume in each trade-size bucket by the total trading volume in all size buckets to first compute the market share of each trade size bucket in Panel C. Additionally, we display Panel C results in Figure 1.3. Comparing the changes across size buckets our analysis reveals small trade sizes capture a bigger share of total trading after the adoption of zero commissions. For example, the percentage of volume in

[21] The Wall Street Journal reports that odd lot trades increased: https://www.wsj.com/articles/tiny-odd lot-trades-reach-record-share-of-u-s-stock-market-11571745600.

trade sizes below 499 shares executed off-exchange by all venues increased by 3.52%, including odd lots (1.47% + 2.05%). Moreover, if we only count the marketable retail volume executed by wholesale market makers identified by Boehmer et al. (2021) method, the proportion of trading size below 499 shares increased even more by 4.83%. In summary, these results are consistent with our first hypothesis that zero commissions are associated with a significantly higher market share of client assets and a larger fraction of odd lot and small trade size volume relative to larger trade size buckets. This suggests retail investors may prefer to pay indirect costs, such as reduced price improvement, instead of direct costs (i.e., commissions) for brokerage services.

1.4.2 Association between Zero-Commissions and Order Routing Decisions

To test the impact of zero commissions on retail broker routing decisions, we use SEC Rule 606 quarterly reports. Table 1.5 presents difference-in-difference results for the average change in the percent of orders routed to wholesale market makers or exchanges weighted by the number of retail brokers for order type before versus after the adoption of zero commission by major brokers in October 2019. We first present the average difference in the percent of orders routed for execution weighted by the number of retail brokers before versus after the zero-commission event in the fall of 2019 for the zero commission brokers using each broker's SEC Rule 606 Q3 and Q4 2019 reports. Then we present the average difference for the control group of brokers that still charge non-zero commissions. For example, the percent of market orders routed to wholesale markets increased by 0.36% and decreased by -0.74% on average by brokers that eliminated and continued to charge commissions, respectively. The second to last column has the difference-in-difference of the average percent of orders routed for execution between those brokers that eliminated commissions and those that did not. In particular, the difference-in-difference is 1.10% for market orders on average and statistically significant. Thus, we conclude that retail brokers that eliminated commissions increasingly routed market orders to wholesale markets makers relative to those brokers that charged commissions. These results also hold for non-directed orders in general and limit and other orders in particular. This is displayed in Figure 1.4(a). Conversely, for the exchanges, the difference-in-difference is negative and statistically significant for non-directed orders in general and market and limit orders in particular which implies that zero commission brokers routed a smaller percent of orders on average to exchanges relative to brokers that charged commissions. This is displayed in Figure 1.4(b).

Table 1.6 presents regressions of the change in the percent of orders (by type) routed to either a wholesale market maker or exchange on a zero-commission broker dummy (ZCBroker Dummy), controlling for broker and listing exchange fixed effects[22]. The ZCBroker Dummy equals one for retail brokers who announced zero-commissions in October 2019 and equals zero for retail brokers charging positive commissions as of April 1, 2020. We calculate the change in the percent of orders routed by brokers from Q3 2019 to Q4 2019 for wholesale market makers and exchanges from the SEC Rule 606 reports provided by retail brokers.[23] Panel A and B show the change in the percent of orders (by type) routed to either a wholesale market maker or exchange, respectively. The coefficient on ZCBroker Dummy in Panel A is positive and statistically significant at the 5% level for

[22] Brokers differ in terms of their size, reputation (as evidenced by customer disputes and disciplinary events), sophistication of mobile tech apps, and physical branch locations.

[23] SEC Rule 606 reports contain aggregated order level statistics across stocks.

non-directed and market orders and in Panel B is negative and statistically significant at the 1% level for limit orders and at the 5% level for non-directed orders. These results suggest those retail brokers that adopted zero commissions increasingly routed more orders to wholesale market makers relative to retail brokers that charge commissions. In summary, the results in Table 1.6 support hypothesis 2 that the adoption of zero commissions affected retail brokers' order routing decisions as orders were increasingly routed to wholesale market makers, allowing brokers to earn more payment for order flow.

Next, we test whether the changes in the broker's routing choices associated with zero commissions affect the distribution of trading volume market share between wholesaler market makers and exchanges. We showed previously that zero commissions are associated with increased retail trading. If zero commission brokers route more order flow to wholesale market makers, the market share of total volume should increase for off-exchanges wholesaler market makers relative to exchanges. To illustrate our findings, we use FINRA transparency and CBOE data to examine the market share of volume by venue sorted by maker-taker or inverse pricing system before versus after zero brokerage commissions are implemented.[24] The result is presented in Figure 1.5 Panel A. It clearly illustrates that the market share of volume significantly increases after the adoption of zero commissions for off-exchange wholesalers which use the PFOF pricing system and decreases for exchange venues irrespective of whether they use maker-taker, taker-maker and flat fee pricing system. Figure 1.5 Panel B shows the statistics for exchange groups, and Panel C shows the results in terms of changes; the market share of volume for all types of exchanges dropped while the wholesale market makers' market share generally

[24] Figure 1.5 shows the market shares for the top five wholesale market makers for the sake of simplicity.

increased. The economic significance of these changes is so large that Citadel and Virtu's combined volume in December 2020 accounts for more market volume than NYSE Group.[25] In summary, Figure 1.5 supports hypothesis 2, which suggests that after zero commissions became common, retail brokers routed orders more intensely to wholesale market makers. Consequently, wholesale market makers' volume increases relative to that of exchanges.

We formally test the second hypothesis that volume increases off-exchange and decreases at exchanges using multivariate OLS regression analysis in Table 1.7.[26] We define our dependent variable off-exchange trading volume shares as executions coded as "D" (off-exchange) in the DTAQ trade file divided by DTAQ total trading volume in Columns (1) and (2).[27] The key explanatory variable is the proportion of zero commission brokers in Panel A and the indicator variable which takes the value 1 when majority of brokers become zero commission brokers in Panel B. Although most zero commission policies were announced and adopted in October 2019, some brokers switched to zero commissions in a later period, and others launched themselves as zero commission brokers from their founding date. The proportion of zero commission brokers (*ZCBroker Proportion*) is a continuous variable, which allows us to include more retail brokers, such as Robinhood and Webull, and fully capture the effect of zero commissions on volume share, even when some brokers continue to offer non-zero commissions. The positive

---

[25] https://qz.com/1969196/citadel-securities-gets-almost-as-much-trading-volume-as-nasdaq/.

[26] The univariate test for a change in the market share of volume by venue type is presented in the Appendix B, Table B.2.2.

[27] Total off-exchange volume share includes executions by Alternative Trading Systems (ATSs), wholesale market makers that internalize retail orders, and over-the-counter (OTC) non-ATS trades.

coefficient for the *ZCBroker Proportion* variable is consistent with our hypothesis and suggests that off-exchange venues increase their share of volume when brokerage firms eliminate commissions. The result in column (1) indicates that a one percentage point increase in the proportion of zero commission brokers is associated with a 0.04 percentage points increase in the share of trading volume executed at off-exchange venues relative to total DTAQ volume. To assess the economic significance of this change we note that 35% of brokers in our sample switched to zero commission policy in October 2019, which implies an increase of an average of 11,410 shares traded per stock and day for off-exchange volumes, or approximately an increase in 70 million shares across all stocks in off-exchange volume per day[28]. All control variables are described in Appendix A. We use the lag(spread) to control for the ex-ante illiquidity and the Amihud illiquidity measure to capture the ex-post price impact at the daily level given total volume. T-statistics are reported in parentheses and are based on standard errors clustered at the date and stock level. In column 2, we re-estimate the regressions with an alternative definition of the liquidity control variable. Here again, we confirm that an increase in ZCB proportion increases off-exchange volume. Control variables have expected signs implying that stocks with higher volume, smaller market capitalization, and lower prices have more off-exchange trading.

Columns (3) and (4) in Table 1.7 Panel A show results for regressions where the alternative dependent variable is the percentage of the volume that is a subset of marketable retail volume executed by wholesale market makers out of total off- and on-exchange

[28] The numbers are calculated as 0.04 increase in off-exchange volume % for every one percent change in ZCB * 35 percent change in ZCB in 2019 * 803157 DTAQ daily average volume per stock (≈11,410) and 0.04*35*5578598644 volume for all stocks (≈7million).

volume. For this calculation, Boehmer et al. (2021) identify transactions as retail buys if the transaction price is just below the round penny and sells if the transaction is just above the round penny and are reported to the FINRA TRF.[29] In Panel B, we focus on the zero-commission event dummy variable (*ZCEvent Dummy)* to sharpen the test of our main findings of the effect of zero commission on the volume share and market quality. The value of *ZCEvent Dummy* takes the value of one if the date is between 9/2019-2/2020, which is the four-month period after the adoption of zero commissions by major brokers, and takes the value of zero if the date is between 6/2019-9/2019, which is the four-month period before the adoption of zero commissions. Overall, the estimated coefficients on ZCEvent Dummy are all positive and statistically significant. The economic significance of the estimates is also sizable. For instance, the results in full specification (column 1) of Table 1.7 Panel B suggest that after zero commission event, the share of volume for off-exchange venues increased by 1.685% which equals an increase of an average of 13,533 shares per stock and day for off-exchange volumes, or approximately an increase in 94 million shares across all stocks in off-exchange volume per day. Furthermore, the volume share of marketable retail orders executed by wholesale market makers that receive price improvement increased 0.435% (column 3) and is statistically significant at the 1% level.

In summary, both results in Table 1.7 Panel A and Panel B are consistent with our second hypothesis that zero commissions significantly increase the market share of off-exchange wholesale market makers. The use of alternative ZCB variable definitions, as

[29] Price improvement from wholesale market makers is not required but is commonly provided to marketable limit and market orders. Our regressions using Boehmer et al. (2021) method to identify retail orders only include that subset of retail marketable orders that execute just above the NBB and below the NBO and no marketable orders that execute at the midpoint, NBBO, or outside the NBBO or any non-marketable limit orders. Therefore, the regressions using Boehmer et al. (2021)method have a smaller coefficient than those where the dependent variable is the total off-exchange volume share.

well as the two testing periods in Table 1.7, helps us demonstrate that the results are not dependent on the pandemic alone because this variable is changing well before and well after the start of the pandemic, and routing decisions are more likely to be affected by off-exchange PFOF versus exchange fees differently whereas the pandemic should generally affect trading volume on all venues similarly.

1.4.3 Association Between the Zero Brokerage Commission and Market Quality

We examine changes in various dimensions of market quality such as price improvement per share, effective spread, realized spread, price impact, and (microstructure) noise. Zero-commissions lower the direct costs of trading, but do they increase the indirect costs by adversely affecting market quality?

One concern regarding the zero- commissions is that retail investors may receive less price improvement per-share when executing marketable orders if retail brokers prefer to earn more payment for order flow. Vlad Tenev, the CEO of Robinhood, confirms that the payment for order flow is an essential revenue source that enables commission-free trading (US House, Committee on House Financial Services, 2021). In fact, the tradeoff between payment for order flow and price improvement for customers has been widely recognized among brokerage firms. In Gensler's (2021) recent testimony before the House Committee on Financial Services, he states that in the SEC's recent enforcement action against Robinhood, the Commission found that :

"… certain principal trading firms seeking to attract Robinhood's order flow told [Robinhood] that there was a tradeoff between payment for order flow and price improvement for customers. Robinhood explicitly offered to accept less price improvement for its customers in exchange for receiving higher payment for order flow for itself. As a

result, many Robinhood customers shouldered the costs of inferior executions; these costs might have exceeded any savings they might have thought they had gotten from a zero commission…"

As commissions decrease, retail brokers may increasingly seek to earn revenue from payment for order flow. Because wholesale market makers probably view both payment for order flow and price improvement as expenses, they may be indifferent to any split between these expenses and their gross profit per trade. Consequently, retail brokers choose whether they earn more payment for order flow or provide more price improvement per-share to their retail clients.[30] For example, a broker that eliminated commissions in October 2019, which offered $7.97 in average net price improvement per order reduced this amount to $6.02 in July 2020, for S&P 500 stocks with 1-9,999 share orders.[31] Therefore, we hypothesize that the amount of price improvement retail investors receive per-share may decrease when commissions are reduced or eliminated. We analyze the magnitude of price improvement per hundred shares using the DTAQ, as this dataset includes odd lots.[32] The results are presented in Table 1.8.

Using the method that Boehmer et al. (2021) proposed, we identified the subset of retail marketable orders that received price improvement and calculated the volume-weighted amount of price improvement per hundred shares by stock for the pre- and post-

---

[30] See item 14 of Securities Act Release No. 10906, "In the Matter of Robinhood Financial, LLC" (Dec. 17, 2020), available at https://www.sec.gov/litigation/admin/2020/33-10906.pdf.

[31] The E*Trade execution quality report for July 2019 and July 2020 are available at https://web.archive.org/web/20190902070137/https://us.etrade.com/trade/execution-quality and https://web.archive.org/web/20200809032323/https://us.etrade.com/trade/execution-quality

[32] Our measurement unit is "cents per hundred shares".

zero commission period[33]. Panel A Table 1.8 reports the price improvement per hundred shares for all stocks in DTAQ that have a closing price greater than $2. In addition, we examine the top 100 stocks that are held by Robinhood users as identified by Robintrack. The results for these top 100 retail popular stocks are in Panel B. For each panel, we first compare the price improvement per hundred shares for the four months before (06/2019-09/2019), and after (11/2019-02/2020) zero commissions are implemented to minimize the confounding events, such as the COVID shock, and then compare the four months before (06/2019-09/2019) and the corresponding four months in 2020 (06/2020-09/2020) after zero commissions are implemented to control for month and quarter effects.

The results in Table 1.8 Panel A suggest that the price improvement for all stocks is not immediately affected by the change in commissions, as the change is statistically insignificant. However, when comparing the price improvement from 6.2019-9.2019 versus 6.2019–9. 2020, the price improvement decreased significantly by -$0.0122 from $0.1716 to $0.1594 per hundred shares, which is a -7.11% decline. For the period from 6.2019-9.2019 versus 11.2020 – 2.2020, Panel B shows that for popular retail stocks, the reduction in the price improvement (-8.62%) is statistically significant after the implementation of zero commissions by major retail brokers. What's more, if we compare the price improvement amount for retail stocks from 6.2019-9.2019 versus 6.2019–9. 2020, price improvement decreases by 11.87%. In sum, the overall results in Table 1.8 suggest that retail brokerages may offer less price improvement per-share to retail marketable orders to compensate for the loss in revenue from eliminating commissions.

[33] As discussed in Boehmer et al. (2020), off-exchange midpoint trades are generally institutional orders; hence, we exclude them from the price improvement calculation.

Using multivariate regression analysis, we examine the effect of zero commissions on price improvement with controlling for other important factors. To better capture retail trading activity, we use the top 100 stocks that are held and heavily traded by Robinhood retail investors as identified by Robintrack; price improvement for these stocks is expected to be affected more sharply by zero commissions. Specifically, we estimate the impact of zero commissions on price improvement in the following regression:

$$PI_{i,t} = \beta_0 + \beta_1 ZCBroker\ Proportion_t + \beta_2 + \beta_2 Log(Volume_{i,t}) + \beta_3 Log(MktCap_{i,t}) + \beta_3 InvPrice_{i,t} + \beta_4 IntraVol_{i,t} + \beta_5 QS_{i,t} + \varepsilon_{i,t} \quad (1.3)$$

$$PI_{i,t} = \beta_0 + \beta_1 ZCEvent\ Dummy_t + \beta_2 + \beta_2 Log(Volume_{i,t}) + \beta_3 Log(MktCap_{i,t}) + \beta_3 InvPrice_{i,t} + \beta_4 IntraVol_{i,t} + \beta_5 QS_{i,t} + \varepsilon_{i,t} \quad (1.4)$$

Where $PI_{i,t}$ is either the volume weighted price improvement (cents) per hundred shares or the volume-weighted percent price improvement per share, aggregated at the daily frequency. Our main variable is the *ZCBroker Proportion* (eq.1.3), which is the proportion of the number of retail brokers that offer zero commission trades, or *ZCEvent Dummy* variable (eq.1.4), which takes the value of zero if the date is before the adoption of zero commissions and one if the date after the adoption of zero commissions by major brokers. The regressions also use firm-level variables.[34] All regressions include industry fixed effects, and standard errors are double clustered at firm and date levels.

Table 1.9 reports the findings from estimating equation (1.3). Table 1.9 further supports the findings in Table 1.8: the coefficient for *ZCBroker Proportion* and *ZCEvent Dummy* are each negative and statistically significant for price improvement measured as

[34] See Petersen and Fialkowski (1994);Stoll (2000); Bacidore, Battalio, and Jennings (2002); Chung, Chuwonganant, and McCormick (2004); Lee and Chung (2009).

absolute value or percentage, suggesting that after the adoption of zero commissions, retail clients of these brokers receive less price improvement per-share for marketable orders executed by wholesale market makers.

Finally, we analyze the effect of zero commissions on liquidity by using DTAQ and SEC Rule 605 data[35]. DTAQ permits us to examine liquidity for odd-lot trade sizes. Quoted spreads between the offer and bid prices are the "advertised" cost of a trade, and the effective spread is the "actual" cost of trading. The half-effective spread, defined as the execution price minus quote midpoint, is the cost of removing liquidity with a marketable order. The realized spread captures the profits that liquidity providers earn by posting standing limit orders (net of losses to informed traders based on changes in quoted midpoint), and price impact is the portion of the transaction cost associated with the price discovery through informed marketable orders. Appendix B provides detailed definitions of spread measures based on Stoll (2000). Intuitively, price impact is the informed trader's profit and is a proxy for adverse selection costs. We use the top 100 stocks that are held by Robinhood retail investors as identified by Robintrack to test the effect of zero commissions on market quality for trades executed both on- and off-exchange using DTAQ data in the following regressions:

$$ML_{i,t} = \beta_0 + \beta_1 ZCBroker\ Proportion\ \beta_2 ShortInterest_{i,t} + \beta_3 logVol_{i,t} + \beta_4 IntraVolatility_{i,t} + \beta_5 \log(MktCap)_{i,t} + \beta_6 InvP_{i,t} + \epsilon \quad (1.5)$$

$$ML_{i,t} = \beta_0 + \beta_1 ZCEvent\ Dummy + \beta_2 ShortInterest_{i,t} + \beta_3 logVol_{i,t} + \beta_4 IntraVolatility_{i,t} + \beta_5 \log(MktCap)_{i,t} + \beta_6 InvP_{i,t} + \epsilon \quad (1.6)$$

In addition, we test the effect of zero commissions on microstructure noise by using the following cross-sectional regressions:

[35] SEC Rule 605 data is used in robust tests. These results are presented in Appendix B, Table B.2.2

$$IntraVolatility_{i,t} = \beta_0 + \beta_1 ZCBroker\ Proportion + \beta_2 ShortInterest_{i,t} + \beta_3 logVol_{i,t} + \log(MktCap)_{i,t} + \beta_5 InvP_{i,t} + \epsilon \quad (1.7)$$

$$IntraVolatility_{i,t} = \beta_0 + \beta_1 ZCEvent\ Dummy + \beta_2 ShortInterest_{i,t} + \beta_3 logVol_{i,t} + \beta_4 \log(MktCap)_{i,t} + \beta_5 InvP_{i,t} + \epsilon \quad (1.8)$$

The dependent variable *ML* represents different measures of liquidity: average time-weighted percent quoted spread; average percent effective spread; average percent price impact computed based on 5-minute interval and 15-second intervals (O'Hara 2015); average percent realized spread computed based on 5-minute and 15-second intervals (O'Hara 2015). We use the Lee and Ready (1991) algorithm to determine the trade direction for spreads calculation. For equations (1.7) and (1.8), following Bacidore, Battalio, and Jennings (2002), we use the average percentage difference between the intraday high and low price to proxy for stock volatility:

$$IntraVolatility = \frac{P_{high;i,t} - P_{low;i,t}}{(P_{hig\ \ ;i,t} + P_{low;i,t})/2}$$

The main explanatory variables of interest are *ZCBroker Proportion* and *ZCEvent Dummy*. *ZCBroker Proportion* is the proportion of retail brokers that offer zero commissions, and *ZCEvent Dummy* takes the value of one if the date is between 9/2019-2/2020, which is the four-month period after the adoption of zero commissions by major brokers and takes the value of zero if the date is between 6/2019-9/2019, which is the four-month period before the adoption of zero commissions. The control variables are motivated by past studies of market liquidity (Stoll 2000; O'Hara and Ye 2011). *ShortInterest* captures the short sale open interest, which is calculated as the number of shares sold short divided by the total number of shares outstanding. *LogVol* is the log of the daily share volume, *IntraVolatility* is the average percentage difference between the intraday high and low price (Bacidore, Battalio, and Jennings 2002), *log(MktCap)* is the market capitalization, and *InvP* is the inverse of the stock daily closing price. We controlled for industry fixed effects, and the standard errors are double clustered at the firm and date level.

Table 1.10 reports the regression results.[36] First, the ZCBroker Proportion coefficients are negative and statistically significant for the average percent effective spread and average percent price impact based on the 5-minute and 15-second time intervals. The fact that the average percent price impact is negative and statistically significant suggests that retail marketable orders become less informed after commissions drop to zero. Second, an increase in the proportion of zero commission brokers is associated with no change in profit to liquidity providers as proxied by realized spreads. The additional fact that realized spreads do not change, but effective spreads decline suggests that wholesale market makers may serve as cost competitors (Battalio 1997). In addition, the coefficient for the ZCBroker Proportion is positive and statistically significant for stock intraday volatility. This suggests that an increase in microstructure noise is associated with a decline in commissions as retail orders are disproportionally uninformed. The overall results support hypothesis three that the zero brokerage commission changes market quality. With a higher proportion of zero commission brokers, effective spread and price impact decrease, and market noise increases while the realized spread is unaffected.

Table 1.10 Panel B reports regression results for market quality using the ZCEvent Dummy as the main explanatory variable of interest. The ZCEvent Dummy coefficients are negative and statistically significant for the average percent effective spread and average percent price impact based on the 5-minute and 15-second time intervals.

[36] We also test the four-month period (06/2019-09/2019) before zero commissions and the corresponding four-month period in 2020 (06/2020-09/2020) for ZCEvent Dummy to control for month and quarter effects. The results are qualitatively the same and presented in the Appendix B, Table B.2.3.

Meanwhile, the changes in percent quoted spread are not statistically different from zero between the four-month period before and immediately after commissions fall to zero. However, using the matched-month-post-event sample period, which allowed the use of zero-commissions to become more commonplace, we find the percent quoted spread experienced a statistically significant decrease at the 5% level (for details see Appendix B, Table B.2.3).

In summary, the results in Table 1.10 support our hypothesis that zero commissions are associated with decreases in effective spread and price impact, increases microstructure noise, and leaving realized spreads unchanged.

To further understand the impact of the zero commissions on market quality, we also test the effect of zero commissions on pricing efficiency measured by the variance of pricing error and variance ratio (results are presented in Appendix B Table B.1). In summary, we find that increased retail trading associated with zero commissions does not appear to significantly impact other measures of price efficiency, such as pricing error and variance ratio, during our sample period.

1.5 Conclusion

We track the evolution of brokerage commission by constructing a time series of the proportion of zero commission brokers. The zero commission events, especially the recent wave in 2019, provide a fertile testing ground for microstructure theories related to the trade-offs between client's direct and indirect costs, brokers' order routing practices, and the potential trade-off between price improvement and payment for order flow. We have three interrelated hypotheses addressing volume shares, order routing, and market quality. We first examine the association between zero commissions and volume shares.

We find that zero-price commissions appear to be a key driver for retail investors in choosing their broker, as we document dramatic increases (decreases) in market share of client assets for zero (positive) commission brokers using retail brokers' 10Q reports. This finding along with increased search interest for the keywords "free stock trading" for PFOF in Google Trends indicates that retail investors likely prefer to pay trading costs in a less direct and observable manner, such as potentially through lower interest paid to cash balances, to paying trading costs more directly through commissions. Consistent with our volume share hypothesis that trade size declines as commission drops to zero, we find that small trade size buckets increase relative to larger ones. Consequently, we infer that retail investors submit more small-sized orders after zero commissions. Brokerages who adopt this new policy no longer earn commissions and their potentially optimal strategy is to sell the retail order flow to wholesaler market makers who pay for order flow.

Second, using DTAQ and SEC Rule 605 and 606 reports, we test an order routing hypothesis and find that retail orders were increasingly routed to and executed by wholesale market makers with exchanges losing market share. Additional execution quality variables are part of the trade-offs. For example, we found a decrease in the amount of price improvement per share after commissions decreased to zero, especially for stocks that are popular among retail investors.

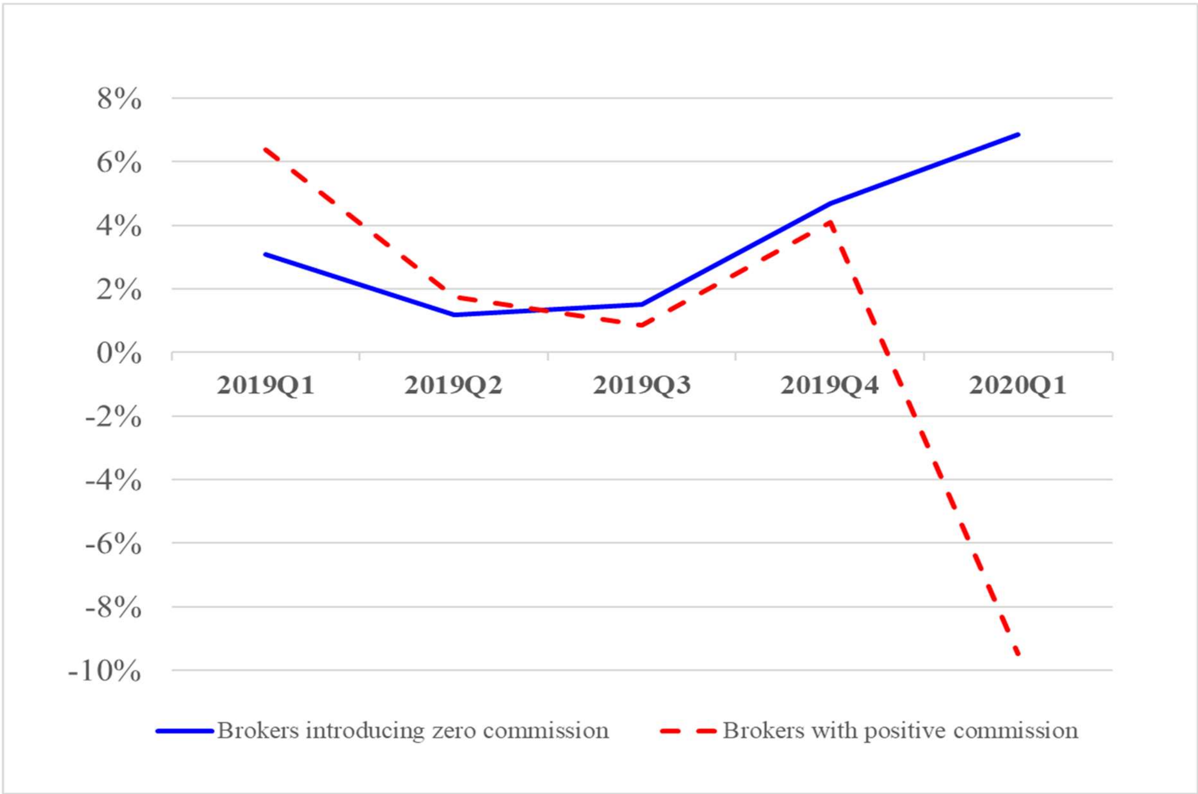
Third, we empirically find that market quality improves as effective spreads and price impact decline. We find that realized spreads are unchanged, suggesting that any new retail orders, triggered by zero commission opportunities are relatively uninformed. The decline in effective spread and price impact is inconsistent with the cream skimming hypothesis of Easley, Kiefer, and O'Hara (1996). The additional fact that effective spreads fall and realized spreads do not change suggests that wholesale market makers serve as cost competitors (Battalio 1997). In addition, we find that intraday volatility increases are associated with the drop in commissions, which also suggests retail investors are uninformed.

Our findings offer important implications for public policy. First, the elimination of the commissions incentivizes retail brokers to sell more orders to wholesale market makers, to earn more revenue from the highly controversial payment for order flow practices, to cover the loss of commission revenue. Retail investors may benefit from more publicly available information on how retail brokers are compensated when making their choice of broker. Such information may be particularly important when the costs that retail investors pay are indirect and unobservable. Second, if commissions are zero, how will brokers further increase retail trader demand? Third, if SEC decides to ban PFOF, would retail brokers again charge commissions or would wholesale market makers merge with retail brokers to internalize flow? Our findings inform the policy debate on these important issues.

Figure 1.1 Net Change in Broker's Client Assets

Figure 1(a) provides the quarterly net change in broker's client assets from Q1 2019 to Q1 2020 for both retail brokers with and without zero commissions. The blue solid line represents the brokers that introduce the zero-commissions in October 2019, and the red dashed line represents the brokers that still charge positive commissions during our sample. The grey vertical line denotes the time of the event when several retail brokers announce zero-commission trading. Figure 1(b) shows the average change in client assets after dropping to zero commissions with the magnitude of the drop. The retail brokers that announced zero-commissions for this figure are: Ally Invest, Charles Schwab, E*Trade, Raymond James, and TD Ameritrade. Retail brokers with non-zero commissions are Edward Jones, LPL, Morgan Stanley, Muriel Siebert, and Stifel. The data is collected from retail brokers' 10-Q reports.[37]

(a) Net Change in Broker's Client Assets after Adopting Zero Commission



[37] Four retail brokers in our later analysis in this chapter are not included in this figure: Fidelity and Zacks Trade are private holding firms. Therefore, their public quarterly financial statements are not available. BB&T Securities LLC merged with SunTrust in fourth quarter of 2019, and Citi Group's 10Q report does not provide the information about net new investors' asset for brokerage services.

(Figure 1.1 Continued)

(b) Change in Client Asset with Magnitude of Drop in Commission by Broker

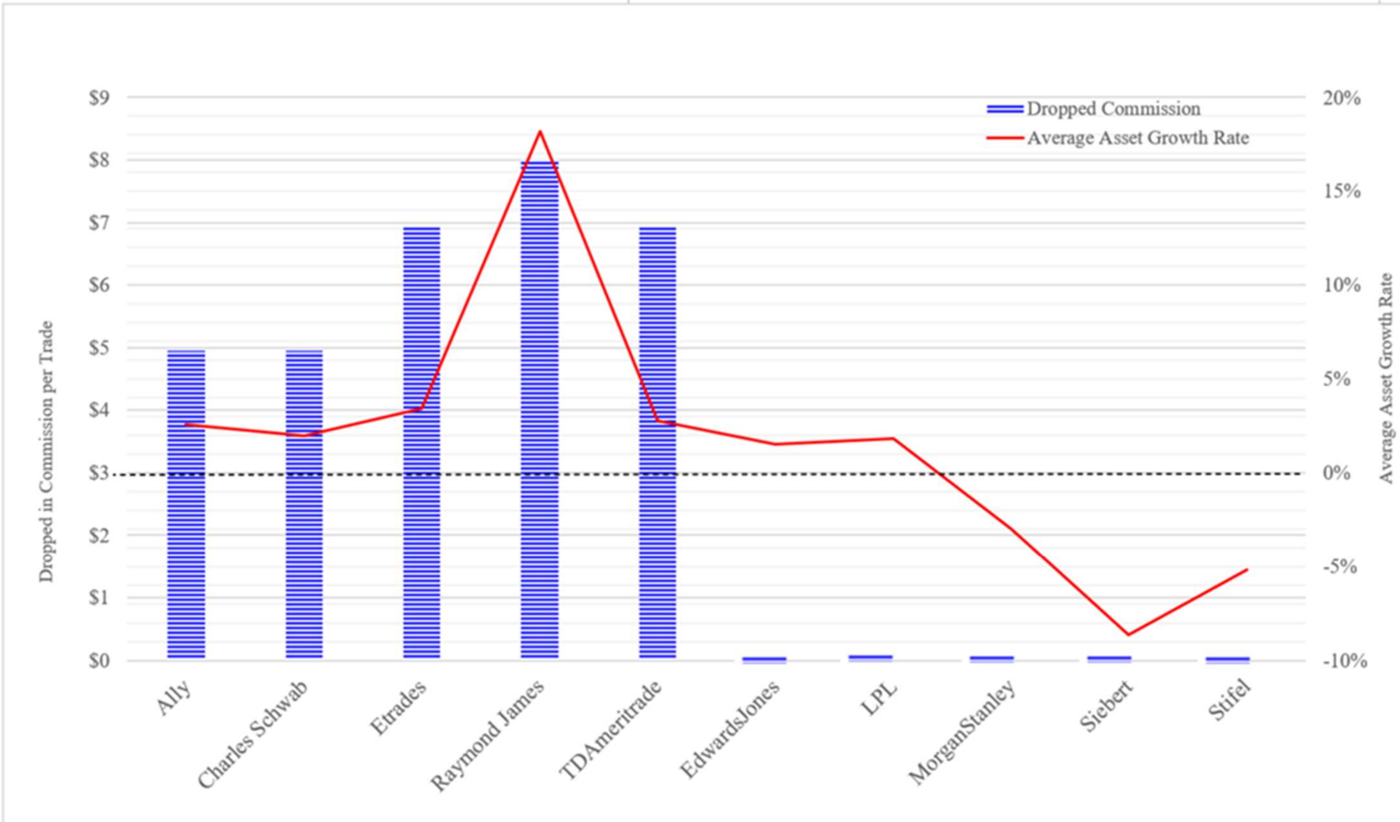


Figure 1.2. Search Interest from Google Trends Index

This figure shows the search interest of "free stock trading" and “PFOF”from 06/2019-06/2020 from Google Trends (https://trends.google.com/trends/?geo=US). Each data point in normalized Google Trends Index is divided by the total searches of the geography and time range it represents to compare relative popularity, and the numbers are on weekly basis and scaled on a range of 0 to 100 based on a topic's proportion to all searches on all topics as defined by Google Trends Index. The grey region shows the time periods that strongly influence the retail trading participation.

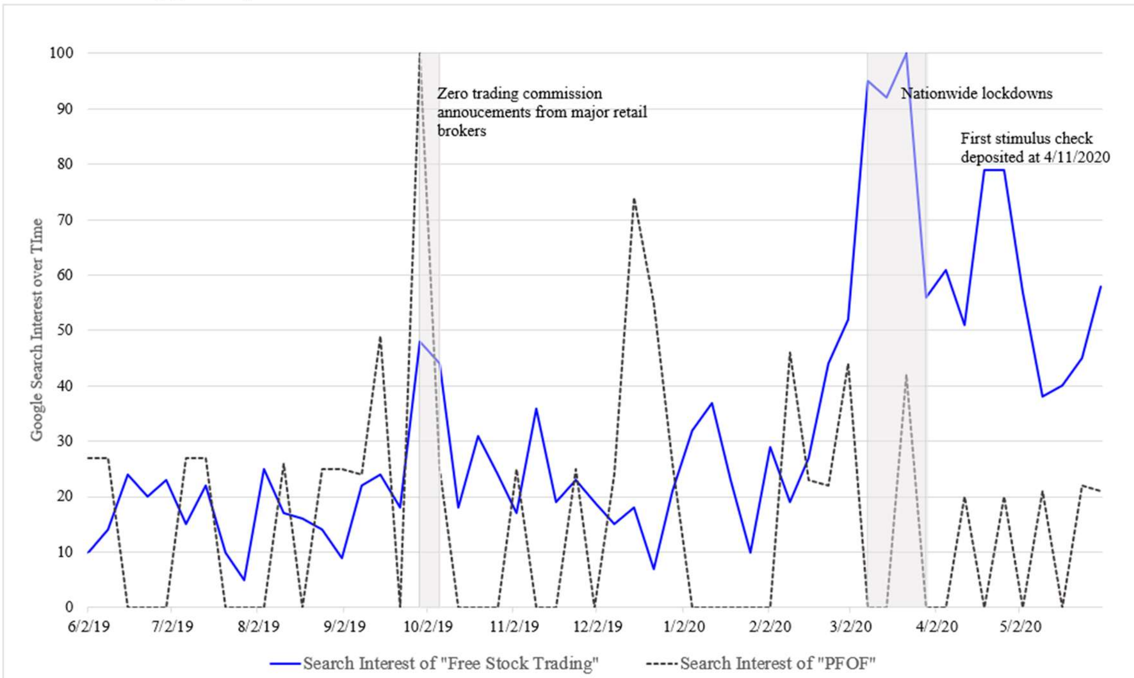


Figure 1.3 Change in Volume by Trade Size Bucket

Panel (a) provides the change in the percentage of volume for each trade size bucket for all off-exchange venues before versus after commissions drop to zero. Panel (b) provides the change in the percent of volume for each trade size bucket before versus after zero commissions drop to zero for the subset of marketable retail orders that received price improvement from wholesale market makers as identified by Boehmer et al. (2021). Our sample includes all stocks that trade above $2.00 during regular trading hours (9:30 am - 4:00 pm) from 06/2019 to 02/2020. Pre (red color with dotted fill) and Post (blue color with solid fill) denote four months before (06/2019-09/2019) and after (11/2019-02/2020) the major retail brokers eliminate commissions. All measures are estimated from DTAQ.

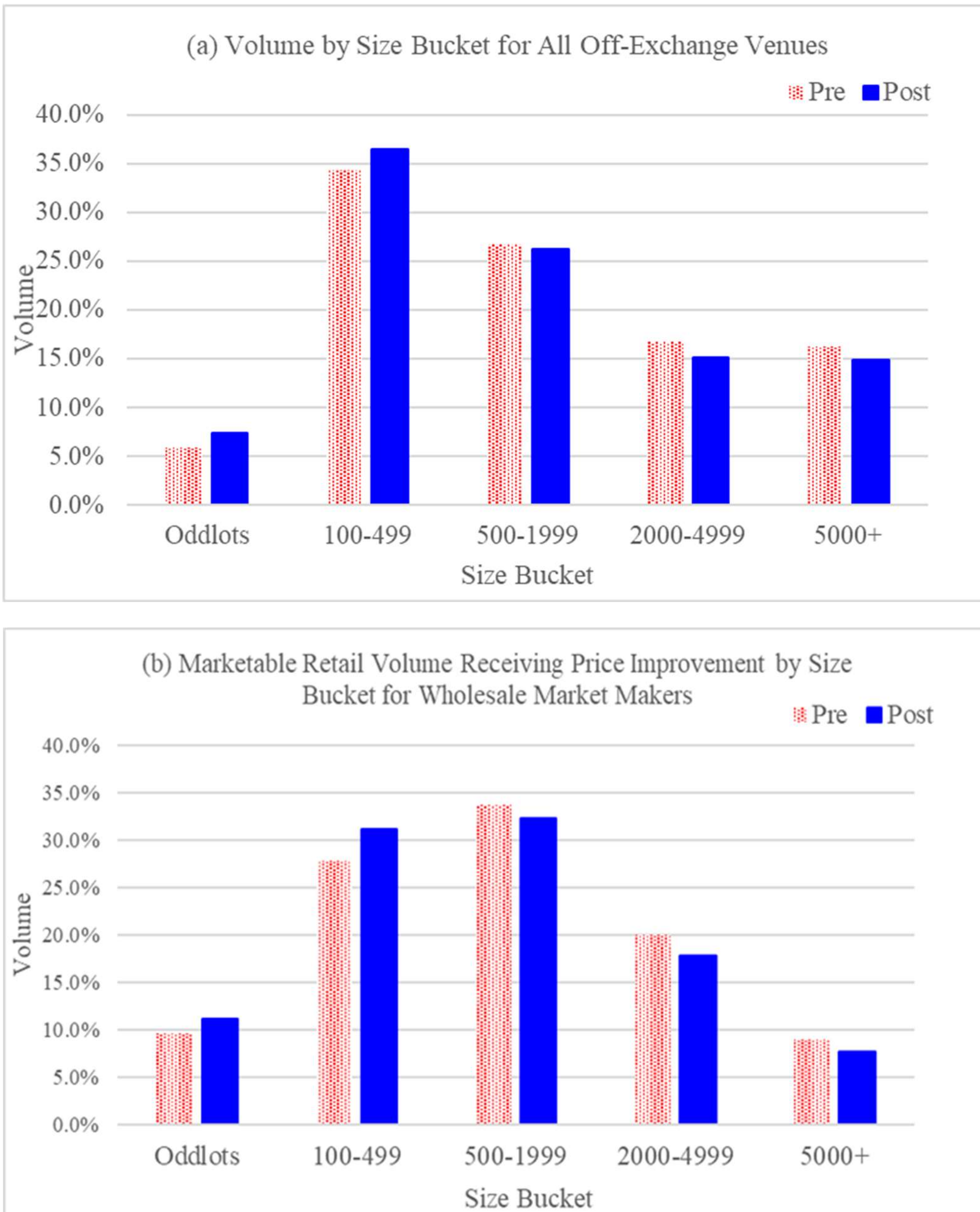


Figure 1.4 Average Change in the Percent of Orders Routed to Wholesale Market Makers and Exchanges by Retail Brokers

This figure provides the average change in the percent of orders routed for execution by retail brokers to different execution venue types weighted by the number of retail brokers for each order type between Q3 and Q4 2019, for retail brokers with and without zero commissions. Panel (a) refers to the change in average percent routed to wholesale market makers and Panel (b) refers to the average change in the percent of orders routed to exchanges between Q3 and Q4 2019 for those retail brokers that eliminated commissions in October 2019 (Blue color with solid fill) and others that still charge commissions (Red color with diagonal strips fill) as of April 1, 2020. The retail brokers that announced zero commissions in October 2019 used in our study are Ally Invest, Charles Schwab, E*Trade, Fidelity, Raymond James, and TD Ameritrade. The retail brokers with non-zero commissions as of April 1, 2020 are BB&T Securities LLC, Citi Group, Edward Jones, LPL Financial, Morgan Stanley, Muriel Siebert, Stifel, and Zacks Trade. The wholesale market makers (Citadel, G1X, Two Sigma, UBS, and Virtu) and the exchanges (Arca, EDGX, Nasdaq, and NYSE) are identified from retail brokers SEC Rule 606 reports.

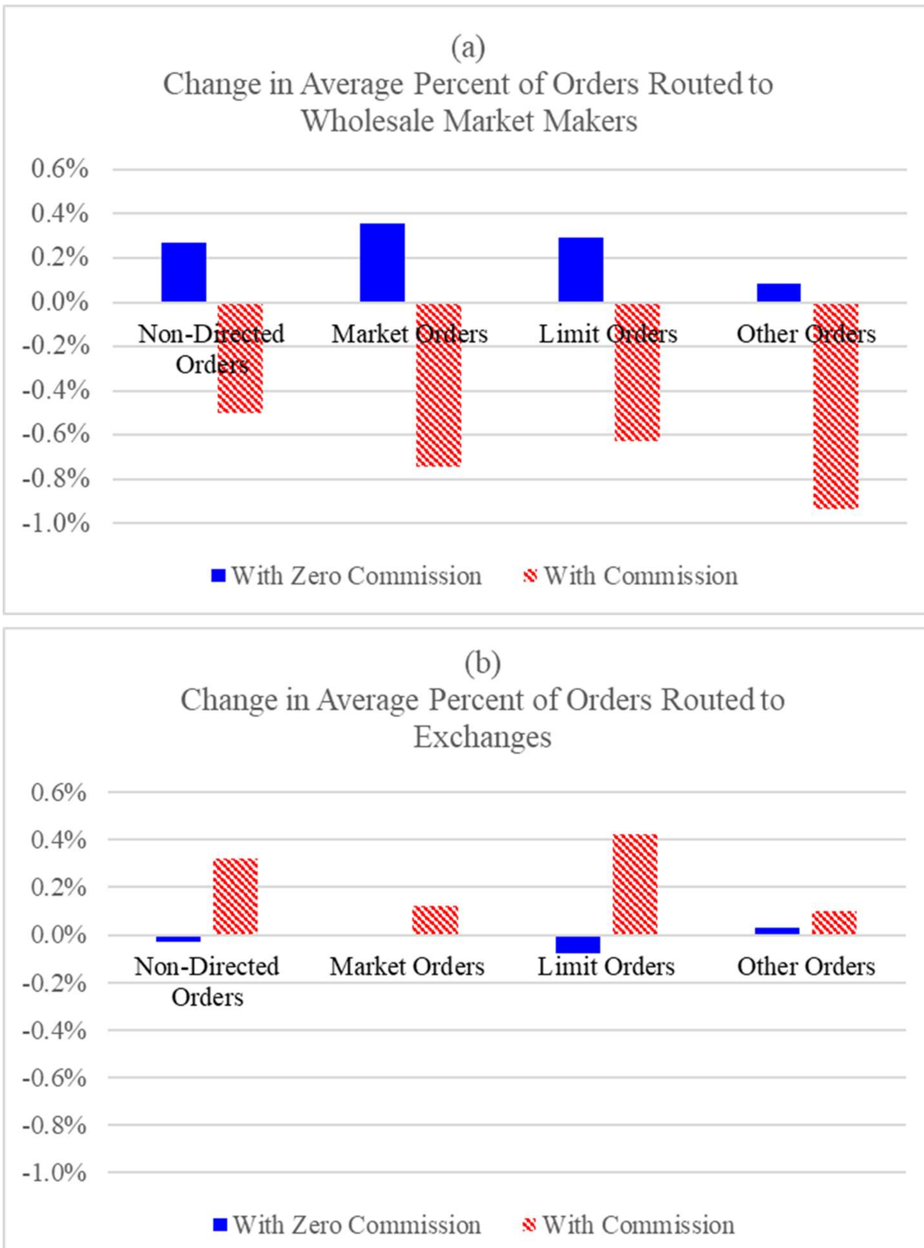
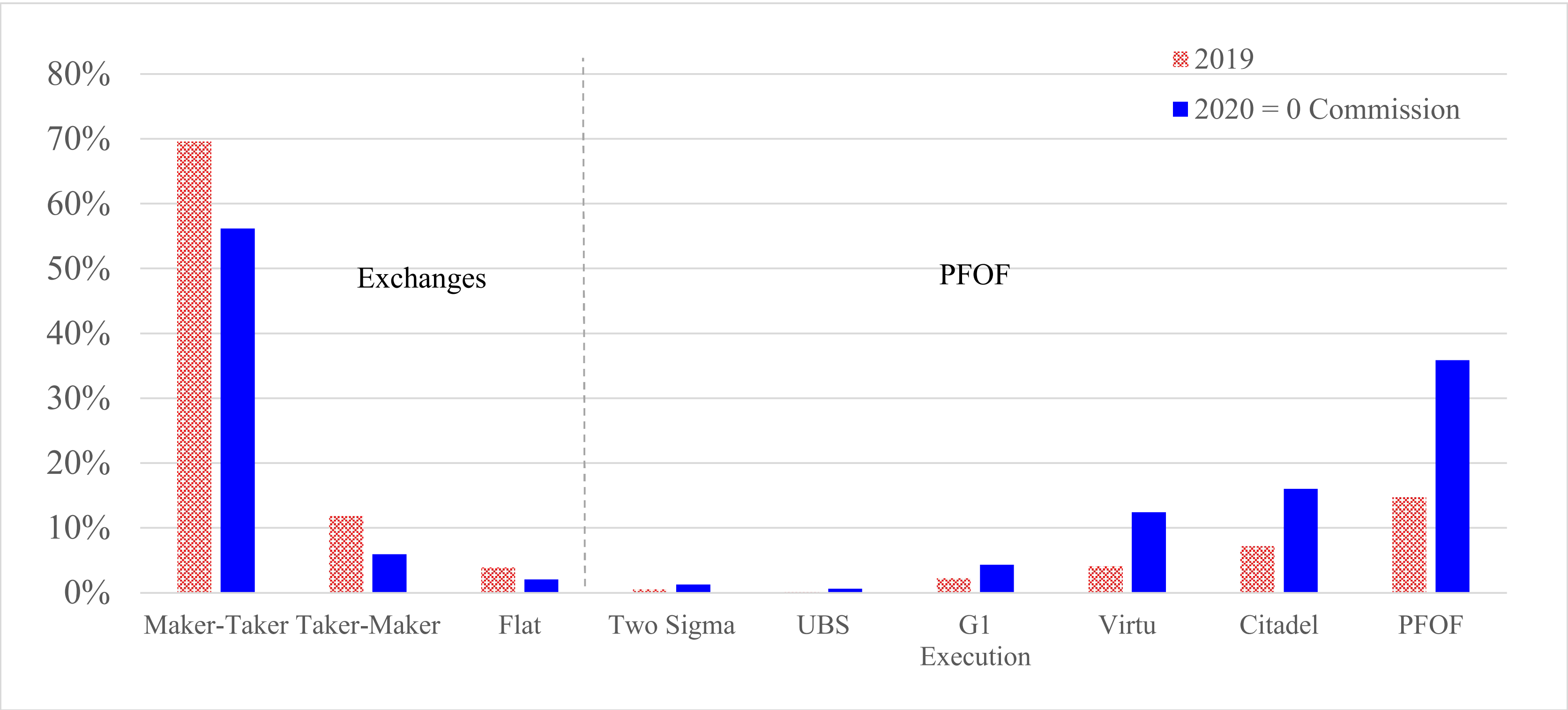


Figure 1.5 U.S. Stock Market Share of Volume by Venue Before vs. After Zero Commissions

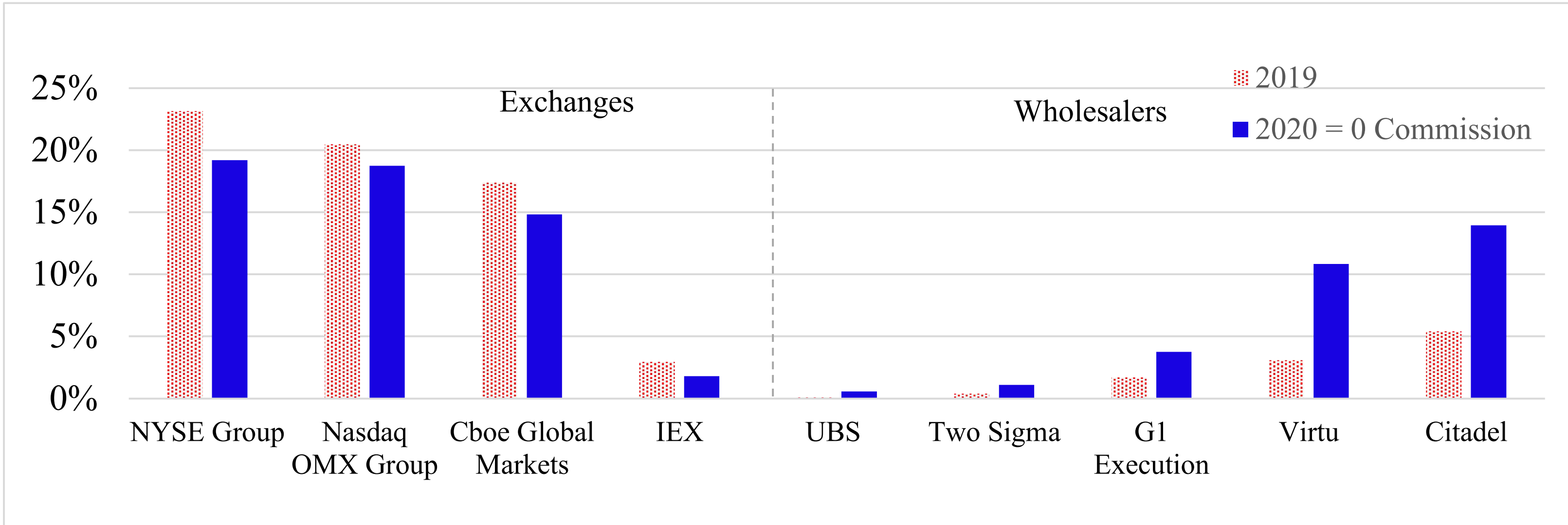
This figure shows the market share of volume by venue before (August 2019) versus after (August 2020) zero commissions were implemented. The market share of volume is calculated as the number of shares executed on a particular venue divided by the total number of shares executed on all venues. Panel A reports the market share of volume by venue pricing system in 2019 (Red color with dotted fill) vs. 2020 (Blue color with solid fill), and Panel B reports the changes in market share of volume by venue before vs. after zero brokerage commission. Maker-Taker refers to the pricing system that liquidity makers receive a rebate and liquidity takers are charged a fee. Taker-Maker refers to the pricing system that liquidity makers are charged a fee and liquidity takers receive a rebate. Flat refers to the pricing system that charges flat fee for both liquidity makers and takers. Volume for NYSE Group (NYSE (N), NYSE Arca (P), NYSE American (A), NYSE National (C) and NYSE Chicago (M)), Nasdaq OMX Group (NASDAQ (Q), NASDAQ BX (B) NASDAQ PSX (X)) and Cboe Global Markets (EDGA Equities (J), EDGX Equities (K), BYX Equities (Y) and BZX Equities (Z)) are from Cboe Global Markets. Volume for wholesale market makers is from FINRA's publicly available (Non-ATS) OTC Transparency Data (https://otctransparency.finra.org). For the sake of simplicity, we only show top five PFOF wholesalers in this figure.

Panel A. Market Share of Volume by Venue Pricing System Before vs. After Zero Commissions



(Figure 1.5 Continued)

Panel B. Market Share of Volume by Venue Before vs. After Zero Commissions



Panel C. Changes in Market Share of Volume by Venue Before vs. After Zero Brokerage Commission

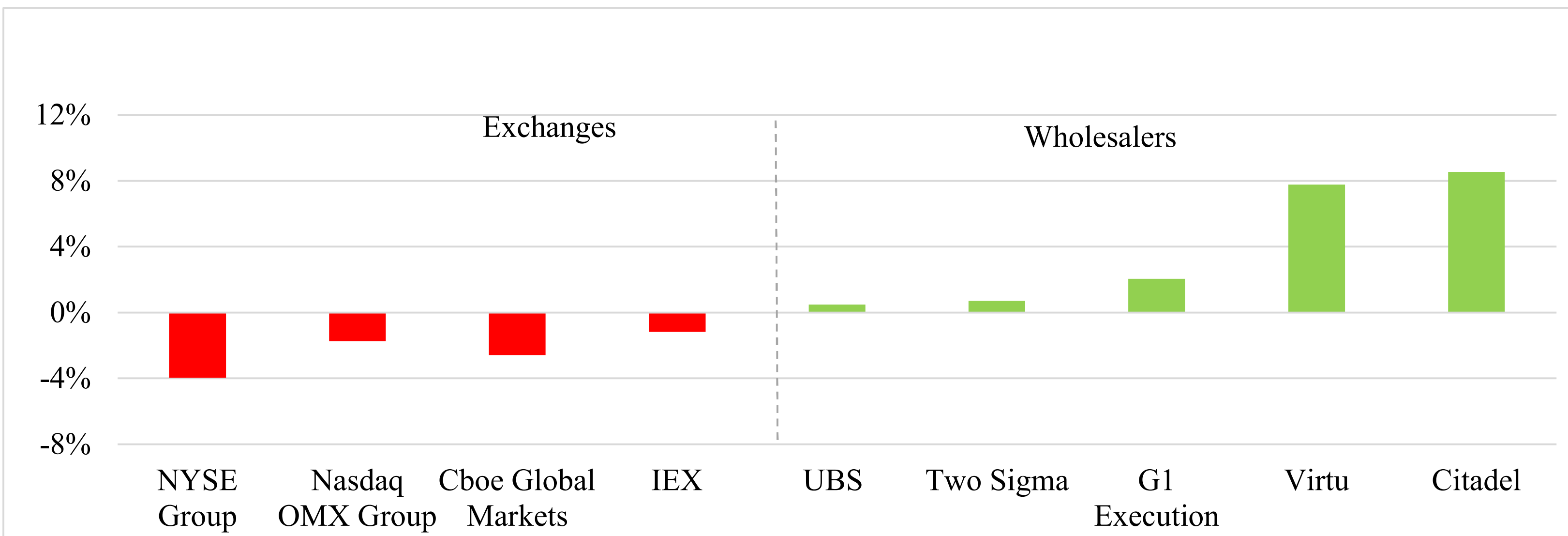


Table 1.1 List of Wholesale Market Makers and Retail Brokers

This table lists the wholesale market makers and retail brokers that are examined in this study. Panel A lists the wholesale market makers and their payments for receiving orders; Panel B lists the retail brokers that charge and do not charge commissions. The payments paid by wholesale market makers are identified from SEC Rule 606, and the commissions charged by retail brokers are from each broker's official website as of April 1, 2020.

Panel A: Wholesale market makers

Brokerage Firm	**Payment/Share**
Citadel	$ 0.0010-0.0021
Virtu	$ 0.0014-0.0024
G1X	$ 0.0015- 0.0020
Two-Sigma	$ 0.0015-0.0020
UBS	$ 0.0017-0.0026

Panel B: Retail Brokers

Brokerage Firm	**Commission**	**Zero-Commission Effective Day**
Interactive Brokers	0	10/9/2019
TD Ameritrade	0	10/3/2019
Charles Schwab	0	10/7/2019
Fidelity	0	10/10/2019
Ally Invest	0	10/9/2019
E*Trade	0	10/7/2019
Raymond James	0	10/21/2019
Zacks Trade	$ 0.01 per share	-
Morgan Stanley	2.25% for <=$199,999 cumulative principal	-
Edwards Jones	2.5% for <$5,999.99	-
Stifel	Minimum (10% Principal, $40)	-
LPL	1.5% of transaction	-
BB&T	2.5% for <$2,000	-
Muriel Siebert	$ 14.95/ trade	-
Citi Group	0.18%-0.24% per trade	-

Table 1.2 Size Analysis

This table presents the difference-in-difference (DID) results for the average change in total number of shares executed for by order size bucket and order type across wholesale market makers (Citadel, G1X, Two Sigma, UBS, Virtu). The sample includes all stocks that trade above $2.00, and the pre- and post- denote four months before and after the major retail brokers implement zero brokerage commissions. The difference (i.e., *Diff*) is calculated as Post minus Pre. Order size is categorized into three groups: 100-1999, 2000-4999, and 5000 or more shares, respectively. The data is obtained from SEC Rule 605 Reports. DID denotes the difference between the size bucket of 100-1999 and 2000-5000 or more. Standard t-tests are used to calculate the difference. Statistical significance at the 10%, 5%, and 1% levels is denoted by *, **, and ***, respectively.

	Small	**Large**		**DID**
Marketable Order	**100-1999**	**2000-4999**	**5000+**	**Small-Large**
Pre	943,761.3	567,736.7	465,358.3	
Post	1,207,569.7	603,521.1	502,308.2	
Diff (+/-)	263,808.4	35,784.4	36,949.9	262,642.9
Diff (%)	27.95%***	6.30%***	7.94%***	20.9%***
T-stat	*(12.04)*	*(2.44)*	*(2.56)*	*(7.44)*
At- or Inside-Quote Limit Order	**100-1999**	**2000-4999**	**5000+**	**Small-Large**
Pre	59,104.8	36,275.4	33,542.6	
Post	83,433.7	45,447.6	45,211.7	
Diff (+/-)	24,328.9	9,172.2	11,669.1	21,832.0
Diff (%)	41.16%***	25.28%***	34.79%***	11.3%*
T-stat	*(9.94)*	*(6.28)*	*(4.17)*	*(1.89)*
Outside-Quote Limit Order	**100-1999**	**2000-4999**	**5000+**	**Small-Large**
Pre	50,630.2	41,883.0	47,471.4	
Post	67,314.2	48,556.2	54,712.2	
Diff (+/-)	16,684.1	6,673.2	7,240.8	16,116.5
Diff (%)	32.95%***	15.93%***	15.25%***	17.38%***
T-stat	*(8.63)*	*(4.17)*	*(3.67)*	*(2.36)*

Table 1.3 Fixed-effects Regressions for Trading Size

This table reports the results from the fixed-effects OLS regression in equation (1.1) and (1.2) for our sample of stocks having a price above \$2.00 from wholesale market makers' Rule 605 reports from 06/2019-02/2020. The dependent variables are the proportion of shares executed for stock *i* in month *t*, in the smaller order size buckets of less than 1,999 shares divided by the total shares executed in all order size buckets. The main independent variable is *ZCEvent Dummy*, which is a dummy variable that equals 1 for the months after than October 2019. *RetailPop$_t$* is a dummy variable equal to 1 if the stock *i* is the top 100 stocks held by Robinhood users in month *t* as identified by Robintrack. All control variables are described in Appendix A. All regressions include the industry fixed effects, and the standard errors are double clustered at the firm and date level. Month fixed effects are included. T-Stats are reported in parentheses. Standard errors are double clustered at the stock and month level. ***, **, * indicate statistical significance at the 0.01, 0.05 and 0.10 level, respectively.

	Proportion of Executed Shares for Order Size Bucket of 100-1,999 Shares			
	(1) Contemporaneous Controls		**(2) Lagged Controls**	
ZCEvent Dummy	0.013	***	0.011	***
	(4.33)		*(4.02)*	
$RetailPop_i$	-0.102	***	-0.106	***
	(-15.48)		*(-15.71)*	
ZCEvent Dummy $\times RetailPop_i$	0.049	***	0.05	***
	(5.42)		*(5.49)*	
$Volatility_t$	-0.604	***		
	(-5.81)			
VIX_t	0.00			
	(1.54)			
$Log(MktCap)_t$	-0.007	***		
	(-13.03)			
$InvPrice_t$	-0.547	***		
	(-13.63)			
Effective $Spread_t$	0.346	***		
	(17.11)			
$Volatility_{t-1}$			-0.512	***
			(-5.00)	
VIX_{t-1}			0.00	
			(0.01)	
$Log(MktCap)_{t-1}$			-0.007	***
			(-12.21)	
$InvPrice_{t-1}$			-0.513	***
			(-12.49)	
Effective $Spread_{t-1}$			0.345	*
			(10.38)	
Intercept	0.745	***	0.742	***
	(125.74)		*(68.41)*	
Time Fixed Effects	Yes		Yes	
R^2	0.24		0.23	
Observations	52,506		52,257	

Table 1.4 Volume by Trade Size Bucket from DTAQ dataset

This table presents univariate results for the average change in volume by trade size bucket executed off-exchange. The sample includes all stocks that trade above $2.00 and pre- and post- denote four months before (06/2019-09/2019) and after (11/2019-02/2020 major retail brokers drop commissions to zero. Panel A reports the change in total volume executed by all off-exchange venues; Panel B reports the change in volume for marketable retail trades that receive price improvement as identified by Boehmer et al. (2021). Panel C shows the change in volume by size bucket for marketable retail trades executed by wholesale market makers that received price improvement versus all off-exchange trades. The data is obtained from DTAQ. Numbers are reported in thousands. Paired t-tests in parenthesis are used to calculate the differences between pre- and post-periods. Statistical significance at the 10%, 5%, and 1% levels is denoted by *, **, and ***, respectively.

Panel A: Total Volume Executed by All Off-Exchange Venues

Order Size	Small			Large		DID
	Odd lots	**100-499**	**500-1999**	**2000-4999**	**5000+**	**Small - Large**
Pre	1,709.92	9,989.94	7,768.73	4,857.99	4,740.38	
Post	2,771.80	13,732.25	9,904.22	5,695.47	5,601.16	
Diff (+/-)	1,061.88	3,742.32	2,135.50	837.48	860.77	5,241.44
Diff (%)	62.10%	37.46%	27.49%	17.24%	18.16%	17.95%***
T-stat	*(2.26)*	*(3.06)*	*(3.27)*	*(4.10)*	*(4.17)*	*(2.47)*

Panel B: Volume of Marketable Retail Trades that Receive Price Improvement Executed from Wholesale Market Makers

Order Size	Small			Large		DID
	Odd lots	**100-499**	**500-1999**	**2000-4999**	**5000+**	**Small - Large**
Pre	396.1	1,155.2	1,396.7	826.9	369.5	
Post	635.9	1,789.3	1,852.8	1,023.9	436.6	
Diff (+/-)	239.8	634.1	456.1	197.0	67.0	1,065.89
Diff (%)	60.53%	54.89%	32.65%	23.83%	18.14%	23.04%***
T-stat	*(7.26)*	*(9.97)*	*(7.86)*	*(4.08)*	*(2.52)*	*(2.22)*

Panel C: Percent of Total Volume from All Off-Exchange Venues vs. Marketable Retail Trades that Received Price Improvement from Wholesale Market Makers

Percent of Total Off-Exchanges Volume				**Percent of Marketable Retail Trades that Received Price Improvement**			
	Pre (%)	Post (%)	Diff. (%)		Pre (%)	Post (%)	Diff. (%)
Odd lots	5.88	7.35	1.47	**Odd lots**	9.56	11.08	1.52
100-499	34.37	36.42	2.05	**100-499**	27.87	31.18	3.31
500-1999	26.73	26.27	-0.46	**500-1999**	33.70	32.29	-1.41
2000-4999	16.71	15.11	-1.61	**2000-4999**	19.95	17.84	-2.11
5000+	16.31	14.86	-1.45	**5000+**	8.92	7.61	-1.31
Total	100	100		**Total**	100	100	

Table 1.5 Average Change in the Percent of Orders Routed to Wholesale Market Makers and Exchanges by Retail Brokers

This table presents difference-in-difference results for the average change in the percent of orders routed for execution by retail brokers to different execution venue types weighted by the number of retail brokers for each order type between Q3 and Q4 2019, for both retail brokers with and without zero commissions. The retail brokers that announced zero commissions in October 2019 used in this analysis are Ally Invest, Charles Schwab, E*Trade, Fidelity, Raymond James, and TD Ameritrade. The retail brokers with non-zero commissions as of April 1, 2020 are BB&T Securities LLC, Citi Group, Edward Jones, LPL Financial, Morgan Stanley, Muriel Siebert, Stifel, and Zacks Trade. The average percent routed for execution is calculated from each broker's SEC Rule 606 Q3 and Q4 2019 reports for the three listing exchanges (Nasdaq, NYSE, and NYSE American) and wholesale market makers (Citadel, G1X, Two Sigma, UBS, and Virtu) before versus after the zero-commission event. Standard t-tests are used to calculate the differences between the two groups. Statistical significance at the 10%, 5% and 1% levels is denoted by *, **, and ***, respectively.

	Broker with zero commission					Broker with positive commission						
Execution Broker/Venue	N	Mean (%)	Stdev (%)	Min (%)	Max (%)	N	Mean (%)	Stdev (%)	Min (%)	Max (%)	DID	t-value
To Wholesale Market Maker												
Non-Directed Orders	65	0.27	2.30	-3.76	2.83	53	-0.50	2.27	-4.21	4.89	0.77*	1.82
Market Orders	65	0.36	2.89	-3.85	3.83	53	-0.74	1.83	-5.01	0.99	1.10**	2.41
Limit Orders	65	0.29	2.22	-3.40	3.83	53	-0.63	1.50	-3.24	1.04	0.92**	2.56
Other Orders	65	0.09	3.40	-7.23	4.58	53	-0.93	2.72	-5.60	4.71	1.02*	1.77
To Exchange												
Non-Directed Orders	198	-0.03	0.31	-3.45	1.17	297	0.32	3.16	-14.60	24.70	-0.34*	-1.84
Market Orders	198	0.00	0.00	0.00	0.00	297	0.12	0.99	-3.01	6.62	-0.12*	-2.12
Limit Orders	198	-0.08	0.77	-9.45	1.52	297	0.42	3.30	-15.60	30.70	-0.50***	-2.52
Other Orders	198	0.03	0.16	-0.47	1.40	297	0.10	3.13	-21.50	25.61	-0.08	-0.42

Table 1.6 Regressions for the Change in the Percent of Orders Routed to Wholesale Market Makers and Exchanges by Retail Brokers

This table presents regressions testing the change in the percent of orders by type routed to either wholesale market makers or exchanges. The zero commission broker dummy (ZCBroker Dummy) equals one for those brokers who announced zero brokerage commission in October 2019 and equals zero for those brokers with non-zero commissions. The retail brokers that announced zero brokerage commissions in October 2019 used in this analysis are Ally Invest, Charles Schwab, E*Trade, Fidelity, Raymond James, and TD Ameritrade. The retail brokers with non-zero commissions as of April 1, 2020 are BB&T Securities LLC, Citi Group, Edward Jones, LPL Financial, Morgan Stanley, Muriel Siebert, Stifel, and Zacks Trade. The dependent variable ΔNon-directed, ΔMarket, ΔLimit and ΔOther are the retail brokers' change in the percent of non-directed, market, limit, and other orders from Q3 to Q4 2019 for wholesale market makers and exchanges. The change in the percent of order by type is from each broker's SEC Rule 606 Q3 and Q4 2019 reports. All regressions include broker and listing exchange fixed effect. T-Stats are reported in parentheses. ***, **, * indicate statistical significance at the 0.01, 0.05 and 0.10 level, respectively.

Panel A: Change in percent of orders routed to wholesale market makers by order type

	ΔNon-Directed	ΔMarket	ΔLimit	ΔOther
ZCBroker Dummy	0.0596**	0.0595**	0.0389	0.0638*
	(2.33)	*(2.16)*	*(1.33)*	*(1.91)*
Intercept	-0.02	-0.005	-0.0133	-0.0255
	(-1.34)	*(-0.29)*	*(-0.77)*	*(-0.30)*
Broker F. E	Yes	Yes	Yes	Yes
Listing F. E	Yes	Yes	Yes	Yes
R^2	0.11	0.11	0.23	0.19
Observations	130	130	130	130

Panel B: Change in percent of orders routed to exchanges by order type

	ΔNon-Directed	ΔMarket	ΔLimit	ΔOther
ZCBroker Dummy	-0.0119**	-0.0001	-0.0161***	0.0018
	(-2.09)	*(-0.07)*	*(-2.67)*	*(0.32)*
Maker-Taker Dummy	0.0023	-0.0010	0.0010	0.0010
	(0.93)	*(-1.33)*	*(0.40)*	*(0.43)*
Intercept	0.0109**	0.0010	0.0161***	-0.0019
	(2.33)	*(0.71)*	*(3.27)*	*(-0.41)*
Broker F. E	Yes	Yes	Yes	Yes
Listing F. E	Yes	Yes	Yes	Yes
R^2	0.14	0.12	0.15	0.16
Observations	462	462	462	462

Table 1.7 Change in Market Share of Volume

This table reports coefficient estimates for OLS regressions of the share of off-exchange daily market volume from DTAQ using controls and the proportion of the zero commission broker or the implementation of zero-brokerage commissions as an event. The sample includes all stocks that trade above $2.00 during regular trading hours (9:30 am - 4:00 pm) from 06/2019-02/2020. For the dependent variables, we consider the percentage of total off-exchange volume share for all order and trader types in columns (1) and (2), and for retail marketable orders that receive price improvement off-exchange as identified by Boehmer et al. (2021) in column (3) and (4) divided by the total DTAQ volume for the stock. Panel A represents the effect of the ZCBroker Proportion, the proportion of retail brokers that offer zero commission trading, on off-exchange volume share, and Panel B shows the effect of ZCEvent Dummy, a dummy variable equals one if the time is after October 2019 and zero before, on off-exchange volume. All variables are described in detail in Appendix A. t-statistics are reported in parentheses and are based on standard errors clustered at the date and stock level. Statistical significance at the 10%, 5%, and 1% levels is denoted by *, **, and ***, respectively.

Panel A: The Effect of the Proportion of Zero Commission Retail Brokers on Change in Market Share of Volume

	Total Off-exchange Volume Share (%)		**Price Improved Off-exchange Retail Volume Share (%)**	
	All Orders and Trader Types	All Orders and Trader Types	Boehmer et al. (2021)	Boehmer et al. (2021)
	(1)	(2)	(3)	(4)
ZCBroker Proportion	0.0405***	0.0390***	0.0104***	0.0115***
	(46.57)	*(45.58)*	*(19.41)*	*(21.96)*
Log (Volume)		0.647***		-0.342***
		(37.22)		*(-30.03)*
Log (MktCap)	0.231***	-0.216***	-0.104***	0.180***
	(14.98)	*(-11.13)*	*(-9.35)*	*(12.29)*
InvPrice	15.399***	13.035***	12.403***	13.263***
	(29.7)	*(30.38)*	*(33.24)*	*(34.4)*
VIX	-0.018***	-0.036***	0.003	0.013***
	(-3.8)	*(-7.58)*	*(0.91)*	*(4.62)*
Lag(Spread*100)	0.127***	0.211***	0.18***	0.104***
	(5.32)	*(5.08)*	*(5.01)*	*(5.48)*
Amihud (x10^5)	-0.007		-0.004	
	(-1.54)		*(-1.53)*	
Intercept	24.756***	27.306***	8.164***	5.815***
	(32.35)	*(35.68)*	*(20.83)*	*(15.11)*
Index F.E.	Yes	Yes	Yes	Yes
Industry F.E.	Yes	Yes	Yes	Yes
R^2	0.20	0.20	0.25	0.25
Observations	1,052,012	1,102,428	1,052,012	1,102,428

(Table 1.7 Continued)

Panel B: The Effect of Zero Commission Event on Change in Market Share of Volume				
	Total Off-exchange Volume Share (%)		**Price Improved Off-exchange Retail Volume Share (%)**	
	All Orders and Trader Types	All Orders and Trader Types	Boehmer et al. (2021)	Boehmer et al. (2021)
	(1)	(2)	(3)	(4)
ZCEvent Dummy	1.685***	1.589***	0.435***	0.485***
	(43.51)	*(42.07)*	*(18.43)*	*(20.94)*
Log (Volume)		0.647***		-0.341***
		(35.61)		*(-28.17)*
Log (MktCap)	-0.194***	-0.226***	-0.119***	0.162***
	(-12.53)	*(-10.95)*	*(-10.34)*	*(10.34)*
InvPrice	15.425***	13.011***	12.45***	13.279***
	(27.62)	*(28.70)*	*(31.15)*	*(32.27)*
VIX	-0.009*	-0.023***	0.004	0.015***
	(-1.72)	*(-4.74)*	*(1.33)*	*(4.90)*
Lag(Spread*100)	0.117***	0.19***	0.167***	0.098***
	(5.11)	*(5.03)*	*(4.89)*	*(5.38)*
Amihud ($x10^5$)	-0.006		-0.004	
	(-1.52)		*(-1.53)*	
Intercept	33.133***	35.610***	6.209***	6.209***
	(41.60)	*(30.32)*	*(15.77)*	*(15.77)*
Index F.E.	Yes	Yes	Yes	Yes
Industry F.E.	Yes	Yes	Yes	Yes
R^2	0.20	0.21	0.25	0.25
Observations	929,149	929,149	1,052,012	1,102,428

Table 1.8 Price Improvement Analysis

This table presents univariate results for the change in the average amount of price improvement per 100 shares for marketable retail orders executed by wholesale market makers as identified by Boehmer et al. (2021) before versus after commissions decline to zero. Panel A reports the price improvement for all stocks that trade above $2.00, and Panel B reports the price improvement for the top 100 stocks that are held by Robinhood users as identified by Robintrack. Pre and Post denote four months before (06/2019 – 09/2019) and after (11/2019 – 02/2020) the major retail brokers implement zero-commissions, or four months before (06/2019-09/2019) zero commissions were widely adopted and the corresponding four months in 2020 (06/2020-09/2020) to control for month and quarter effects. The data is obtained from DTAQ trade. Paired t-tests are used to calculate the differences between pre- and post-periods. Statistical significance at the 10%, 5%, and 1% level is denoted by *, **, and ***, respectively.

Panel A: All stocks					
	Pre (¢)	Post (¢)	Diff. +/-	Diff (%)	T-Stat
06/2019-09/2019 vs. 11/2019-02/2020	17.16	17.33	0.16	0.95%	1.42
06/2019-09/2019 vs. 06/2020-09/2020	17.16	15.94	-1.22	-7.11%	-12.83***
Panel B: Top 100 popular retail stocks as identified by Robintrack					
	Pre (¢)	Post (¢)	Diff. +/-	Diff (%)	T-Stat
06/2019-09/2019 vs. 11/2019-02/2020	16.26	14.86	1.40	-8.62%	-7.71***
06/2019-09/2019 vs. 06/2020-09/2020	16.26	14.33	1.93	-11.87%	-8.61***

Table 1.9 Regressions for Price Improvement on Zero Commission Event

This table presents coefficient estimates when regressing price improvement on the ZCBroker Proportion or ZCEvent Dummy for the top 100 stocks that are held by Robinhood users as identified by Robintrack and which have a price greater than $2.00. The dependent variables are the volume weighted price improvement (in cents) per hundred shares and volume weighted percent price improvement per share; both measures are aggregated at daily level. Following Boehmer et al. (2021), the trades have midpoint price improvement are eliminated in the calculation. Panel A reports the results from regressing price improvement measures on the proportion of the number of retail brokers that offer zero commission trading, ZCBroker Proportion. Panel B reports the results from regressing price improvement measures on dummy variable, ZCEvent Dummy, which equals one if the time is after October 2019, and zero before. All variables are described in Appendix A. The sample period is from 06/2019-02/2020 for Panel A. For Panel B. column (1) is the sample for four months before and after the major retail brokers implement zero commission. column (2) is the four months before (06/2019-09/2019) zero commissions were widely adopted and the corresponding four months in 2020 (06/2020-09/2020) to control for month and quarter effects. The data is obtained from DTAQ. All regressions include the industry fixed effects, and the standard errors are double clustered at the firm and date level. T-Stats are reported in parentheses. Standard errors are double clustered at the stock and date level. ***, **, * indicate statistical significance at the 0.01, 0.05 and 0.10 level, respectively.

Panel A: Regressions for Price Improvement on Proportion of the Zero Commission Retail Broker

	Price Improvement per 100 Shares (¢)		**Price Improvement per Share (%)**	
	6/2019-2/2020		6/2019-2/2020	
ZCBroker Proportion	-0.0234	***	-0.0001	***
	(-8.96)		*(-5.77)*	
LogVol	-0.5031	***	-0.0123	***
	(-8.09)		*(-25.72)*	
Log(MktCap)	0.0531	**	-0.0011	***
	(2.09)		*(-3.92)*	
InvP	-0.8687	***	0.1642	***
	(-3.12)		*(27.85)*	
IntraVolatility	-0.0344		0.0040	***
	(-1.32)		*(8.90)*	
Quoted Spread ($)	2.482	***	0.0056	
	(5.26)		*(1.24)*	
Constant	21.6566	***	0.3070	***
	(19.53)		*(38.05)*	
Industry F.E.	Yes		Yes	
R^2	0.041		0.721	
Observations	14,840		15,059	

(Table 1.9 Continued)

Panel B: Regressions for Price Improvement on Zero Commission Event				
	Price Improvement per 100 Shares (¢)		**Price Improvement per Share (%)**	
	(1) 6/2019-9/2019 vs. 11/2019-2/2020	(2) 6/2019-9/2019 vs. 6/2020-9/2020	(1) 6/2019-9/2019 vs. 11/2019-2/2020	(2) 6/2019-9/2019 vs. 6/2020-9/2020
ZCEvent Dummy	-1.009***	-1.293***	-0.007***	-0.012***
	(-8.70)	*(-11.41)*	*(-7.32)*	*(-12.26)*
LogVol	-0.962***	-0.879***	0.001	-0.002***
	(-12.55)	*(-12.66)*	*(0.85)*	*(-3.78)*
Log(MktCap)	0.511***	0.405***	-0.015***	-0.017
	(10.97)	*(9.76)*	*(-23.96)*	*(-27.99)*
InvP	0.044	0.969***	0.120***	0.092***
	(0.14)	*(3.10)*	*(10.42)*	*(10.72)*
IntraVolatility	0.039	-0.026	0.003***	0.001***
	(1.48)	*(-1.20)*	*(5.04)*	*(3.68)*
Quoted Spread ($)	-0.833	0.161	0.090***	0.053***
	(-1.51)	*(0.82)*	(15.21)	(27.36)
Constant	21.838***	21.607***	0.135***	0.391***
	(17.93)	*(19.84)*	*(39.55)*	*(31.55)*
Industry F.E.	Yes	Yes	Yes	Yes
R^2	0.051	0.049	0.761	0.707
Observations	12,864	13,284	12,864	13,284

Table 1.10 Fixed-effects Regressions for Market Quality Measures

This table reports the results from regressing market quality measures on ZCBroker Proportion or ZCEvent Dummy for the top 100 stocks that are held by Robinhood users as identified by Robintrack and which have a price greater than $2.00. The dependent variables are: Average time-weighted percent quoted spread, average percent effective spread, average percent price impact computed based on 5-minute interval and 15-second intervals, average percent realized spread computed based on 5-minute and 15-second intervals and stock intraday volatility. Panel A reports the results from regressing market quality measures on the proportion of the number of retail brokers that offer zero commission trading, ZCBroker Proportion. Panel B reports the results from regressing market quality measures on dummy variable, ZCEvent Dummy, which equals one if the time is after October 2019, and zero before. All regressions include the industry fixed effects, and the standard errors are double clustered at the firm and date level. The data is obtained from DTAQ and the sample period is from 06/2019-02/2020. T-Stats are reported in parentheses. Standard errors are double clustered at the stock and date level. ***, **, * indicate statistical significance at the 0.01, 0.05 and 0.10 level, respectively.

Panel A: The Effect of the Proportion of Zero Commission Retail Brokers on Market Quality

	Market Liquidity				**Profit to Liquidity Providers and Market Noise**		
	Quoted Spread *(%)*	Effective Spread *(%)*	Price Impact: 5-min *(%)*	Price Impact: 15-sec *(%)*	Realized Spread: 5-min *(%)*	Realized Spread: 15-sec *(%)*	IntraVolatility (%)
ZCBroker Proportion	0.006	-0.005**	-0.008***	-0.007***	0.004	0.003	0.005***
	(1.34)	*(-1.96)*	*(-3.98)*	*(-5.73)*	*(1.43)*	*(1.58)*	*(3.72)*
ShortInterest	-0.034***	-0.018***	0.009***	0.019***	-0.027***	-0.028***	0.011***
	(-4.64)	*(-4.78)*	*(2.63)*	*(8.28)*	*(-6.98)*	*(-8.59)*	*(5.11)*
LogVol	-0.007***	0.000	0.000	-0.005***	0.000	-0.001*	0.012***
	(-4.88)	*(-0.70)*	*(-0.62)*	*(-12.77)*	*(0.03)*	*(-1.89)*	*(28.84)*
IntraVolatility	0.240***	0.270***	0.741***	0.511***	-0.471***	-0.164***	
	(5.81)	*(6.95)*	*(11.05)*	*(16.30)*	*(-9.46)*	*(-5.16)*	
Log(MktCap)	-0.031***	-0.018***	-0.012***	-0.011***	-0.006***	-0.006	-0.007***
	(-43.25)	*(-38.20)*	*(-23.94)*	*(-40.34)*	*(-11.44)*	*(-15.37)*	*(-33.15)*
InvP	0.176***	0.197***	0.063***	0.017***	0.134***	0.188***	0.007***
	(17.54)	*(25.08)*	*(10.94)*	*(5.69)*	*(15.77)*	*(25.03)*	*(3.70)*
Constant	1.036***	0.539***	0.334***	0.376***	0.205***	0.229***	0.012***
	(39.79)	*(56.09)*	*(35.35)*	*(66.84)*	*(18.75)*	*(25.24)*	*(2.22)*
Industry F.E.	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R2	0.66	0.89	0.54	0.67	0.63	0.77	0.27
Observations	16,310	16,310	16,310	16,310	16,310	16,310	16,310

(Table 1.10 Continued)

Panel B: The Effect of the Zero Commission Event on Market Quality

	Market Liquidity				Profit to Liquidity Providers and Market Noise		
	Quoted Spread *(%)*	Effective Spread *(%)*	Price Impact: 5-min *(%)*	Price Impact: 15-sec *(%)*	Realized Spread: 5-min *(%)*	Realized Spread: 15-sec *(%)*	IntraVolatility (%)
ZCBroker Proportion	0.000	-0.002***	-0.003***	-0.002***	0.00	0.00	0.204***
	(-0.44)	*(-6.34)*	*(-4.29)*	*(-4.53)*	*(0.75)*	*(-0.24)*	*(4.41)*
ShortInterest	0.002***	0.005***	0.008***	0.017***	-0.002	-0.005***	1.228***
	(0.53)	*(2.73)*	*(2.87)*	*(8.84)*	*(-0.92)*	*(-2.87)*	*(5.70)*
LogVol	-0.016***	-0.008***	-0.005***	-0.007***	-0.003***	-0.006***	0.991***
	(-21.12)	*(-19.81)*	*(-7.62)*	*(-16.92)*	*(-5.82)*	*(-16.26)*	*(27.30)*
IntraVolatility	-0.012***	0.272***	0.552***	0.408***	-0.28***	-0.062***	
	(-17.21)	*(9.57)*	*(8.13)*	*(11.79)*	*(-5.87)*	*(-3.23)*	
Log(MktCap)	0.23***	-0.005***	-0.006***	-0.009***	0.001	0.002***	-0.659***
	(8.39)	*(-10.58)*	*(-7.78)*	*(-23.70)*	*(1.17)*	*(5.66)*	*(-23.14)*
InvP	0.616***	0.515***	0.222***	0.064***	0.294***	0.407***	0.175
	(38.50)	*(46.01)*	*(16.01)*	*(9.71)*	*(21.02)*	*(41.60)*	*(0.31)*
Constant	0.632***	0.292***	0.235***	0.347***	0.057***	0.050***	2.226***
	(40.09)	*(30.95)*	*(16.21)*	*(44.77)*	*(4.29)*	*(5.77)*	*(3.30)*
Industry F.E.	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R2	0.66	0.89	0.54	0.67	0.63	0.77	0.27
Observations	16,310	16,310	16,310	16,310	16,310	16,310	16,310

CHAPTER 2: TRADING VENUE PREFERENCE: CRITICAL ROLE OF INSTITUTIONAL OWNERSHIP

2.1 Introduction

Traders incur certain costs to acquire proprietary information, and how they use that newly acquired knowledge to rebalance their portfolios matters. The timing of their trades and the selected trade venue can materially affect the success of their strategy. More recently, both institutional and retail traders have used off-exchange trading venues to rebalance their holdings for the advantages they offer traders. Foley and Putniņš (2016) explain that dark pools, a type of off-exchange trading, have lower costs, less information leakage, and, most advantageously, larger orders can avoid being front-run. The ability to hide their orders, which effectively means information, allows traders to earn a higher profit (Bloomfield, O'Hara, and Saar 2005) because they can get better prices (Garvey, Huang, and Wu 2016). However, these benefits come at a cost. Orders sent to dark pools are less likely or take longer to execute (Garvey, Huang, and Wu 2016; Zhu 2014). Hence, traders have to balance their needs to manage price impact and execution immediacy (Menkveld, Yueshen, and Zhu 2017).

One of the factors that can affect routing preference for either off-exchange venues or the lit market is the expectation of information release, which is the focus of our study. In our research, we examine how trade routing preferences change around two very different firm-level event types: scheduled and unscheduled events. We believe the nature of the scheduled and unscheduled events should have different impacts on order routing decisions. Scheduled announcements, such as earnings announcements, are associated with higher information asymmetry because not all traders can interpret the information as explained by the authors and not all traders are able to acquire private information before the announcement (Kim and Verrecchia 1994; Crego 2020). Nonetheless, because the timing of earnings announcements is known in advance, informed traders, such as institutional investors, can seek information ahead of the release and wait for the announcement to confirm their privately acquired information. At this time, informed traders would route their orders based on their accessibility and level of confidence regarding the information (Bloomfield, O'Hara, and Saar 2005; Ye 2016).

Conversely, liquidity traders are keenly aware of the adverse selection cost and are likely to refrain from trading until the information asymmetry is resolved (Chae 2005). Furthermore, the results from the previous quarter's earnings can positively or negatively impact the stock price. While there are consensus estimates, the actual earnings are not confirmed until the announcement, which can increase the information asymmetry around the scheduled event. In contrast to scheduled events, unscheduled events, such as share repurchase announcements, are not associated with higher information asymmetry because the event is unexpected, giving fewer opportunities for traders to acquire information ex-ante. Thus, the disparities in privately held information are not as great. Additionally, share repurchase announcements, in general, have a predictable impact on the stock price. Most announcements result in an immediate stock price increase lasting from days to months (Ofer and Thakor 1987; Ikenberry, Lakonishok, and Vermaelen 1995; Kracher and Johnson 1997; Peyer and Vermaelen 2009; Bargeron, Kulchania, and Thomas 2011). Because of the different levels of information asymmetry associated with both event types, we believe traders will have specific preferences depending on the opportunity to gather information ex-ante.

Our research meaningfully extends the complementary work of Chae (2005), Crego (2020) and Menkveld, Yueshen, and Zhu (2017). Chae (2005) explains that information asymmetry before scheduled announcements materially affects trading volume, but trading volume is unrelated to proxies of information asymmetry in the context of unscheduled announcements. Crego (2020) suggests that public information releases can worsen the adverse selection problem. Our research confirms that higher information asymmetry still exists with scheduled announcements and that volume share, specifically for off-exchange trading venues, increases around scheduled announcements. Our evidence that traders prefer off-exchange venues around scheduled events is robust at the daily and intraday (1-minute and half-hour frequencies) levels even during the COVID-19 pandemic. Moreover, we find that the level of institutional ownership potentially could be a significant predictor of traders' inclination for using off-exchange trading venues, particularly around scheduled events. Firms with a high level of institutional ownership have more analyst attention, higher trading volume, more traders, and hence more visibility (Schwartz and Shapiro 1991), which makes it more difficult for traders to use their privately acquired information around scheduled events.

Our research also builds on the work of Menkveld, Yueshen, and Zhu (2017) by providing additional insights beyond the information urgency shocks from the minute before the event to four minutes post-announcement. Menkveld, Yueshen, and Zhu (2017) examine the VIX, macroeconomic data releases, and earnings surprises and find that traders turn to the lit market when there is a positive urgency shock due to these events. In our research, we look at two important corporate events, including earnings announcements, in general, not just the earnings surprises. We also expand the event type to include unscheduled corporate announcements, which differ significantly from the information asymmetry standpoint. Our research also complements theirs from the data perspective. While Menkveld, Yueshen, and Zhu (2017) analyze 117 stock transaction activities for one month in 2010, we extend this data to provide a more updated and complete understanding of routing preference. Our data covers all firms that had earnings and repurchase announcements from 2014 to 2020, and the off-exchange volume share is examined under both daily and intraday trading frequency.

The study proceeds as follows. In section 2.2, we outline our development of the hypotheses. We describe the data and explain the methodology in section 2.3. Section 2.4 has our findings, and our concluding remarks are in section 2.5.

2.2 Literature Review and Hypothesis Development

Accounting for approximately 30% of the equity trading volume, off-exchanges provide traders another option to execute their strategies. Menkveld, Yueshen, and Zhu (2017) propose that traders prioritize trading venues based on liquidity, execution certainty, and the value of their proprietary information. According to the authors, the pecking order hypothesis of trading venues states that traders prefer routing to low-cost-low-immediacy venues, such as midpoint dark pools. Traders will switch from dark to lit venues, which are high-cost-high-immediacy venues when there is an information urgency shock and the drop in dark pool volume should be significant. Zhu (2014) argues that dark pools are less attractive to informed traders because their trades are less likely to fill. We believe this finding is true if the informed traders all have the same information. The information shock may not have the same impact on traders as they may have heterogeneous expectations depending on the event type.

If there is heterogeneity in information or expectations, off-exchange trading venues may still be useful to traders. Bloomfield, O'Hara, and Saar (2005) argue that informed traders can profit using exchanges that allow orders to be partially or fully hidden, but only if the information is of high value. Extending this line of research further, Ye (2016) discusses information risk in three levels. If the informed traders have weak signals about a given stock, they will most likely not trade. Those with moderate signals will prefer to route their orders to dark pools to get better pricing because they are less confident about making a profit using such information. Execution is less of a concern. The traders with strong signals prefer higher execution probabilities and will route their orders to lit exchanges as they tend to be more liquid than dark pools. Clearly, trader's routing preferences depends on the quality of the information he or she obtains. This conflict may be especially true around events with different timing. In our study, we examine if routing preference is influenced by two different event types—scheduled and unscheduled.

We use earnings announcements as the scheduled events and share repurchase announcements as the unscheduled events. The timing of these earnings announcements is known in advance, and the event is a reoccurring one allowing traders to acquire private information ex-ante. The opportunity to gather private information before the announcement and confirm that information with the announcement can increase the adverse selection costs for uninformed traders (Chae 2005; Crego 2020). In contrast, traders do not know if or when the firms will announce share repurchases. As an added level of complexity, traders also do not know if the firms will follow through with actual repurchases. Bhattacharya and E. Jacobsen (2016) find that 24% of the announcing firms do not repurchase shares within the same fiscal year as the announcement, and 13% of the announcing firms do not repurchase shares within four years after the announcement. This lack of commitment combined with the unscheduled nature of share repurchase announcements can affect the traders' ability to gather information around this type of event. Finally, the two announcement types have different impacts on the stock price. For earnings announcements, if the firm beats expectations, then a price increase is likely to follow, and the reverse is likely to be true if the firm does not exceed estimates. Since traders do not know the results definitively, it is even more critical for them to acquire private information before the earnings announcement, which increases the information asymmetry around the scheduled event.

However, for repurchase announcements, the stock price tends to increase after the event, as documented in the prior studies.[38] Since the result is more predictable for share repurchase announcements, there is less motivation to seek private information. Overall, repurchase announcements do not increase information asymmetry as much when compared to earnings announcements.

Because of all these reasons, we believe that traders may have different routing preferences depending on the event type. In the case of earnings announcements, there is higher information asymmetry because informed traders would prefer to reveal their information only after they have recuperated the information acquisition cost and executed their strategy. This is more likely to happen with off-exchange trading. As for share repurchase announcements, the unexpected nature of the event does not allow traders to plan before the event and eliminates the need to hide any proprietary information using alternative exchanges.

[38] See Ofer and Thakor (1987); Ikenberry, Lakonishok, and Vermaelen (1995); Peyer and Vermaelen (2009); Bargeron, Kulchania, and Thomas (2011).

Hypothesis 1: Routing preference for off-exchange trading venues is influenced by scheduled events, but it is not influenced by unscheduled events.

Next, we explore the driving forces behind the order routing preferences in our second hypothesis. We believe that the preference for off-exchange trading around scheduled events may be moderated by institutional ownership.[39]

First, as discussed in many previous papers, institutional investors are considered sophisticated investors, and in general, they have more information advantages than other market participants.[40] In Ali, Klasa, and Zhen Li (2008) and Campbell, Ramadorai, and Schwartz (2009), they find that institutional investors tend to trade aggressively around earnings announcements, especially to exploit mispricing. Therefore, we believe institutional investors may trade in off-exchange venues to maintain their information advantage. Second, as off-exchange trading venues may have lower liquidity than the lit exchanges, traders with proprietary information may find difficulties filling their orders. Rubin (2007) explains that the liquidity of a firm's stock is positively related to total institutional holdings. The liquidity comes from the institution's higher trading activity, which reveals information and provides other traders opportunities to rebalance their portfolios. Hence, when traders want to rebalance their holdings of stocks with high institutional ownership, they potentially could do so off-exchange because these stocks are

[39] Beside analyzing institutional ownership, we also consider the analyst forecast dispersion as proxy for the disagreement (Buti, Rindi, and Werner 2017). The overall difference between high and low dispersion for off-trading volume share are insignificant around both scheduled and unscheduled events. We also tested the market risk exposure (beta) as the potential driving force for the routing decision. Again, the results are insignificant.

[40] See Grinblatt and Titman (1993); Daniel et al. (1997); Wermers (1999, 2000); Chen, Jegadeesh, and Wermers (2000); Ali, Klasa, and Zhen Li (2008); Boehmer and Kelley (2009) and Baruch, Panayides, and Venkataraman (2017).

more liquid. Routing to dark could be complementary to a dynamic order-splitting strategy to rebalance portfolios as it also does not reveal too much information while lowering the cost of trading (Choi, Larsen, and Seppi 2019). With higher liquidity in the off-exchange trading venues for higher institutional ownership stocks, more traders may prefer routing their orders away from the lit exchanges to protect their proprietary information.

Hypothesis 2: The level of institutional ownership affects the trading venue preference around firm scheduled events.

In our last set of tests, we examine if trading preference changes during crisis time, especially during the COVID-19 pandemic. We believe the COVID-19 Pandemic period is important to research for two reasons. First, COVID-19 Pandemic significantly affects market liquidity and increase market volatility (Baker et al., 2020; Albulescu, 2020; Haroon and Rizvi,2002). The changes in liquidity and market volatility increase execution uncertainty, thus potentially altering traders routing decisions. For instance, Golstein and Kavajecz (2004) show that during the volatile October 1997 period, traders withdrew from the electronic market and routed their orders to the floor. Second, COVID-19 Pandemic also affects information dissemination. Du (2021) and Li and Wang (2021) show that the information asymmetry increases, and public information quality worsens during the COVID-19 Pandemic period. Furthermore, COVID-19's lockdown and work-from-home restrictions could impede information flow even further (Cumming et al., 2021, Cahill et al., 2021). In summary, we focus our attention on the COVID-19 pandemic because it is a unique event that caused the local, state, and federal governments to place not only social but also economic restrictions. These restrictions affect the stock market significantly more than previous health crises in 1918–1919, 1957–1958, and 1968 (Baker et al. 2020).Even though our understanding of the impacts of the pandemic is limited, we do know much more about the persistent behavior of traders. We believe that during times of crisis traders will be reluctant to use lit markets especially if they have proprietary information. Information acquisition is costly, and we hypothesize that the COVID-19 pandemic should not impact their preference to route off-exchange around scheduled events.

Hypothesis 3: The COVID-19 pandemic does not change routing preferences around scheduled and unscheduled events. Traders still prefer to route their orders to off-exchange venues around scheduled events, and they do not change preference for either off-exchange or lit markets around unscheduled events.

2.3 Data and Methodology

Our analysis is based on daily individual National Market System (NMS) stock-level data in regular trading hours (9:30 am - 4:00 pm) from NYSE Daily Trade and Quote (DTAQ) database. We test firm earnings announcements as the scheduled events and repurchase announcements as the unscheduled event. The firm announcements are obtained from two databases: the dates of the earnings announcement are from IBES, and the repurchase announcement dates are from Thomson Reuters SDC. The institutional ownership data is from SEC form 13F. We also obtain data from CRSP, COMPUSTAT, and IBES for control variables such as firm size, SIC codes, analyst coverage. A detailed list of the variables and their descriptions is included in Appendix A. Table 2.1 summarizes the caveats discussed below.

We only include firms that had both earnings and repurchasing announcements from 2014.01 to 2019.12. Our final sample consists of 1,002 firms with 20,150 earnings announcement events and 1,479 repurchase announcement events. Panel A of Table 2.1

presents our main variable of interest, *Off-exchange Trading Volume Share*, which is calculated as the total volume that is executed in an off-exchange trading venue divided by the overall trading volume for the given time interval. The average proportion of off-exchange trading volume is around 33.0% using a daily interval, 31.3% using a 30-minute interval, and 29.3% using a 1-minute interval. Panel B of Table 2.1 reports the summary statistics for our main control variables, and Panel C and D of Table 2.1 reports the number of events in each month of the sample periods. The number of earnings announcements by month in Panel C shows a clear seasonal pattern. Earnings are announced in February for the first quarter, April/May for the second quarter, July/August for the third quarter, and Oct/Nov for the fourth quarter. On the other hand, Panel D suggests that repurchase announcements do not follow any seasonal patterns. The number of repurchase announcements is equally distributed across months.

Our main variable of interest is the proportion of off-market trading volume given the designated time intervals. We use both daily and intraday level intervals to test our results. Following Baruch, Panayides, and Venkataraman (2017), our event windows for the daily interval include the five days before (Days [-5,-1]), the five days after (Days [+1,+5]), and the day of the announcement (Day [0]). The control window is calculated by averaging the proportion of off-market trading volume by firm in Days [-30, -10]. For the intraday frequency, we test the off-exchange trading volume share under 30-minute and 1-minute intervals for the day before (Day[-1]), the announcement event day (Day[0]), and the day after (Day [+1]) the announcement. We also calculate the steady-state by averaging the proportion of off-market trading volume at event month, excluding Days [-1, +1] and days for other firm's announcements if there are any. To test the effects of institutional ownership on off-exchange trading, we split the firms into three groups based on the proportion of the shares held by institutional investors and categorize them as low-, mid-, and high-institutional ownership stocks.

To test Hypothesis 1, we estimate the following regression model:

$$OffVolShare_{i,t} = \beta_0 + \beta_1 AnnoucementD_{i,t} + \delta\, X_{i,t} + \epsilon_{i,t} \qquad (2.1)$$

where i and t indicate a firm and a trading day, respectively. The dependent variable $OffVolShare_{i,t}$ is the off-exchange trading volume share. The key independent variable is the $AnnoucementD_{i,t}$ variable, which takes the value of 1 if t is the announcement day, and 0 otherwise. $X_{i,t}$ is a set of control variables that are used in previous literature to control the heterogeneity of the firm's information environment, including the firm size, price, analyst coverage, quoted spread, firm- and market-level volatility.

Extending the above benchmark specification, the modeling for Hypothesis 2 on the effects of institutional ownership on routing preference around scheduled events is as follows:

$$OffVolShare_{i,t} = \beta_0 + \beta_1 AnnoucementD_{i,t} + \beta_2 AnnoucementD_{i,t} \times IO\_High_{i,t} + \beta_3 IO\_High_{i,t} + \delta X_{i,t} + \epsilon_{i,t} \qquad (2.2)$$

Where $IO\_High_{i,t}$ is the dummy variable that equals one if the firm is in the high-institutional ownership group, and equals zero else.

2.4 Empirical Results

Before testing our hypotheses, we examine the information asymmetry of scheduled and unscheduled events using two proxies: the Amihud Illiquidity Measure in Amihud (2002) and the cumulative abnormal log turnover in Chae (2005). Both proxies show evidence of higher information asymmetry associated with scheduled events. The results are in Appendix C, Table C.1. With the higher level of information asymmetry confirmed, we can now focus on our main research questions of trade routing preference.

2.4.1 Routing Preference by Scheduled vs. Unscheduled event

Figure 2.1 and Figure 2.2 present the average volume share of the off-market trading on the day before, the announcement day, and the day after the announcement using 30-minutes trading intervals and 1-minture trading intervals, respectively.[41] The horizontal dash line is the steady-state value of the average proportion of off-exchange trading volume with no earnings and repurchase announcement. The firm's off-exchange trading volume share is close to its steady-state for both earnings and repurchase announcement on the day before the announcement. Notably, Figure 2.1 Panel A shows that the off-exchange trading volume shares are significantly higher than the steady-state on the announcement day and the day after the earnings announcement. In contrast, the off-exchange trading volume shares for repurchase announcements in Figure 2.1 Panel B do not show an uptrend pattern for the announcement day and the day after the announcement. Overall, Figure 2.1 supports the first hypothesis, suggesting that routing preferences are different for the scheduled and unscheduled events.

We also examine the proportion of off-exchange trading around firm announcements using a 1-minute interval for the first 15 minutes shown in Figure 2.2. These patterns are similar to the ones shown in Figure 2.1. Hence, we believe that routing preferences are different based on the event type.

Table 2.2 presents the univariate results to test Hypothesis 1. We apply paired t-test to examine the changes in the off-exchange trading volume on the announcement day

[41] The volume share in figure 2.1 and figure 2.2 are normalized at its steady state.

compared to the steady-state for the 30-minute trading interval.[42] The estimation consists of 1,002 firms with both earnings announcements and repurchase announcements between January 2014 and December 2019. The steady-state off-exchange trading volume is calculated as the average proportion of a firm's off-exchange trading volume given the designated interval with no earnings and repurchase announcement. We report the difference of off-exchange trading volume share using the 30-minute interval in Panel A Table 2.2 and 1-minute interval for the first 15 minutes in Panel B Table 2.2. Overall, the results in Table 2.2 strongly support Hypothesis 1. Most of the differences in off-exchange trading volume share for earnings announcements (Diff 1) in both Panel A and Panel B are positively significant at the 0.1% level. The increases in the earnings announcement day off-exchange trading volume share range from 3.06% to 6.03% using the 30-minute interval and from 0.44% to 6.39% using the 1-minute interval. In contrast, the changes in off-exchange trading volume share for repurchase announcements are smaller and statistically insignificant compared to the changes associated with earnings announcements. In summary, Table 2.2 suggests that the scheduled and unscheduled events have different impacts on traders in routing their orders.

To control the heterogeneity in the firm's information environment and market volatility, we examine the effects of scheduled and unscheduled events on routing preferences by using multivariate regressions. For all regression specifications, we include year-month time fixed effects and the standard errors are double clustered at firm-month level to account for unobserved heterogeneity. Table 2.3 reports the results of the regression of the daily proportion of off-exchange trading around earnings and repurchase

[42] We also did the paired t-test for the changes in off-exchange trading volume share at day before and after the earnings and repurchase announcement with the steady state. The results are presented in Appendix D.

announcements on the event day dummy variable with a set of controls. *EventD* is the variable of interest, which takes the value of 1 if *t* is the announcement day and 0 otherwise. We find the estimated coefficient on *EventD* is positive and statistically significant at the 1% level for earnings announcements and it is insignificant for share repurchase announcements. The coefficient for *EventD* implies that, after controlling for salient firm and market characteristics, the proportion of off-exchange trading volume increases by 2.13% on the earnings announcement day but remains the same on the repurchase announcement day.

Next, we analyze whether our findings in Table 2.3 are supported by examining the intraday trading level volume share. We regress the proportion of off-exchange trading by each 30-minute intraday time segment on the announcement day dummy variable with a set of controls, which include firm size *Ln(Size)*, price *InvP*, quoted spread *Spread*, volume turnover *Turnover*, number of analyst coverage *Ln(Analyst Coverage)*, firm-level trading volatility *Volatility*, and market-level volatility *VIX*. We also include year-month time fixed effect, and the standard errors are double clustered at firm-month level. The results are reported in Table 2.4 and the estimated coefficients of control variables are not reported for brevity. Table 2.4 Panel A shows the coefficient estimates for earnings announcements, and Table 2.4 Panel B shows the coefficient estimates for repurchase announcements. Consistent with the findings in Table 2.3, the *EventD* coefficient estimates are positive and significant at 1% level for earnings announcements shown in Table 2.4 Panel A and are insignificant for repurchase announcements shown in Tale 2.4 Panel B. Collectively, the results in Table 2.3 and Table 2.4 support our first hypothesis even after controlling for firm size, spread, turnover, analyst coverage, and volatility. In summary, the results are robust in daily and intraday-trading frequencies after controlling for other variables that may cause the changes in routing venues. Therefore, we postulate that investor's routing preference for off-exchange trading venues is influenced by scheduled events but is not influenced by unscheduled events.

2.4.2 Routing Preference by Institutional Ownership

To try to better understand the mechanism behind the main finding, we test if the preference for using off-exchange trading around scheduled events is moderated by institutional ownership. We first separate firms into three groups based on the proportion of the institutional ownership, and then analyze the changes in off-exchange trading volume share, which is computed as the difference between the average trading volume given the event window and the control window (Days [-30, -10]).

Table 2.5 reports the changes in off-exchange trading volume share for scheduled versus unscheduled announcements by institutional ownership groups using daily intervals. Panel A shows the descriptive statistics for off-exchange trading volume share by institutional ownership groups. Panel B in Table 2.5 presents the changes in off-exchange trading volume share around earnings announcements.

Overall, Table 2.5 Panel B provides preliminary evidence that the changes in off-exchange trading volume share around scheduled announcements could be due to the level of institutional ownership. The off-exchange trading volume share for earnings announcements does not change significantly for stocks with low institutional ownership, and it does increase for stocks with mid- or high institutional ownership. Notably, for stocks with high institutional ownership, the proportion of off-exchange trading starts to increase before the day of the announcement, and the total off-exchange trading volume share increases by 4.86% on the actual earnings announcement day. On the other hand, the changes in off-exchange trading volume share for unscheduled events are not as significant as scheduled events. Panel C in Table 2.5 shows that the overall changes in off-exchange trading volume share for unscheduled events are not significant for stocks with low- and mid-institutional ownership. Notably, the off-exchange trading volume share only increases by 1.56% for stocks with high-institutional ownership on the day of the repurchase announcement. In summary, our overall findings in Table 2.5 support the second hypothesis, which postulates that high institutional ownership does influence routing preference around scheduled events.

Next, we investigate whether the findings in Table 2.5 are still valid under the intraday trading level. Table 2.6 presents the changes in off-exchange trading volume share for the day before, the announcement day, and the day after the earnings and repurchase announcement in 30-minute intervals grouped by institutional ownership. Table 2.6 Panel A reports the changes in off-exchange trading volume share for earnings announcement (scheduled announcement) and Panel B reports the results for repurchase announcement (unscheduled announcements). The change in off-exchange trading volume share using the 30-minute intervals is calculated as the difference between the firm's proportion of the off-exchange trading volume and its trading steady state for the given interval, and the steady state is the average proportion of the off-exchange trading volume with no earnings and repurchase announcements. Overall, the results in Table 2.6 are statistically similar in Table 2.5. The order routing preferences are strongly influenced by the proportion of institutional ownership. Stocks with high institutional ownership have higher off-exchange trading volume share around scheduled events than stocks with low institutional ownership.

In Table 2.7, we apply daily frequency data to regress the proportion of off-exchange trading volume on *EventD* and its interaction term with *IO_High*, a dummy equals one if the firm belongs to high-institutional ownership. To accurately measure this interaction effect, we also control for the *IO_High* dummy and all of the controls specified in Equation (2.2). The positive and significant coefficient estimates for *EventD* and its interaction term with *IO_High* in column (1) suggest that there is more off-exchange trading for scheduled events; furthermore, the firm with high institutional ownership has higher off-exchange trading on the day of the scheduled announcement than the firm with low institutional ownership. In contrast, the insignificant coefficient estimates for *EventD* and its interaction term with *IO_High* in Table 2.7 column (2) suggest that the unchanged routing behavior for unscheduled events is not altered by institutional ownership.

Table 2.8 presents the regressions of the scheduled (Panel A) and unscheduled event dummy (Panel B) on the proportion of off-exchange trading volume by institutional ownership under the 30-minute interval frequency. Similar to Table 2.7, we interact *EventD* with *IO_High* to test whether firms with high institutional ownership experience more off-exchange trading on the event day. The results in Table 2.8 Panel A, consistent with findings in Table 2.7, suggest that high institutional ownership indeed influences routing preference around scheduled events. Likewise, Table 2.8 Panel B shows that the estimates for *Event_D* and the interaction term are insignificant, suggesting that traders do not change their routing preference on the day of the unscheduled event, regardless of the institutional ownership. In summary, our findings in Table 2.8 support Hypothesis 2 that institutional ownership can significantly impact the order routing around the scheduled event.

2.4.3 Routing Preference under COVID-19 Pandemic Period

So far, we have demonstrated that the order routing preference is different under scheduled and unscheduled events. Additionally, the increased trading in off-exchange venues for the scheduled announcement is mainly driven by institutional investors. In this section, we examine Hypothesis 3 to test whether the routing preferences change during crisis time. We focus on the scheduled and unscheduled events during the COVID-19 pandemic period since it affects market liquidity (Baker et al. 2020) and increases market volatility and uncertainty (Albulescu 2021). We use January 2020 to June 2020 as the event window and examine the routing changes for firms that have earnings and repurchase announcements.

Table 2.9 reports the findings for the changes in routing venues around earnings announcements under a 30-minute interval in the COVID-19 pandemic period. *Diff1*, *Diff2*, and *Diff3* represent the difference in the off-exchange trading volume share on the day before, the announcement day, and the day after the announcement with the steady state, respectively. Consistent with the previous analysis, the steady state is calculated as the average proportion of off-exchange trading volume share for days without announcement events, given the designated trading time interval. *Diff2* and *Diff3* are positive and strongly significant through all time segments, suggesting that there is more off-exchange trading around scheduled events.

Table 2.10 reports the differences in off-exchange trading volume share around repurchase announcements using 30-minute trading intervals in the COVID-19 pandemic period. Notably, *Diff1* is insignificant across all time segments. Most of *Diff2* and *Diff3* are insignificant, showing that most investors are unaware of the unscheduled event, thereby not strategically switching the routing venues. These results are consistent with those in

Tables 2.2 and 2.3, again suggesting that the order routing decision is significantly influenced by scheduled events and not influenced by unscheduled events, despite the volatile market environment.

2.5 Conclusion

As more research is conducted on off-exchange trading, we will learn more about this opaque market. It appears that traders tend to use off-exchange trading venues when they can acquire information before the event. Information acquisition is a costly process, and routing orders off-exchange gives traders better pricing to recuperate the costs and potentially profit from the transactions. However, traders are not willing to bear this execution risk when it comes to events that are non-reoccurring, and the timing of the announcement is unknown like with share repurchases. In fact, routing preference does not change around unscheduled events. These findings suggest that these traders are rational, and they take on risk, in this case, execution risk, when the opportunity to find information is available. Even under unprecedented, unpredictable times, their rational behavior persists evident by their unchanging trade routing preference.

Figure 2.1 The Proportion of Off-Exchange Trading Around Firm Announcements by 30-minutes Interval

This figure plots the volume share of the off-market trading on the day before, the announcement day, and the day after the firm announcements under 30-minutes trading intervals around the earnings announcement (Panel A) and the repurchase announcement (Panel B). The horizontal solid line is the steady-state value of the average proportion of off-exchange trading volume with no earnings and repurchase announcements. The data sample includes off-market trading volume share for 1,002 firms that have both earnings announcements and repurchase announcements between January 2014 and December 2019.

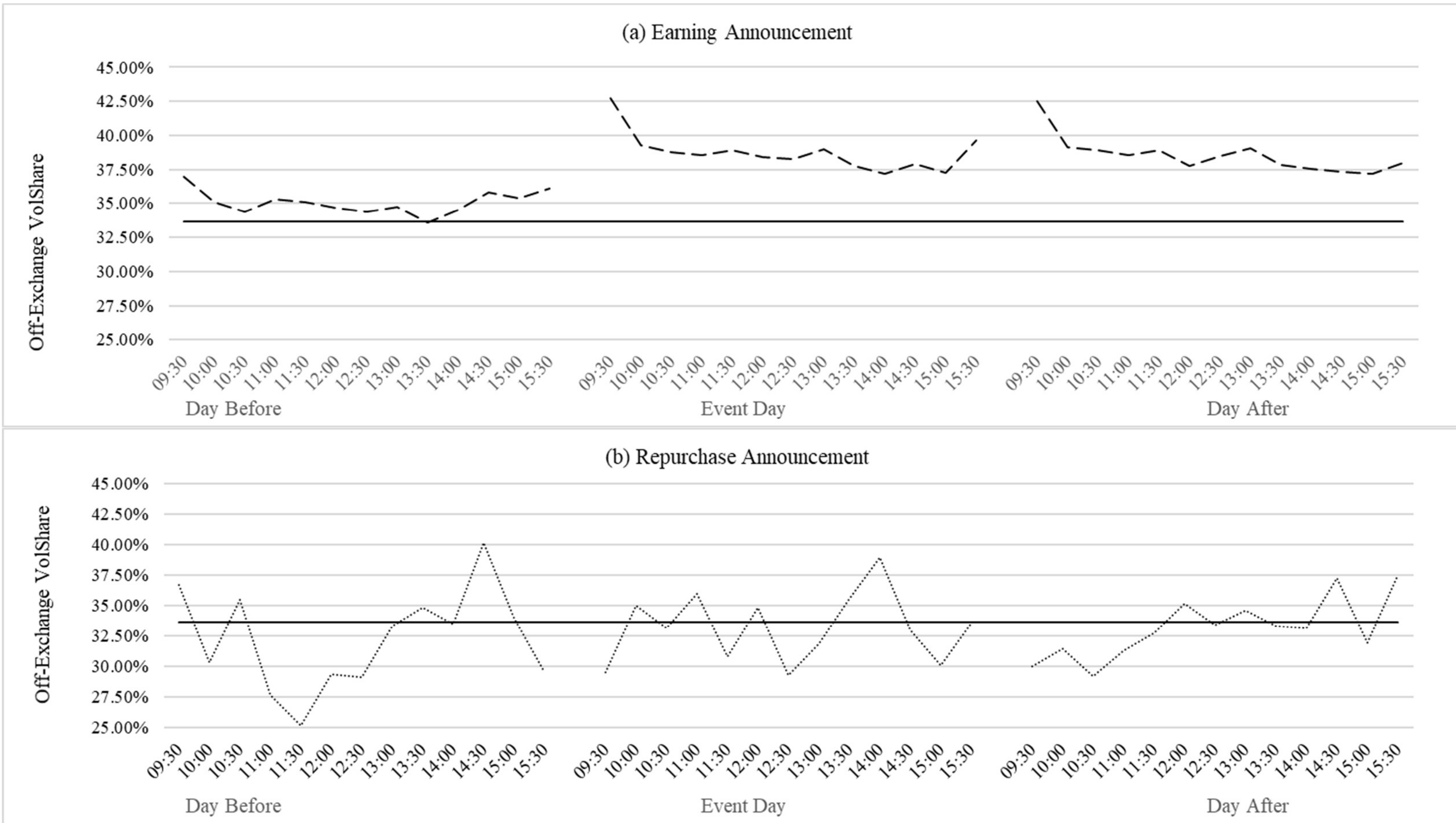


Figure 2.2 The Proportion of Off-Exchange Trading Around Firm Announcements by 1-minutes Interval

This figure plots the volume share of the off-market trading on the day before, the announcement day, and the day after the firm announcement using 1-minute trading intervals around the earnings announcement (Panel A) and the repurchase announcement (Panel B). The horizontal solid line is the steady-state value of the average proportion of off-exchange trading volume with no earnings and repurchase announcements. The data sample includes off-market trading volume share for 1,002 firms that have both earnings and repurchase announcements between January 2014 and December 2019.

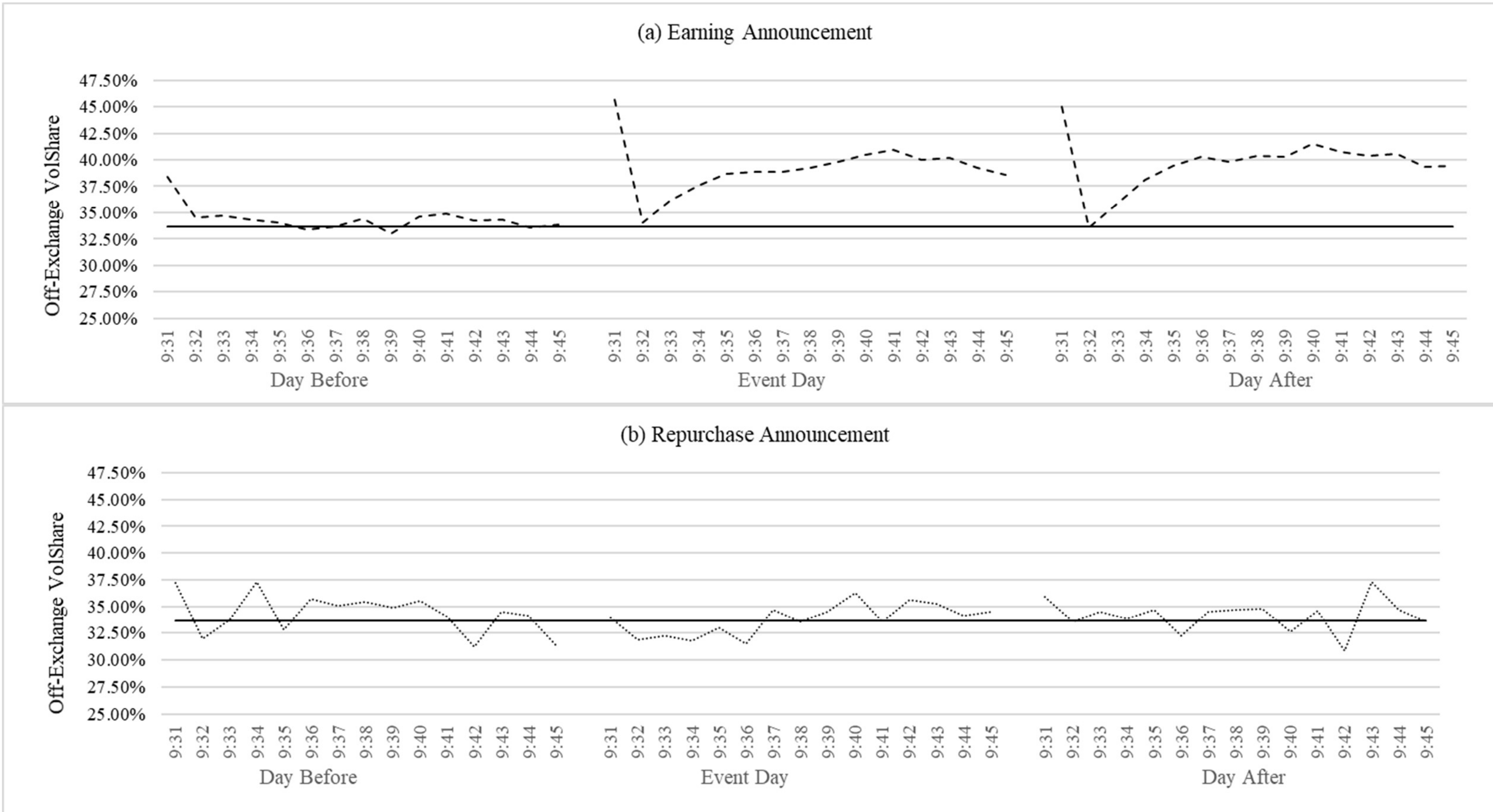


Table 2.1 Descriptive Statistics for Earnings and Share Repurchase Announcements

This table provides information on the statistical attributes of the variables used in this paper. Panel A shows the characteristics of the dependent variables, the proportion of off-exchange trading volume for the daily, 30-minute, and 1-minute intervals of 1,002 firms from January 2014 to June 2020. The events are matched by firm and date. Panel B provides a statistical summary of the control variables reported as daily frequency, all control variables are winsorized at 1% and 99% level. Panel C and Panel D show the number of earnings and repurchase announcements used in our sample for each month.

Variable	N	Mean	Median	Std.Dev	Min	Max
Panel A: Proportion of off-exchange trading volume						
Daily Interval	334,742	0.330	0.310	0.129	0.00	1.00
30-minutes Interval	6,487,102	0.313	0.281	0.186	0.00	1.00
1-minutes Interval	6,639,370	0.293	0.169	0.334	0.00	1.00
Panel B: Control variables						
Institutional Ownership (%)	334,742	0.369	0.282	0.352	0.000	1.000
Firm Size (in millions)	334,742	12.936	2.526	31.216	0.033	211.053
Price ($)	334,742	50.009	34.520	48.790	1.780	270.320
Turnover	334,742	8.261	6.040	7.713	0.253	45.991
Spread	334,742	0.032	0.010	0.053	0.010	0.370
Analyst Coverage	334,742	10.241	8.00	7.882	1.00	33.00
Volatility	334,742	0.034	0.026	0.029	0.000	1.401
VIX	334,742	14.818	13.860	3.829	9.140	40.740

Panel C: Number of Earnings Announcement Events in Our Sample

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2014	256	421	133	417	398	44	496	320	52	488	334	62
2015	284	446	156	479	365	49	481	346	53	449	371	63
2016	250	493	137	420	404	48	419	391	46	404	388	52
2017	241	451	147	363	440	53	377	405	43	399	382	50
2018	234	448	143	357	419	48	382	381	37	421	329	52
2019	246	425	122	358	388	44	407	326	44	428	293	52
All	1,511	2,684	838	2,394	2,414	286	2,562	2,169	275	2,589	2,097	331

Panel D: Number of Repurchase Announcement Events in Our Sample

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2014	39	58	33	33	54	31	43	40	32	48	47	59
2015	37	64	47	26	27	24	19	22	23	19	35	23
2016	27	30	16	9	23	26	12	9	9	11	22	8
2017	10	19	14	16	16	20	9	12	8	8	18	7
2018	14	17	16	20	11	20	9	9	8	12	13	13
2019	7	13	5	7	5	13	6	3	3	7	5	1
All	134	201	131	111	136	134	98	95	83	105	140	111

Table 2.2 Differences in Off-exchange Trading Volume Share for Firm Scheduled vs. Unscheduled Announcements

This table presents the paired t-test results for the differences in the proportion of off-exchange trading volume share for earnings (scheduled) and repurchase (unscheduled) announcements with the steady-state. Panel A reports the differences in half-hour intervals, and Panel B reports the difference in 1-minute intervals for the first 15 minutes. The sample includes off-market trading volume share for 1,002 firms that have both earnings and repurchase announcements between January 2014 and December 2019. The steady-state is calculated as the average proportion of the off-exchange trading volume share with no earnings and repurchase announcements. Diff1 is the difference of off-exchange trading volume share between the day with earnings announcement and the steady-state; Diff2 is the difference of off-exchange trading volume share between the day with repurchase announcement and the steady-state. Paired t-tests are used to calculate the differences, and t-statistics are reported in parentheses. Statistical significance at the 5%, 1%, and 0.1% levels is denoted by *, **, and ***, respectively.

Panel A: Difference in half-hour interval

Time	**Steady State**	**Earnings Announcement**	**Diff 1**	**Repurchase Announcement**	**Diff 2**
9:30-10:00	27.08%	33.10%	6.03%***	27.96%	0.89%
			(29.04)		*(1.31)*
10:00-10:30	33.35%	37.96%	4.62%***	33.98%	0.63%
			(21.61)		*(0.71)*
10:30-11:00	33.33%	37.26%	3.93%***	34.31%	0.98%
			(19.27)		*(1.16)*
11:00-11:30	33.78%	37.67%	3.90%***	34.52%	0.74%
			(17.84)		*(0.81)*
11:30-12:00	33.38%	37.32%	3.94%***	33.66%	0.27%
			(18.42)		*(0.27)*
12:00-12:30	32.97%	36.62%	3.65%***	34.85%	1.88%*
			(15.24)		*(1.97)*
12:30-13:00	32.88%	36.28%	3.40%***	32.67%	-0.21%
			(16.31)		*(-0.22)*
13:00-13:30	32.47%	36.47%	4.00%***	32.39%	-0.08%
			(18.76)		*(-0.14)*
13:30-14:00	33.22%	36.28%	3.06%***	34.21%	0.99%
			(14.07)		*(1.26)*
14:00-14:30	32.97%	35.85%	2.88%***	33.22%	0.25%
			(14.06)		*(0.4)*
14:30-15:00	32.46%	36.11%	3.66%***	32.75%	0.29%
			(17.80)		*(0.56)*
15:00-15:30	31.50%	34.79%	3.29%***	30.19%	-1.31%
			(17.23)		*(-1.65)*
15:30-16:00	26.19%	30.30%	4.11%***	26.94%	0.75%
			(24.42)		*(1.55)*

(Table 2.2 Continued)

Panel B: Difference in 1-minute interval

Time	Steady State	Earnings Announcement	Diff 1	Repurchase Announcement	Diff 2
9:30-10:00	6.25%	8.50%	2.25%***	6.31%	0.06%
			(13.56)		*(0.22)*
10:00-10:30	34.21%	34.65%	0.44%***	32.38%	-1.83%
			(1.11)		*(-1.09)*
10:30-11:00	32.94%	35.39%	2.45%***	31.62%	-1.32%
			(6.59)		*(-0.72)*
11:00-11:30	32.20%	35.91%	3.71%***	30.40%	-1.80%
			(10.01)		*(-1.17)*
11:30-12:00	31.33%	36.02%	4.69%***	30.78%	-0.55%
			(11.91)		*(-0.33)*
12:00-12:30	29.55%	34.17%	4.63%***	27.69%	-1.86%
			(12.15)		*(-1.29)*
12:30-13:00	30.17%	34.91%	4.74%***	31.10%	0.93%
			(11.41)		*(0.76)*
13:00-13:30	30.36%	35.45%	5.09%***	30.32%	-0.03%
			(12.31)		*(0.17)*
13:30-14:00	30.10%	35.63%	5.53%***	30.89%	0.79%
			(13.04)		*(0.68)*
14:00-14:30	29.60%	35.59%	6.00%***	31.92%	2.32%
			(13.49)		*(1.59)*
14:30-15:00	29.29%	35.68%	6.39%***	29.24%	-0.05%
			(13.93)		*(0.65)*
15:00-15:30	29.79%	35.43%	5.64%***	31.58%	1.80%
			(12.87)		*(1.45)*
15:30-16:00	30.45%	36.36%	5.91%***	31.90%	1.45%
			(13.77)		*(1.44)*

Table 2.3 The Effects of Scheduled vs. Unscheduled Events on Proportion of Off-exchange Trading Volume

This table shows the results of the regression of the daily proportion of off-exchange trading volume share around earnings announcements (Col1) and repurchase announcements (Col2) on the event dummy variable (EventD) with a set of controls and year-month fixed effects. EventD is the variable of interest, which takes the value of one if t is the announcement day and zero otherwise. The sample includes 1,002 firms that have both earnings and repurchase announcements between January 2014 and December 2019. The t-statistics are reported in parentheses and are based on the standard errors clustered at the firm-month level. The ***, **, * indicate p-values of 1%, 5% and 10%, respectively. The detailed control variable definitions are provided in Appendix A.

	(1) **Earnings Announcement** **OffVolshare**	**(2)** **Repurchase Announcement** **OffVolshare**
EventD	0.0213***	-0.004
	(26.22)	*(-0.92)*
Ln(Size)	0.0036***	0.0006
	(4.69)	*(0.22)*
InvP	0.5376***	0.5407***
	(37.37)	*(9.30)*
Spread	0.2134***	0.1253*
	(15.32)	*(1.82)*
Turnover	0.0023***	0.0030***
	(34.73)	*(8.84)*
Ln(Analyst Coverage)	-0.0101***	-0.0146***
	(-8.03)	*(-2.89)*
VIX	-0.0031***	-0.0033***
	(-25.15)	*(-3.88)*
Volatility	0.0480**	-0.0525
	(2.52)	*(-0.46)*
Intercept	0.2899***	0.3433***
	(25.89)	*(8.45)*
Time FE	Yes	Yes
Observations	164,086	6,073
R^2	0.178	0.184

Table 2.4 The Effects of Scheduled vs. Unscheduled Events on Proportion of Off-exchange Trading Volume in 30-Minute Interval

This table shows the results of the regressions of the proportion of off-exchange trading around firm earnings announcements (Panel A) and repurchase announcements (Panel B) on the event dummy variable with a set of controls and year-month fixed effects by 30 minute intraday time segments. The dependent variable is the proportion of off-exchange trading volume by designated intraday time segment. EventD is the variable of interest, which takes the value of one if t is the announcement day and zero otherwise. The controls include Ln(Size), InvP, Spread, Turnover, Ln(Analyst Coverage), Volatility, and VIX. The sample includes 1,002 firms that have both earnings and repurchase announcements between January 2014 and December 2019. The t-statistics are reported in parentheses and are based on standard errors clustered at the firm-month level. ***, **, * indicate p-values of 1%, 5% and 10%, respectively. The detailed control variable definitions are provided in Appendix A.

Panel A. Proportion of off-exchange trading volume for earnings announcement

	Event_D	**Controls**	**Time FE**	**Intercept**	**Obs.**	**R^2**
9:30-10:00	0.0295***	Yes	Yes	0.0528***	164,086	0.088
	(22.34)			*(5.10)*		
10:00-10:30	0.0209***	Yes	Yes	0.2285***	164,063	0.072
	(13.78)			*(17.06)*		
10:30-11:00	0.0183***	Yes	Yes	0.2344***	164,017	0.068
	(12.34)			*(17.61)*		
11:00-11:30	0.0209***	Yes	Yes	0.2664***	163,963	0.065
	(13.87)			*(19.39)*		
11:30-12:00	0.0196***	Yes	Yes	0.2311***	163,902	0.060
	(12.86)			*(17.51)*		
12:00-12:30	0.0159***	Yes	Yes	0.2274***	163,822	0.059
	(10.38)			*(16.67)*		
12:30-13:00	0.0164***	Yes	Yes	0.2324***	163,721	0.056
	(10.56)			*(16.89)*		
13:00-13:30	0.0184***	Yes	Yes	0.2345***	163,621	0.056
	(12.19)			*(16.96)*		
13:30-14:00	0.0164***	Yes	Yes	0.2189***	163,449	0.052
	(10.91)			*(16.66)*		
14:00-14:30	0.0155***	Yes	Yes	0.2492***	163,306	0.056
	(10.84)			*(19.10)*		
14:30-15:00	0.0183***	Yes	Yes	0.2488***	163,113	0.058
	(12.71)			*(18.57)*		
15:00-15:30	0.0176***	Yes	Yes	0.2705***	162,931	0.072
	(13.24)			*(20.36)*		
15:30-16:00	0.0235***	Yes	Yes	0.1876***	162,716	0.134
	(23.76)			*(16.93)*		
All time segments	0.0193***	Yes	Yes	0.2214***	2,122,549	0.061
	(26.97)			*(20.03)*		

(Table 2.4 Continued)

Panel B. Proportion of off-exchange trading volume for repurchase announcement						
	Event_D	**Controls**	**Time FE**	**Intercept**	**Obs.**	**R^2**
9:30-10:00	0.0010	Yes	Yes	0.1491***	6,073	0.051
	(0.15)			*(3.25)*		
10:00-10:30	-0.0026	Yes	Yes	0.3402***	6,072	0.074
	(-0.33)			*(6.83)*		
10:30-11:00	0.0050	Yes	Yes	0.2918***	6,064	0.072
	(0.63)			*(5.90)*		
11:00-11:30	0.0007	Yes	Yes	0.3498***	6,062	0.074
	(0.09)			*(6.97)*		
11:30-12:00	0.0012	Yes	Yes	0.3049***	6,060	0.054
	(0.16)			*(6.38)*		
12:00-12:30	0.0156	Yes	Yes	0.3240***	6,053	0.040
	(1.63)			*(6.36)*		
12:30-13:00	-0.0029	Yes	Yes	0.2316***	6,045	0.071
	(-0.35)			*(5.06)*		
13:00-13:30	-0.0101	Yes	Yes	0.2677***	6,034	0.056
	(-1.32)			*(5.13)*		
13:30-14:00	-0.0006	Yes	Yes	0.2937***	5,997	0.036
	(-0.07)			*(5.93)*		
14:00-14:30	0.0024	Yes	Yes	0.2574***	5,973	0.054
	(0.31)			*(5.38)*		
14:30-15:00	-0.0033	Yes	Yes	0.2695***	5,958	0.053
	(-0.45)			*(5.53)*		
15:00-15:30	-0.0133*	Yes	Yes	0.2583***	5,944	0.072
	(-1.83)			*(5.94)*		
15:30-16:00	0.0068	Yes	Yes	0.1922***	5,918	0.113
	(1.29)			*(5.01)*		
All time segments	-0.0002	Yes	Yes	0.2669***	76,072	0.054
	(-0.05)			*(7.46)*		

Table 2.5 Changes in Off-exchange Trading Volume Share for Scheduled vs. Unscheduled Announcements in Daily Interval by Institutional Ownership Group

This table presents univariate results for the off-exchange trading volume share, using daily intervals for earnings and repurchase announcements grouped by the level of institutional ownership. The data sample includes off-market trading volume share for 1,002 firms that have both earnings and repurchase announcements between January 2014 and December 2019 Panel A reports the statistics summary for off-exchange trading volume share for each institutional ownership group. Each firm is placed into a low, mid, or high institutional ownership group based on the rank of the number of shares held by institutions divided by the number of shares outstanding. Panel B reports the changes in off-exchange trading volume share for earnings announcements and Panel C reports the changes in off-exchange trading volume share for repurchase announcements. *LOW, MID* and *HIGH* are the low-, mid- and high-institutional ownership, respectively. The change in off-exchange trading volume share is the difference between the average trading volume given the event window and the control window (Days [-30, -10]). Paired t-tests are used to calculate the differences, and t-statistics are reported in parentheses. Statistical significance at the 5%, 1%, and 0.1% levels are denoted by *, **, and ***, respectively.

Panel A: Descriptive Statistics for Off-exchange Trading Volume Share in Daily Interval by Institutional Ownership group

Off-exchange Trading Volume Share	Mean	Median	Stdev	Min	Max
LOW	37.18%	34.44%	16.69%	0.02%	100.00%
MID	31.29%	30.20%	10.15%	0.17%	100.00%
HIGH	30.57%	29.44%	9.95%	0.38%	100.00%

Panel B: Changes in Off-exchange Trading Volume Share for Earnings Announcement in Daily Interval

Event Window	LOW	MID	HIGH
Days [-5, -1]	0.52%	0.45%	0.25%*
	(0.53)	*(1.29)*	*(2.40)*
Day [0]	2.16%	1.94%***	4.86%***
	(1.23)	*(3.62)*	*(30.29)*
Days [+1, +5]	1.92%	1.02%**	1.11%***
	(1.90)	*(2.83)*	*(10.42)*
Days [-5, +5]	1.28%	0.85%**	1.07%***
	(1.62)	*(2.94)*	*(12.38)*

Panel C: Changes in Off-exchange Trading Volume Share for Repurchase Announcement in Daily Interval

Event Window	LOW	MID	HIGH
Days [-5, -1]	0.57%	0.36%	0.16%
	(0.48)	*(0.68)*	*(0.80)*
Day [0]	-0.16%	-0.67%	1.56%***
	(-0.08)	*(-0.63)*	*(5.12)*
Days [+1, +5]	1.51%	0.83%	0.65%**
	(1.22)	*(1.20)*	*(3.14)*
Days [-5, +5]	0.95%	0.50%	0.51%**
	(0.92)	*(0.96)*	*(3.18)*

Table 2.6 Changes in Off-exchange Trading Volume Share at Earnings and Repurchase Announcements in 30-Minute Interval by Institutional Ownership Group

This table presents univariate results for the changes in off-exchange trading volume share for the day before (Day [-1]), the announcement day (Day [0]), and the day after (Day [+1]) with the steady state for earnings and repurchase announcements grouped by the level of institutional ownership. The steady state is calculated as the average proportion of the off-exchange trading volume share with no earnings and repurchase announcements. LOW, MID, HIGH denotes low, mid, and high institutional ownership groups, respectively. Each firm is placed into a low, mid, or high institutional ownership group based on the rank of the number of shares held by institutions divided by the number of shares outstanding. The data sample includes off-market trading volumeshare for 1,002 firms that have both earnings and repurchase announcements between January 2014 and December 2019. Panel A reports the changes in off-exchange trading volume share for earnings announcements, and Panel B reports the changes in off-exchange trading volume share for repurchase announcements. Paired t-tests are used to calculate the differences, and the t-statistics are reported in parentheses. Statistical significance at the 5%, 1%, and 0.1% levels is denoted by *, **, and ***, respectively.

Panel A: Changes in Off-exchange Trading Volume Share in 30 minutes Intervals for Earnings Announcement by the Institutional Ownership Group

	LOW			MID			HIGH		
Time	Day [-1]	Day [0]	Day [+1]	Day [-1]	Day [0]	Day [+1]	Day [-1]	Day [0]	Day [+1]
9:30-10:00	0.06%	1.20%	4.51%***	2.26%***	6.87%***	6.07%***	2.39%***	7.13%***	6.66%***
	(0.05)	*(1.1)*	*(4.6)*	*(6.46)*	*(16.85)*	*(16.01)*	*(12.21)*	*(33.49)*	*(30.74)*
10:00-10:30	0.69%	3.43%*	3.24%**	1.49%***	4.85%***	4.67%***	1.05%***	5.28%***	4.96%***
	(0.54)	*(2.53)*	*(3.07)*	*(3.82)*	*(12.00)*	*(11.66)*	*(5.20)*	*(23.87)*	*(26.33)*
10:30-11:00	-1.67%	0.62%	4.52%***	0.89%*	4.25%***	3.94%***	1.13%***	4.84%***	4.68%***
	(-1.09)	*(0.44)*	*(3.7)*	*(2.12)*	*(10.2)*	*(9.58)*	*(6.08)*	*(22.3)*	*(23.59)*
11:00-11:30	1.42%	2.40%	1.38%	0.93%*	3.82%***	4.22%***	1.09%***	4.88%***	4.15%***
	(1.25)	*(1.71)*	*(1.13)*	*(2.4)*	*(9.49)*	*(9.79)*	*(5.35)*	*(22.67)*	*(21.31)*
11:30-12:00	-0.64%	1.75%	3.14%**	1.59%***	4.10%***	4.07%***	1.09%***	4.77%***	4.25%***
	(-0.45)	*(1.48)*	*(3.11)*	*(3.5)*	*(9.79)*	*(9.83)*	*(5.44)*	*(22.48)*	*(22.22)*
12:00-12:30	0.53%	2.63%*	3.00%*	1.33%**	3.76%***	3.42%***	1.12%***	4.26%***	4.03%***
	(0.41)	*(2.2)*	*(2.29)*	*(2.96)*	*(8.04)*	*(9.06)*	*(5.70)*	*(20.12)*	*(19.37)*
12:30-13:00	0.46%	-0.67%	2.51%*	1.19%**	3.03%***	3.97%***	0.86%***	4.57%***	3.48%***
	(0.33)	*(-0.49)*	*(2.35)*	*(2.7)*	*(7.8)*	*(9.36)*	*(4.37)*	*(22.11)*	*(16.71)*

(Table 2.6 Continued)

	LOW			MID			HIGH		
Time	Day [-1]	Day [0]	Day [+1]	Day [-1]	Day [0]	Day [+1]	Day [-1]	Day [0]	Day [+1]
13:00-13:30	-0.65%	3.61%**	4.39%***	1.30%***	4.77%***	4.04%***	1.78%***	4.43%***	3.91%***
	(-0.48)	*(3.05)*	*(3.31)*	*(3.1)*	*(12.03)*	*(10.23)*	*(7.81)*	*(21.05)*	*(17.57)*
13:30-14:00	-2.04%	1.36%	2.52%*	0.29%	3.03%***	3.14%***	0.96%***	3.85%***	2.44%***
	(-1.34)	*(1.15)*	*(2.16)*	*(0.63)*	*(7.51)*	*(7.95)*	*(4.91)*	*(18.68)*	*(12.92)*
14:00-14:30	-1.90%	0.76%	1.45%	1.22%**	3.08%***	2.76%***	1.11%***	3.51%***	2.76%***
	(-1.63)	*(0.67)*	*(1.23)*	*(3.07)*	*(7.79)*	*(7.10)*	*(5.59)*	*(18.22)*	*(15.86)*
14:30-15:00	0.87%	2.64%**	1.80%	1.43%***	3.97%***	2.44%***	1.45%***	3.79%***	2.78%***
	(0.68)	*(2.34)*	*(1.81)*	*(3.38)*	*(10.54)*	*(6.45)*	*(7.88)*	*(18.69)*	*(14.17)*
15:00-15:30	0.26%	1.93%	1.43%	1.71%***	3.28%***	2.52%***	1.60%***	3.81%***	2.45%***
	(0.17)	*(1.91)*	*(1.13)*	*(4.21)*	*(8.52)*	*(6.13)*	*(9.32)*	*(21.52)*	*(13.79)*
15:30-16:00	-2.91%**	4.12%***	3.78%***	2.38%***	4.01%***	2.70%***	2.38%***	4.48%***	2.87%***
	(-2.86)	*(5.31)*	*(4.19)*	*(7.15)*	*(13.32)*	*(9.58)*	*(19.29)*	*(32.52)*	*(20.79)*

(Table 2.6 Continued)

Panel B. Changes in Off-exchange Trading Volume Share in 30 minutes Intervals for Repurchase Announcement by The Institutional Ownership Group

	LOW			MID			HIGH		
Time	Day [-1]	Day [0]	Day [+1]	Day [-1]	Day [0]	Day [+1]	Day [-1]	Day [0]	Day [+1]
9:30-10:00	8.73%*	2.76%	-0.76%	-1.20%	0.07%	3.03%	0.76%	1.31%*	2.33%***
	(2.12)	*(0.71)*	*(-0.21)*	*(-0.52)*	*(0.03)*	*(1.4)*	*(1.01)*	*(1.98)*	*(3.23)*
10:00-10:30	4.53%	2.04%	-3.08%	-4.22%	-2.23%	3.07%	0.32%	0.95%	2.56%***
	(1.05)	*(0.46)*	*(-0.79)*	*(-1.64)*	*(-0.88)*	*(1.18)*	*(0.39)*	*(1.37)*	*(3.56)*
10:30-11:00	5.46%	2.73%	-4.52%	-3.53%	0.85%	1.24%	0.68%	0.83%	1.99%**
	(1.48)	*(0.6)*	*(-0.95)*	*(-1.48)*	*(0.32)*	*(0.43)*	*(0.81)*	*(1.07)*	*(2.62)*
11:00-11:30	-0.44%	1.38%	-4.22%	-0.58%	0.04%	0.65%	-0.01%	0.70%	1.47%*
	(-0.13)	*(0.37)*	*(-1.48)*	*(-0.21)*	*(0.01)*	*(0.24)*	*(-0.01)*	*(0.98)*	*(1.96)*
11:30-12:00	-4.41%	-8.55%*	-3.57%	-1.29%	2.00%	-0.47%	-0.02%	0.96%	0.95%
	(-0.93)	*(-2.15)*	*(-1.01)*	*(-0.47)*	*(0.70)*	*(-0.16)*	*(-0.03)*	*(1.20)*	*(1.28)*
12:00-12:30	-7.30%*	-2.52%	0.04%	-7.86%	3.77%	5.22%*	-0.05%	2.99%***	2.19%**
	(-2.06)	*(-0.59)*	*(0.01)*	*(-3.2)*	*(1.19)*	*(1.99)*	*(-0.06)*	*(3.49)*	*(3.03)*
12:30-13:00	3.59%	-1.36%	2.14%	-5.00%	-3.42%	0.15%	0.63%	1.42%	0.65%
	(1.06)	*(-0.30)*	*(0.60)*	*(-1.9)*	*(-1.36)*	*(0.06)*	*(0.77)*	*(1.75)*	*(0.82)*

(Table 2.6 Continued)

	LOW			MID			HIGH		
Time	Day [-1]	Day [0]	Day [+1]	Day [-1]	Day [0]	Day [+1]	Day [-1]	Day [0]	Day [+1]
13:00-13:30	4.20%	4.54%	1.59%	-3.08%	-4.41%	1.71%	0.86%	0.63%	1.29%
	(0.93)	*(1.15)*	*(0.49)*	*(-1.13)*	*(-1.71)*	*(0.61)*	*(0.99)*	*(0.87)*	*(1.63)*
13:30-14:00	-1.94%	1.41%	-6.84%	-1.39%	1.06%	-0.92%	-0.81%	1.46%	1.48%
	(-0.46)	*(0.36)*	*(-1.72)*	*(-0.48)*	*(0.38)*	*(-0.35)*	*(-0.98)*	*(1.75)*	*(1.87)*
14:00-14:30	2.03%	8.70%*	-1.02%	-0.91%	-0.39%	2.45%	-0.42%	-0.51%	-0.33%
	(0.49)	*(1.94)*	*(-0.22)*	*(-0.33)*	*(-0.15)*	*(0.98)*	*(-0.5)*	*(-0.71)*	*(-0.48)*
14:30-15:00	13.12%	10.49%**	5.89%	2.34%	-5.75%**	1.79%	0.65%	1.20%	0.72%
	(3.09)	*(2.97)*	*(1.39)*	*(0.84)*	*(-2.27)*	*(0.69)*	*(0.83)*	*(1.6)*	*(1.07)*
15:00-15:30	2.90%	-3.76%	1.08%	-0.54%	-5.01%*	6.13%*	-0.31%	0.02%	2.11%**
	(0.71)	*(-0.84)*	*(0.35)*	*(-0.21)*	*(-2.15)*	*(2.26)*	*(-0.48)*	*(0.02)*	*(2.90)*
15:30-16:00	1.07%	-0.30%	0.06%	-0.39%	1.76%	3.06%	0.66%	0.56%	0.67%
	(0.33)	*(-0.12)*	*(0.02)*	*(-0.25)*	*(0.90)*	*(1.65)*	*(1.26)*	*(1.27)*	*(1.35)*

Table 2.7 The Effects of Scheduled vs. Unscheduled Events on Proportion of Off-exchange Trading Volume by Institutional Ownership

This table shows the results of the regression of the proportion of off-exchange trading around firm earnings announcements (Col1) and repurchase announcements (Col2) on the Event dummy variable (EventD) with a set of controls including an interaction term between EventD and IO_High. EventD is the variable of interest, which takes the value of one if t is the announcement day and zero otherwise. IO_High is a binary variable equal to one if the firm is in the high-institutional ownership group. The sample includes 1,002 firms that have both earnings and repurchase announcements between January 2014 and December 2019. The t-statistics are reported in parentheses and are based on the standard errors clustered at the firm-month level. ***, **,* indicate p-values of 1%, 5% and 10%, respectively. The detailed control variable definitions are provided in Appendix A.

	(1) Earnings Announcement OffVolshare	**(2) Repurchase Announcement OffVolshare**
EventD	0.0145***	-0.004
	(10.06)	*(-0.92)*
EventD × IO_High	0.0106***	0.0131
	(6.66)	*(1.28)*
IO_High	-0.0263***	-0.0383***
	(-18.09)	*(-5.67)*
Ln(Size)	0.0043***	0.0024
	(5.85)	*(0.89)*
InvP	0.5147***	0.5141***
	(35.42)	*(8.71)*
Spread	0.1961***	0.1151*
	(14.37)	*(1.73)*
Turnover	0.0023***	0.0030***
	(35.81)	*(9.05)*
Ln(Analyst Coverage)	-0.0088***	-0.0108**
	(-7.21)	*(-2.21)*
VIX	-0.0030***	-0.0034***
	(-24.59)	*(-4.16)*
Volatility	0.0509***	-0.0740
	(2.74)	*(-0.65)*
Intercept	0.2930***	0.3377***
	(26.88)	*(8.57)*
Time FE	Yes	Yes
Observations	164,086	6,073
R^2	0.178	0.184

Table 2.8 The Effects of Scheduled vs. Unscheduled Events on Proportion of Off-exchange Trading Volume by Institutional Ownership in 30-Minute Interval

This table shows the results of the regressions of the proportion of off-exchange trading volume share around earnings announcements (Panel A) and repurchase announcements (Panel B) on the Event dummy variable with a set of controls including an interaction term between EventD and IO_High in 30-minute intraday segments. The dependent variable is the proportion of off-exchange trading volume share by the designated intraday time segment. EventD is the variable of interest, which takes the value of one if t is the announcement day and zero otherwise. IO_High is a binary variable equal to one if the firm is in the high-institutional ownership group. Controls include Ln(Size), InvP, Spread, Turnover, Ln(Analyst Coverage), Volatility, and VIX. The sample includes 1,002 firms that have both earnings and repurchase announcements between January 2014 and December 2019. The t-statistics are reported in parentheses and are based on the standard errors clustered at the firm-month level. ***, **, * indicate the p-values of 1%, 5% and 10%, respectively. The detailed control variable definitions are provided in Appendix A.

Panel A. Proportion of off-exchange trading volume for earnings announcement								
	Event_D	**EventD × IO_High**	**IO_High**	**Controls**	**Time FE**	**Intercept**	**Obs.**	**R^2**
9:30-10:00	0.0245***	0.0079***	-0.0164***	Yes	Yes	0.0548***	164,086	0.089
	(10.23)	*(2.92)*	*(-10.49)*			*(5.30)*		
10:00-10:30	0.0144***	0.0101***	-0.0266***	Yes	Yes	0.2315***	164,063	0.075
	(5.13)	*(3.25)*	*(-14.66)*			*(17.58)*		
10:30-11:00	0.0107***	0.0118***	-0.0261***	Yes	Yes	0.2375***	164,017	0.071
	(3.84)	*(3.82)*	*(-14.58)*			*(18.07)*		
11:00-11:30	0.0128***	0.0126***	-0.0272***	Yes	Yes	0.2697***	163,963	0.069
	(4.61)	*(4.09)*	*(-15.25)*			*(19.98)*		
11:30-12:00	0.0127***	0.0108***	-0.0267***	Yes	Yes	0.2343***	163,902	0.063
	(4.38)	*(3.38)*	*(-14.89)*			*(18.07)*		
12:00-12:30	0.0088***	0.0111***	-0.0266***	Yes	Yes	0.2307***	163,822	0.063
	(2.99)	*(3.41)*	*(-14.88)*			*(17.18)*		
12:30-13:00	0.0065**	0.0155***	-0.0248***	Yes	Yes	0.2359***	163,721	0.059
	(2.20)	*(4.81)*	*(-13.98)*			*(17.38)*		
13:00-13:30	0.0128***	0.0086***	-0.0248***	Yes	Yes	0.2375***	163,621	0.059
	(4.53)	*(2.72)*	*(-14.05)*			*(17.42)*		
13:30-14:00	0.0099***	0.0101***	-0.0249***	Yes	Yes	0.2221***	163,449	0.056
	(3.47)	*(3.23)*	*(-14.34)*			*(17.13)*		
14:00-14:30	0.0076***	0.0124***	-0.0252***	Yes	Yes	0.2526***	163,306	0.060
	(2.87)	*(4.19)*	*(-14.76)*			*(19.66)*		
14:30-15:00	0.0157***	0.0038	-0.0247***	Yes	Yes	0.2516***	163,113	0.062
	(5.85)	*(1.29)*	*(-14.60)*			*(19.07)*		
15:00-15:30	0.0121***	0.0085***	-0.0261***	Yes	Yes	0.2739***	162,931	0.077
	(4.86)	*(3.10)*	*(-15.84)*			*(21.03)*		
15:30-16:00	0.0213***	0.0033*	-0.0177***	Yes	Yes	0.1899***	162,716	0.138
	(11.90)	*(1.69)*	*(-13.29)*			*(17.48)*		
All time segments	0.0130***	0.0097***	-0.0244***	Yes	Yes	0.2243***	2,122,549	0.064
	(11.22)	*(7.50)*	*(-17.36)*			*(20.75)*		

(Table 2.8 Continued)

Panel B. Proportion of off-exchange trading volume for repurchase announcement								
	Event_D	**EventD × IO_High**	**IO_High**	**Controls**	**Time FE**	**Intercept**	**Obs.**	**R^2**
9:30-10:00	-0.0090	0.0163	-0.0268***	Yes	Yes	0.1457***	6,073	0.055
	(-0.64)	*(1.06)*	*(-3.27)*			*(3.23)*		
10:00-10:30	-0.0091	0.0106	-0.0303***	Yes	Yes	0.3358***	6,072	0.078
	(-0.54)	*(0.59)*	*(-3.41)*			*(6.82)*		
10:30-11:00	0.0097	-0.0077	-0.0316***	Yes	Yes	0.2860***	6,064	0.076
	(0.56)	*(-0.41)*	*(-3.74)*			*(5.92)*		
11:00-11:30	-0.0030	0.0062	-0.0402***	Yes	Yes	0.3436***	6,062	0.080
	(-0.17)	*(0.33)*	*(-4.81)*			*(7.02)*		
11:30-12:00	-0.0064	0.0124	-0.0351***	Yes	Yes	0.3000***	6,060	0.059
	(-0.37)	*(0.67)*	*(-4.18)*			*(6.43)*		
12:00-12:30	0.0172	-0.0025	-0.0314***	Yes	Yes	0.3187***	6,053	0.044
	(0.81)	*(-0.11)*	*(-3.65)*			*(6.33)*		
12:30-13:00	-0.0206	0.0286	-0.0304***	Yes	Yes	0.2287***	6,045	0.075
	(-1.14)	*(1.47)*	*(-3.60)*			*(5.07)*		
13:00-13:30	-0.0225	0.0201	-0.0391***	Yes	Yes	0.2630***	6,034	0.062
	(-1.36)	*(1.11)*	*(-4.66)*			*(5.18)*		
13:30-14:00	0.0028	-0.0054	-0.0306***	Yes	Yes	0.2886***	5,997	0.040
	(0.16)	*(-0.28)*	*(-3.83)*			*(5.92)*		
14:00-14:30	0.0218	-0.0310*	-0.0223***	Yes	Yes	0.2517***	5,973	0.057
	(1.28)	*(-1.71)*	*(-2.72)*			*(5.34)*		
14:30-15:00	-0.0211	0.0284	-0.0363***	Yes	Yes	0.2660***	5,958	0.059
	(-1.28)	*(1.59)*	*(-4.65)*			*(5.62)*		
15:00-15:30	-0.0331**	0.0319*	-0.0418***	Yes	Yes	0.2543***	5,944	0.081
	(-2.12)	*(1.88)*	*(-5.75)*			*(6.07)*		
15:30-16:00	0.0152	-0.0132	-0.0236***	Yes	Yes	0.1880***	5,918	0.119
	(1.28)	*(-1.05)*	*(-3.95)*			*(5.01)*		
All time segments	0.0057	0.009	-0.0326***	Yes	Yes	0.262***	76,072	0.059
	(0.81)	*(1.17)*	*(-5.02)*			*(7.60)*		

Table 2.9 Differences in Off-exchange Trading Volume Share for Scheduled Announcements in COVID-19 Pandemic Period

This table presents univariate results for the differences in the proportion of off-exchange trading volume share for earnings announcements with the steady state in half-hour intervals. The data sample includes off-exchange trading volume share for 772 firms with earnings announcements between January 2020 and June 2020. The steady state is calculated as the average proportion of off-exchange trading volume share with no earnings and repurchase announcements by month. Diff1, Diff2, and Diff 3 are the off-exchange trading volume share difference for the day before, the announcement day, and the day after the earnings announcement and the steady state, respectively. Paired t-tests are used to calculate the differences, and the t-statistics are reported in parentheses. Statistical significance at the 5%, 1%, and 0.1% levels is denoted by *, **, and ***, respectively.

Time	**Steady State**	**Day Before**	**Diff1**	**Event Day**	**Diff2**	**Day After**	**Diff3**
9:30-10:00	26.71	28.07	1.36***	32.02	5.31***	32.63	5.93***
			(3.37)		*(13.13)*		*(14.51)*
10:00-10:30	34.65	35.97	1.31**	37.90	3.25***	37.63	2.98***
			(2.71)		*(7.23)*		*(6.61)*
10:30-11:00	33.84	35.33	1.49**	36.90	3.06***	37.66	3.82***
			(3.23)		*(6.73)*		*(7.99)*
11:00-11:30	34.03	34.97	0.94*	37.71	3.68***	37.26	3.23***
			(2.05)		*(8.38)*		*(7.11)*
11:30-12:00	33.53	34.61	1.08*	36.86	3.33***	37.47	3.94***
			(2.20)		*(7.01)*		*(7.83)*
12:00-12:30	33.73	34.87	1.14*	36.96	3.23***	37.24	3.51***
			(2.35)		*(6.98)*		*(7.22)*
12:30-13:00	32.76	34.41	1.65***	35.33	2.57***	35.67	2.91***
			(3.41)		*(5.47)*		*(6.24)*
13:00-13:30	33.18	34.54	1.36**	36.17	2.99***	36.51	3.34***
			(2.96)		*(6.68)*		*(6.90)*
13:30-14:00	32.97	33.40	0.43	35.40	2.44***	35.58	2.62***
			(0.92)		*(5.59)*		*(5.58)*
14:00-14:30	32.80	33.79	0.99*	36.16	3.37***	34.91	2.12***
			(2.14)		*(7.62)*		*(4.61)*
14:30-15:00	31.61	32.59	0.98*	34.41	2.80***	34.90	3.30***
			(2.32)		*(6.44)*		*(7.19)*
15:00-15:30	31.35	33.19	1.84***	34.04	2.69***	33.35	2.00***
			(4.29)		*(6.95)*		*(4.86)*
15:30-16:00	25.63	28.18	2.55***	29.20	3.57***	28.79	3.16***
			(8.67)		*(12.47)*		*(11.24)*

Table 2.10 Differences in Off-exchange Trading Volume Share for Unscheduled Announcements in COVID-19 Pandemic Period

This table presents univariate results for the differences in the proportion of off-exchange trading volume share for earnings announcements and the steady state by half-hour intervals. The data sample includes off-exchange trading volume share for 150 firms that have earnings announcements between January 2020 and June 2020. The steady state is calculated as the average proportion of off-exchange trading volume share with no earnings and repurchase announcements by month. Diff1, Diff2, and Diff3 are the off-exchange trading volume share difference for the day before, the day of, and the day after the earnings announcement and the steady state, respectively. Paired t-tests are used to calculate the differences, and the t-statistics are reported in parentheses. Statistical significance at the 5%, 1%, and 0.1% levels is denoted by *, **, and ***, respectively.

Time	Steady State	Day Before	Diff1	Event Day	Diff2	Day After	Diff3
9:30-10:00	30.47	30.95	0.49	21.05	-9.41	30.15	-0.32
			(0.00)		*(-3.33)*		*(-0.36)*
10:00-10:30	42.39	45.91	3.53	41.73	-0.65	42.99	0.60
			(0.02)		*(-0.46)*		*(-0.03)*
10:30-11:00	40.39	37.79	-2.59	39.47	-0.92	35.00	-5.39
			(-0.05)		*(-0.42)*		*(-1.44)*
11:00-11:30	40.79	41.74	0.95	42.17	1.39	38.95	-1.83
			(-0.01)		*(0.02)*		*(-0.6)*
11:30-12:00	40.42	45.89	5.47	46.87	6.44	42.45	2.03
			(0.03)		*(1.08)*		*(0.24)*
12:00-12:30	40.40	43.53	3.13	37.88	-2.52	49.77	9.37
			(0.01)		*(-0.67)*		*(1.69)*
12:30-13:00	40.05	44.98	4.94	43.30	3.26	44.70	4.66
			(0.03)		*(0.52)*		*(0.65)*
13:00-13:30	41.19	38.99	-2.20	41.31	0.12	40.04	-1.16
			(-0.05)		*(-0.35)*		*(-0.35)*
13:30-14:00	42.60	41.83	-0.77	41.19	-1.41	50.44	7.84*
			(-0.03)		*(-0.66)*		*(1.85)*
14:00-14:30	40.87	46.71	5.84	38.81	-2.06	48.47	7.60
			(0.03)		*(-0.75)*		*(1.22)*
14:30-15:00	40.71	45.83	5.12	29.91	-10.80***	38.66	-2.04
			(0.02)		*(-3.99)*		*(-0.05)*
15:00-15:30	37.16	39.71	2.56	34.45	-2.71	38.83	1.67
			(0.01)		*(-0.92)*		*(0.01)*
15:30-16:00	30.18	33.19	3.02	31.52	1.35	31.74	1.56
			(0.02)		*(0.10)*		*(-0.20)*

CHAPTER 3: MARKET FRAGMENTATION AND MANIPULATION

3.1 Introduction

Equity trading in the U.S. is currently dispersed across 16 national exchanges, more than thirty alternative trading systems, and numerous broker-dealers and wholesale market makers (SEC, 2021). Based on pre-trade opacity, the trading venues can be separated into lit- and off-exchanges. The bid and ask quote information is posted publicly at lit-exchange, while an off-exchange does not provide price quotation information. Currently, all 16 U.S. national securities exchanges are defined as lit-exchanges and are regulated by U.S. Securities and Exchange Commission (SEC). At the same time, off-exchanges are regulated by the Financial Industry Regulatory Authority (FINRA). FINRA separates off-exchanges broadly into two groups. The first group is the Alternative Trading System (ATS), which matches the buyer and seller without any intermediary. Institutional investors are more likely to utilize ATSs to trade. The second group encompasses over-the-counter (OTC) non-ATS dealers, or wholesale market makers, which provide liquidity by buying and selling stocks as a counterparty. Most marketable orders placed by retail investors in the U.S. have been found to be executed through wholesalers (O'Hara 2015; Boehmer et al. 2021; Jain et al. 2020).

Overall, lit- and off-exchanges have different trading system structures, which affect the venue's pricing rule and provide different degrees of transparency and execution quality. Given this highly fragmented trading environment, examining the determinants of the investors' routing order decisions and associated impact on the market has become an important research topic in the literature. Several dynamic trading fragmentation studies show that the final venue routing decision may depend on multiple trade-offs between the transaction cost, execution probability, and information asymmetry risk[43]. Routing volume to a venue could decrease when that venue has a high execution risk, high asymmetry information risk, and low liquidity.

Meanwhile, variation in investors' sentiment is another critical factor that affects routing changes. Any release of macroeconomic and firm news updates investors' beliefs towards the future and affects their sentiment. The change in sentiment not only affects the stock price, volume, and volatility around the event, but also the market liquidity and information asymmetry, thus altering the order routing decision[44].

The issue of stock manipulation has received considerable critical attention by market since it could cause a significant loss to market participants. For instance, an alleged stock manipulation case in 2016 generated more than 17 million in gross trading proceeds.[45] Yet, most academic studies in the relation between market fragmentation and information shock have only focused on either broad macroeconomic announcements or firm operational announcements. There has been little quantitative analysis of the relation between stock manipulation and market fragmentation due to insufficient data for stock manipulations. Intuitively, manipulation is different from other information shocks or firm announcements in several ways. First, stock market manipulation is typically an intentional action performed by an informed trader seeking profit; hence it is difficult to detect. That is, many traders are unaware of manipulation when it happens. Second, manipulation distorts resource allocation, reducing market efficiency in the short term.

---

[43] See Friederich and Payne (2007), Menkveld, Yueshen, and Zhu (2017), Brolley (2020).

[44] See Chae (2005), Kurov et al. (2019) and Menkveld, Yueshen, and Zhu (2017).

[45] See https://www.justice.gov/usao-nj/pr/new-york-man-indicted-17-million-microcap-stock-manipulation-scheme.

Moreover, stock manipulation could harm investor confidence and discourage participation in the long term (Jarrow 1992; Pirrong 1995; Comerton-Forde and Putniņš 2014). In this paper, we use a novel source of manipulation data to expand on the innovative financial market misconduct literature that explores the impact of stock manipulation on dynamic trading fragmentation. To our knowledge, this is the first study that examines the changes in routing venues on market manipulation.

We use stock continuous stock trading manipulation alert from SMARTS, Inc. and Capital Market CRC (CMCRC) as proxies of stock market manipulation, and we investigate the changes in trading volume by exchange around manipulation events. Our baseline analysis includes a U.S. stock population of 1,722 unique firms identified to have at least one manipulation event from 2014.01 to 2018.12. We recognize that stocks with price manipulation may not be random; thereby, our study may have a selection bias issue. To address the potential sample selection bias issue, we employ the Heckman 2-stage selection model. Results from the Heckman 2-stage selection model confirm that selection bias is not a factor in explaining the relation of fragmentation and market manipulation.

Previous studies on stock manipulation suggest that it could significantly increase stock illiquidity and volatility[46]. As a theoretical model prediction, when the bid-ask spread is wider, and market volatility is higher, informed trading increases in off-exchanges while overall off-exchange volume share decreases (Zhu 2014). As a model prediction, order flow should move to exchanges with higher transparency during periods of high market volatility. However, empirical studies motivated by such predictions find modest support. On the one hand, Jiang, McInish, and Upson (2012) find that the trading volume shifts

[46] See Hillion and Suominen (2004), Comerton-Forde and Putniņš (2011), Aggarwal and Wu (2006).

from off-exchange to lit-exchanges when the prices are volatile. On the other hand, Garvey, Huang, and Wu (2016) suggest high volatility could reduce the liquidity in the lit exchange, and their results document a positive relation between volatility and dark trading volume. We contribute to the debate by showing manipulation does not equally impact the trading volume in each exchange. More importantly, changes in off-exchange trading volume share from manipulation are positively associated with retail trading attention. In addition, further analysis shows that higher retail trading participation during manipulation events mitigates its detrimental effects on market liquidity. Our results confirm the liquidity provision role for retail trading and show that retail trading induced from manipulation is uninformed.

The remainder of the chapter is organized as follows. Section 3.2 reviews relative literature and develops our hypotheses. Section 3.3 presents our data and methodology. Section 3.4 reports our main empirical results of the effects of manipulation on off-exchange trading, and the additional analysis on the consequence of price manipulation changes in off-exchange trading volume. The conclusion and policy implication are presented in section 3.5.

3.2 Literature Review and Hypothesis Development

3.2.1 Stock Manipulation

Stock manipulation is a significant concern for policymakers and investors. According to Allen and Gale (1992), market manipulation can be subject to three categories: *Information-based manipulation* is performed by spreading misleading information by informed traders without disclosing any real information. *Action-based manipulation*, where the manipulator acts to intentionally change a firm's value in order to make a profit. The third category is *Trade-based manipulation*, where a trader attempts to continually buy or sell the same stock to create a price momentum.

Much of the current literature on manipulation pays particular attention to its determinants. For instance, Allen and Gale (1992) points out that profit is the primary reason why stock manipulation happens, and Peng and Röell (2014) suggests that the existence of noise traders in the market makes stock price manipulation possible. Overall, stock market manipulation is typically an intentional action performed by an informed trader, and previous literature suggests that stock price manipulation can be performed either internally or through external market participants (Aitken, Cumming, and Zhan 2015; Cumming et al. 2020; Yuan et al. 2009). Chakraborty and Yılmaz (2004) suggest that insiders may be more likely to adopt manipulative trading strategies when there is uncertainty about the existence of the insider. Likewise, manipulation could also be due to the internal agency problem. Short-term contracts can encourage executive focus excessively on short term performance, and such a short-termism increase the likelihood of fraudulent behavior (Peng and Roell 2008; 2014). The equilibrium model from Goldman and Slezak (2006) also demonstrates that the manager who are compensated on the firm stock have incentive to upwardly biases disclosed information.

Furthermore, many theoretical and empirical studies have shown evidence that financial intermediaries may have incentives to initiate stock manipulation. For instance, the model developed by Hillion and Suominen (2004) shows that a broker may manipulate the closing price to alter the customer's inference of that broker's execution quality. Such a theoretical prediction enjoys empirical support in work by Atanasov, Davies, and Merrick (2015) and McNally, Shkilko, and Smith (2017), who show that the financial intermediaries have magnified the effect of the alleged manipulative trades. Additionally, Bernile, Sulaeman, and Wang (2015) argues that some intermediaries, such as institutions, tend to act as informed investors during a manipulation event and may have improved the price efficiency. Notably, a study by Comerton-Forde and Putniņš (2014) shows that stocks with high information asymmetry and low liquidity are more likely to be manipulated. Indeed, manipulation has a significantly detrimental effect on the market by dislocating the price, resulting in a rise in volatility, volume, and illiquidity (Hillion and Suominen 2004; Aggarwal and Wu 2006; Comerton-Forde and Putniņš 2011a).

3.2.2 Market Trading Fragmentation

Equity trading in the U.S. is currently dispersed across 16 national exchanges, more than thirty alternative trading systems, and numerous broker-dealers and wholesale market makers (SEC, 2021). Based on pre-trade opacity, the trading venues can be separated into lit- and off-exchanges. Lit-exchange refers to an exchange where quote information (bid and ask) are posted publicly. Whereas off-exchange refers to a venue that does not provide quote information. As can be seen, under the current highly fragmented market, traders have many options in choosing venues to execute their orders. The routing order decision is not only affected by the market structure design, but also influenced by trade-offs between transaction costs, execution quality, and adverse selection concerns. Friederich and Payne (2007) examine the trade-off on routing decisions and suggest that the investor's routing decision is driven by execution and information risks. The order routing decreases when the venue has a high execution risk, high asymmetry information risk, and low liquidity. Menkveld, Yueshen, and Zhu (2017) suggests that the investor routing order decision is focused on the trade-off between execution cost and execution immediacy.

While (Brolley 2020) suggests that the trade-off consideration for the investor is between immediacy vs. price improvement. Furthermore, many theoretical and empirical market microstructure studies have found that the routing order decision under the fragmented market environment is influenced by market and trading conditions. The theoretical model predicts that when the bid-ask spread is wider and market volatility is higher, informed trading increases in off-exchanges while overall off-exchange volume share decreases (Zhu 2014). Per the model's prediction, order flow should move to exchanges with higher transparency during periods of high market volatility. However, empirical studies motivated by these predictions find modest support. On the one hand, Jiang, McInish, and Upson (2012) find that the trading volume shifts from off-exchange to lit-exchanges when prices are volatile. On the other hand, Garvey, Huang, and Wu (2016) suggest that high volatility could reduce liquidity in the lit exchange, and their results document a positive relation between volatility and dark trading volume.

Additionally, retail trading participation may have a direct link with off-exchange volume and the stock manipulation. Under most microstructure theoretical discussions, retail investors are treated as uninformed noise traders, and it is assumed that the trade direction from retail traders would be equally distributed (Shleifer and Summers 1990; Easley, Hvidkjaer, and O'Hara 2002; Foucault, Sraer, and Thesmar 2011; Zhu 2014). However, much empirical evidence points out that retail trading also conveys information about future stock prices. In addition, retail investors' trading also obtains a strong herding pattern.

Although it is possible that investors may hold heterogeneous beliefs towards stock price movement, over one-third of investors may be associated with short-term investments and speculation purpose (Leuz et al. 2021). Such motivations are especially true for the retail investors, who are likely attracted by stocks with lottery features and present a gambling preference (Gao and Lin 2015; Han and Kumar 2013; Dimpfl and Jank 2016). In summary, as suggested in above literatures, retail investors are typically uninformed and more likely to engage in speculation with strong herding preference. Therefore, we posit that retail traders, compared with sophisticated institutional investors, are more likely to be triggered when the price manipulation happens, and take action. Furthermore, De Long et al. (1990) suggest that if uninformed noise traders base their trading decisions on sentiment, it will lead to more noise trading, exacerbating mispricing and volatility. Hatheway, Kwan, and Zheng (2017) points out that most off-exchanges are exempt from the fair-access requirement and do not display quote information under the current regulatory environment. Hence, dark venues can implement order segmentation through price discrimination and attract more informed order flow from the lit market. O'Hara (2015) and Boehmer et al. (2021) also document that most marketable orders placed by retail investors in the U.S. equity market are either internalized or executed by wholesale market makers, which belong to off-exchanges.

The above market fragmentation and retail trading details suggest the following hypothesis for stock manipulation:

Hypothesis 1: Stock manipulation does not equally impact the trading volume in each exchange, and changes in off-exchange trading volume share by stock manipulation are positively associated with retail trading intensity.

Next, we consider the potential impact of stock manipulation with retail trading volume on the market liquidity. Changes in market venue trading volume due to stock manipulation may be associated with two different impacts on the market liquidity. On one hand, manipulation directly harms pricing accuracy and increases the cost of trading. As a result, manipulation discourages market participation and harms market liquidity (Goldstein and Guembel 2008; Comerton-Forde and Putniņš 2011b). On the other hand, stock manipulation may induce more retail trading participation, which could provide liquidity. For instance, Greene and Smart (1999) examines noise trading activity around the publication of the "Investment Dartboard" in Wall Street Journal, and their study suggests that increased noise trading is positively associated with market liquidity. Similarly, Barrot, Kaniel, and Sraer (2016) shows that retail trading could play an important role in providing liquidity, especially when institutional liquidity dries up. Furthermore, previous studies find that the orders submitted by retail investors are typically uninformed (Black 1986; Foucault, Sraer, and Thesmar 2011). Based on the market-structure model from Glosten and Milgrom (1985), increased noise trading means a decrease in adverse selection risk, assuming that informed trading is exogenously given and does not depend on the level of the noise trading. Therefore, given the reduced adverse selection cost, the market maker will decrease the spreads when faced with a larger proportion of noise traders. As such, we posit that if the stock manipulation successfully triggers more retail trading participation, and if the increase in retail trading is uninformed, then the increased proportion of noise trading after manipulation should provide liquidity and decreases quoted spreads. Given such considerations, our second hypothesis is as follows:

Hypothesis 2a: Manipulation negatively affects market quality, while retail trading tends to mitigate the negative impact on market quality.

In contrast, Kyle (1985) model assumes that the informed trading volume can be endogenously determined. As such, informed traders could adjust their trading strategy based on uninformed trading volume. Hence, informed traders may trade more aggressively during the stock manipulation period, and the increase in informed trading may offset the effects of the increased noise trading. As such, the change in retail trading volume should have no significant impact on market liquidity. Given the above discussion, our alternative hypothesis on market quality is:

Hypothesis 2b: Manipulation negatively affects market quality, while retail trading volume does not have a mitigating effect on market quality.

3.3 Data and Methodology

3.3.1 Data

We obtain manipulation data from SMARTS, Inc., and Capital Market CRC (CMCRC) in Sydney. Following Aitken, Cumming, and Zhan (2015), we use suspected manipulation cases since they have real financial consequences. Our proxy for stock market manipulation is based on the continuous trading manipulation alert which was used by surveillance authorities. The continuous trading manipulation measurement uses multiple metrics to capture market manipulation activities. Specifically, said measurement detects an abnormal 30-minute change of liquidity, returns, and transaction costs based on certain rules, and all parameters were picked by surveillance authorities. The detailed methodology of continuous trading manipulation alert is explained in the Appendix A.

Since we focus on studying volume share changes in the U.S. equity market, we only include stocks traded in those markets. To exclude potential confounding firm events that could influence the order flow, we remove firms in our sample that have the earnings, repurchasing, or M&A announcements at the identified date that has the potential price manipulation. The information about firm earnings announcement is obtained from IBES, repurchasing information is obtained from Thompson Reuters, and M&A information is from Thomson Financial DataStream. Trading volume and market quality measures are constructed from the NYSE TAQ database. We use retail identification methodology from Boehmer et al. (2021) to identify market orders placed by retail investors. Appendix A presents detailed definitions of all variables used in the analysis.

Our final sample included 1,722 unique firms traded in the U.S. market and were identified to have at least one stock manipulation event during our sample period from 2014.01 through 2018.12. Table 3.1 shows summary statistics for all variables. The average daily off-exchange volume share is 32.91%, and the off-exchange trading volume share for the most firms is between 24.04% and 39.06%. The average daily trading volume initiated by retail investors takes around 8.35% of the total trading volume. The percentiles of the *Retail Volume Share (%)* measures show that there is a wide variation in retail trading; the 25th percentile of the proportion of retail trading volume is 3.02%, and the 75th percentile number is 9.07%. The market volatility, proxied by the CBOE VIX index, is 14.59 on average during the sample period. The average closing price is $52.10, and the average firm size is 14.879 (expressed as a natural logarithm), corresponding to $2.8 million market capitalization. The average value for the quoted spread is 0.066 in dollar value and 0.173 as a percentage. The average value for effective spreads, realized spread, and price impact is 0.125, 0.041, and 0.084, in percentages, respectively.

3.3.2 Methodology

Since our sample consists of firms that were identified to have continuous trading manipulation, selection bias issues may arise with an OLS approach. Therefore, to address endogeneity concerns, we apply a two-stage Heckman selection model to test our first hypothesis, which focuses on the impact of stock price manipulation and retail trading on dynamic market fragmentation. The first-stage regression estimates the probability of retail trading increasing by applying a probit model. Said estimate is then incorporated within the second-stage regression in which the coefficient of interest is the manipulation dummy variable. The two-stage regression model has the following format:

$$Prob(RetailVS_{i,t} = 1) = \alpha + \beta V_{i,t} + \gamma I_{i,t} + \epsilon_{i,t} \quad (1)$$

$$Dvolshare_{i,t} = \delta + \theta Manipulation_{i,t} + \lambda V_{i,t} + IMR_i + \varepsilon_{i,t} \quad (2)$$

In the first stage probit model, the dependent variable is an indicator variable equal to one if the proportion of the retail trading volume on the stock manipulation day is greater than its benchmark state and equal to zero otherwise. The benchmark state is calculated as the average proportion of retail trading volume prior manipulation from day t=-30 to t= -5. We exclude days that have any firm earnings, M&A, and repurchasing announcements. V_i is a vector of control variables, including stock price, firm size, quote spread, and market volatility. I_i represents an instrument, stock intraday volatility, which is excluded from the second stage equation. It is important to recognize that the instrument may not be exogenous, which could bias results. In the second stage regression, $Dvolshare_{i,t}$ is the proportion of the volume that traded in the off-exchange for stock i at time t. $Manipulation_{i,t}$ is an indicator variable, which is equal to 1 for stock i at the price manipulation day and equal to 0 otherwise. IMR_i is the inverse Mills Ratio of the Heckman model and is intended to correct for self-section bias. The IMR is defined as $\lambda_j = \phi(\rho_j)\varphi(\rho_j)$, where ρ_j is the predicted probability of switching. Standard errors are clustered at the firm-date level (Petersen 2009; Thompson 2011).

For the second hypothesis, which focuses on the impact of stock price manipulation and retail trading on market quality and liquidity, we use four measurements that proxy for different dimensions of market liquidity: quoted spread, effective spread, realized spread, and price impact. To control for the impact of the stock price on spreads, all measures are weighted by trading price and presented as a percentage. The most well-used liquidity measurement is quoted spread, which is the" advertised" cost of a trade, and it reflects a market center's posted willingness to trade. The percent quoted spread we use is calculated as the difference between the ask and bid scaled by the quoted midpoint.

Next, the effective spread is the" actual" cost of trading. The effective spread is the most relevant measure to assess trading costs for marketable orders since the half-effective spread measures the cost for removing liquidity with a marketable order. The percent effective spread we use is calculated as follows:

$$EffectiveSpread(\%) = 2D_t \frac{P_t - M_t}{M_t}$$

Where D_t is the trade direction that is signed based on Lee and Ready's(1991) algorithm. D_t is equals +1 for buyer-initiated trades and equals -1 for seller-initiated trades.

The effective spread can be further decomposed into two measures: the realized spread, which measures the inventory risk for market makers, and the price impact, which measures the adverse selection risk. The percent realized spread is calculated as follows:

$$RealizedSpread(\%) = 2D_t \frac{P_t - M_{t+5}}{M_t}$$

Where M_{t+5} is the bid-ask midpoint five minutes after trade at t.

Finally, price impact reflects the portion of the transaction cost due to the presence of informed marketable orders. Intuitively, price impact is the informed trader's profit and thus is a proxy for adverse selection. An increase in the price impact indicates a higher adverse selection risk and an increase in the adverse selection costs for liquidity providers. The percent price impact is calculated as follows:

$$PriceImpact(\%) = 2D_t \frac{M_{t+5} - M_t}{M_t}$$

The above four liquidity measures are calculated from the TAQ database and aggregated at the daily frequency by share-weighting average for all trades occurring during continuous trading hours. In general, a lower value corresponds to better liquidity.

3.4 Empirical Results

3.4.1 The Heckman Two-stage Estimation Procedure

The Heckman first stage results are reported in Table 3.2. In addition to the Probit model results, the table reports the first stage marginal effects *dP/dx* (x is an independent variable) evaluated at the means of all variables and corresponding z-statistics. Many coefficients are statistically significant and show that the stock price, firm size, firm liquidity, market volatility, and firm volatility correlate with the volume of market order initiated by retail investors. Notably, the standardized Market Volatility coefficient and standardized Bid-ask Spread coefficient are both negative and statistically significant at the 1% level, while the standardized firm intra-day volatility coefficient is negative and statistically significant at the 1% level. The figures suggest that retail trading is more likely to increase when firm-level volatility increases, while it is more likely to decrease when stock liquidity and market-level volatility decreases.

Table 3.3 presents the second stage of the Heckman regression for equation (2). The regression includes the Inverse Mill's Ratio generated from equation (1) to control the potential selection bias. The coefficient for *Manipulation* is 2.176, and it is positively and statistically significant at 1% level. This result suggests that the off-exchange trading volume share increases by 2.18% when there is continuous trading manipulation. Given the average daily trading volume per stock is 803,157 shares and average price is $52, the manipulation on average results a $910,416 dollar volume (or 17,508 shares) increases in off-exchange.

Collectively, the results from Table 3.2 and Table 3.3 support *Hypothesis 1*, suggesting that the market manipulation does not equally impact trading volume in each exchange, and off-exchanges gain more trading volume during market manipulation.

To examine whether the increased off-exchange trading volume from manipulation is associated with institutional investors or retail investors, we break down the off-exchange trading volume into two groups based on FINRA classification. The first group is the Alternative Trading System (ATS), which matches the buyer and seller without any intermediary. Institutional investors are more likely to utilize ATSs to trade. The second group is over-the-counter (OTC) non-ATS dealers, or wholesale market makers, which provide liquidity by buying and selling stocks as a counterparty. Since marketable orders placed by retail investors in the U.S. have been found to be executed in OTC market makers, we use OTC volume to proxy retail trading volume (O'Hara 2015; Boehmer et al. 2021; Fan, Cai, and Bodenhausen 2022).

Figure 3.1 graphically shows the change in the off-exchange volume share and the change in the proportion of Alternative Trading System (ATS) and over-the-counter (OTC) volume at the week before, the week of, and the week after the incidence of continuous trading manipulation. We collect off-exchange volume data from the Financial Industry Regulatory Authority (FINRA) Transparency Database. The data includes the weekly volume executed at each ATS and OTC market makers for all equities. We matched the volume information from FINRA with our manipulation sample firm list and calculated the proportion of the OTC volume over the total off-exchange volume. Panel A in Figure 3.1 shows that the proportion of OTC trading volume to total off-exchange volume increases by 5% during the week that has market manipulation. The result suggests that a stock's executed volume proportionally decreases in ATS venues and proportionally increases in OTC market makers venues when there is continuous trading manipulation. In Panel B, we further group stocks by changing off-exchange volume share on the manipulation day. The red group represents stocks with increased off-exchange volume share on the manipulation day. The blue group represents stocks whose off-exchange volume share does not increase at the manipulation day. Overall, Panel B shows that the proportion of OTC volume significantly increases during the week with manipulative trading for those stocks with increased off-exchange volume share, suggesting that the increased off-exchange volume is mainly from retail investors who are triggered by market manipulation and place more aggressive marketable orders.

3.4.2 Market Liquidity

All the analyses conducted in the chapter so far focus on changes in the trading venue fragmentation around the stock manipulation event. We now proceed to the next hypothesis to analyze the impact of the stock manipulation on market quality and test the role of retail trading participation. Thus, we compare average liquidity before and after stock manipulation by conducting a 10-day event window, t[-5,5]. Figure 3.2 shows the time-series of liquidity measures in the 10 days around a manipulation event, relative to the benchmark average liquidity measures[47]. Panel (a) shows the results for all stocks in our sample, and Panel (b) and (c) are sub-samples categorized by whether this manipulation event has been raised attention by the retail investor.

As expected, all the liquidity measures sharply increase the day when manipulation takes place (t=0), indicating that stock manipulation harms liquidity. Notably, the price impact increases by over 45% compared to the benchmark, showing that the manipulation increases information asymmetry risk. The spreads quickly drop back to near the benchmark level the following trading day (t=1). Still, the post-manipulation spreads are relatively greater than with the pre-manipulation spreads. We should note that the retail attention group (Panel b) and non-retail attention group (Panel C) show clearly different patterns for the quoted spread. The quoted spread quickly drops below the benchmark level days after manipulation for the retail attention group, while remaining over the benchmark level for the non-retail attention group. The findings suggest that the impacts of stock manipulation on market liquidity may be different depending on whether the manipulation event got retail attention.

We next apply the following difference-in-difference model to validate our hypothesis that manipulation increases the illiquidity curve, while the retail trading flow dampens illiquidity:

$$\begin{aligned} Liquidity_{i,t} = \alpha + \beta_1 Post_{i,t} + \beta_2 Retail_i + \beta_3 Post_{i,t} \times Retail_i + \gamma Controls_{i,t} \\ + FE + \epsilon_{i,t} \end{aligned} \tag{3}$$

[47] The benchmark is calculated using an estimation window from t= -30 to t=-6.

Where $Post_{i,t}$ is a dummy variable equals one if the date is after manipulation and equals zero before it takes place. The dependent variable, $Liquidity_{i,t}$ is our measure for market liquidity and adverse selection risk. If the manipulation has toxic effects on the market liquidity, then the Post coefficient β_1 should be statistically significantly related to the dependent variable in each regression in the direction that implies less liquidity and high adverse selection. Given that $Retail_i$ identifies whether the stock *i* has raised attention by retail investors at the manipulation day, the sign and the statistical significance of the estimated coefficient β_3 is the focus of our research. One on hand, if retail trading acts as noise trading, based on the Glosten-Milgrom model, the increased proportion of noise trading should narrow quoted spreads after stock manipulation. Therefore, we should expect the coefficient β_3 to be negative. On the other hand, based on Kyle's model prediction, if the effects of increased noise trading are offset by increased informed trading, the coefficient β_3 could be zero. We include a vector of stock-level controls that have been identified from previous literature (i.e., stock price, firm size, trading volume and firm-level volatility). Additionally, *F.E.* represents a vector of fixed effects, which include industry and month fixed effects to absorb any variation which is common across industries and unobserved heterogeneity. $\epsilon_{i,t}$ represent error terms, which we double clustered at the firm-date level to minimize the number of uncorrelated observations (Petersen 2009; Thompson 2011).

We first conduct a 10-day event window t[-5,5]to examine the immediate impact of stock manipulation and retail attention on market quality. Table 3.4 reports the results of estimating equation (3). Indeed, the manipulation coefficient is positive and highly statistically significant for all liquidity measures, suggesting that stock manipulation has a toxic effect on liquidity. For instance, the *Post* (coeff. =0.9785, t-stat=4.49) in column (1) suggests that the average percent quoted spread widens up by 0.98 bps after stock manipulation. Notably, the key coefficient of interest, β_3 , describing the post manipulation period for stocks that attracted retail attention during the manipulation day, is negative (close to -1.02 for quoted spread, and -0.16 for effective spread) and statistically significant at conventional levels. In addition, the coefficient of interaction term is statistically insignificant in column (3) for the realized spread (inventory risk) but is negative and statistically significant in column (4) for price impact (asymmetric information). Therefore, we find that price impact is negatively related with uninformed trading. Taking the results in columns (3) and (4) together, our results suggest that retail investors behave like noise traders. Furthermore, the overall findings in Table 3.4 favor the predictions from Glosten and Milgrom's model; increased retail trading induced from stock manipulation decreases asymmetric information risk. Thus, retail trading helps to attenuate the rise in illiquidity due to stock manipulation,

To test whether our findings in Table 3.4 could last for a longer period, we conduct a 20 day window t[-10,10]. The results are presented in Table 3.5. Again, for quoted spread and effective spread, the interaction terms between manipulation and retail attention are negative and statistically significant, i.e., -0.4957 and -0.2305, suggesting that high retail trading participation during the manipulation day mitigates the negative impact on the liquidity from manipulation. Moreover, the interaction term's coefficient for realized spread is insignificant, while being negative and statically significant for price impact, again suggesting that the stocks with high retail trading at manipulation day have relatively less informed order flow after the manipulation. The overall findings in Table 3.5 are consistent with Table 3.4 in which we find support for the Glosten and Milgrom model, mainly that increased proportion of noise trading after manipulation provides liquidity and decreases quoted spreads. The participation of retail trading plays an important role to mitigate the negative impact of stock manipulation on market quality.

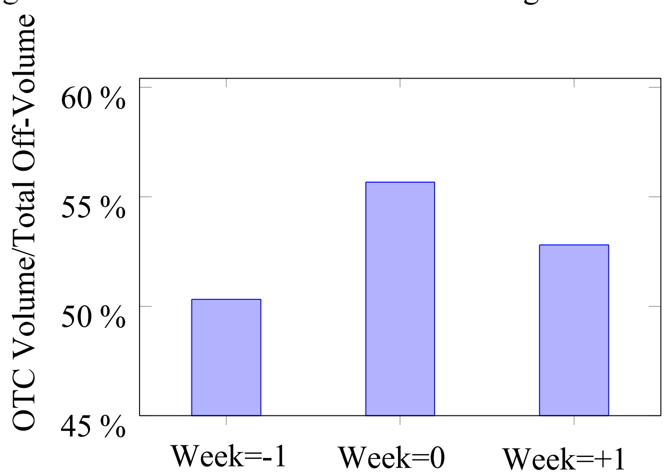
3.5 Conclusion

In this chapter, we investigate the economic and statistical significance of the dynamics of market fragmentation and retail trading around the stock manipulation events in the U.S. market. Using the 2-stage Heckman selection approach, we document that the off-exchanges volume significantly increases during stock manipulation, and we further find that the increased off-exchange volume is associated with retail trading participation. Moreover, our difference-in-difference analysis shows that although stock manipulation harms market liquidity, increased retail trading tends to mitigate this negative impact, as retail investors act as noise traders. From a practical standpoint, our findings are likely to be useful to regulators and policymakers to understand about how retail trading participation affects outcomes from stock manipulation. In sum, we are the first to document the impact of price manipulation on retail volume and trading fragmentation, and our findings contribute to other works in the field of finance that study financial market misconduct in a significant way as we shed light on the role of the retail trading on the stock manipulation.

Figure 3.1 Proportion of OTC Volume Around Continuous Trading Manipulation

This figure shows the change in over-the-counter (OTC) trading volume around stock continuous trading manipulation. The OTC volume share is calculated as the number of shares executed on OTC venues divided by the total number of shares executed on all off exchanges. Panel B groups stocks by changes in off-exchange volume share at the manipulation day. The red color group represents stocks with increased off-exchange volume share on the manipulation day. The blue group represents stocks whose off-exchange volume share does not increase on the manipulation day. The sample includes all stocks that had continuous trading manipulation alerts during 2014.01-2018.12. Trading volume is obtained and calculated from FINRA Transparency Data.

(a) Average OTC Volume Over Total Off-Exchange Volume by Week



b) Grouped by Changes in Off-Exchange Volume Share at Manipulation Day

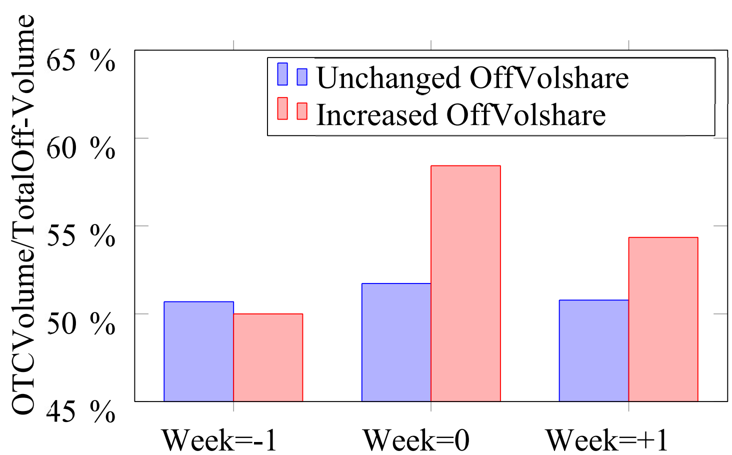


Figure 3.2 Daily Market Liquidity around Manipulation Event

These figures present the time-series of liquidity measures from t=-5 to t=5, relative to the control period of the manipulation at t=[-30,-6].The grey line represent the upper and lower bands of 95% percent confidence interval. The vertical lines at t=0 represent the manipulating event day. The sample includes all stocks that experienced continuous trading manipulation during 2014.01-2018.12.Panel (a) shows the results for all stocks in sample, and panel (b) and (c) are sub-s that categorized by whether this event has been raised attention by retail investor.

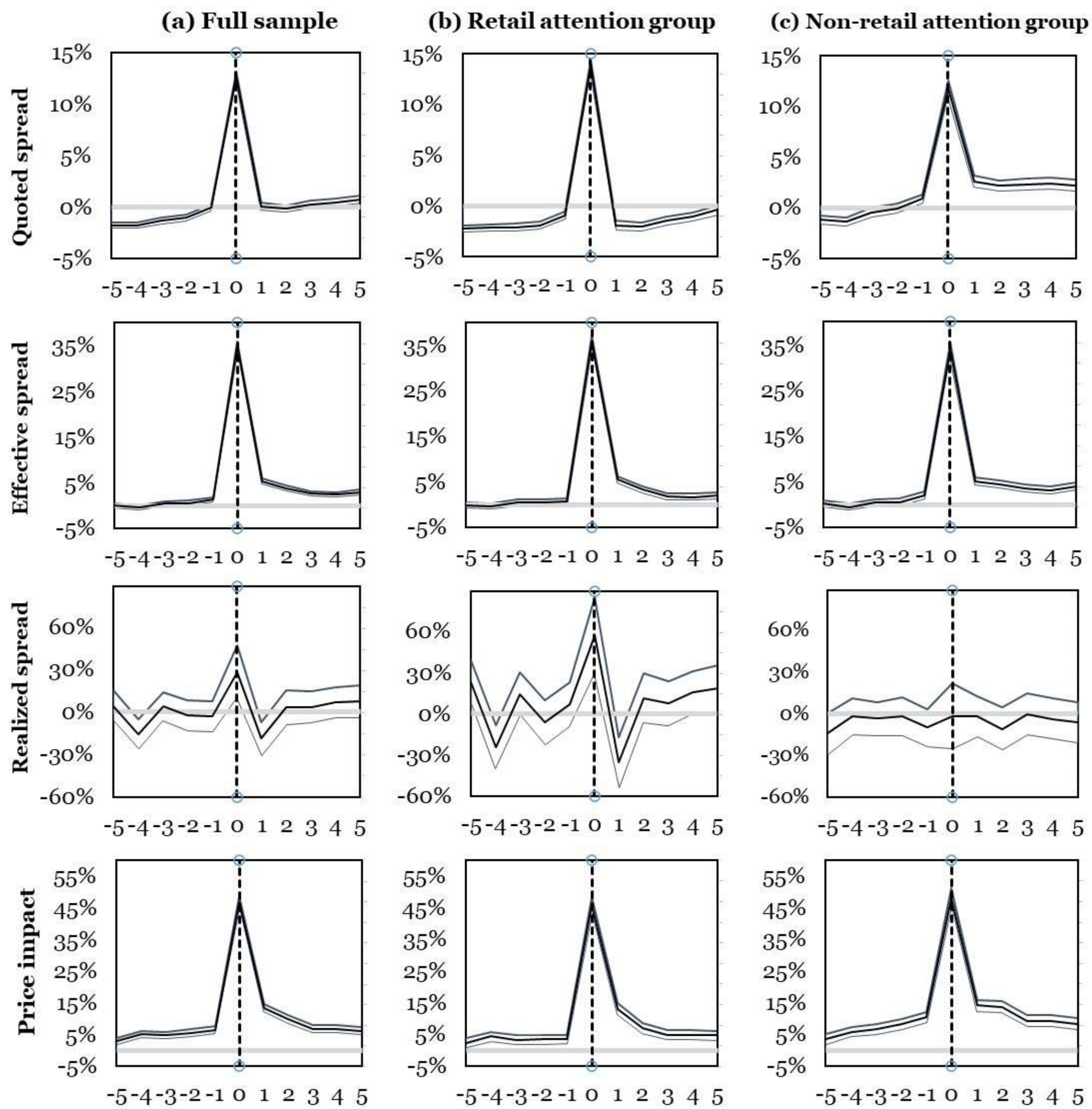


Table 3.1 Summary Statistics

This table presents summary statistics for the variables used in the main analysis. The sample includes 1,722 firms (534,495 firm-day observations in 21 trading days window) that traded in U.S. equity market and were identified have at least one continuous trading manipulation alert from 2014.01 through 2018.12. The observations are on a firm-day level. Independent variable definitions are provided in Appendix A.

	N	**Mean**	**STDEV**	**25th Pctl**	**Median**	**75th Pctl**
Off-Exchange Volume Share (%)	534,495	32.905	12.867	24.043	30.431	39.055
Retail Volume Share (%)	534,495	8.346	11.429	3.020	4.963	9.069
Closing Price ($)	534,495	52.096	92.066	17.620	35.220	63.680
Market Volatility (VIX)	534,495	14.585	4.207	11.840	13.430	15.970
Firm Intraday Volatility (%)	534,494	2.454	2.160	1.251	1.899	2.952
Log(MktCap)	534,495	14.900	1.720	13.745	14.879	16.044
Quoted Spread ($)	534,494	0.066	0.182	0.014	0.028	0.063
Quoted Spread (%)	534,495	0.173	0.375	0.051	0.097	0.184
Effective Spread (%)	534,495	0.125	0.248	0.038	0.068	0.131
Realized Spread (%)	534,495	0.041	0.242	-0.005	0.014	0.048
Price Impact (%)	534,495	0.084	0.241	0.024	0.049	0.096

Table 3.2 The Results of First-stage Heckman Models

This table presents results for the first stage of a hackman model that is to estimate the effect of continuous trading manipulation on the changes in firm off-exchange trading volume share while controlling for endogenous selection. The dependent variable is an indicator variable, equal to one for firm with the proportion of retail market order volume during manipulation day is higher than the steady state and equal to zero otherwise. The retail market order volume is calculated using the method proposed by Boehmer et al. (2021). Column (1) reports the original results from the Probit model, and Column (2) reports the marginal effects that are evaluated at the means of all variables and corresponding z-statistics. The sample includes all firms that were identified to have at least one continuous trading manipulation alert from 01/2014-12/2018. Independent variable definitions are provided in Appendix A. z-statistics are indicated in parenthesis, and ***, **, * indicate p-values of 1%, 5%, and 10%, respectively.

First-stage Probit Regression	**(1)**		**(2)**	
	Coefficient	**z-stat**	**Marginal Effects**	**z-stat**
Inverse Price	-0.228***	*(-17.73)*	-0.087***	*(-17.63)*
Market Cap	0.074***	*(67.54)*	0.027***	*(62.91)*
Bid-ask Spread	-0.075***	*(-7.89)*	-0.022***	*(-6.28)*
Market Volatility	-0.016***	*(-36.63)*	-0.006***	*(-34.41)*
Firm Intraday Volatility	0.060***	*(65.96)*	0.022***	*(62.74)*
Intercept	-0.887***	*(-49.23)*		
Observations	521,396			
Pseudo R2	1.29%			

Table 3.3 The Results of Second-stage Heckman Models

This table presents the second stage results of a hackman model to estimate the effect of continuous trading manipulation on the changes in firm off-exchange trading volume share while controlling for endogenous selection. The dependent variable is the total proportion of the volume that is executed at off-exchanges for firm i at t. The main interest variable is Manipulation, which is an indicator variable that equals one at the day when the firm i was identified to have a potential continuous trading manipulation and zero otherwise. The inverse Mill's Ratio of the Heckman model is intended to control for selection bias. The sample includes all firms that were identified to have at least one continuous trading manipulation alert from 01/2014-12/2018. Control variable definitions are provided in Appendix. Standard errors are double clustered at the firm-date level. The robust t-statistics are indicated in parenthesis, and ***, **, * indicate p-values of 1%, 5%, and 10%, respectively.

Second-stage OLS Regression	**Off-Exchange Volume Share (%)**	
	Coefficient	**t-stat**
Manipulation	2.173***	*(26.63)*
Inverse Price	9.060***	*(10.39)*
Market Cap	-1.985***	*(-39.78)*
Bid-ask Spread	-0.836***	*(-4.97)*
Market Volatility	-0.256***	*(-17.66)*
Inverse Mill's Ratio	13.270***	*(8.50)*
Intercept	56.244***	*(55.57)*
Observations	511,791	
Adjusted R^2	9.53%	

Table 3.4 The Results of Stock Manipulation on Market Quality in 10 Days Window

This table reports coefficient estimates for OLS regressions of 10-days event window (five trading days before and after) from regressing market quality measures (in bps) on manipulation event day dummy Post, retail attention dummy Retail D, and their interaction term with controls. The dependent variables are: Average time-weighted percent quoted spread, average percent effective spread, average percent price impact computed based on 5-minute interval, average percent realized spread computed based on 5-minute intervals. All control variables are described in Appendix A. The sample includes all stocks that have at least one continuous trading manipulation alert during 01.2014-12.2018. All regressions include the industry and month fixed effects, and the standard errors are double clustered at the firm and date level. T-Stats are reported in parentheses. Standard errors are double clustered at the stock and date level, and ***, **, * indicate p-values of 1%, 5%, and 10%, respectively.

	(1) Quoted Spread	**(2) Effective Spread**	**(3) Realized Spread**	**(4) Price Impact**
Post	0.9785***	0.2381***	0.0985	0.0577
	(4.49)	*(3.40)*	*(0.52)*	*(1.05)*
Retail	-0.0564	-0.3362***	-0.0509	-0.2946***
	(-0.24)	*(-3.44)*	*(-0.44)*	*(-4.48)*
Post x Retail	-1.0233***	-0.1561*	0.0846	-0.1212*
	(-3.82)	*(-1.80)*	*(0.42)*	*(-1.73)*
Inverse Price	41.2696***	25.2840***	27.3583***	9.3765***
	(9.47)	*(10.19)*	*(9.65)*	*(7.95)*
Market Cap	-1.9828***	-2.1772***	-0.5311***	-1.4891***
	(-9.67)	*(-18.92)*	*(-4.53)*	*(-21.42)*
Log(Volume)	-6.5788***	-2.4409***	-1.6304***	-1.1911***
	(-30.48)	*(-24.25)*	*(-12.89)*	*(-19.38)*
Firm Intraday Volatility	2.8243***	1.5767***	0.0055	1.5460***
	(17.29)	*(20.10)*	*(0.06)*	*(22.44)*
Intercept	116.7842***	67.1209***	29.8496***	39.6612***
	(41.09)	*(52.88)*	*(18.40)*	*(55.64)*
Industry Fixed Effect	Yes	Yes	Yes	Yes
Month Fixed Effect	Yes	Yes	Yes	Yes
Observations	247,654	247,572	247,571	247,571
R-squared	0.217	0.507	0.061	0.365

Table 3.5 The Results of Stock Manipulation on Market Quality in 20 Days Window

This table reports coefficient estimates for OLS regressions of 20-days event window (five trading days before and after) from regressing market quality measures (in bps) on manipulation event day dummy Post, retail attention dummy Retail D, and their interaction term with controls. The dependent variables are: Average time-weighted percent quoted spread, average percent effective spread, average percent price impact computed based on 5-minute interval, average percent realized spread computed based on 5-minute intervals. All control variables are described in Appendix A. The sample includes all stocks that have at least one continuous trading manipulation alert during 01.2014-12.2018. All regressions include the industry and month fixed effects, and the standard errors are double clustered at the firm and date level. T-Stats are reported in parentheses. Standard errors are double clustered at the stock and date level, and ***, **, * indicate p-values of 1%, 5%, and 10%, respectively.

	(1) Quoted Spread	**(2) Effective Spread**	**(3) Realized Spread**	**(4) Price Impact**
Post	0.6585***	0.2130**	0.1366	0.0748
	(3.74)	*(2.02)*	*(0.99)*	*(0.57)*
Retail	-0.2326	-0.2562*	-0.1432	-0.1129
	(-1.19)	*(-1.92)*	*(-1.53)*	*(-1.27)*
Post x Retail	-0.4957**	-0.2305*	0.0892	-0.3195**
	(-2.20)	*(-1.68)*	*(0.60)*	*(-2.25)*
Inverse Price	40.6742***	43.9938***	28.6484***	15.3508***
	(10.84)	*(12.54)*	*(13.07)*	*(8.67)*
Market Cap	-1.9905***	-1.7260***	-0.5565***	-1.1760***
	(-11.73)	*(-12.33)*	*(-5.33)*	*(-11.81)*
Log(Volume)	-6.4478***	-3.4748***	-1.6290***	-1.8381***
	(-35.07)	*(-25.87)*	*(-14.86)*	*(-18.31)*
Firm Intraday Volatility	2.9441***	2.2426***	-0.0602	2.2962***
	(22.42)	*(21.19)*	*(-0.55)*	*(19.16)*
Intercept	114.9060***	71.9524***	30.2231***	41.7453***
	(45.72)	*(39.04)*	*(22.07)*	*(35.04)*
Industry Fixed Effect	Yes	Yes	Yes	Yes
Month Fixed Effect	Yes	Yes	Yes	Yes
Observations	484,774	484,623	484,622	484,621
R-squared	0.211	0.356	0.064	0.112

REFERENCES

Adams, Samuel, Connor Kasten, and Eric K Kelley. 2021. "Do Investors Save When Market Makers Pay? Retail Execution Costs Under Payment for Order Flow Models." *Available at SSRN 3975667*.

Aggarwal, Rajesh K., and Guojun Wu. 2006. "Stock Market Manipulations." *The Journal of Business* 79 (4):1915-1953. doi: 10.1086/503652.

Aitken, Michael, Douglas Cumming, and Feng Zhan. 2015. "High frequency trading and end-of-day price dislocation." *Journal of Banking & Finance* 59:330-349. doi: 10.1016/j.jbankfin.2015.06.011.

Albulescu, Claudiu Tiberiu. 2021. "COVID-19 and the United States financial markets' volatility." *Finance Research Letters* 38:101699. doi: 10.1016/j.frl.2020.101699.

Ali, Ashiq, Sandy Klasa, and Oliver Zhen Li. 2008. "Institutional stakeholdings and better-informed traders at earnings announcements." *Journal of Accounting and Economics* 46 (1):47-61. doi: 10.1016/j.jacceco.2008.06.001.

Allen, Franklin, and Douglas Gale. 1992. "Stock-Price Manipulation." *Review of Financial Studies* 5 (3):503-529. doi: 10.1093/rfs/5.3.503.

Amihud, Yakov. 2002. "Illiquidity and stock returns: cross-section and time-series effects." *Journal of Financial Markets* 5 (1):31-56.

Amihud, Yakov, and Haim Mendelson. 1991. "Volatility, efficiency, and trading: Evidence from the Japanese stock market." *The Journal of Finance* 46 (5):1765-1789.

Atanasov, Vladimir, Ryan J. Davies, and John J. Merrick. 2015. "Financial intermediaries in the midst of market manipulation: Did they protect the fool or help the knave?" *Journal of Corporate Finance* 34:210-234. doi: 10.1016/j.jcorpfin.2015.07.011.

Bacidore, Jeffrey M, Robert H Battalio, and Robert H Jennings. 2002. "Depth improvement and adjusted price improvement on the New York Stock Exchange." *Journal of Financial Markets* 5 (2):169-195.

Baker, Scott R, Nicholas Bloom, Steven J Davis, and Stephen J Terry. 2020. Covid-induced economic uncertainty. National Bureau of Economic Research.

Bakos, Yannis, Henry C Lucas Jr, Wonseok Oh, Gary Simon, Siva Viswanathan, and Bruce W Weber. 2005. "The impact of e-commerce on competition in the retail brokerage industry." *Information Systems Research* 16 (4):352-371.

Barber, Brad M, and Terrance Odean. 2013. "The behavior of individual investors." In *Handbook of the Economics of Finance*, 1533-1570. Elsevier.

Barber, Brad M, Terrance Odean, and Ning Zhu. 2008. "Do retail trades move markets?" *The Review of Financial Studies* 22 (1):151-186.

Bargeron, Leonce, Manoj Kulchania, and Shawn Thomas. 2011. "Accelerated share repurchases." *Journal of Financial Economics* 101 (1):69-89. doi: 10.1016/j.jfineco.2011.02.004.

Barrot, Jean-Noel, Ron Kaniel, and David Sraer. 2016. "Are retail traders compensated for providing liquidity?" *Journal of Financial Economics* 120 (1):146-168. doi: 10.1016/j.jfineco.2016.01.005.

Bartlett, Robert P, Justin McCrary, and Maureen O'Hara. 2022. "The Market Inside the Market: Odd-Lot Quotes." *Available at SSRN 4027099*.

Baruch, Shmuel, Marios Panayides, and Kumar Venkataraman. 2017. "Informed trading and price discovery before corporate events." *Journal of Financial Economics* 125 (3):561-588. doi: 10.1016/j.jfineco.2017.05.008.

Battalio, Robert, Shane A. Corwin, and Robert Jennings. 2016. "Can Brokers Have It All? On the Relation between Make-Take Fees and Limit Order Execution Quality." *The Journal of Finance* 71 (5):2193-2238. doi: 10.1111/jofi.12422.

Battalio, Robert H. 1997. "Third Market Broker-Dealers: Cost Competitors or Cream Skimmers?" *The Journal of Finance* 52 (1):341-352. doi: 10.1111/j.1540-6261.1997.tb03819.x.

Battalio, Robert H., and Tim Loughran. 2008. "Does Payment For Order Flow To Your Broker Help Or Hurt You?" *Journal of Business Ethics* 80 (1):37-44. doi: 10.1007/s10551-007-9445-x.

Battalio, Robert, Robert Jennings, and Jamie Selway. 2001. "The Relationship Among Market-Making Revenue,Payment for Order Flow, and Trading Costs forMarket Orders." *Journal of Financial Services Research* 19 (1):39-56. doi: 10.1023/a:1011181317099.

Bell, David E, Ralph L Keeney, and John DC Little. 1975. "A market share theorem." *Journal of Marketing Research* 12 (2):136-141.

Bernile, Gennaro, Johan Sulaeman, and Qin Wang. 2015. "Institutional trading during a wave of corporate scandals: "Perfect Payday"?" *Journal of Corporate Finance* 34:191-209. doi: 10.1016/j.jcorpfin.2015.07.004.

Bhattacharya, Utpal, and Stacey E. Jacobsen. 2016. "The share repurchase announcement puzzle: Theory and evidence." *Review of Finance* 20 (2):725-758.

Black, Fischer. 1986. "Noise." *The Journal of Finance* 41 (3):528-543. doi: 10.1111/j.1540-6261.1986.tb04513.x.

Bloomfield, Robert, Maureen O'Hara, and Gideon Saar. 2005. "The "make or take" decision in an electronic market: Evidence on the evolution of liquidity." *Journal of Financial Economics* 75 (1):165-199. doi: 10.1016/j.jfineco.2004.07.001.

Boehmer, Ekkehart, Robert Jennings, and Li Wei. 2007. "Public Disclosure and Private Decisions: Equity Market Execution Quality and Order Routing." *Review of Financial Studies* 20 (2):315-358. doi: 10.1093/rfs/hhl011.

Boehmer, Ekkehart, Charles M. Jones, Xiaoyan Zhang, and Xinran Zhang. 2021. "Tracking Retail Investor Activity." *The Journal of Finance*. doi: 10.1111/jofi.13033.

Boehmer, Ekkehart, and Eric K. Kelley. 2009. "Institutional Investors and the Informational Efficiency of Prices." *Review of Financial Studies* 22 (9):3563-3594. doi: 10.1093/rfs/hhp028.

Brennan, Michael J, and Tarun Chordia. 1993. "Brokerage commission schedules." *The Journal of Finance* 48 (4):1379-1402.

Brennan, Michael J, and Patricia J Hughes. 1991. "Stock prices and the supply of information." *The Journal of Finance* 46 (5):1665-1691.

Brolley, Michael. 2020. "Price Improvement and Execution Risk in Lit and Dark Markets." *Management Science* 66 (2):863-886. doi: 10.1287/mnsc.2018.3204.

Buti, Sabrina, Barbara Rindi, and Ingrid M. Werner. 2017. "Dark pool trading strategies, market quality and welfare." *Journal of Financial Economics* 124 (2):244-265. doi: 10.1016/j.jfineco.2016.02.002.

Cahill, Daniel, Choy Yeing Chloe Ho, and Joey W. Yang. "The COVID-19 pandemic: How important is face-to-face interaction for information dissemination?." Global Finance Journal (2021): 100674.

Campbell, John Y., Tarun Ramadorai, and Allie Schwartz. 2009. "Caught on tape: Institutional trading, stock returns, and earnings announcements." *Journal of Financial Economics* 92 (1):66-91. doi: 10.1016/j.jfineco.2008.03.006.

Chae, Joon. 2005. "Trading volume, information asymmetry, and timing information." *The Journal of Finance* 60 (1):413-442.

Chakraborty, Archishman, and Bilge Yılmaz. 2004. "Informed manipulation." *Journal of Economic Theory* 114 (1):132-152. doi: 10.1016/s0022-0531(03)00101-7.

Chen, Hsiu-Lang, Narasimhan Jegadeesh, and Russ Wermers. 2000. "The value of active mutual fund management: An examination of the stockholdings and trades of fund managers." *Journal of Financial and Quantitative Analysis*:343-368.

Choi, Jin Hyuk, Kasper Larsen, and Duane J. Seppi. 2019. "Information and trading targets in a dynamic market equilibrium." *Journal of Financial Economics* 132 (3):22-49. doi: 10.1016/j.jfineco.2018.11.003.

Chordia, T., R. Roll, and A. Subrahmanyam. 2008. "Liquidity and market efficiency." *Journal of Financial Economics* 87 (2):249-268. doi: 10.1016/j.jfineco.2007.03.005.

Chung, Kee H, Chairat Chuwonganant, and D Timothy McCormick. 2004. "Order preferencing and market quality on NASDAQ before and after decimalization." *Journal of Financial Economics* 71 (3):581-612.

Chung, Kee H, Chairat Chuwonganant, and D Timothy McCormick. 2006. "Order preferencing, adverse-selection costs, and the probability of information-based trading." *Review of Quantitative Finance and Accounting* 27 (4):343-364.

Chung, Kee H, Albert J Lee, and Dominik Rösch. 2020. "Tick size, liquidity for small and large orders, and price informativeness: Evidence from the Tick Size Pilot Program." *Journal of Financial Economics* 136 (3):879-899.

Cimon, David A. 2021. "Broker routing decisions in limit order markets." *Journal of Financial Markets* 54:100602. doi: 10.1016/j.finmar.2020.100602.

Comerton-Forde, Carole, Katya Malinova, and Andreas Park. 2018. "Regulating dark trading: Order flow segmentation and market quality." *Journal of Financial Economics* 130 (2):347-366. doi: 10.1016/j.jfineco.2018.07.002.

Comerton-Forde, Carole, and Tālis J. Putniņš. 2011a. "Measuring closing price manipulation." *Journal of Financial Intermediation* 20 (2):135-158. doi: 10.1016/j.jfi.2010.03.003.

Comerton-Forde, Carole, and Tālis J. Putniņš. 2011b. "Pricing accuracy, liquidity and trader behavior with closing price manipulation." *Experimental Economics* 14 (1):110-131. doi: 10.1007/s10683-010-9259-z.

Comerton-Forde, Carole, and Tālis J. Putniņš. 2014. "Stock Price Manipulation: Prevalence and Determinants." *Review of Finance* 18 (1):23-66. doi: 10.1093/rof/rfs040.

Crego, Julio A. 2020. "Why does public news augment information asymmetries?" *Journal of Financial Economics* 137 (1):72-89. doi: 10.1016/j.jfineco.2019.05.020.

Cumming, Douglas, Shan Ji, Sofia Johan, and Monika Tarsalewska. 2020. "End-of-Day Price Manipulation and M&As." *British Journal of Management* 31 (1):184-205. doi: 10.1111/1467-8551.12374.

Cumming, Douglas J., Christopher Firth, John Gathergood, and Neil Stewart. "Covid, work-from-home, and securities misconduct." Center for Financial Studies Working Paper 666 (2021).

Daniel, Kent, Mark Grinblatt, Sheridan Titman, and Russ Wermers. 1997. "Measuring mutual fund performance with characteristic-based benchmarks." *The Journal of Finance* 52 (3):1035-1058.

De Long, J Bradford, Andrei Shleifer, Lawrence H Summers, and Robert J Waldmann. 1990. "Noise trader risk in financial markets." *Journal of Political Economy* 98 (4):703-738.

Dimpfl, Thomas, and Stephan Jank. 2016. "Can Internet Search Queries Help to Predict Stock Market Volatility?" *European Financial Management* 22 (2):171-192. doi: 10.1111/eufm.12058.

Du, Mengqiao. "Locked-in at Home: Female Analysts' Attention at Work during the COVID-19 Pandemic." Available at SSRN 3741395 (2020).

Easley, David, Soeren Hvidkjaer, and Maureen O'Hara. 2002. "Is information risk a determinant of asset returns?" *The Journal of Finance* 57 (5):2185-2221.

Easley, David, Nicholas M Kiefer, and Maureen O'Hara. 1996. "Cream-skimming or profit-sharing? The curious role of purchased order flow." *The Journal of Finance* 51 (3):811-833.

Eaton, Gregory W, T Clifton Green, Brian Roseman, and Yanbin Wu. 2021. "Retail Trader Sophistication and Stock Market Quality: Evidence from Brokerage Outages." *Available at SSRN 3776874*.

Ernst, Thomas, and Chester Spatt. 2021. "Payment for Order Flow and Asset Choice." Working Paper.

Fan, Xiaomeng, Fengyan Cindy Cai, and Galen V Bodenhausen. 2022. "The boomerang effect of zero pricing: when and why a zero price is less effective than a low price for enhancing consumer demand." *Journal of the Academy of Marketing Science*:1-17.

Foley, Sean, and Tālis J Putniņš. 2016. "Should we be afraid of the dark? Dark trading and market quality." *Journal of Financial Economics* 122 (3):456-481.

Foucault, Thierry, David Sraer, and David J. Thesmar. 2011. "Individual Investors and Volatility." *The Journal of Finance* 66 (4):1369-1406. doi: 10.1111/j.1540-6261.2011.01668.x.

Fox, Merritt B, Lawrence Glosten, and Gabriel Rauterberg. 2019. *The new stock market*: Columbia University Press.

Friederich, Sylvain, and Richard Payne. 2007. "Dealer Liquidity in an Auction Market: Evidence from the London Stock Exchange." *The Economic Journal* 117 (522):1168-1191. doi: 10.1111/j.1468-0297.2007.02071.x.

Gao, Xiaohui, and Tse-Chun Lin. 2015. "Do individual investors treat trading as a fun and exciting gambling activity? Evidence from repeated natural experiments." *The Review of Financial Studies* 28 (7):2128-2166.

Garvey, Ryan, Tao Huang, and Fei Wu. 2016. "Why do traders choose dark markets?" *Journal of Banking & Finance* 68:12-28. doi: 10.1016/j.jbankfin.2016.02.011.

Gensler, Gary (Chairman of the U.S. Securities and Exchange Commission). “Testimony Before the House Committee on Financial Services” (Date: 5/6/2021) Text from: https://www.sec.gov/news/testimony/gensler-testimony-20210505#_ftn2

Glosten, Lawrence R, and Paul R Milgrom. 1985. "Bid, ask and transaction prices in a specialist market with heterogeneously informed traders." *Journal of Financial Economics* 14 (1):71-100.

Goldman, Eitan, and Steve L. Slezak. 2006. "An equilibrium model of incentive contracts in the presence of information manipulation." *Journal of Financial Economics* 80 (3):603-626. doi: 10.1016/j.jfineco.2005.05.007.

Goldstein, Itay, and Alexander Guembel. 2008. "Manipulation and the Allocational Role of Prices." *Review of Economic Studies* 75 (1):133-164. doi: 10.1111/j.1467-937x.2007.00467.x.

Goldstein, Michael A., Paul Irvine, Eugene Kandel, and Zvi Wiener. 2009. "Brokerage Commissions and Institutional Trading Patterns." *Review of Financial Studies* 22 (12):5175-5212. doi: 10.1093/rfs/hhp083.

Goldstein, Michael A., and Kenneth A. Kavajecz. 2004. "Trading strategies during circuit breakers and extreme market movements." *Journal of Financial Markets* 7 (3):301-333. doi: 10.1016/j.finmar.2003.11.003.

Greene, Jason, and Scott Smart. 1999. "Liquidity Provision and Noise Trading: Evidence from the “Investment Dartboard” Column." *The Journal of Finance* 54 (5):1885-1899. doi: 10.1111/0022-1082.00171.

Grinblatt, Mark, and Sheridan Titman. 1993. "Performance measurement without benchmarks: An examination of mutual fund returns." *Journal of Business*:47-68.

Han, Bing, and Alok Kumar. 2013. "Speculative retail trading and asset prices." *Journal of Financial and Quantitative Analysis* 48 (2):377-404.

Haroon, Omair, and Syed Aun R. Rizvi. 2020. "Flatten the Curve and Stock Market Liquidity – An Inquiry into Emerging Economies." *Emerging Markets Finance and Trade* 56 (10):2151-2161. doi: 10.1080/1540496x.2020.1784716.

Hasbrouck, Joel. 1993. "Assessing the quality of a security market: A new approach to transaction-cost measurement." *The Review of Financial Studies* 6 (1):191-212.

Hatheway, Frank, Amy Kwan, and Hui Zheng. 2017. "An Empirical Analysis of Market Segmentation on U.S. Equity Markets." *Journal of Financial and Quantitative Analysis* 52 (6):2399-2427. doi: 10.1017/s0022109017000849.

Heimer, Rawley, and Alp Simsek. 2019. "Should retail investors' leverage be limited?" *Journal of Financial Economics* 132 (3):1-21. doi: 10.1016/j.jfineco.2018.10.017.

Hendershott, Terrence, and Pamela C. Moulton. 2011. "Automation, speed, and stock market quality: The NYSE's Hybrid." *Journal of Financial Markets* 14 (4):568-604. doi: 10.1016/j.finmar.2011.02.003.

Hillion, Pierre, and Matti Suominen. 2004. "The manipulation of closing prices." *Journal of Financial Markets* 7 (4):351-375. doi: 10.1016/j.finmar.2004.04.002.

Ho, Thomas, and Hans R Stoll. 1981. "Optimal dealer pricing under transactions and return uncertainty." *Journal of Financial Economics* 9 (1):47-73.

Holden, Craig W, and Stacey Jacobsen. 2014. "Liquidity measurement problems in fast, competitive markets: Expensive and cheap solutions." *The Journal of Finance* 69 (4):1747-1785.

Ikenberry, David, Josef Lakonishok, and Theo Vermaelen. 1995. "Market underreaction to open market share repurchases." *Journal of Financial Economics* 39 (2-3):181-208. doi: 10.1016/0304-405x(95)00826-z.

Jain, Pankaj K, Suchi Mishra, Shawn O'Donoghue, and Le Zhao. 2020. "Trading Volume Shares and Market Quality in a Zero Commission World." *Available at SSRN 3741470*.

Jarrow, Robert A. 1992. "Market Manipulation, Bubbles, Corners, and Short Squeezes." *The Journal of Financial and Quantitative Analysis* 27 (3):311. doi: 10.2307/2331322.

Jennings, Richard W. 1965. "The New York Stock Exchange and the Commission Rate Struggle." *Cal L. Rev.* 53:1119.

Jiang, Christine X, Thomas H McInish, and James Upson. 2012. "Market fragmentation and information quality: The role of TRF trades." *Available at SSRN 1960115*.

Kaniel, Ron, Gideon Saar, and Sheridan Titman. 2008. "Individual Investor Trading and Stock Returns." *The Journal of Finance* 63 (1):273-310. doi: 10.1111/j.1540-6261.2008.01316.x.

Kelley, Eric K., and Paul C. Tetlock. 2013. "How Wise Are Crowds? Insights from Retail Orders and Stock Returns." *The Journal of Finance* 68 (3):1229-1265. doi: 10.1111/jofi.12028.

Kim, Oliver, and Robert E Verrecchia. 1994. "Market liquidity and volume around earnings announcements." *Journal of Accounting and Economics* 17 (1-2):41-67.

Kracher, Beverly, and Robert R Johnson. 1997. "Repurchase announcements, lies and false signals." *Journal of Business Ethics* 16 (15):1677-1685.

Kumar, Alok, and Charles M. C. Lee. 2006. "Retail Investor Sentiment and Return Comovements." *The Journal of Finance* 61 (5):2451-2486. doi: 10.1111/j.1540-6261.2006.01063.x.

Kurov, Alexander. 2008. "Information and noise in financial market: evidence from the E-mini index futures " *Journal of Financial Research* 31 (3):247-270. doi: 10.1111/j.1475-6803.2008.00239.x.

Kurov, Alexander, Alessio Sancetta, Georg Strasser, and Marketa Halova Wolfe. 2019. "Price drift before US macroeconomic news: Private information about public announcements?" *Journal of Financial and Quantitative Analysis* 54 (1):449-479.

Kyle, Albert S. 1985. "Continuous Auctions and Insider Trading." *Econometrica* 53 (6):1315. doi: 10.2307/1913210.

Larrymore, Norris L, and Albert J Murphy. 2009. "Internalization and market quality: An empirical investigation." *Journal of Financial Research* 32 (3):337-363.

Lee, Charles M. C., and Mark J. Ready. 1991. "Inferring Trade Direction from Intraday Data." *The Journal of Finance* 46 (2):733-746. doi: 10.1111/j.1540-6261.1991.tb02683.x.

Lee, Kaun Y, and Kee H Chung. 2009. "Information-Based Trading and Price Improvement." *Journal of Business Finance & Accounting* 36 (5-6):754-773.

Leuz, Christian, Steffen Meyer, Maximilian Muhn, Eugene F. Soltes, and Andreas Hackethal. 2021. "Who Falls Prey to the Wolf of Wall Street? Investor Participation in Market Manipulation." *SSRN Electronic Journal*. doi: 10.2139/ssrn.3073817.

Li, Frank Weikai, and Baolian Wang. "The gender effects of covid-19 on equity analysts." Available at SSRN 3857376 (2021).

Mackintosh, Phil. 2021. "A New Way to Look at Retail Trading Trends." Nasdaq, Last Modified November 18, 2021. https://www.nasdaq.com/articles/a-new-way-to-look-at-retail-trading-trends.

Malinova, Katya, and Andreas Park. 2015. "Subsidizing Liquidity: The Impact of Make/Take Fees on Market Quality." *The Journal of Finance* 70 (2):509-536. doi: 10.1111/jofi.12230.

McNally, William J., Andriy Shkilko, and Brian F. Smith. 2017. "Do Brokers of Insiders Tip Other Clients?" *Management Science* 63 (2):317-332. doi: 10.1287/mnsc.2015.2287.

Menkveld, Albert J., Bart Zhou Yueshen, and Haoxiang Zhu. 2017. "Shades of darkness: A pecking order of trading venues." *Journal of Financial Economics* 124 (3):503-534. doi: 10.1016/j.jfineco.2017.03.004.

O'Hara, Maureen, and Mao Ye. 2011. "Is market fragmentation harming market quality?" *Journal of Financial Economics* 100 (3):459-474. doi: 10.1016/j.jfineco.2011.02.006.

O'Donoghue, Shawn M. 2022. "Transaction fees: Impact on institutional order types, commissions, and execution quality." *Journal of Financial Markets*:100717.

O'Hara, Maureen. 2015. "High frequency market microstructure." *Journal of Financial Economics* 116 (2):257-270. doi: 10.1016/j.jfineco.2015.01.003.

Ofer, Aharon R, and Anjan V Thakor. 1987. "A theory of stock price responses to alternative corporate cash disbursement methods: Stock repurchases and dividends." *The Journal of Finance* 42 (2):365-394.

Ozik, Gideon, Ronnie Sadka, and Siyi Shen. 2021. "Flattening the Illiquidity Curve: Retail Trading During the COVID-19 Lockdown." *Journal of Financial and Quantitative Analysis* 56 (7):2356-2388. doi: 10.1017/s0022109021000387.

Parlour, Christine A, and Uday Rajan. 2003. "Payment for order flow." *Journal of Financial Economics* 68 (3):379-411.

Peng, Lin, and Ailsa Roell. 2008. "Manipulation and equity-based compensation." *American Economic Review* 98 (2):285-90.

Peng, Lin, and Ailsa Röell. 2014. "Managerial Incentives and Stock Price Manipulation." *The Journal of Finance* 69 (2):487-526. doi: 10.1111/jofi.12129.

Petersen, Mitchell A. 2009. "Estimating standard errors in finance panel data sets: Comparing approaches." *The Review of Financial Studies* 22 (1):435-480.

Petersen, Mitchell A, and David Fialkowski. 1994. "Posted versus effective spreads: Good prices or bad quotes?" *Journal of Financial Economics* 35 (3):269-292.

Peyer, Urs, and Theo Vermaelen. 2009. "The Nature and Persistence of Buyback Anomalies." *Review of Financial Studies* 22 (4):1693-1745. doi: 10.1093/rfs/hhn024.

Pirrong, Stephen Craig. 1995. "The self-regulation of commodity exchanges: the case of market manipulation." *The Journal of Law and Economics* 38 (1):141-206.

Royal, James. 2019. "In the race to zero-fee broker commissions, here's who the big winner is." https://www.bankrate.com/investing/zero-fee-broker-commissions-long-term-investors-win/

Rubin, Amir. 2007. "Ownership level, ownership concentration and liquidity." *Journal of Financial Markets* 10 (3):219-248. doi: 10.1016/j.finmar.2007.04.002.

Schwartz, Robert Alan, and James E. Shapiro. *The challenge of institutionalization for the equity markets*. Salomon Bros. Center for the Study of Financial Institutions, Leonard N. Stern School of Business, New York University, 1991.

Shampanier, Kristina, Nina Mazar, and Dan Ariely. 2007. "Zero as a special price: The true value of free products." *Marketing Science* 26 (6):742-757.

Shleifer, Andrei, and Lawrence H. Summers. 1990. "The Noise Trader Approach to Finance." *Journal of Economic Perspectives* 4 (2):19-33. doi: 10.1257/jep.4.2.19.

Stambaugh, Robert F. 2014. "Presidential Address: Investment Noise and Trends." *The Journal of Finance* 69 (4):1415-1453. doi: 10.1111/jofi.12174.

Stoll, Hans R. 2000. "Presidential address: friction." *The Journal of Finance* 55 (4):1479-1514.

Thompson, Samuel B. 2011. "Simple formulas for standard errors that cluster by both firm and time." *Journal of Financial Economics* 99 (1):1-10.

US House, 2021. Committee on House Financial Services. Game Stopped? Who Wins and Loses When Short Sellers, Social Media, and Retail Investors Collide? February 18, 2021.

Wermers, Russ. 1999. "Mutual Fund Herding and the Impact on Stock Prices." *The Journal of Finance* 54 (2):581-622. doi: 10.1111/0022-1082.00118.

Wermers, Russ. 2000. "Mutual fund performance: An empirical decomposition into stock-picking talent, style, transactions costs, and expenses." *The Journal of Finance* 55 (4):1655-1695.

Ye, Linlin. 2016. "Understanding the impacts of dark pools on price discovery." *Available at SSRN 2874957*.

Yuan, Rongli, Jason Zezhong Xiao, Nikolaos Milonas, and Joe Hong Zou. 2009. "The Role of Financial Institutions in the Corporate Governance of Listed Chinese Companies." *British Journal of Management* 20 (4):562-580. doi: 10.1111/j.1467-8551.2008.00602.x.

Zhu, Haoxiang. 2014. "Do Dark Pools Harm Price Discovery?" *Review of Financial Studies* 27 (3):747-789. doi: 10.1093/rfs/hht078.

APPENDICES

Appendix A: Variable Definitions

Chapter 1: Trading Volume Shares and Market Quality: Pre- and Post- Zero Commissions

Variable	Definition
ZCBroker Proportion	The proportion of the number of retail brokers that offer zero-commission trades.
ZCBroker Dummy	Dummy equals one for brokers that announced zero commissions in October 2019 and equals zero for those brokers with non-zero commissions
ZCEvent Dummy	Dummy variable equals one if the time is after October 2019, and zero before. We exclude the month of October 2019 from the analysis.
RetailPop	Dummy variable equals one if the stock belongs to the top 100 stocks held by most Robinhood users in given the period, *t*
Amihud (x10^5)	Amihud illiquidity ratio multiplied by a factor of 10^5
Log(Daily Volume)	Natural log of the average daily trading dollar-volume
Log(Trade)	Natural log of the number of daily trades
Log(MktCap)	Natural log of market capitalization
InvPrice	The inverse of the closing price
IntraVolatility	The average percentage difference between the intraday high and low price
VIX	Daily Volatility index
lag(Spread*100)	Lag of the quoted spread multiplied by a factor of 100
SI	The number of shares sold short divided by total number of shares outstanding
Percent Quoted Spread	The difference bid and ask divided by the midpoint M_t
Percent Effective Spread	The difference between each trade price and midpoint M_t multiplied by twice the trading direction divided by the midpoint M_t
Percent Realized Spread	The difference between each trade price and the midpoint in five minutes M_{t+5} divided by the midpoint M_t
Percent Price Impact	The five-minute difference between the midpoint M_t and M_{t+5} multiplied by twice the trading direction and divided by the midpoint M_t

Variable	Definition
OffVolshare	The proportion of off-exchange trading volume share at the given time interval
EventD	Dummy variable =1 if there is a firm event announcement at day t
IO	Number of shares held by institutions divided by the number of shares outstanding
IO_High	Dummy variable =1 if the firm has a high level of institutional ownership
Ln(Size)	Natural logarithm of firm market capitalization
Ln(Analyst Coverage)	Natural logarithm of the number of analysts
Analyst Forecast Dispersion	The standard deviation in the nearest earnings per share forecasts
Spread	Firm's quoted spread at the previous trading day
Volatility	The difference between the daily high and low price divided by the closing midpoint
InvP	The inverse of the share price
Turnover	The number of shares traded divided by the number of shares outstanding
VIX	Cboe Volatility Index

Variable	Definition
Manipulation	An indicator variable that equals 1 if the number of Continuous Trading Manipulation alert is greater than one, and 0 otherwise. The continuous trading manipulation metric detects abnormal 30-minute change of liquidity, returns and transaction cost based on the following rules: 1. For every 30-minute window (j) after opening of the current trading day (t), calculate the following metrics for every security in the market. (a) Total trading value over the past 30 mins (Val) (b) Total trading volume over the past 30 mins (Vol) (c) Return over the past 30 mins (Ret) (d) Average effective spread over the past 30 mins (EffSpr) (e) Average quoted spread over the past 30 mins (QuotedSpr) 2. For every security in the market, calculate the average value of the above metrics for each 30-minute window (j) over the past 30 trading days (t-1 to t-31). 3. For the jth 30-minute window of the current trading day (t) (a) For security i, calculate the difference (Security Deltai,j,t,m) between metric m for the current window (j) and the average metric value for the same window (j) over the past 30 trading days. (Note that for the trading volume and trading value metric, the difference is calculated as the percentage change.) (b) Calculate the average value of Deltai,j,t,m across all securities (Mkt Deltaj,t,m). Note that for the 30-minute return metric, index returns is used to calculate the average delta. (c) Calculate the difference between (Security Deltai,j,t,m) and (Mkt Deltaj,t,m) for the current trading day (Current _Security Deltai,j,t,m) and the average daily difference over the past 30 trading days (Hist Security Deltai,j,t,m) (d) If there are 3 or more metrics with (CurrentSecurity Deltai,j,t,m) that is more than 3 standard deviations away from HistSecurity Deltai,j,t,m , increase the number of Continuous Trading Manipulation alert by one.
Post	Dummy variable equals one if the time is after manipulation day, and zero before
Retail	Dummy variable equals one if the proportion of retail trading volume at the manipulation day (t=0) is higher than the benchmark calculated by averaging t=-30 to t=-6. The retail trading volume is identified by using Boehmer et al. (2021) methodology. The proportion of retail trading volume is calculated as the total retail trading volume at day t divided by the total trading volume at day t
Market Volatility	Daily close CBOE Volatility Index (VIX)

Bid-ask spread	Also refer as Quoted Spread ($), measured as daily high price minus daily low price
Firm Intraday Volatility	100*percentage difference between daily high and low price
Inverse Price	One over daily closing price
Market Cap	The natural log of the firm market value defined as the number of outstanding shares (in 1,000) multiplied by the market price per share
Log(Volume)	The natural log of the daily share volume

Appendix B: Additional Tests for Chapter 1: Trading Volume Shares and Market Quality: Pre- and Post- Zero Commissions

B.1 The Impact of Zero Brokerage Commissions on Price Efficiency

Could an increase in retail trading from zero brokerage commissions affect market efficiency? In this section, we evaluate the impact of zero commissions on price efficiency by using two different measures: pricing error and variance ratio.

The first price efficiency measure that we used is the adjusted variance of pricing error (Boehmer and Kelley 2009) . As in the generalized Roll model, the transaction price p_t can be decomposed into the efficient price m_t that follows a random-walk and the transitory part as pricing error s_t .Hasbrouck (1993) suggests the variance of the pricing error $\sigma^2(s)$ measures how accurately the price p_t follows the efficient price m_t . Therefore, lower pricing error variance suggests better market efficiency. Following Hasbrouck (1993), we use a five-lag vector autoregression model to estimate the variance of the pricing error $\sigma^2(s)$ based on intraday data for each stock-day (Chung, Lee, and Rösch 2020). We take the square root of $\sigma^2(s)$ to get the standard deviation of the pricing error $\sigma(s)$ and scale $\sigma(s)$ by the standard deviation of price $\sigma(p)$ to control for cross-sectional differences in the return variance (Boehmer and Kelley 2009). The smaller the ratio $\frac{\sigma(s)}{\sigma(p)}$ is, the more efficient the price.

An alternative price efficiency measure is the variance ratio (Amihud and Mendelson 1991; Chordia, Roll, and Subrahmanyam 2008; O'Hara and Ye 2011). We defined the variance ratio as the absolute value of one minus the ratio of the variance of 1 minute to four of the variances of 15-second midpoint return:

$$VR = |1 - \frac{\sigma^2_{1min;i,t}}{\sigma^2_{15sec;i,t}}|$$

The intuition is that when the market is more efficient (i.e., when the price follows a random walk process), the variance ratio should be zero. In other words, smaller VR is better in terms of efficiency.

We regress pricing error as measured by $\frac{\sigma(s)}{\sigma(p)}$ on a dummy variable, ZCB Dummy, which takes on a value of one after zero commissions come into effect. The results are presented in Table B.1. Overall, we find that the regression coefficient is not statistically different from zero. However, when the variance ratio is regressed on a dummy representing the zero-commission event its regression coefficient is positive and statistically significant at the 10% level. Consequently, we find limited evidence that zero brokerage commissions worsened price efficiency.

Table B.1 Price Efficiency

This table reports the results from regressions of market efficiency measures on a zero-commission dummy for the top 100 stocks most frequently held by Robinhood users as identified by Robintrack. The sample includes stocks having a price greater than \$2.00. The price efficiency measures are the ratio of the standard deviation of pricing error to the standard deviation of price σ(s)/σ(p), and the absolute value of one minus the ratio of the variance of 1 minute to four of the variances of 15-second midpoint return *VR*. The main independent variable is *ZCEvent Dummy*, which is a dummy variable equal to 1 if the time is greater than October 2019 and equal to 0 before that. Controls include the natural log of market capitalization, inverse of the share price, natural log of dollar trading volume, daily volatility index (VIX), stock and date fixed effects. All dependent variables are computed from DTAQ database; market capitalization, trading volume and closing price are from CRSP. VIX volatility index is from CBOE. St The sample period is from 06/2019-02/2020. T-Stats are reported in parentheses. Standard errors are double clustered at the stock and date level. ***, **, * indicate statistical significance at the 0.01, 0.05 and 0.10 level, respectively.

	$\frac{\sigma(s)}{\sigma(p)}$	***VR***
ZCEvent Dummy	0.016	0.071 *
	(1.29)	*(1.79)*
Log(MktCap)	-0.008	-0.001
	(-0.56)	*(-1.2)*
LogVol	0.010 ***	0.031 ***
	(19.12)	*(31.84)*
InvP	-0.144 ***	-0.254 ***
	(-9.99)	*(-22.89)*
VIX	0.002 ***	0.004 ***
	(2.46)	*(2.13)*
Stock & Date Fixed Effect	Yes	Yes
R^2	0.29	0.26
Observations	14,225	14,225

B.2 Robustness Tests

B.2.1 Change in Trading Volume Share by Execution Venue Type

Table B.2.1 presents the univariate differences for the change in the market share of trading volume by venue type. Because the SEC Rule 606 reports are broken out by listing venue, Panel A reports the average change in trading volume share for NYSE-listed stocks, Panel B reports for Nasdaq-listed stocks, and Panel C reports for NYSE American-listed stocks and stocks listed on other regional exchanges. The pre- and post-periods denote the seven weeks before and after the major retail brokers' implementation of zero brokerage commission. Results in Table B show that the changes in the zero-commission broker's order routing behavior indeed impact the overall market trading volume share. After the implementation of zero brokerage commission, the market share of trading volume declines for exchanges, especially inverted exchanges which pay rebates to liquidity demanders. These inverted exchanges may previously have been preferred by brokers who were routing marketable orders to exchanges. The percentage of market share of volume increased for off-exchange venues, which include executions by Alternative Trading Systems (ATSs), wholesale market makers that internalize retail orders, and over the counter (OTC) non-ATS trades that are not internalized retail orders. Specifically, Nasdaq-listed stocks have the greatest trading volume increases at off-exchange venues and trading volume declines at exchanges.

Table B.2.1 Change in Trading Volume Share by Execution Venue Type

This table presents univariate results for the change in the trading volume share by execution venue type. The sample includes all stocks that trade above $2.00 during regular trading hours (9:30 am - 4:00 pm) from 8/12/2019-11/29/2019. The pre- and post-periods denote the seven weeks before (8/12-9/27/2019) and after (10/14-11/29/2019) the major retail brokers' implementation of zero brokerage commission. The data is calculated and obtained from the DTAQ database. The Investors Exchange (i.e., IEX) uses a flat fee model for transaction fees. Standard t-tests are used to calculate the differences between pre- and post-periods. Statistical significance at the 10%, 5%, and 1% levels is denoted by *, **, and ***, respectively.

	Trade Volume Share		
	Change. +/-	T-Stat	
Panel A: NYSE-Listed Securities			
Make-take exchanges	-0.42%	-6.49	***
Take-make exchanges	-0.31%	-11.72	***
Off-exchange	0.96%	12.68	***
IEX	-0.23%	-14.90	***
Number of Observations	161,667		
Panel B: Nasdaq-Listed Securities			
Make-take exchanges	-1.18%	-13.67	***
Take-make exchanges	-0.30%	-9.95	***
Off-exchange	1.55%	15.95	***
IEX	-0.07%	-3.70	***
Number of Observations	129,513		
Panel C: NYSE American-Listed Securities			
Make-take exchanges	-0.88%	-5.96	***
Take-make exchanges	-0.12%	-3.03	***
Off-exchange	1.01%	6.62	***
IEX	-0.01%	-0.54	
Number of Observations	174,042		

B.2.2 Change in Market Quality

Table B.2.2 presents the results of the effect of zero commission event on market quality of marketable orders using SEC rule 605 reports. This test includes the five largest wholesale market makers (Citadel, Virtu, G1X, Two Sigma and UBS) that are identified from retail broker's Rule 606 reports. We focus on the market quality in a dimension of liquidity, and we test the changes in the quoted spread, effective spread, realized spread, and price impact four months before and after the major retail brokers implement a zero-brokerage commission. All the measurements in Table B.2.2 were presented as a dollar per hundred shares and were calculated as share weighted.

Table B.2.2 Change in Market Quality for Wholesale Market Makers

This table presents univariate results for changes in liquidity of marketable orders across wholesale market makers (Citadel, Virtu, G1X, Two Sigma, and UBS). The sample includes all stocks that trade above $2.00. The pre- and post- periods denote four months before and after the major retail brokers implement a zero brokerage commission. All the measurements in this test were presented as dollar per hundred shares and were calculated as share weighted from SEC Rule 605 reports. Paired t-tests are used to calculate the differences between pre- and post-periods. Statistical significance at the 10%, 5%, and 1% levels is denoted by *, **, and ***, respectively.

	Pre ($/100 shares)	Post ($/100 shares)	Diff. +/- ($/100 shares)	t-value	
Quoted Spread	8.55	8.329	-0.222	-2.91	***
Effective Spread	5.835	5.388	-0.447	-13.72	***
Price Impact	3.181	2.433	-0.749	-15.18	***
Realized Spread	2.653	2.955	0.302	5.95	***

Table B.2.3 Fixed-effects Regressions for Market Quality Measures

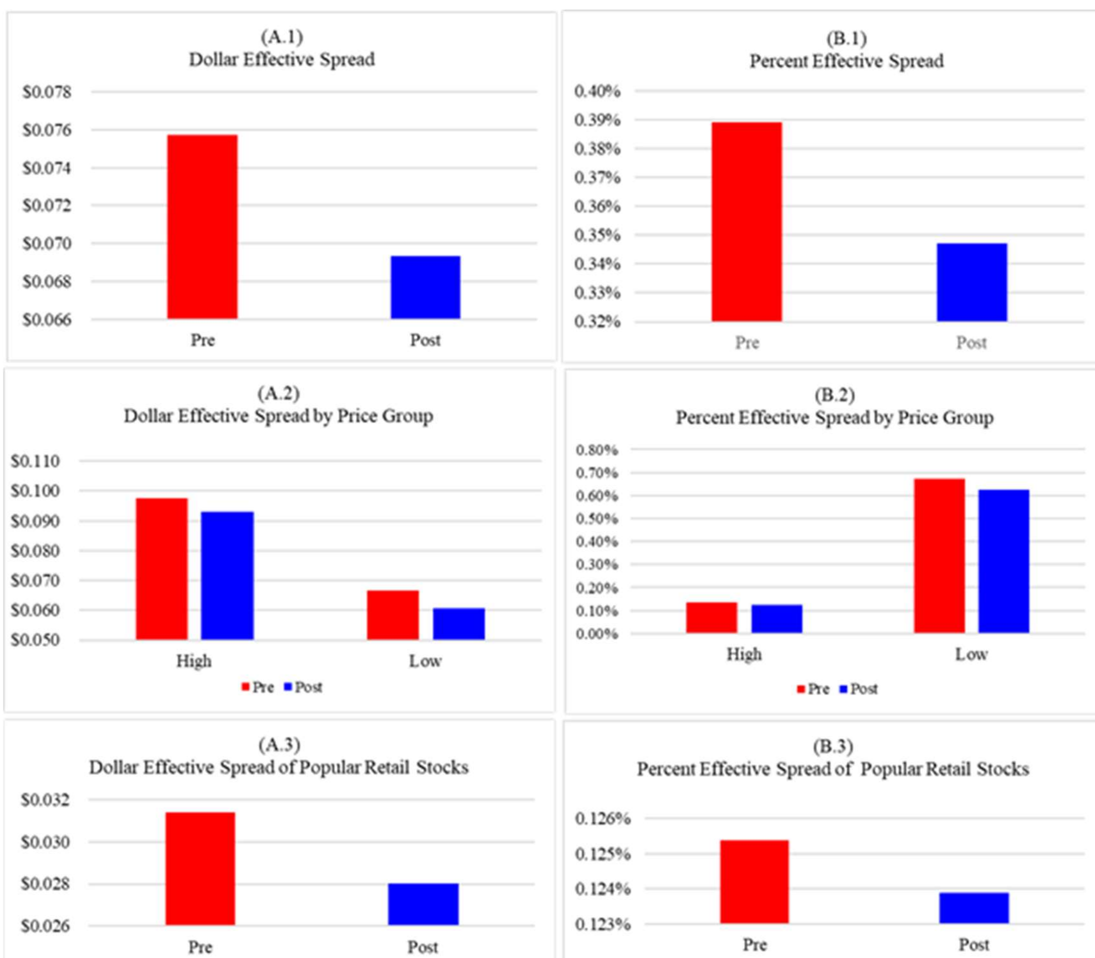
This table reports the results from regressions of market quality measures on a zero-commission dummy for the top 100 stocks that are most frequently held by Robinhood users as identified by Robintrack and that have a price greater than $2.00. The dependent variables in Panel A are the three liquidity measures: Time-weighted percent quoted spread, averaged percent effective spread and averaged percent price impact, computed from Daily TAQ database. The dependent variables in Panel B are average percent realized spread and stock intraday volatility IntraVolatility, which is the average percentage difference between the intraday high and low price (Bacidore, Battalio, and Jennings, 2002). ZCEvent Dummy is the main explanatory variable of interest, which takes the value of one if the date is between 06/2020-09/2020 which is after zero commissions are implemented by major brokers and equals zero if the date is between 06/2019-09/2019 which is the period before zero commissions are implemented. ShortInterest captures the short sale open interest, which is calculated as the number of shares sold short divided by the total number of shares outstanding. logVol is the natural log of the daily share volume, Log(MktCap) is the natural log of market capitalization of stock i, InvP is the inverse of the stock's daily closing price. We control for industry fixed effects, and the standard errors are double clustered at the firm and date level. Stock short interest information is from the Compustat Supplemental Short Interest File, and market capitalization and closing price is from CRSP. All regressions include the industry fixed effects. T-Stats are reported in parentheses. Standard errors are double clustered at the stock and date level. ***, **, * indicate statistical significance at the 0.01, 0.05 and 0.10 level, respectively.

	Quoted Spread *(%)*	**Effective Spread *(%)***	**Price Impact *(%)***	**Realized Spread *(%)***	**Intra Volatility*(%)***
ZCEvent Dummy	-0.004**	-0.009***	-0.011***	0.00	0.007***
	(-2.24)	*(-4.51)*	*(-3.50)*	*(0.50)*	*(6.28)*
ShortInterest	0.029***	0.049***	0.019*	0.03**	0.00
	(2.58)	*(4.50)*	*(1.82)*	*(2.88)*	(0.01)
LogVol	-0.018***	-0.007***	-0.004**	-0.003*	0.01***
	(-15.02)	*(-5.06)*	*(-2.31)*	*(-1.76)*	*(14.81)*
IntraVolatility	0.189***	0.139***	0.243***	-0.104*	
	(5.10)	*(4.66)*	*(3.83)*	*(-1.85)*	
Log(MktCap)	-0.016***	-0.012***	-0.013***	0.001	-0.008***
	(-11.10)	*(-10.29)*	*(-11.54)*	*(1.10)*	*(-21.50)*
InvP	0.338***	0.353***	0.192***	0.161***	-0.036***
	(7.51)	*(9.94)*	*(7.27)*	*(6.05)*	*(-10.47)*
Constant	0.835***	0.508***	0.483***	0.025	0.062***
	(21.98)	*(15.08)*	*(14.72)*	*(0.73)*	*(6.63)*
Industry F.E	Yes	Yes	Yes	Yes	Yes
R^2	0.71	0.47	0.36	0.1123	0.225
Observations	4,658	4,658	4,658	4,658	4,658

Figure B.2.1 presents the effects of zero commissions on dollar effective spread, effective spread by price group (high versus low), and effective spread for the top 100 stocks held by Robinhood investors graphically. Each security is allocated to a price group, high versus low, defined relative to the median share price in the period before commissions drop to zero.

Figure B.2.1 Change in Effective Spread

This figure provides the aggregate change in average dollar and percent effective spread. Our sample includes all stocks that trade above $2.00 during regular trading hours (9:30 am - 4:00 pm) from 8/12/2019-11/29/2019. The pre- and post-periods denote the seven weeks before (8/12-9/27/2019) and after (10/14-11/29/2019) the major retail brokers' implementation of zero brokerage commissions. All measures are obtained and calculated from DTAQ database. We use the liquidity measurement as proposed by Holden and Jacobsen (2014) and use Lee and Ready (1991) algorithm to identify the buy/sell direction. A.2 and B.2 report the dollar and percent effective spread by price group (each security is placed into a low or high price category relative to the median share price in the pre-event sample period). A.3 and B.3 report the subsample of dollar and percent effective spread for top 100 stocks held by most Robinhood users.



B.2.3 Identification of Buy/Sell Orders and Liquidity Measures

The following measures of market liquidity are proposed by Holden and Jacobsen (2014). We use these liquidity measures to analyze market quality. For measuring spreads, we use the DTAQ intraday data to link quote and trade and identify all the trades that fit our criteria into buy and sell by using the following algorithm.

First, we match each stock trade with the prevailing NBBO quote at the end of the previous millisecond. Next, we compute the midpoint for each NBBO quote, and then classify the trading direction ("Buy" or "Sell") for each trade using the following three conventions

Trade Direction	**Direction Sign**	**Lee and Ready (1991)**
Buy	+1	When trade price is higher than the assigned quote midpoint
Sell	-1	When trade price is lower than the assigned quote midpoint
Tick Test		When the trade price does not fit the above buy/sell direction criteria
		Buy (+1): When the price for last trade is lower than the current trade Sell (-1): When the price for last trade is higher than the current trade

Finally, after identifying the trading direction, we use the following liquidity measures to examine the market quality

<u>Quoted Spread</u>

Percent	The difference between the national best offer (NBO) minus the national best bid (NBB) divided by the midpoint M_t of the NBB and NBO for a given time interval

<u>Effective Spread</u>

Percent	The difference between each trade price and midpoint M_t of assigned NBB and NBO multiplied by twice the trading direction divided by the midpoint M_t of associated NBB and NBO

<u>Realized Spread</u>

Percent_5min	The difference between each trade price and the midpoint M_{t+5}, five minutes after the midpoint of the associated NBB and NBO divided by the midpoint M_t of the associated NBB and NBO
Percent_15sec	The difference between each trade price and the midpoint M_{s+15}, fifteen seconds after the midpoint of the associated NBB and NBO divided by the midpoint M_s of the associated NBB and NBO

<u>Price Impact</u>

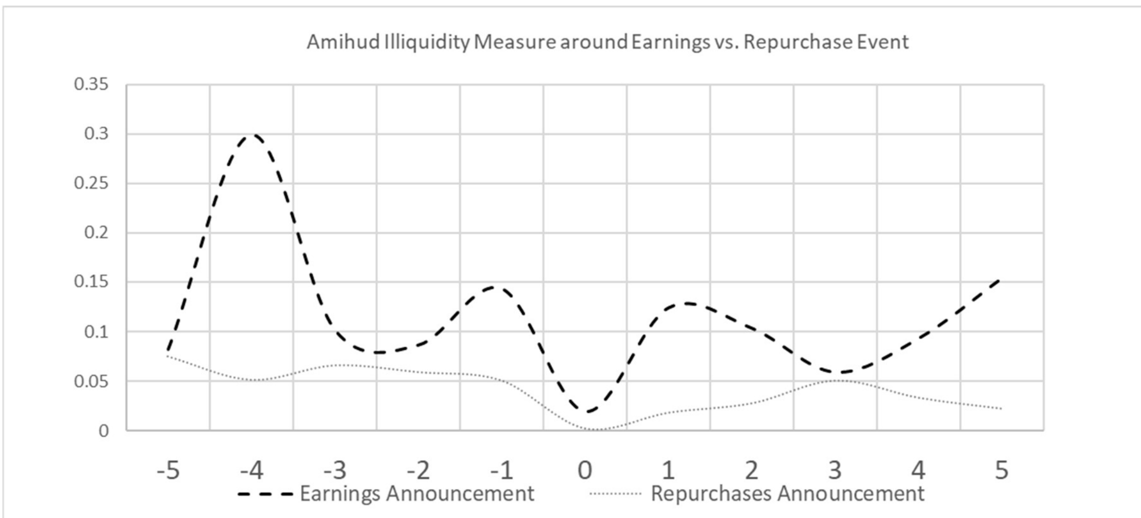
Percent_5min	The five-minute difference between the midpoint M_t and M_{t+5} of the NBB and NBO multiplied by twice the trading direction and divided by the midpoint M_t
Percent_15sec	The fifteen seconds difference between the midpoint M_s and M_{s+15} of the NBB and NBO multiplied by twice the trading direction and divided by the midpoint M_s

Appendix C: Additional Tests for Chapter 2: Trading Venue Preference: Critical Role of Institutional Ownership

Table C.1. Confirmation of Higher Information Asymmetry around Scheduled Events using Amihud Illiquidity Measure and the Cumulative Abnormal Log(Turnover)

Table C.1 shows the information asymmetry around the earnings and repurchases announcement. The information asymmetry is proxied by the Amihud illiquidity measure and cumulative abnormal log(Turnover). Panel A reports the average daily Amihud illiquidity measures. The solid line represents the Amihud illiquidity measures around earnings announcement, and the dash line shows the Amihud illiquidity around repurchase announcement. Panel B plots the average cumulative abnormal log(turnover) around earnings and repurchase announcements. The definition and calculation of cumulative abnormal log(turnover) are following Chae (2005). The sample includes 1,002 firms that have both earnings and repurchase announcements between January 2014 and December 2019.

Panel A: Amihud Illiquidity Measure



Panel B: Cumulative Abnormal Log(Turnover)

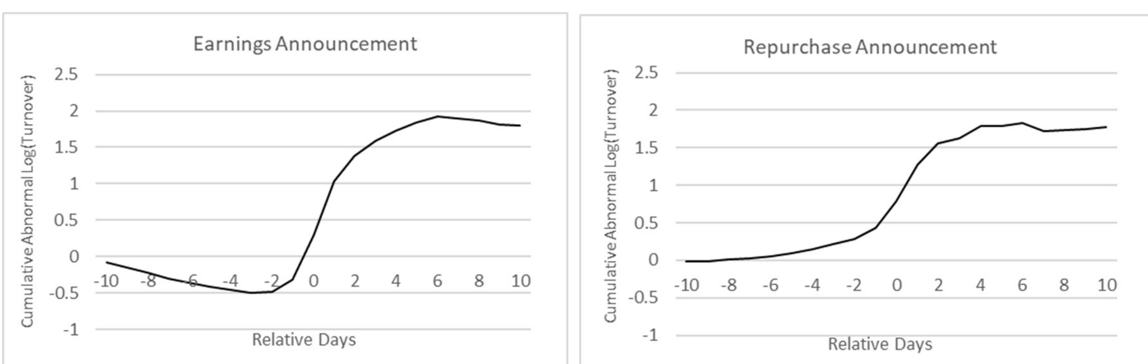


Table C.2. Differences in Off-exchange Trading Volume Share at Day Before the Earnings and Repurchase Announcements

This table presents the paired t-test results for the differences in the proportion of off-exchange trading volume share for the day before the earnings and repurchase announcements with the steady state in half-hour intervals. The sample includes off-market trading volumeshare for 1,002 firms that have both earnings and repurchase announcements between January 2014 and December 2019. The steady-state is calculated as the average proportion of the off-exchange trading volume share with no earnings and repurchase announcements. Diff1 is the difference of off-exchange trading volume share between the day with earnings announcement and the steady-state; Diff2 is the difference of off-exchange trading volume share between the day with repurchase announcement and the steady-state. Paired t-tests are used to calculate the differences, and the t-statistics are reported in parentheses. Statistical significance at the 5%, 1%, and 0.1% levels is denoted by *, **, and ***, respectively.

		Off-exchange Trading Volume Share Before Announcements			
Time	**Steady State**	**Earnings Announcement**	**Diff1**	**Share Repurchase Announcement**	**Diff 2**
9:30-10:00	27.08%	29.08%	2.00%***	27.72%	0.65%
			(11.12)		*(0.94)*
10:00-10:30	33.35%	34.32%	0.97%***	33.28%	-0.06%
			(4.15)		*(0.12)*
10:30-11:00	33.33%	34.28%	0.95%***	33.06%	-0.27%
			(4.21)		*(-0.15)*
11:00-11:30	33.78%	34.82%	1.04%***	33.43%	-0.35%
			(5.26)		*(-0.36)*
11:30-12:00	33.38%	34.36%	0.98%***	32.48%	-0.90%
			(4.97)		*(-1.03)*
12:00-12:30	32.97%	34.15%	1.18%***	30.33%	-2.64%***
			(4.76)		*(-3.16)*
12:30-13:00	32.88%	33.62%	0.74%***	32.50%	-0.38%
			(3.88)		*(-0.51)*
13:00-13:30	32.47%	33.71%	1.25%***	32.32%	-0.15%
			(5.95)		*(-0.19)*
13:30-14:00	33.22%	33.78%	0.56%***	31.75%	-1.47%
			(2.73)		*(-1.55)*
14:00-14:30	32.97%	33.90%	0.93%***	32.21%	-0.76%
			(4.18)		*(-0.75)*
14:30-15:00	32.46%	33.63%	1.17%***	33.89%	1.43%
			(5.17)		*(1.87)*
15:00-15:30	31.50%	32.77%	1.27%***	31.09%	-0.41%
			(5.83)		*(-0.15)*
15:30-16:00	26.19%	28.26%	2.07%***	26.17%	-0.02%
			(11.38)		*(0.49)*

Table C.3. Differences in Off-exchange Trading Volume Share at Day After the Earnings and Repurchase Announcements

his table presents the paired t-test results for the differences in the proportion of off-exchange trading volume share for the day after the earnings and repurchase announcements with the steady-state in half-hour intervals. The sample includes off-exchange trading volumeshare for 1,002 firms that have both earnings and repurchase announcements between January 2014 and December 2019. The steady-state is calculated as the average proportion of the off-exchange trading volume share with no earnings and repurchase announcements. Diff1 is the difference of off-exchange trading volume share between the day with earnings announcement and the steady-state; Diff2 is the difference of off-exchange trading volume share between the day with repurchase announcement and the steady-state. Paired t-tests are used to calculate the differences, and the t-statistics are reported in parentheses. Statistical significance at the 5%, 1%, and 0.1% levels is denoted by *, **, and ***, respectively.

		Off-exchange Trading Volume Share After Announcements			
Time	**Steady State**	**Earnings Announcement**	**Diff1**	**Share Repurchase Announcement**	**Diff 2**
9:30-10:00	27.08%	33.10%	6.03%***	27.96%	0.89%
			(29.04)		*(1.31)*
10:00-10:30	33.35%	37.96%	4.62%***	33.98%	0.63%
			(21.61)		*(0.71)*
10:30-11:00	33.33%	37.26%	3.93%***	34.31%	0.98%
			(19.27)		*(1.16)*
11:00-11:30	33.78%	37.67%	3.90%***	34.52%	0.74%
			(17.84)		*(0.81)*
11:30-12:00	33.38%	37.32%	3.94%***	33.66%	0.27%
			(18.42)		*(0.27)*
12:00-12:30	32.97%	36.62%	3.65%***	34.85%	1.88%*
			(15.24)		*(1.97)*
12:30-13:00	32.88%	36.28%	3.40%***	32.67%	-0.21%
			(16.31)		*(-0.22)*
13:00-13:30	32.47%	36.47%	4.00%***	32.39%	-0.08%
			(18.76)		*(-0.14)*
13:30-14:00	33.22%	36.28%	3.06%***	34.21%	0.99%
			(14.07)		*(1.26)*
14:00-14:30	32.97%	35.85%	2.88%***	33.22%	0.25%
			(14.06)		*(0.4)*
14:30-15:00	32.46%	36.11%	3.66%***	32.75%	0.29%
			(17.80)		*(0.56)*
15:00-15:30	31.50%	34.79%	3.29%***	30.19%	-1.31%
			(17.23)		*(-1.65)*
15:30-16:00	26.19%	30.30%	4.11%***	26.94%	0.75%
			(24.42)		*(1.55)*

VITA

LE ZHAO

Born, Dingxi, China

2008-2012	B.A., Management Tianjin University of Commerce Tianjin, China
2014-2015	M.S., Hospitality Management Florida International University Miami, Florida
2016-2017	M.S., Finance Florida International University Miami, Florida
2018 -2022	Doctoral Candidate Florida International University Miami, Florida

PUBLICATION AND PRESENTATIONS

Mishra, S., & Zhao, L. (2021). *Order Routing Decisions for a Fragmented Market: A Review.* Journal of Risk and Financial Management, in press.

Jain, P. K., Mishra, S., O'Donoghue, S., & Zhao, L. (2020). *Trading Volume Shares and Market Quality: Pre-and Post-Zero Commissions.* Paper presented at the Southwestern Finance Association 2022 Annual Meeting, New Orleans, Louisiana.

Jain, P. K., Mishra, S., O'Donoghue, S., & Zhao, L. (2020). *Trading Volume Shares and Market Quality: Pre-and Post-Zero Commissions.* Paper presented at the Southern Finance Association 2021 Annual Meeting, Captiva Island, Florida.

Jain, P. K., Mishra, S., O'Donoghue, S., & Zhao, L. (2020). *Trading Volume Shares and Market Quality: Pre-and Post-Zero Commissions.* Paper presented at the Financial Management Association 2021 Annual Meeting, Denver, Colorado.

Jain, P. K., Mishra, S., O'Donoghue, S., & Zhao, L. (2020). *Trading Volume Shares and Market Quality: Pre-and Post-Zero Commissions.* Paper presented at the Southern Finance Association 2021 Annual Meeting, Captiva Island, Florida.

Jain, P. K., Mishra, S., O'Donoghue, S., & Zhao, L. (2020). *Trading Volume Shares and Market Quality: Pre-and Post-Zero Commissions.* Paper presented at the 2021 Florida Finance Conference, Gainesville, Florida.

Jain, P. K., Mishra, S., O'Donoghue, S., & Zhao, L. (2020). *Trading Volume Shares and*

Market Quality: Pre-and Post-Zero Commissions. Paper presented at the 2021 Eastern Finance Association 2021 Annual Meeting, online.

Parhizgari, A. and Zhao, L. (2021). *Climate Change, Technological Innovation, and Firm Performance.* Paper presented at 2021 International Conference on Applied Business and Economics, online.

Parhizgari, A. and Zhao, L. (2021). *Climate Change, Technological Innovation, and Firm Performance.* Paper presented at 2021 Global Finance Conference, online.