Democratizing or Demoralizing: The Impact of Robinhood on Trading Costs and Volatility*

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Abstract

Order collaring, the automatic conversion of default market orders into limit orders with 5% spread over prior prices, has been utilized at Robinhood to protect retail investors from trading at unfavorable prices. In this paper, we provide empirical evidence that this policy harms retail traders in the form of higher trading costs. Using two quasi-experiments involving Robinhood's trading hours and the discontinuity around 5% spread, we find that Robinhood customers have higher likelihood of paying extreme spreads over close prices. Further, the policy is associated with extreme price movements in stocks. We estimate that the economic loss of the retail traders due to order collaring is on the order of millions of dollars per day.

Keywords: Retail Investors, Order Collaring, Order Anticipation, Extreme Price Movements

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1. Introduction

Retail trading behavior has been an important topic of study for academics and regulators. The older traditional line of research on retail trading has examined the investment decisions of retail investors illustrating that they suffer from many systematic biases (Barber and Odean, 2013).[1] However, the retail trading landscape has recently changed dramatically with the introduction of zero-commission trading by Robinhood in 2013. Many retail brokers followed the zero-commission trading trend due to fierce competition. Overall, this major shift has made it more affordable for individual investors to participate in the stock market, removing a barrier to entry and leading to a significant increase in the number of retail traders. Amplified by the concurrent major shift to 'working-from-home' due to the COVID-19 pandemic, retail traders have become an important part of equity trading in the United States. Using publicly available data, Rosenblatt Securities estimates that the market share of retail traders increased to 47% in January 2021 at the apex of the 'meme-stock' frenzy.[2] Given their increasing importance and the empirical evidence that net retail order imbalance can predict future returns (Boehmer et al., 2021), NASDAQ has started to sell data tracking the activity of retail traders which amounts to trading over $30 billion per day.[3]

As a front-runner driving the shift to zero-commission trading, Robinhood, with its easy-to-use and gamified mobile app, has scored the highest number of retail traders on its platform. In 2022, Robinhood reported 22.9 million funded customer accounts with $71 billion in assets under custody.[4,5] Given its growing market share, it is important to

[1] A recent developing literature has started to question this finding, at least at the aggregate level. For example, using proprietary data set from a wholesaler, Kelley and Tetlock (2013) find that retail traders' aggregate order flow positively predicts firms' monthly stock returns. Similarly, Boehmer et al. (2021) show that individual stocks with net buying by retail investors outperform stocks with negative imbalances.

[2] In March 2022, Rosenblatt Securities estimates the retail market share to be 28% well above the historical estimates of 10%.

[3] https://data.nasdaq.com/databases/RTAT/data

[4] https://investors.robinhood.com/news/news-details/2022/Robinhood-Markets-Inc.-Reports-August-2022-Operating-Data/default.aspx

[5] Despite its popularity among retail investors, Robinhood is still quite small when comparing assets under management versus other brokerage firms. For example, Charles Schwab has $6.6 trillion and Interactive Brokers has $267 billion in assets under custody.

understand how Robinhood's specific features affect its users and the market-wide price volatility.

Upon opening the main trading screen on the Robinhood App, an investor faces a particular set of default order options. After designating a trade quantity in dollar or share units, one can trade a particular stock by simply 'swiping up' on the screen. Robinhood automatically converts most default orders into limit orders using a 5% price collar. This practice is called order collaring (OC). On its website, Robinhood states that the rationale for OC is "to protect its customers from executing at unfavorable prices." For example, if a customer wants to buy one share of a security with a last trade price of $100 via a default order, Robinhood will convert this default order into a limit buy order with a maximum price of $105. In this paper, we examine the (unintended) consequences of order collaring on retail investors and overall market quality.

One potential concern that can harm a retail investor is order anticipation. Given that Robinhood's OC rule is public information and has been implemented since its early days[6], we expect market makers or strategic traders to place quotes around the 5% spread of the last transaction (limit buy or sell) to exploit the higher willingness to pay embedded in the automatically collared order. For example, with an inactive Rule 605[7] in after-hours trading and the accompanied reduction in execution quality requirements, market makers may quote excessive spreads as predicted by the high-frequency market making model in Aït-Sahalia and Sağlam (2023). These excessive spreads enable them to profit off collared orders at the expense of Robinhood traders. Further, Robinhood seems to be incentivizing after-hours trading with an expansion of their after-hours trading hours in 2022[8] and the introduction of 24 hour trading in 2023.[9]

[6] https://www.reddit.com/r/RobinHood/comments/42q1zd/is_a_collar_a_fee/

[7] Rule 605 requires that trading centers measure execution quality versus NBBO at the time of order execution. Note, "the Rule applies only to market orders or limit orders that are received by a market center during regular trading hours and, if executed, executed during such time." Full text of Rule 605 can be found at https://www.sec.gov/rules/2001/03/disclosure-order-execution-and-routing-practices

[8] https://www.cnbc.com/2022/03/29/robinhood-adds-four-additional-hours-to-extended-trading-for-client
html

[9] https://www.forbes.com/sites/antoniopequenoiv/2023/05/10/robinhood-launching-24-hour-weekday-stock-

As noted earlier, retail trading accounted for almost half of all trading. Thus, the OC rule would also change how market makers quote during regular market hours as well. Specifically, in periods of high volatility, we expect the OC rule to be in the detriment of retail investors especially for illiquid stocks. We expect the OC rule to be even more prominent and costlier in after-hours trading. Since many Robinhood investors are typically inexperienced, they may use the default order options, i.e., collared orders, when submitting trades in this period. Further, a higher portion of Robinhood orders are collared in after-hours trading as shown in Table 1. For these reasons, to provide suggestive evidence of causality between the OC rule and higher trading costs, we examine trades occurring in the after-hours period extensively.

We first provide long-term time series evidence that there is significant dollar volume exposed to extreme spreads compared to the close prices in recent years when Robinhood is gaining popularity. We find that the excessive spreads are not simply a function of increasing dollar volume but instead it correlates directly with Robinhood's popularity among retail traders. Second, we use two quasi-experiments to examine the impact of the OC rule on transaction prices and retail trading costs. First, Robinhood's after-hours trading session finishes at 6:00 PM before March 29, 2022. Thus, we expect that the effect of the 5% order collaring policy will be more pronounced before 6:00 PM when compared to the period right after 6:00 PM. Second, Robinhood extended their after-hours trading session until 8:00 PM on March 29, 2022. We also utilize this shock to run a difference-in-differences regression to examine the impact of OC on trading costs. We use the discontinuity around the 5% spread to define our control variables. In both analyses, we find that the number of trades occurring at extreme spreads is significantly higher when Robinhood actively converts default buy (sell) orders to limit orders with 5% above (below) the last transaction price.

In addition, we examine how prices exhibit extreme volatility due to the presence of the OC rule at 5%. Since retail traders are subject to excessive spreads up to 5% on each trade, correlated retail trading on Robinhood (e.g., successive retail buys) may cause sudden price movements as strategic market makers know that their default orders will be converted

to limit orders priced at a 5% differential over the prior transaction prices. Consequently, the OC rule can cause extreme price volatility as observed on *meme stocks* that are traded heavily by retail investors.

The current explanation of the unprecedented price volatility observed in January 2021 is primarily based on a short-squeeze theory. In their report, the SEC found that short covering, however, did not make up the majority of buying pressure for the duration of the GameStop (GME) price runup.[10] We investigate whether the OC rule could have also played a substantial role in these extreme price movements. Computing maximum and minimum transaction prices around the closure of Robinhood, we find consistent evidence suggesting that the OC rule is potentially introducing extreme volatility to the observed prices.

To our knowledge, this is the first paper that examines the economics of the order collaring. Our paper has important policy implications with regard to protecting retail investors, ensuring best execution, and reducing extreme volatility. First, one of the long standing mission of the SEC is to protect investors. Our findings regarding this unexplored retail broker practice may be valuable to the policymakers at the SEC as we are able to quantify the potential cost of this OC policy to retail investors. Given that this policy is advertised to be implemented with the goal of protecting investors, it is important to inform the regulators regarding its negative effects. Further, there are two more retail brokers, WealthSimple and DriveWealth, that employ similar order collaring practices, suggesting that this policy is not an isolated practice at a single retail broker.[11] Relatedly, our analysis is informative on how retail brokers, subject to the duty of best execution from the SEC and FINRA, handle retail orders. The duty of best execution[12] is a legal obligation to each retail broker to ensure that

[10] https://www.sec.gov/files/staff-report-equity-options-market-struction-conditions-early-2021.pdf

[11] https://web.archive.org/web/20230326151246/https://help.wealthsimple.com/hc/en-ca/articles/360058451433

[12] The obligation for best execution comes from FINRA rule 5310, which states "In any transaction for or with a customer or a customer of another broker-dealer, a member and persons associated with a member shall use reasonable diligence to ascertain the best market for the subject security and buy or sell in such market so that the resultant price to the customer is as favorable as possible under prevailing market conditions." The full FINRA rule 5310 can be found at https://www.finra.org/rules-guidance/rulebooks/finra-rules/5310

its clients' trades are executed in the most advantageous manner possible. If the OC rules are hurting retail investors, then this would certainly be at odds with the best execution duty. Finally, and maybe most importantly, our paper provides a novel mechanism in explaining the unprecedented extreme price movements observed in stocks with a high share of retail trading. Extreme price movements can lead prices to deviate significantly from fundamentals. Given that only buy orders are subject to the OC rule at Robinhood during intraday trading, extreme price run-ups are more likely. This prediction is consistent with the widespread price run-ups observed extensively in January 2021. Further, higher volatility observed in transaction prices can make prices less informative for corporate managers who make real investment decisions based on their stock prices. Thus, establishing that OC rules are causally associated with extreme price movements would provide valuable insights to policymakers in achieving market stability.

The remainder of this paper is organized as follows. Section 2 provides a brief literature review. In Section 3, we provide the institutional details relevant to our formal analyses and identification strategies. In Section 4, we describe the data set and provide brief time-series trends and statistics. In Section 5, we formally quantify the impact of the OC rule on the transactions with extreme spreads over the prior prices. Section 6 informs us that the OC rules can be also playing a role in short-term extreme price movements. Finally, we conclude in Section 7.

2. Related Literature

On the theoretical side, the most closely related paper is Aït-Sahalia and Sağlam (2023) which examines the effect of an informative signal about the type of trader submitting a market order (patient or impatient) opposite the liquidity provided by a high-frequency market maker (HFMM). Patient traders are willing to pay a spread of δ whereas impatient traders are willing to pay a spread greater than δ to improve the likelihood of an execution.

If the accuracy of the HFMM's signal improves, then the HFMM is better able to price discriminate among patient and impatient low frequency traders and exploit this ability to engage in predatory trading against impatient traders. In the model, this predatory quoting behavior leads to higher average bid-offer spread in the long-run equilibrium.

On the empirical side, our paper is related to the growing literature examining the impact of retail trading on market quality. Eaton et al. (2022) study the effect of retail trading on market quality, showing that Robinhood outages, negatively impacting retail participation, reduce price volatility and reduce quoted spreads. They use data from RobinTrack to show that Robinhood outages, representing a reduction in retail trading, are associated with reduced trade imbalances and depth-weighted quote imbalances. That effect is not consistent with outages at other retail brokerages, which, in contrast, lead to an increase in volatility and broaden spreads. This analysis goes on to theorize that Robinhood traders contribute to volatility.

Barber et al. (2022) use Robinhood's "Top Mover" list to show that retail traders act in herds and that specific herding events are likely to be followed by negative stock returns. Specifically, they show that Robinhood's app has a significant impact on investor behavior. For example, Robinhood's "Top Mover" list contributes to herding episodes where groups of users follow into specific securities. This analysis shows that unsophisticated investors that follow attention induced trading, based on things like Robinhood's "Top Mover" list, experience negative returns in the following months.

While our analysis in this paper does not focus on attention induced trading patterns, it does have a connection to how the default UI options, like default order types, on Robinhood affect investor behavior. Further, we contribute to the literature by providing evidence that savvy investors can exploit behavioral changes due to Robinhood's application. In order to profit, investors could design a trading strategy to provide liquidity around 5% above or below the last sale and closing their position at a much smaller premium.

Fedyk (2022) explores the unique investing behaviors of users on the Robinhood trading

platform, focusing on how they differ from those of previously studied individual investors. Using the Robintrack dataset, she finds that Robinhood users show a preference for investing in large, well-known companies that are going through difficult times, likely in anticipation of a rebound in their stock prices. On paper, portfolios representative of Robinhood users outperform the standard benchmarks, suggesting that these unconventional investment behaviors may have led to better-than-expected returns. However, due to lack of actual trade data, she does not quantify the real investment performance of the retail traders.

Our paper is also related to the studies examining the links between attention, noise trading and liquidity. Peress and Schmidt (2020) isolate US news events that distract noise traders to show that reduced retail trading is associated with lower liquidity in the market. Seasholes and Wu (2007) show that specific attention-grabbing events persuade investors to buy stocks. Further, it goes on to show that savvy investors take advantage of these trends to produce positive returns from both attention-based buying and liquidity provisions. Our analysis follows this narrative showing how experienced investors take advantage of opportunities to provide liquidity to Robinhood investors seeking to enter positions with collared orders at a premium.

Our paper is also related to the broad literature on order anticipation. Clark-Joseph (2013) examines whether HFTs use small trades to explore the price impact of E-mini futures for future exploitation. Bessembinder et al. (2016) studies the liquidity around predictable traders emerging from the rollovers of oil futures and do not find exploitative predatory trading. Sağlam (2020) finds that large institutional orders have higher trading costs if their execution leaves predictable patterns. Hirschey (2021) finds empirical evidence suggesting that high-frequency traders (HFTs) may increase the trading cost of non-HFTs by trading ahead of them.

Finally, our paper is related to understanding the market quality implications of aggregate dark venue executions (e.g., Buti et al., 2011; Comerton-Forde and Putniņš, 2015; Foley and Putniņš, 2016). Exchange code 'D' is used in TAQ data set to identify all trading within

ATSs as well as settled trades at the broker-dealers. There are a few studies that use this classification to examine the impact of dark pool trades on market quality (e.g., O'Hara and Ye, 2011; Hatheway et al., 2017; Farley et al., 2018). Given the special nature of the routing relationships between retail brokers and high-frequency market makers, our paper re-highlights the vast heterogeneity in the dark pool executions.

3. Institutional Details

3.1. Overview

Robinhood, founded in 2013, was the first retail brokerage to enable commission-free trading for retail traders. Without commissions, Robinhood's main revenue source is payment for order flow (PFOF). PFOF is a practice in which a brokerage receives payment from a third party market maker, like Citadel Securities or Virtu Financial, in exchange for directing its clients' orders to that third party for execution. Typically, these orders are executed at the far side of the spread with some price improvement over the best available prices in round lots displayed on public exchanges. Since retail orders are expected to be uninformed, market makers can profit from internalizing them (even after some price improvement) because they experience less adverse selection costs. Uninformed orders allow market makers to pocket a big fraction of the bid-ask spread over the long-run.

PFOF has been a controversial topic because it creates a potential conflict of interest, as the broker may have an incentive to prioritize its own financial interests over those of its clients (Battalio et al., 2016). However, it is also argued that payment for order flow can benefit individual investors by providing them with faster and more efficient order execution as well as reduced costs in the form of brokerage fees (i.e. commission free trading). With regard to retail brokerage's financial incentives, PFOF brokerages make more revenue when traders trade more frequently, not when traders make more return.

Since trades from retail brokers are almost entirely routed through third party market

makers, they are reported through the FINRA trade reporting facility (TRF), identified by the exchange code 'D'. We will extensively use trades with this exchange code, as the vast majority of the Robinhood trades would be executed by wholesalers in the dark.

3.2. Robinhood User Interface and Trade Execution

To gain a full understanding of Robinhood's trade execution practices, it is important to understand the user experience in their mobile application. By default, traders choosing to buy or sell are directed to complete a dollar based market order, which allows for fractional shares. Alternatively, a trader can choose to adjust the default trade type to be share-based in the top right corner of the screen. The user interface flow for dollar-based and share-based order types can be seen in Figure 1 and Figure 2, respectively. There are additional complex order types referred to as "Conditional Orders" available as well. For example, the user interface flow for a conditional order type, limit order, can be seen in Figure 3. After choosing to trade in dollars or shares, a trader must designate the amount of dollars or shares they would like to trade, select "Review," and swipe up to complete the trade.

If a trader wanted to submit a standard limit order by designating her own limit price, she must navigate through 9 screen-steps, which is 125% more than the steps required for both default order types. Additionally, unlike default dollar- and share-based order types, Robinhood does not save any "Conditional Order" type. When the trader returns to the mobile platform to trade again, they must go through the entire flow, including re-choosing the order type.

3.3. Order collaring

Investors using Robinhood's trading platform face two particular default options, dollar-based or share-based trades, in their main trading screen. Robinhood states that "…to help protect our customers from potential price volatility, Robinhood automatically converts most

market orders into limit orders using a 5% price collar."[13] To compute the limit order price, Robinhood uses the last trade price on a NASDAQ exchange (the NASDAQ Stock Market, NASDAQ OMX BX, or NASDAQ OMX PHLX) at the time of order submission.[14]

There are potentially three reasons for this 5% collaring rule. First, especially in the after-hours market, if the bid-ask spread is greater than 5%, then putting the bound at 5%, Robinhood aims to protect its users from executing when the bid-ask spread is extremely high. Second, on the purchase side, Robinhood wants to make sure that the clients have enough capital to cover the trade as the market order makes the transaction price uncertain potentially due to significant latency in Robinhood's order submission technology. Third, having a large collar of 5% during after-hours period also increases the probability of a trade getting filled. As noted previously, Robinhood makes more money when traders trade more often.

Although all three reasons are plausible, the most important factor seems to be the assurance of enough capital stated in the second reason, especially during market hours. This conjecture is supported by the warning screen[15] that comes up in the Robinhood trading platform if a trader does not have enough capital to transact at the extreme price set by the 5% order collaring rule. Table 1 shows the conditions that will lead to default orders being collared. During market-hours, we observe that only default share-based buy orders are collared. Since Robinhood can guarantee the presence of enough capital in dollar-based buys by lowering the number of shares bought in the event of a higher market price, the collaring does not apply to these types of orders. Table 1 also shows that all market orders in AH are collared, suggesting that Robinhood would like to protect retail investors from executing at extreme unfavorable prices. However, it is an empirical question whether this

[13] https://web.archive.org/web/20221208173112/https:/robinhood.com/us/en/support/articles/market-order/

[14] http://web.archive.org/web/20230523174429/https://robinhood.com/us/en/support/articles/limit-order/

[15] If you have exactly $1.60 in your Robinhood account and attempt to trade a stock with a mark price of $1.60, you will receive a warning stating, "Not Enough Buying Power: Because this order has a maximum cost of $1.68, you don't have enough buying power in your account to place this order."

objective is achieved at the aggregate level.

On the other side, there are potential (unintended) consequences of OC that can harm the retail investor. For example, with an inactive Rule 605[16] in after-hours trading and the accompanied reduction in execution quality requirements, market makers may quote excessive spreads as predicted by the high-frequency market making model in Aït-Sahalia and Sağlam (2023). These excessive spreads enable increased market maker profits from executing collared orders at the expense of Robinhood traders. Thus, stocks with quoted spreads less than 10% could be adversely affected by OC. The protections associated with OC would only be valuable if the stock being traded has a quoted spread higher than 10% surrounding the last trade price on a NASDAQ exchange.

Table 2 illustrates a snapshot of after-hours trading in AMC Entertainment on February 14th, 2022. We find that 'D' exchange trades are trading at approximately 4% premium within the same second compared to previous trades executed on other exchanges ('P', 'T'). Although we do not have direct evidence that these orders have originated from Robinhood, given the OC rule and the corresponding 'D' exchange trades, we expect these to have originated from Robinhood.

Finally, it is worth noting that the potential increase in spreads is not limited to just AH trading. Given that share-based buy trades are collared at 5% at all times, this rule can also cause higher spreads during regular trading hours. For example, in line with this hypothesis, Eaton et al. (2022) find lower spreads for stocks with high retail interest when Robinhood suffers technological outages. Our analysis will point to another channel for the observed increase in spreads through the OC rule.

[16]Rule 605 requires that trading centers measure execution quality versus NBBO at the time of order execution. Note, "the Rule applies only to market orders or limit orders that are received by a market center during regular trading hours and, if executed, executed during such time." Full text of Rule 605 can be found at https://www.sec.gov/rules/2001/03/disclosure-order-execution-and-routing-practices

3.4. Robinhood's trading hours and MOC implementation

Table 1 illustrates the time intervals for pre-market (PM), regular-hours, and after-hours trading that the Robinhood platform uses. Up until March 29, 2022, AH trading ended at 6:00 PM. On this date, Robinhood extended the limit to 8:00 PM. In our following analyses, we will make use of both of these features. Since Robinhood is not active after 6:00 PM before March 29, 2022, we do not expect Robinhood's OC implementation having any impact between 6:00 PM and 8:00 PM, which provides us an invaluable discontinuity to explore econometrically. Similarly, we will also utilize the extension of the AH trading to 8:00 PM on March 29, 2022 as another positive shock to the usage of OC and we will examine its impact on prices and extreme volatility in Section 5.

4. Data

4.1. Description

Our data set is constructed from mainly three sources. Our transaction and quote data came from the NYSE Trade and Quote (TAQ) database. Our close prices and spread statistics came from WRDS Intraday Indicators (millisecond) data set. We use the Center for Research in Security Prices (CRSP) to obtain firm-level data such as shares outstanding and share code.

Share codes from the CRSP data set were used to filter tickers to only common stocks with share codes of 10 or 11. We obtain approximately 4900 common stocks in our sample between 2020 and 2022.[17] The intraday indicators data set contains summary statistics for each stock (e.g., open price, close price, total volume after hours, and total dollar volume after hours). The TAQ data set contains trade and quote information for each stock including the exchange code, price, and quantity traded.

[17] This number is relatively higher compared to older studies. The reason for this increase is the significant IPO activity in recent years.

Since we do not perfectly know which trades are coming through Robinhood, we specifically use the trades with an exchange code 'D' suggesting that these trades are executed at off-exchange venues. To collar the orders, Robinhood explicitly states that they use the last transaction price on a NASDAQ exchange. To identify NASDAQ trades, exchange codes, "T", "Q", "B", and "X" are used in accordance to TAQ participant code documentation.[18] The "T" exchange code corresponds to the NASDAQ Stock Exchange, LLC (in Tape A, B securities). The "Q" exchange code corresponds to the NASDAQ Stock Exchange, LLC (in Tape C securities). The "B" exchange code corresponds to the NASDAQ OMX BX exchange. The "X" exchange code corresponds to the NASDAQ OMX PSX exchange.

With each trade's corresponding last NASDAQ price identified, a percent change from the last NASDAQ price or the close price was calculated using the following equations:

$$Percentage\ Change\ From\ Last\ NASDAQ = 100 \times Sign \times \frac{Transaction\ Price - Last\ NASDAQ\ Price}{Last\ NASDAQ\ Price}$$

$$Percentage\ Change\ From\ Close = 100 \times Sign \times \frac{Transaction\ Price - Close\ Price}{Close\ Price}$$

where *Sign* takes a value of 1 (-1) if the transaction price is higher (lower) than the last NASDAQ trade. We will use the term 'excessive spread' to refer to trades that have a large percentage change compared to the last NASDAQ trade.

Additionally, for each trade, we define two loss metrics from retail trader's perspective, *Loss Markup NASDAQ* and *Loss Markup Close*:

$$Loss\ Markup\ NASDAQ = Size \times Sign \times (Price - Last\ NASDAQ\ Price)$$

$$Loss\ Markup\ Close = Size \times SignClose \times (Price - Close\ Price)$$

where *SignClose* takes a value of 1 (-1) if the transaction price is higher (lower) than the close price.

[18] https://www.nyse.com/publicdocs/nyse/data/Daily_TAQ_Client_Spec_v3.0.pdf

4.2. Time-series trends on the cost of the MOC rule in AH trading

To examine the overall trends in after-hours trading and the frequency of the trades with excessive spreads, we compute the correlation between the monthly total dollar volume and the loss markup over the close price, a potential proxy of the cost to retail traders using the Robinhood platform. We compute both statistics for a tight interval between 5:45 PM and 6:00 PM during which the Robinhood platform is open. We use the period between January 2014 and April 2022 for this analysis.

The top panel in Figure 4 plots the total dollar volume of the trades occurring in this 15-minute interval before 6:00 PM. In the bottom panel, the solid black line plots the monthly dollar loss of the trades that have a spread of at least 1% and at most 5% with respect to the close price. For example, if a one-share trade occurs on a security for $102 while its close price is $100, then we record this trade as having a $2 loss. If these total loss values were independent of Robinhood user activity, we would expect to see a high correlation between these two series as some constant fraction of all trades can have a high spread for idiosyncratic reasons. However, we find that this correlation is pretty low, namely 37%. While the losses peak in the post-Covid era, the total dollar volume in this interval does not exhibit any major spikes. Similarly, while the total dollar volume spikes up starting from early 2018, we do not see a similar increase in total dollar loss markup with respect to the close.

The red dashed line in the bottom panel of Figure 4 plots the relative Google search interest for the keyword "Robinhood." The values are normalized according to maximum value achieved in January 2021. Search interest on the company goes up around 2018 and remains constant up until the Covid period in March 2020 from where the search volume goes up dramatically. The highest interest is around the meme-stock period in January-February 2021.

Compared to the dollar volume series in the top-panel, this proxy for the popularity of the Robinhood trading platform explains the variation in the total loss markup in a much

better fit. Consistently, the correlation between the normalized search counts and the total loss markup increases to 66%. This high correlation is achieved despite the obvious deficiency of the normalized count measure. For example, in January 2021, it is quite probable that the search counts have peaked because of the newsworthiness of the platform during the meme-stock frenzy.

To examine the rough cost estimate of Robinhood's OC, we compare our total loss markup between 5:45 PM and 6:00 PM to the loss markup realized in the following 15 minutes, i.e., between 6:00 PM and 6:15 PM. We find that before the large increase in retail investor interest in Robinhood in 2020, the average difference was $330K while after 2020, this difference jumps to $1.8M. This implies a rough cost estimate of $1.5 million per 15 minutes, which is highly economically significant.

5. The impact of OC on prices: Evidence from quasi-experiments

In the following sections, we provide multiple evidence that market participants anticipate overpriced (underpriced) limit buy (sell) orders from retail traders and we illustrate that retail traders lose significantly due to trades occurring at extreme spreads when compared to close prices or previous on a NASDAQ exchange. We utilize two identification strategies: First, Robinhood's after-hours trading session finishes at 6:00 PM before March 29, 2022. Thus, we expect that the 5% order collaring will be more pronounced before 6:00 PM when compared to the period after 6:00 PM. Second, Robinhood extended the after-hours trading session to until 8:00 PM on March 29, 2022. We utilize these shocks to run a difference-in-differences regression to examine the impact of OC. Finally, we also provide evidence that our results extend to other spread ranges using after-hour trades on GME.

5.1. Evidence from Robinhood's closure at 6:00 PM

If other market participants are exploiting Robinhood's OC rule, we should observe trades at the maximum 5% spread around the last NASDAQ trade. Given that the OC rule is enforced during after-hours trading period during which there is less liquidity, we can examine trading activity occurring approximately at the 5% limit (for both buy and sell orders). Further, Robinhood's after-hours trading has ended at 6:00pm before March 2022 which allows us to compare trading at the extreme spreads for a time interval before and after 6:00 PM.

5.1.1. Visual evidence

The top panel in Figure 5 illustrates all after-hours transactions appearing in 'D' exchanges in April 2019 with approximately 5% spread to the last NASDAQ trade for the sixty minutes before and after 6:00 PM. The bottom panel in Figure 5 plots the same activity for April 2020. Both plots provide striking visual evidence that Robinhood's OC rule is exploited by other market participants.

First, we observe that the number of trades that occur exactly at a 5% spread is significantly higher in the pre-closure period. Specifically, 5% spread trades are the mode of the trade price distribution in both months. Similarly, in both plots, there are almost no trades which are slightly above the 5% spread while there is a large cluster of trades that occur right below this threshold. When compared to the post-closure period during which Robinhood trading platform is closed, these patterns seem quite abnormal.

5.1.2. Diff-in-Diff analysis

Since Robinhood is putting a cap on the realized transaction at around 5% change over the last NASDAQ transaction price, trades occurring at even higher spreads cannot be coming from Robinhood. We can use these trades as control variables to account for the potential change in trading activity after 6:00 PM. We will use all after hours transactions happening between 5:30 PM and 6:30 PM and having a spread either in the range $(4.85\%, 5.0\%]$ or

$(5.0\%, 5.15\%)$ with respect to the last NASDAQ transaction price.[19] The latter range will serve as a control group. Period 1 (2) will consist of the time interval between 5:30 PM and 6:00 PM (6:00 PM and 6:30 PM) whereas treatment spread range 1 (2) will correspond to $(4.85\%, 5.00\%]$ $((5.0\%, 5.15\%))$, respectively.

Let $NumTrades_{i,t,j,k}$ measure the number of trades of the ith stock on day t in period $j \in \{1, 2\}$ and treatment price level, $k \in \{1, 2\}$. Let $Treat_{i,t,j,k}$ be equal to 1 if k is 1 and 0 in all other cases and let $Post_{i,t,j,k}$ be equal to 1 if j equals 2 and 0 otherwise. We can run the following regression to quantify the impact of the MOC rule on transactions with extreme spread:

$$(1) \qquad NumTrades_{i,t,j,k} = \alpha + \beta_1 Treat_{i,t,j,k} \times Post_{i,t,j,k} + \beta_2 Treat_{i,t,j,k} + \beta_3 Post_{i,t,j,k} + \epsilon_{i,t,k}.$$

We exclude trades with transaction prices below \$1. We adjust our standard errors by clustering at the stock-day level.

Table 3 illustrates the regression result. The coefficient on $Treat \times Post$ is negative and statistically significant implying that when compared to a control group, number of trades that are occurring at extreme spreads have dropped after Robinhood's closure at 6:00 PM. The coefficients are also economically significant. On an absolute basis, the drop in number of trades is approximately 0.4 in this 30-minute interval. It is also important to compare the magnitude relative to the existing number of trades in the treatment group before 6:00 PM. The coefficient on $Treat$ is roughly 0.5, thus the relative drop is approximately 80%.

5.2. Evidence from Robinhood's extension of the after-hours trading period

Robinhood extended the after-hours trading session from 4:00-6:00 PM to 4:00-8:00 PM on March 29, 2022. We employ this shock to run a difference-in-differences regression to

[19] If there is no last transaction price on NASDAQ in after-hours trading, we take the close price of the security.

examine the impact of OC rule.

5.2.1. Visual evidence

The top panel in Figure 6 illustrates after-hours transactions appearing in the 'D' exchanges in March 2022 but before the extension date. Similarly, the bottom panel in Figure 6 illustrates after-hours transactions appearing in 'D' exchanges in April 2022 which is the first month after the extension of the after-hours trading. In both panels, we plot the trades having a spread between 2% and 7% over the last NASDAQ trade. These plots provide another striking visual evidence that Robinhood's OC rule leads to retail trades executing at extreme spreads. Compared to the top panel in which Robinhood is not active after 18:00, we find that trades occurring at or right below the 5% threshold increases substantially after 18:00 suggesting that retail traders do indeed pay extreme trading costs on the Robinhood trading platform.

5.2.2. Diff-in-Diff analysis

As we did in the previous section, we now formally examine the effect using a diff-in-diff methodology. We take trades occurring between 6:20 PM and 8:00 PM having a spread in the range $(5\%, 5.15\%)$ as controls and use trades in the period but having a spread in the range $(4.85\%, 5\%]$ as the treatment group. Formally, let $NumTrades_{i,t,k}$ measure the number of trades of the ith stock on day t in the treatment spread $j \in \{1, 2\}$. As before, the treatment spread range 1 (2) will correspond to $(4.85\%, 5.00\%]$ $((5.0\%, 5.15\%))$, respectively. Let $Treat_{i,t,k}$ be equal to 1 if k is 1 and 0 in all other cases. Finally, let $Extended_{i,t,j}$ be equal to 1 if t is later than March 29, 2022 and 0 otherwise. We take the following periods: March 1, 2022 to March 28, 2022 and April 1, 2022 to April 28, 2022. We run the following regression to quantify the impact of the OC rule on the number of transactions with extreme

spread:

$$(2) \quad NumTrades_{i,t,k} = \alpha + \beta_1 Treat_{i,t,k} \times Extended_{i,t,k} + \beta_2 Treat_{i,t,k} + \beta_3 Extended_{i,t,k} + \epsilon_{i,t,k}.$$

We adjust our standard errors by clustering at the stock-day level. We again exclude trades with transaction prices below $1.

Table 4 illustrates the regression result. The coefficient on *Treat*×*Extended* is positive and statistically significant implying that when compared to the control group, number of trades that are occurring at extreme spreads have increased after the extension of the Robinhood's after-hours trading period. The coefficients are also economically significant. On an absolute basis, the increase in number of trades is approximately 0.4 in this 80-minute interval. It is also important to compare the magnitude relative to the existing number of trades in the treatment group. The coefficient on *Treat* is roughly 0.09, thus the relative increase is also very significant.

5.3. Generalization to other spread ranges

We have primarily used the tight spread range around 5% for identification purposes. Namely, we have utilized that range to define treatment and control groups and causally link the OC rule to transactions with extreme spreads. However, OC potentially affects the transaction price at any other spread interval within the defined collar. Specifically, for liquid names, there may be transactions below the 5% threshold but still at elevated spreads because of the OC. Thus, the impact of the OC to retail traders is dramatically higher as it allows market makers to extract higher value due to the aggressive willingness or impatience embedded in the limit order prices with 5% spread to the last transaction price on NASDAQ exchange.

To illustrate this, we examine after-hours trading in GME in January 2021. At this time, Robinhood did not allow any after-hours trading after 6:00 PM. We specifically focus on transactions having spreads between (+1%,+3%) when compared to the close price on the

same day. Figure 7 plots these realized spreads around Robinhood's closure at 6:00 PM. We find that before 6:00 PM there are many trades executing at spreads higher than 1.8% whereas in the post-closure period, there are almost no trades in the same range as shown by few blue dots in the top-right quadrant of the plot. Note that there is still ample trading activity in the post-closure period with spreads below the 1.8% level, implying that trades with extreme spreads are the ones that are mainly executed before the Robinhood's closure at 6:00 PM. Overall, this visual evidence highlights the significant impact of the OC for transactions having spreads smaller than the 5% cutoff.

6. Order Collaring and Excessive Volatility

6.1. Visual Evidence from Gamestop Price Run-up

We first provide visual evidence of the OC effect on large price swings using the GameStop price run-up on January 26th, 2021. In Figure 8, the plot illustrates the minutely average price path of the GameStop's common stock. In Figure 9, the top panel plots the spread of the 'D' exchange trades having a spread in (0.25%, 5%) when compared to the last trade on NASDAQ. The bottom panel plots the spread of the 'D' exchange trades having a spread in (-5%, -0.25%) when compared to the last trade in NASDAQ.

There are several striking patterns in these plots. First, before the closure of Robinhood, there are many dark trades with excessive spreads, e.g., higher than 1% and less than -1%, when compared to the last transaction on a NASDAQ exchange. However, these numbers go down to almost zero if we consider the period after 6:00 PM during which Robinhood is inactive. Second, we find that excessive positive (negative) spreads are occurring even when the price is decreasing (increasing) implying that the price patterns are not driving these excessive spreads. Third, excessive volatility in GME's price is much higher when Robinhood is open. Before 6PM, there are several episodes of 10% moves in both positive and negative direction. On the other hand, after 6:00 PM, when Robinhood is closed, the

stock trades in a much tighter range. Given that there are retail brokerages active after 6:00 PM (e.g., TD Ameritrade, E*Trade), the drop in excessive spreads and price volatility cannot be explained purely by a drop in retail trading. If retail traders are submitting aggressive limit orders with large spreads to the last transaction prices, one would expect to see this in the post-closure period of Robinhood. Overall, these plots are consistent with the correlation between excessive price moves and Robinhood's OC. Note that this is another significant concern on top of the documented loss for retail investors as the prices lose their informativeness for other market participants and also for corporate managers who make real investment decisions based on their stock prices.

6.2. Extreme volatility before 6:00 PM

Because of the active OC before 6:00 PM, we expect more extreme volatility before 6:00 PM when compared to the period after 6:00 PM. To test this hypothesis for all commons stocks, we compute the maximum and minimum transaction price realized in the after-hours period. Period 1 (2) will consist of the time interval between 4:00 PM and 6:00 PM (6:00 PM and 8:00 PM). Let $MaxP_{i,t,j}$ ($MinP_{i,t,j}$) be the maximum (minimum) transaction price of the ith stock on day t in period $j \in \{1, 2\}$.[20] Let $JumpN_{i,t,j}$ be a binary variable taking a value of 1 if $\frac{MaxP_{i,t,j} - MinP_{i,t,j}}{P_{i,t}} \geq N\%$ where $P_{i,t}$ is the close price of the ith security on day t. Finally, Let $Before6PM_{i,t,j}$ be equal to 1 if j equals 1 and 0 otherwise. We can run the following regression to examine the impact of the OC rule on the extreme volatility observed before 6:00 PM:

$$JumpN_{i,t,j} = \alpha + Before6PM_{i,t,j} + \epsilon_{i,t,j},$$

where we use three different values for N: 3%, 6% and 10%. We again exclude stocks with close prices below \$1 on that day. We adjust our standard errors by clustering at the

[20] If there are transactions for the stock in a period, we use the close price for the maximum and the minimum.

stock-day level.

Table 5 illustrates the regression results. In all specifications of N, the coefficient on *JumpN* is positive and statistically significant implying that when compared to the period after 6:00PM, there is significant jump activity in transaction prices. The coefficients are also economically significant. On an absolute basis, the increase in the frequency of 3% and more jumps is 4%. Note that our universe includes all common stocks so the coefficient captures the rate increase in a sample of more than 3500 securities.

It is also important to compare the magnitude relative to the existing number of jumps in the post-closure period. The coefficient on *Constant* is roughly 2%, implying that extreme jump movements are two times more likely in the pre-closure period. Overall, these results are consistent with the losses suffered by retail investors and provide another concern for regulators as the OC is potentially introducing extreme volatility to the observed prices.

7. Conclusion

This paper studies the economics of the default order collaring policy at Robinhood. Since market orders do not have price certainty, Robinhood automatically converts some default orders into limit orders using a 5% spread over prior transaction prices to protect their customers from executing at unfavorable prices or extreme spreads. Our analysis instead points to a positive relation between retail execution costs and the OC rule.

We use two quasi-experiments to study the effect of the OC rule on retail trading costs. First, Robinhood's after-hours trading session finishes at 6:00 PM before March 29, 2022. Second, Robinhood extended the after-hours trading session to until 8:00 PM on March 29, 2022. In both cases, we utilize the discontinuity around the 5% spread to define our control variables and design a diff-in-diff regressions. In both of these analyses, we find that the number of trades occurring at extreme spreads is significantly higher when Robinhood's OC policy is active.

In addition, we examine the presence of extreme volatility due to the presence of the OC rule at 5%. We use the meme-stock trading period in early 2021 to illustrate how excessive spreads may be playing a role in the formation of extreme price run-ups. Comparing the spreads before and after 6:00 PM (when the Robinhood closes), we find consistent evidence suggesting retail investors exposed to the OC rule pay excessively high spreads compared to the last trade price on a NASDAQ exchange.

Using the time-series data on the spread of the transactions occurring in the short interval around 6:00 PM, we estimate the cost of the OC policy to be at least in the order of millions per day. Our paper has important implications with regards to the best execution responsibility of the brokers and how a particular set of retail order handling policies can be harmful to the investor. Moreover, if the OC rule is introducing noise into stock prices, then financial markets become less informative for corporate managers who are responsible for making real investment decisions based on their stock prices.

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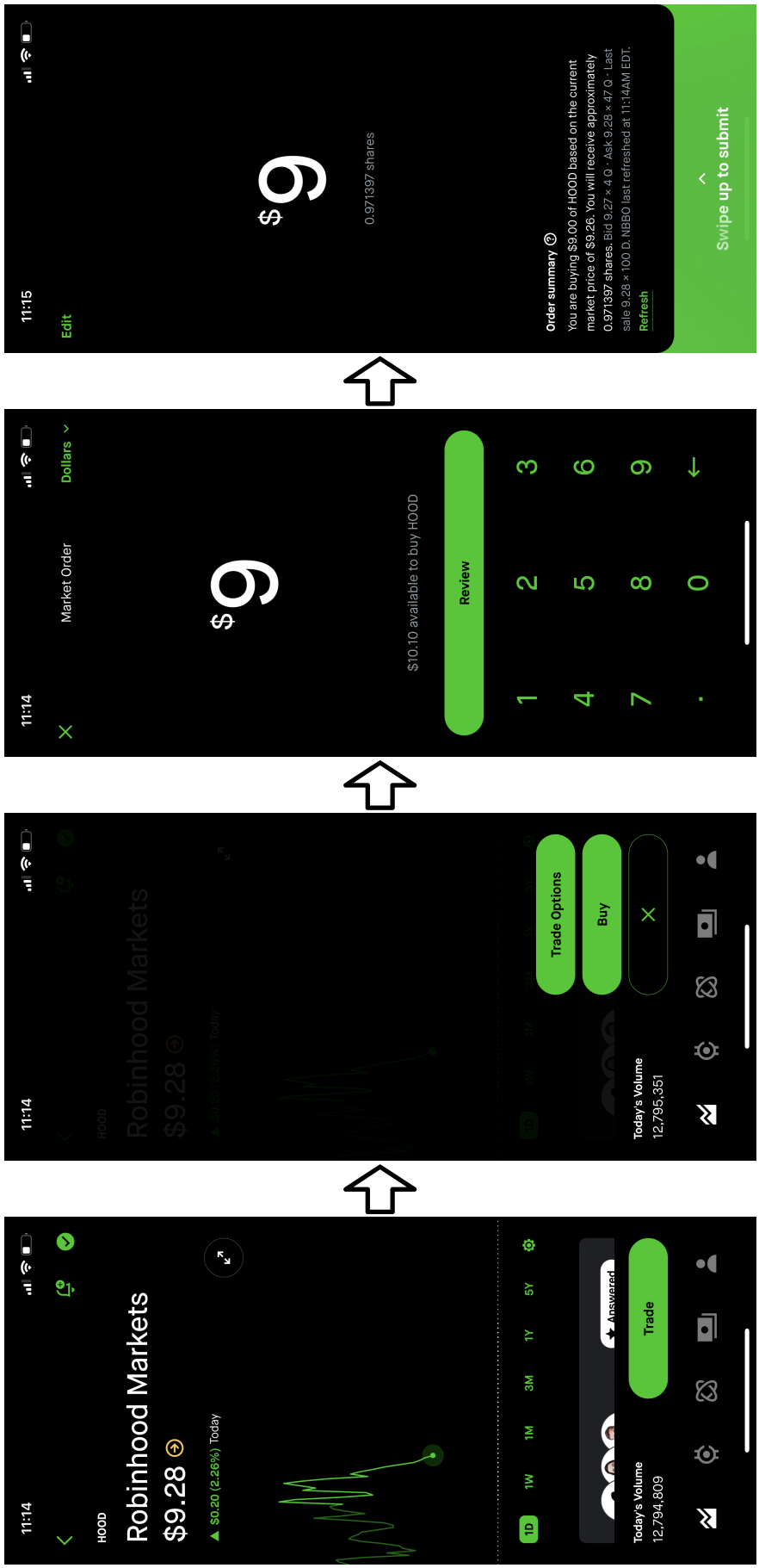

Figure 1: The user-interface flow for submitting dollar-based orders on Robinhood mobile trading platform.

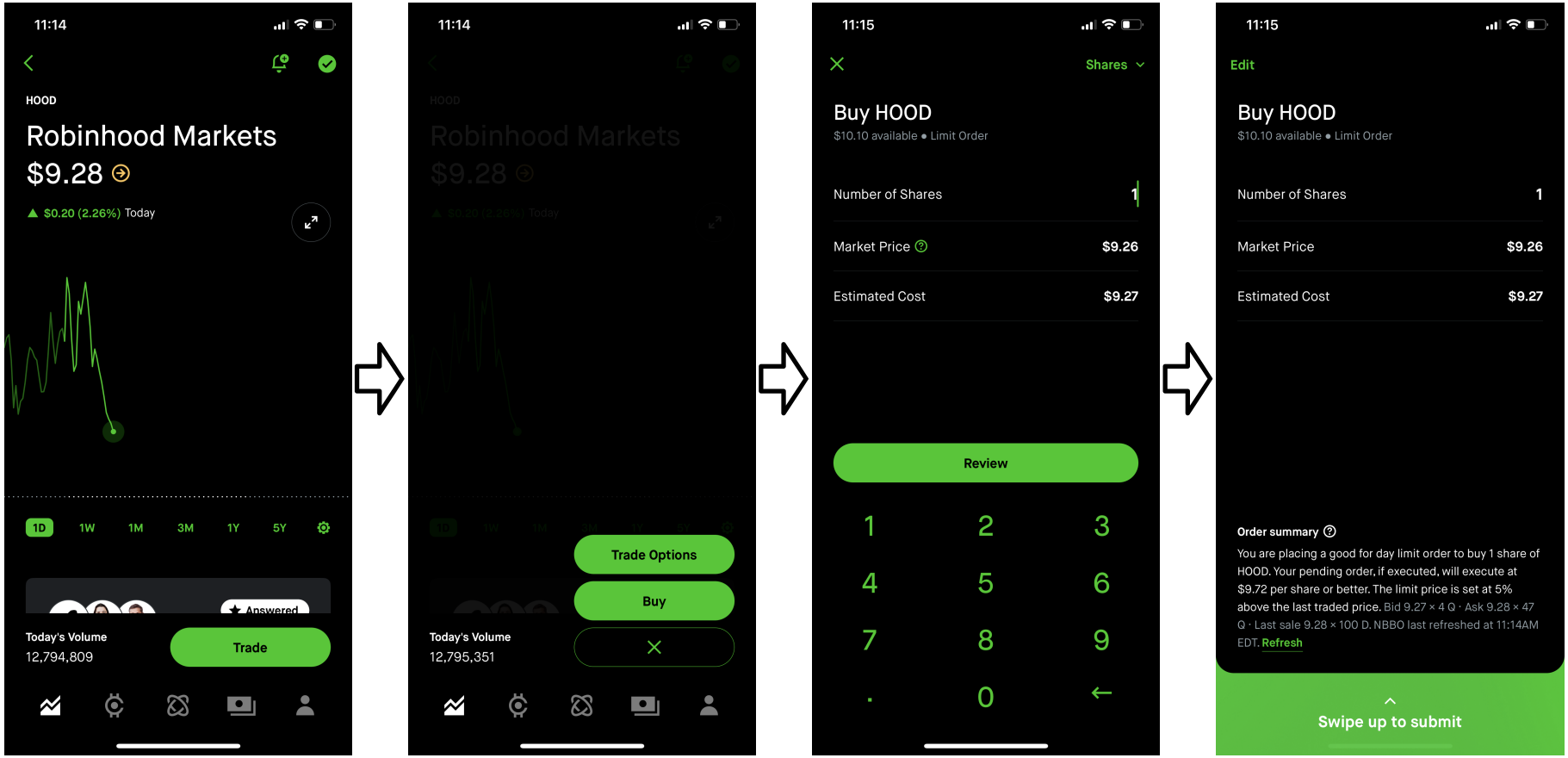

Figure 2: The user-interface flow for submitting share-based orders on Robinhood mobile trading platform.

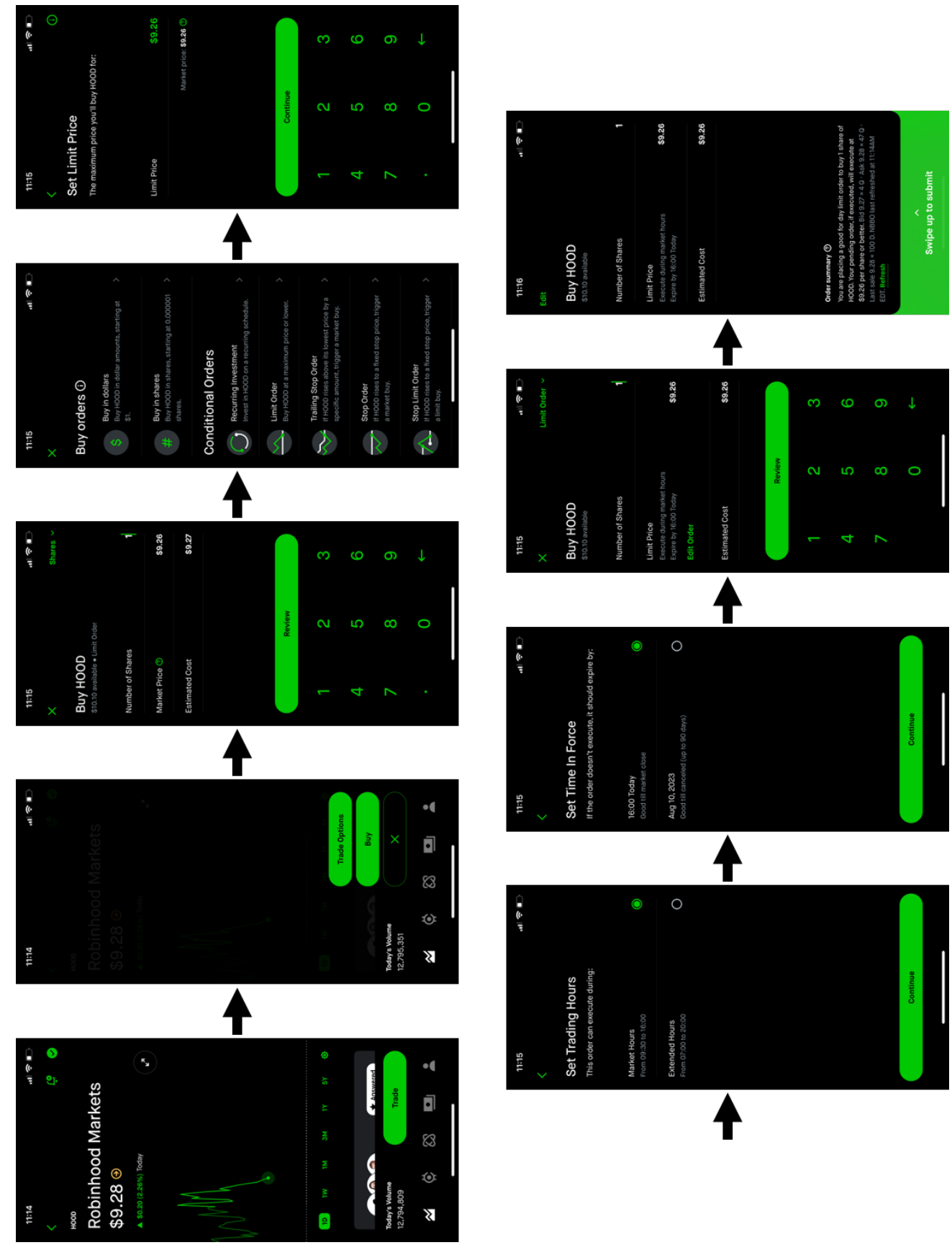

Figure 3: The user-interface flow for submitting a standard limit order on Robinhood mobile trading platform.

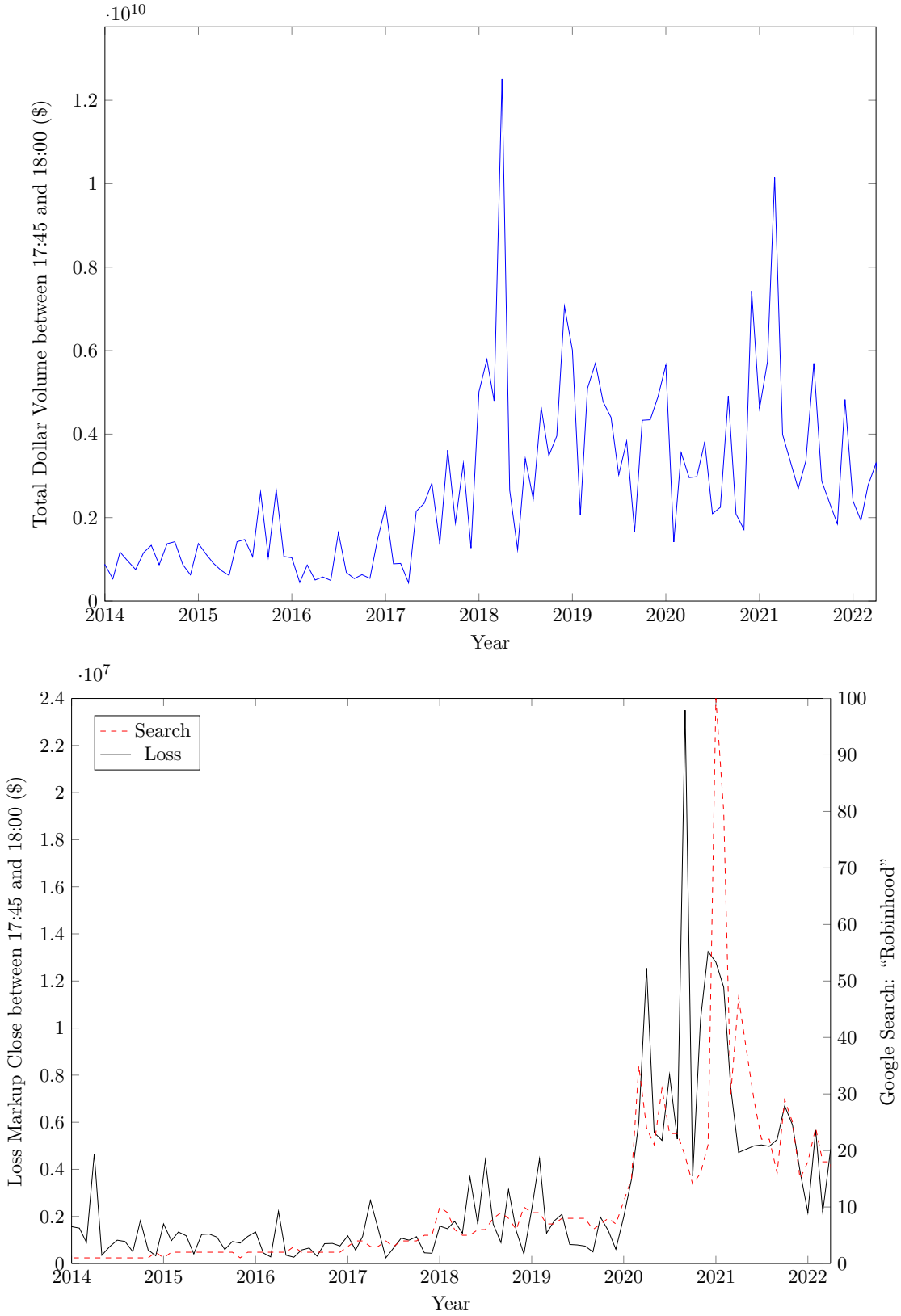

Figure 4: Total dollar volume of the trades occurring between 5:45 PM and 6:00 PM (top panel), the monthly dollar loss of the trades occurring between 5:45 PM and 6:00 PM and having a spread in the range of (1%,5%) with regards to the close price (bottom panel, black solid line) and Google search interest for "Robinhood" between January 2014 and March 2022 (bottom panel, red dashed line)

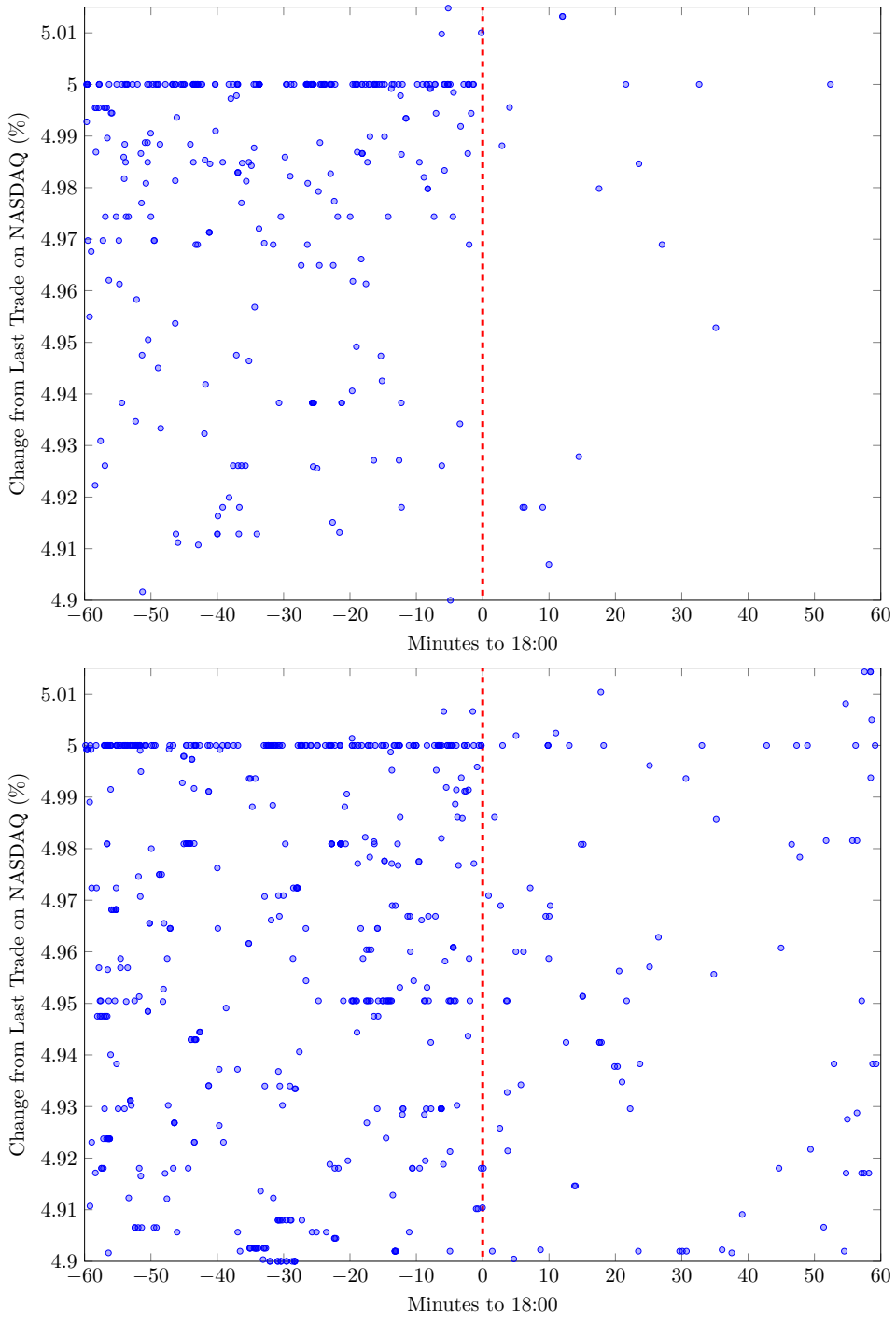

Figure 5: The distribution of after-hours transactions appearing in 'D' exchanges with approximately 5% spread to last trade on a NASDAQ exchange around 18:00 in April 2019 (top panel) and April 2020 (bottom panel). In this time period, Robinhood does not execute after-hours orders after 18:00.

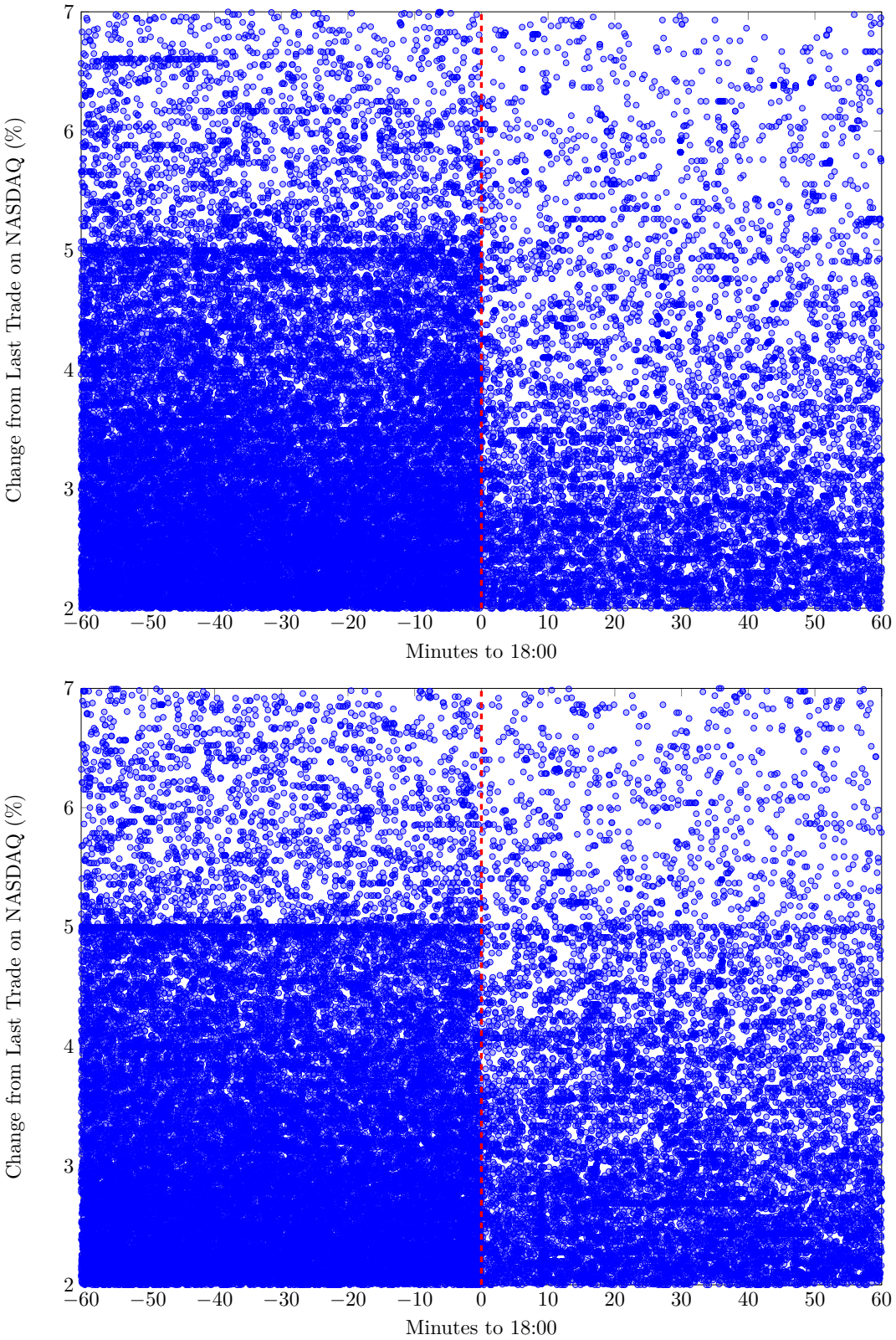

Figure 6: The distribution of after-hours transactions appearing in 'D' exchanges with approximately 5% spread to last NASDAQ trade around 18:00 in March 2022 (top panel) and April 2022 (bottom panel). On March 29, 2022, Robinhood extended its after-hours trading to till 8:00 PM.

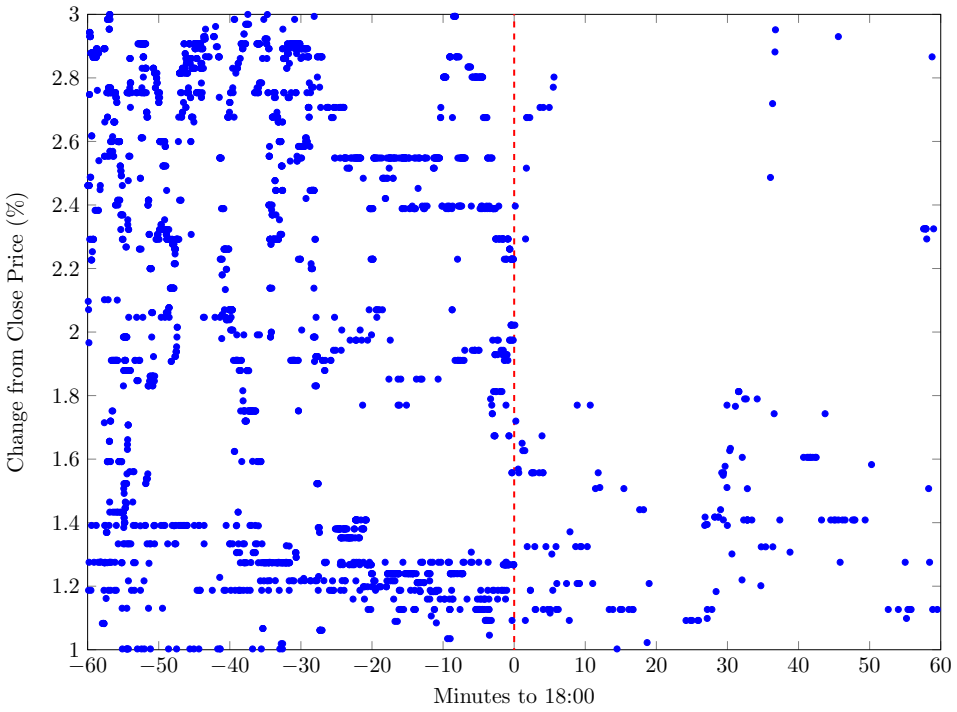

Figure 7: The distribution of after-hours transactions appearing in 'D' exchanges for GME within (1%,3%) spread to the close price in January 2021, when Robinhood does not allow any trading after 6:00 PM.

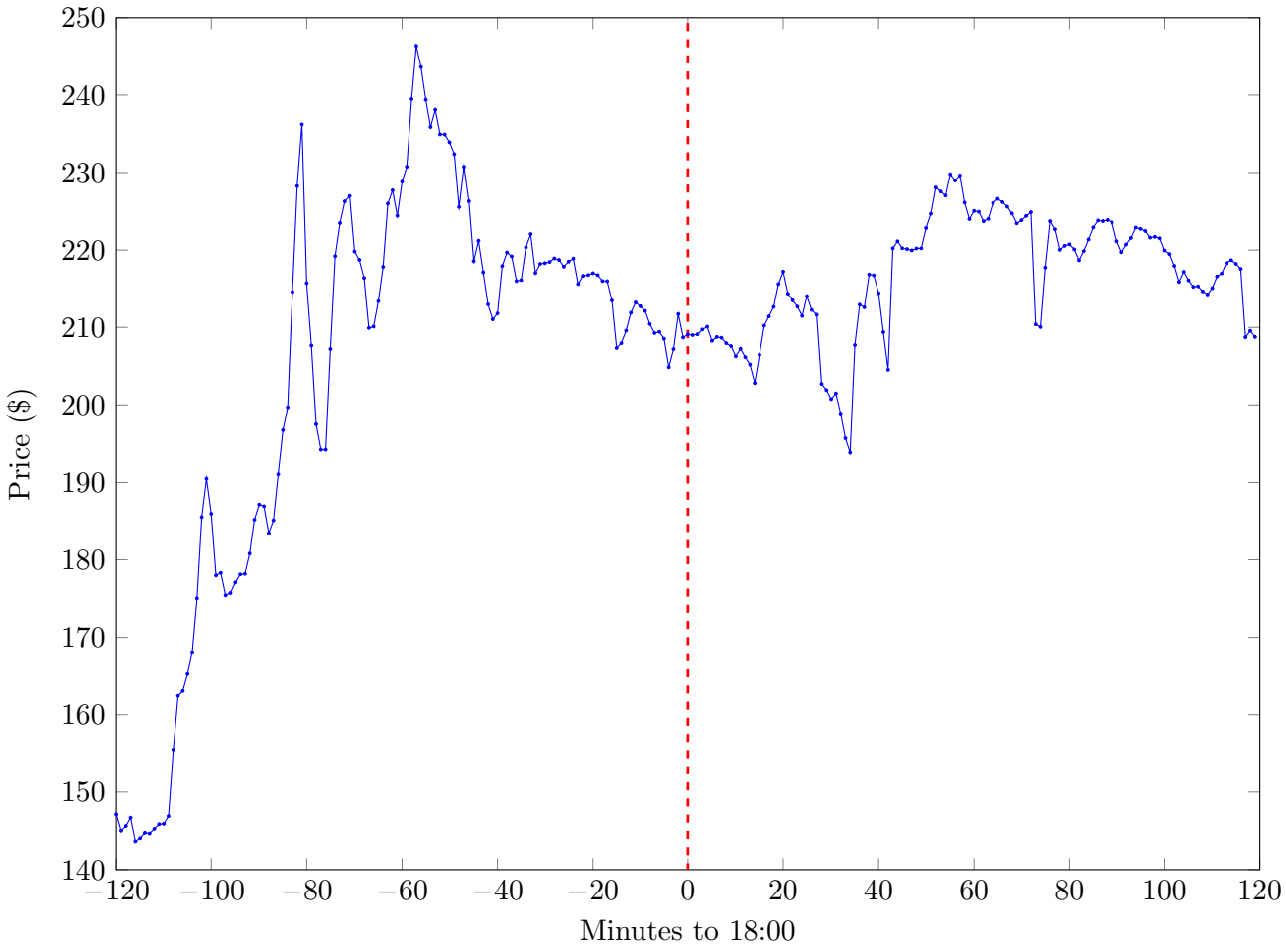

Figure 8: The price path of GME on January 26, 2021 in the after-hours trading period. On this day, Robinhood does not allow any trading after 6:00 PM.

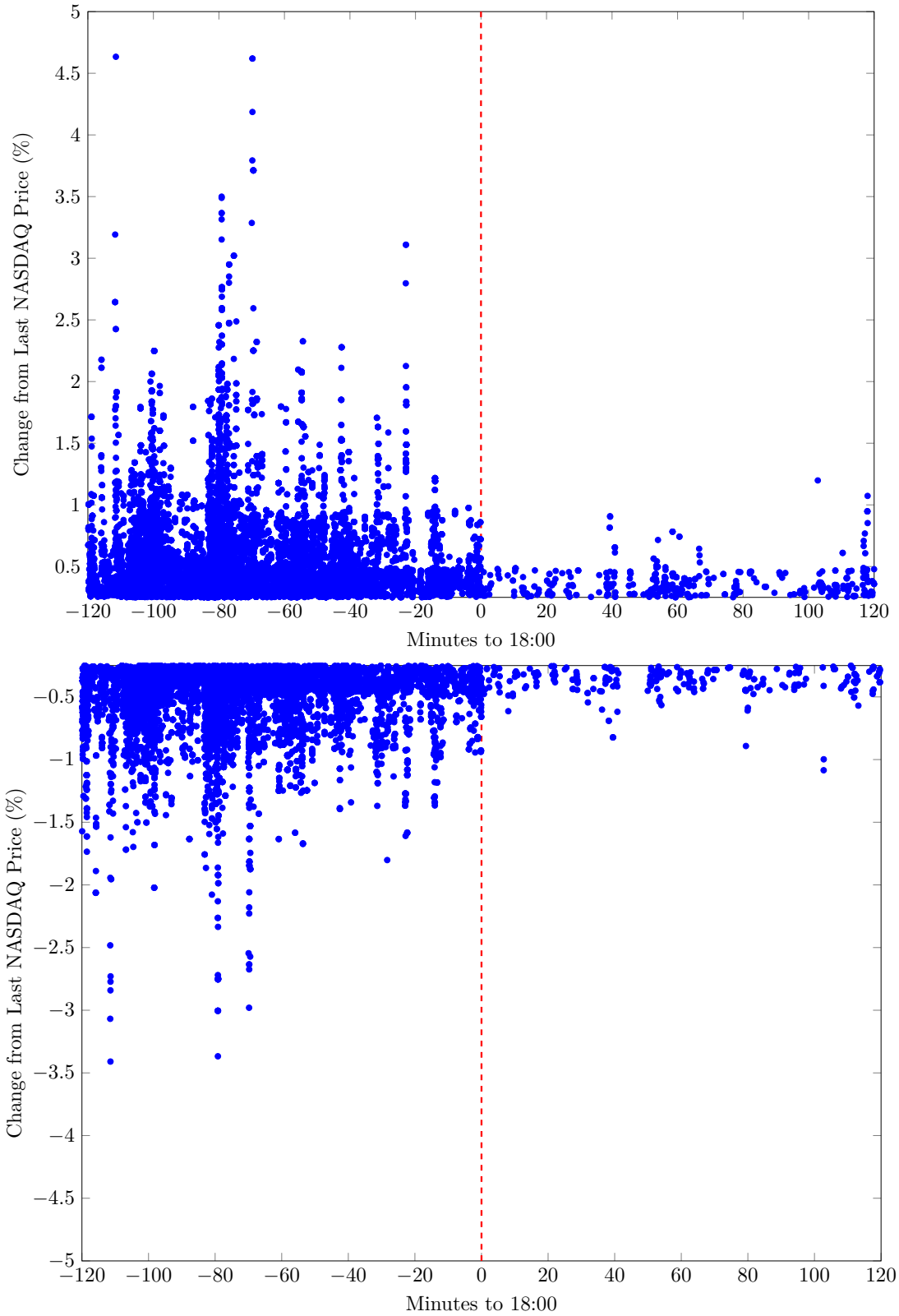

Figure 9: The distribution of after-hours transactions on January 26, 2021 appearing in 'D' exchanges within (0.25%,5%) spread to last NASDAQ trade (top panel) and the distribution of after-hours transactions on the same day appearing in 'D' exchanges within (-5%,-0.25%) spread to last NASDAQ trade (bottom panel). On this day, Robinhood does not allow any trading after 6:00 PM.

Table 1: Order collaring on Robinhood

Market session	Pre-market	Market hours	After-hours
Before March 29, 2022			
Time Period	9–9:30 AM	9:30 AM–4 PM	4–6 PM
Share-based market buys	✓	✓	✓
Share-based market sells	✓		✓
Dollar-based market buys	✓		✓
Dollar-based market sells	✓		✓
After March 29, 2022			
Time Period	7–9:30 AM	9:30 AM–4 PM	4–8 PM
Share-based market buys	✓	✓	✓
Share-based market sells	✓		✓
Dollar-based market buys	✓		✓
Dollar-based market sells	✓		✓

Table 2: Snapshot of after-hours trading in AMC Entertainment on February 14th, 2022.

Notes: This table illustrates a snapshot of after-hours trading in AMC Entertainment on February 14th, 2022. In the table you can see that 'D' exchange trades are trading at approximately 4% premium compared to trades executing on other exchanges ('P', 'T').

Date	Time	Symbol	Exchange	Size	Price
20220214	16:00:00.00	AMC	Close Price		$ 17.75
20220214	17:49:31.94	AMC	D	500	$ 18.62
20220214	17:49:32.16	AMC	D	25	$ 18.62
20220214	17:49:32.71	AMC	D	400	$ 18.63
20220214	17:49:33.61	AMC	D	1300	$ 18.60
20220214	17:49:35.02	AMC	P	2	$ 17.91
20220214	17:49:35.02	AMC	P	422	$ 17.90
20220214	17:49:35.02	AMC	P	5	$ 17.90
20220214	17:49:35.02	AMC	T	71	$ 17.90
20220214	17:49:35.09	AMC	P	1	$ 17.94
20220214	17:49:35.76	AMC	D	20	$ 18.63
20220214	17:49:35.96	AMC	T	10	$ 17.90
20220214	17:49:36.43	AMC	D	4	$ 18.63
20220214	17:49:38.15	AMC	D	5	$ 18.65
20220214	17:49:38.79	AMC	D	55	$ 18.63
20220214	17:49:39.34	AMC	D	75	$ 18.66
20220214	17:49:39.77	AMC	D	1000	$ 18.66
20220214	17:49:41.47	AMC	D	534	$ 18.67
20220214	17:49:41.51	AMC	D	293	$ 18.67
20220214	17:49:41.88	AMC	D	135	$ 18.66
20220214	17:49:42.29	AMC	D	1	$ 18.68

Table 3: Diff-in-Diff analysis around Robinhood closure around 6:00 PM

Notes: $NumTrades_{i,t,j,k}$ measure the number of trades of the ith stock on day t in period $j \in \{1,2\}$ and treatment price level, $k \in \{1,2\}$. $Treat_{i,t,j,k}$ is equal to 1 if k is 1 and 0 in all other cases and $Post_{i,t,j,k}$ is equal to 1 if j equals 2 and 0 otherwise. Here, period 1 (2) consists of the time interval between 5:30 PM and 6:00 PM (6:00 PM and 6:30 PM) whereas treatment spread range 1 (2) corresponds to $(4.85\%, 5.00\%]$ $((5.0\%, 5.15\%))$, respectively. Standard errors are given in parentheses and are adjusted by double-clustering on stock and day.

	Dependent variable:
	NumTrades
	(1)
Treat × Post	-0.39^{***}
	(0.13)
Treat	0.48^{***}
	(0.12)
Post	-0.17
	(0.11)
Constant	0.46^{***}
	(0.10)
Observations	2,756
Adjusted R^2	0.02

Table 4: Diff-in-Diff analysis around Robinhood's extension of the after-hours trading to 8:00 PM

Notes:$NumTrades_{i,t,k}$ measures the number of trades of the ith stock on day t in the treatment spread $j \in \{1, 2\}$. The treatment spread range 1 (2) corresponds to $(4.85\%, 5.00\%]$ $((5.0\%, 5.15\%))$, respectively. $Treat_{i,t,k}$ is equal to 1 if k is 1 and 0 in all other cases. $Extended_{i,t,j}$ is equal to 1 if t is later than March 29, 2022 and 0 otherwise. We take the following periods: March 1, 2022 to March 28, 2022 and April 1, 2022 to April 28, 2022. Standard errors are given in parentheses and are adjusted by double-clustering on stock and day.

	Dependent variable:
	NumTrades
	(1)
Treat × Extended	0.34^{**}
	(0.15)
Treat	0.09
	(0.08)
Extended	-0.07
	(0.13)
Constant	0.32^{***}
	(0.09)
Observations	1,536
Adjusted R^2	0.03

Table 5: Extreme volatility before and after 6:00 PM

Notes: Before6PM is a binary variable taking a value of 1 if the trade occurs before 6:00 PM or otherwise. $JumpN_{i,t,j}$ is a binary variable taking a value of 1 if $\frac{MaxP_{i,t,j}-MinP_{i,t,j}}{P_{i,t}} \geq N\%$ where $P_{i,t}$ is the close price of the ith security on day t. Standard errors are given in parentheses and are adjusted by double-clustering on stock and day.

	Dependent variable:		
	Jump3	Jump6	Jump10
	(1)	(2)	(3)
Before6PM	0.04^{***}	0.02^{***}	0.01^{***}
	(0.002)	(0.001)	(0.001)
Constant	0.02^{***}	0.01^{***}	0.003^{***}
	(0.001)	(0.001)	(0.0002)
Observations	1,710,206	1,710,206	1,710,206
Adjusted R^2	0.01	0.004	0.001