The "Actual Retail Price" of Equity Trades

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ABSTRACT

We compare execution quality of six brokerage accounts across five brokers by generating a sample of 85,000 simultaneous market orders. Commission levels and payment for order flow (PFOF) differ across our accounts. We find that execution prices vary significantly across brokers: the mean account-level round-trip cost ranges from –0.07% to –0.46% excluding any commissions. The dispersion is due to off-exchange wholesalers systematically giving different execution prices for the same trades to different brokers. Across brokers, variation in PFOF cannot explain the large variation in price execution. We provide several suggestions for more informative disclosures on execution quality.

JEL Classifications: G12 (asset pricing, trading volume), G14 (market efficiency), G50 (household finance, general)

Keywords: retail trading, execution quality, bid/ask spread, market microstructure, payment for order flow, commissions, broker-dealers

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"…investors should be mindful of how their orders are handled, including the difference between 'free' and 'no commissions'."
SEC Staff Report on Equity and Options Market Structure Conditions in Early 2021

Zero commissions have transformed the landscape for retail investors, bringing affordable investments to the masses. Robinhood started this "democratization" of equity investing by having commission-free trading since 2015. All other major retail brokers followed suit in late 2019. Removing commissions was made possible by an offsetting revenue stream, "payment for order flow" (PFOF) in which off-exchange venues pay brokers to route retail orders to them.

The PFOF practice, however, has raised concerns about potential conflicts of interests between brokers and retail investors. In particular, an essential question is whether higher PFOF is associated with a lower quality of execution. Investors should realize that "no-commission" trading does not mean "free" trading. Even with zero commissions, trading systematically generates transaction costs due to the usual gap between buying and selling prices, i.e., the bid-ask spread. In the United States, the practice of PFOF is accepted by the Securities and Exchange Commission (SEC), which has required extensive additional disclosures for the brokers and market centers.[1] The hope was that these disclosures would improve the ability of customers to determine the quality of broker-dealer services.

Our findings, however, indicate that the current disclosure regime is insufficient and provides limited information regarding the quality of price execution across brokers. In practice, it is very hard to compare the actual retail price execution quality of different brokers. Self-reporting is haphazard and inconsistent across brokers.[2] All brokers claim to provide "price

[1] In what follows, we will be using interchangeably the terms "venues" and "market centers." In regulatory reports, the first is used for routing trades, the second for execution. In our analysis, however, we focus on six major OTC market makers, so the terms are equivalent.
[2] See a comparison of disclosures in Appendix C.

improvement" over the National Best Bid Offer (NBBO) price, a benchmark that is easily beaten, albeit often narrowly.[3] Datasets used in prior academic research either cover a single broker (e.g., proprietary datasets of trades as in Kothari et al. (2021)) or do not identify the brokers that route orders (e.g., the Transactions and Quotes (TAQ) database).

In this paper, we run a carefully controlled experiment to identify variation in price execution across by opening individual accounts at five brokers and two accounts at one broker that offers accounts with and without commissions. Importantly, there is a fair amount of variation in practices across these brokers. The five brokers selected offer zero commissions accounts. Three brokers collect PFOF for equity market orders and route nearly all their trades to the same six market centers, which are off-exchange wholesalers. PFOF per share varies across these three brokers. The fourth broker has zero commissions and accepts no PFOF yet still routes nearly all trades to these six wholesalers. The fifth broker offers accounts with and without commissions, the latter with PFOF. Also, this broker sends orders to trading venues that differ from these six wholesalers.

Our experiment generated approximately 85,000 trades over the December 21, 2021, to June 9, 2022, period. We selected 128 stocks sorted by various factors to be representative of the underlying stock population. We placed orders at different brokers that were identical in type (market orders), ticker (stock), size (dollars and shares traded), and submission time.[4] All trades were intraday, i.e., we bought equities after the market opens and then sold them within 30

[3] For example, in our trades, the NBBO is beaten over 90% of the time.

[4] Importantly, our experiment was designed so that our results are not driven by any latency differences in our trading (i.e., systematic differences in execution times). This was ensured by randomizing broker submission orders. We verified that this led to essentially no differences in average execution times when comparing parallel trades for any two brokers (i.e., each broker was first half the time). These results are reported in Appendix A. For our trades, we also show that the effect of trade order on price execution is economically small and statistically insignificant. These results are reported later in the paper.

minutes, spread throughout the day. We then compared execution prices across brokers and venues across this large sample. Since we placed the trades, we know whether each trade is a purchase or sale, which is crucial to measure price improvement. In contrast, in the many empirical studies based on the TAQ database, the trade direction must be approximated.[5]

In summary, we find very large variations in "actual retail price" execution across brokers. While we were aware that such trading would not be "free," we were surprised by the range of execution prices for our simultaneous identical trades. Across our six brokerage accounts, we calculated that the average round trip cost ranged from –0.07% to –0.46%; the average price improvement varied from $0.03 to $0.08 per share. Such dispersion is statistically significant, and economically important, as we shall see later.

Our next step is to relate these differences to broker and venue characteristics. We use regulatory reports (Rule 606 reports) to examine routing practices by our brokers in terms of venues where they send orders, as well as the amount of PFOF received. We find that PFOF explains almost none of the cross-broker variation in execution prices. For example, two brokers with no PFOF have worse price execution on our trades than one of the brokers with PFOF. More generally, the size of PFOF payment, which ranges from $0.001 to $0.002 per share, is a tiny fraction of our observed variations in price improvement.

We then turn to the main six execution venues to investigate the sources of our price differences. We combine the venue routing data from the brokers (Rule 606) with other regulatory reports (Rule 605) that describe average stock-level execution quality for each market center. We

[5] In contrast to a trading experiment, the typical approach in empirical research is to use the Lee and Ready (1991) algorithm or more recently Boehmer et al. (2021). These assign buy (sell) signals from trades executed above (below) the midpoint or based on the amount of subpenny price improvement respectively. The problem, however, is that these algorithms misclassify many entries, as we shall see later, and understate the extent of price improvement.

proceed with a decomposition of the potential drivers of execution differences, similar to a portfolio performance attribution.

The dispersion we observe could be due to three factors: venue choice, stock routing, and broker execution. First, brokers can choose to route orders to the various venues in different proportions, which we call "venue choice." Some brokers could, for instance, send more orders to venues that have worse average price execution. Second, brokers could send more trades to venues that have worse-than-average executions for these stocks, which we call "stock routing." Third, venues could have different price execution for exactly the same orders coming from different brokers, which we call "broker execution."

To determine if venue choice could explain our findings, we compute the expected price improvement assuming that all our stocks are sent to venues in proportion to the data on Form 606, i.e., ignoring stock routing and broker execution differences. The choice of market centers does not explain execution differences because there is little dispersion in the average execution of the portfolio across venues and limited variation in venue weights across brokers. Likewise, stock routing—differences in how stocks are routed to venues—does not explain the observed variation in execution based on information from Form 606 data. Even if we systematically route stocks to the venues with the worst price execution on a stock-by-stock basis, the resulting variation is less than what we observe for our trades across brokers.

To investigate whether brokers are systematically giving different price execution regardless of venue or stock routing decisions, we obtain specific routing data for every trade for four of our brokers.[6] We therefore know which venue executed each trade. Indeed, under SEC

[6] We have requested and not yet received data from the fifth broker.

Rule 606(b)(1), brokers are required to provide such details to their customers upon request. Using this information, we find that our observed execution differences are largely explained by "broker execution." We come to this conclusion by calculating the difference in price executions for matched trades, i.e., exactly the same trades executed by the same venue for different brokers at the same time. All the execution differences we observe are explained by this driver. In addition, broker execution differences are not due to one venue only but are systematic across all the venues.

After presenting our empirical evidence, we discuss potential economic explanations for the variation in observed execution across brokers including variation in PFOF across brokers, the characteristics (quality) of broker order flow, the size of the broker's order flow, and variation in broker's objectives regarding the execution of investors trades. Across brokers, variation in PFOF cannot explain the large variation in price execution. However, the quality of broker order flow, the size of broker order flow, and variation in objectives across brokers might all contribute to the variation that we observe across brokers.

Our paper makes several contributions to the literature. We run a uniquely large and long-running experiment trading equities simultaneously across multiple brokers to evaluate the execution of market orders. We find economically large price execution differences between brokers: Aggregated over all retail trades, we estimate a single basis point of cost (or savings) is equivalent to approximately $2 billion annually. We also show that such differences could not be predicted from current regulatory disclosures. We also document that these differences are not explained by PFOF. Finally, we show that these differences are due to different brokers receiving different execution quality at the same market centers for identical trades, rather than the selection of venues by brokers or their routing practices.

Levy (2022) also runs a trading experiment looking at PFOF and price execution. His experiment uses 1,000 trades over four weeks, focuses on a comparison of two brokers (Robinhood and TD Ameritrade), and attributes differences in price execution to PFOF. Once we include more brokers with more heterogeneous PFOF amounts (including no PFOF) as well as consider the magnitudes of the differences in PFOF and price execution, we do not find a relation between PFOF arrangements and price execution.

Bakos et al. (2005) perform an experiment similar to ours based on 64 simultaneous trials at three brokers in 1999, a period when trading differed substantially from today's markets and off-exchange trading was not common. They find (p.263) "…no difference among brokers on overall price improvements" though total trading costs (including commissions) (p.364) "…for inexpensive online brokers are significantly less than total trading costs either for the two voice brokers or the two more expensive online brokers." Kothari et al. (2021) examine a sample of Robinhood (RH) trades matched to TAQ transaction data. Estimating the trade direction for odd lots, they report relative price improvement of 2.9bp for RH trades versus 1.6bp for off-exchange trades vs 1.1bp for on-exchange trades. They do not compare different brokers.

Our results have several policy implications. Few retail investors would expect such large discrepancies in price execution across brokers. Indeed, price improvement claims by brokers are not directly comparable nor, in our view, useful. The NBBO benchmark is based on orders for 100 shares or more (round lots), while odd lots now account for more than 60% of all trades. As a result, the NBBO is an easy benchmark to beat, with trades routinely executing within the NBBO spread. Thus, simply reporting the fraction of trades that receive any price improvement over the NBBO is not very useful to investors. The current disclosure environment is insufficiently informative, and investors would benefit from more detailed execution information.

In particular, brokers could provide execution-quality statistics, as those suggested by CFA Institute (2017); market centers could also disclose execution information at the broker level rather than simply in aggregate. A more modest but easy to implement improvement would be to provide execution quality statistics for trades below 100 shares. More generally, changes to the NBBO could be made to reflect the increasingly large fraction of small retail trades. Displaying quotes for quantities less than 100 shares could tighten spreads, lowering the potential for execution differences.[7]

Finally, it is important to note that we only examined one specific aspect of brokerage trading. Our experiment was based solely on placing small "market" orders for equities during the day.[8] We do not evaluate other types of orders or options trading. We only examine execution quality in terms of price improvement, while other aspects may be important as well. We do not consider other features that investors might value when selecting brokers, in particular the breadth of offerings, e.g., U.S. stocks only vs. global stocks and other asset classes; the ability to short; investment and margin fees; quality of research and educational products; ease of platform use, trading tools, and mobile apps; customer service, and so on.

The remainder of the paper is organized as follows. Section I gives a description of the trading environment, including retail brokers, best execution, and market regulation. Section II then discusses the setup for our trading experiment. Section III presents our results, comparing price execution quality across brokers. We then turn to potential explanations, with Section IV focusing on PFOF and Section V analyzing routing decisions and execution across venues.

[7] Recognizing these issues, the SEC (2020) has adopted changes to the definition of round lots that decrease the number of shares below the standard lot size of 100 for stocks with higher prices. Implementation is likely to be several years away, however.

[8] Market orders are the most common retail trades for most of our brokers, averaging about 38% of non-directed orders for equities.

Finally, Section VI discusses why brokers may receive different price execution while Section VII concludes and provides policy prescriptions.

I. Trading Environment

A. Retail Brokers

Broker-dealers are financial intermediaries in the business of buying and selling securities on behalf of their customers. Table I describes the major U.S. retail brokers, including the five in our experiment. Traditionally, brokers charged transaction-based commissions or fees to generate revenues. After Robinhood introduced its "commission-free" model to retail investors in 2015, the five other firms in the table followed in 2019, as indicated.

<Insert Table I about here>

Though these firms charge zero commissions, four of them receive revenue through PFOF paid by the wholesalers in exchange for the right to trade brokers' customer flows.[9] The shift to zero commissions has coincided with further changes in the industry, e.g., two online brokers were acquired in 2020 and Robinhood went public in 2021. Our trading experiment uses five retail brokers, E*Trade (acquired by Morgan Stanley), Fidelity, Interactive Brokers, Robinhood, and TD Ameritrade (acquired by Schwab.)[10]

[9] Brokers also earn money from interest revenue, including margin interest, and fees on other products.
[10] We did not include Schwab in our set of brokers primarily because they do not offer access to their API to retail clients. Additionally, TD Ameritrade accounts are planned to be integrated into Schwab by 2023.

These five brokers we selected are among the top institutions in terms of retail trading volume. Table II compares their Daily Average Trades (DAT) for the first quarter of 2022. These statistics measure the average number of trades per day and are widely used to compare retail trading activity across brokers.[11] TD Ameritrade has by far the most active retail investor base. Across these five brokers, the total trading volume is enormous, averaging around 14 million trades per day. Taking the typical retail trade size of $8,000,[12] this translates into a notional retail volume of around $114 billion per day, or $28 trillion per year.[13]

<Insert Table II about here>

B. Market Orders and Best Execution

Once our "market" orders are submitted, each broker needs to choose a trading venue for execution. Venue types include (1) a national securities exchange such as the NYSE or Nasdaq, (2) an Alternative Trading System (ATS),[14] or (3) an OTC (i.e., off-exchange) market-maker, such as Citadel.[15] Alternatively, brokers can "internalize" an order by sending it to another division of the firm to be filled out of its own inventory. In 2021, about 53% of the total trading volume was on public exchanges, 9% on ATSs, and 38% executed by off-exchange market makers.[16] In

[11] Because these numbers are self-reported, they may not be strictly comparable across brokers. Fidelity, in particular, as a private company does not publish financial statements, and includes institutional trades in its DART numbers.
[12] As estimated by Mackintosh (2021), "A Deep Dive into Dark Trades", NASDAQ.
[13] As a reference, SIFMA (2022) indicates that the average volume of daily trading in U.S. equities was $719 billion over the same period, so our 5 retail brokers represent 16% of total volume. Note that our numbers should only be considered as indicative, and probably overstate the amount of retail trading for these brokers. On the other hand, there are many more retail online and discount brokers (Tiburon (2022) lists a total of 62.)
[14] ATSs are computerized systems such as Electronic Communication Networks (ECNs) that automatically match buyers and sellers of securities. A "dark pool" refers to an ATS that is not "lit", meaning that it does not publicly display pre-trade quotations. They are less regulated than exchanges but are still subject to the 1998 Regulation ATS.
[15] OTC market-makers become counterparties to trades, unlike ATSs. A particular category consists of "wholesalers", which actively make two-sided markets in securities for other broker-dealers. Both ATSs and OTC market-makers must also operate as broker-dealers, so are still subject to SEC and FINRA oversight. They generally charge no execution fees or fees that are lower than exchanges.
[16] At: www.finra.org/investors/insights/where-do-stocks-trade.

contrast to public exchanges, off-exchange venues do not have to quote the same prices to customers.

The choice of the venue should be driven by the legal requirement for brokers to provide "best execution," in other words to put clients' interests first. Formally, this duty "requires a broker-dealer to seek the most favorable terms reasonably available under the circumstances for a customer's transaction."[17] Best execution relies on several factors, including total trade cost, execution speed, and the likelihood that the trade will be executed.

Cost evaluation includes broker commissions, exchange fees or rebates, as well as the "price improvement." Price improvement is measured relative to the prevailing best quote, defined as the National Best Bid and Offer ("NBBO"). The NBBO reflects the best priced "bid" (NBB) and "offer" (NBO) resting on exchange order books, taken across all national exchanges, for "round lots", i.e., for 100 shares or a multiple thereof. When evaluating price improvement, however, it is important to note that the NBBO does not include many of the best prices available on exchanges, such as "odd lots"[18] and non-displayed orders. Indeed, a significant amount of activity transacts within the NBBO (even on exchanges.) [19]

Formally, "price improvement" occurs when the execution price is strictly better than the NBBO. This is commonly reported as the fraction of trades with prices improved across orders. This is hardly informative, however, because it does not quantify the size of the improvement.

[17] FINRA Regulatory Notice 21-23, "Best Execution and Payment for Order Flow" (June 23, 2021). At: www.finra.org/rules-guidance/notices/21-23. FINRA has codified certain specific requirements around best execution in Rule 5310 (Best Execution and Interpositioning).
[18] Odd lots are orders for less than 100 shares. These have increased steadily over time, from 15% to 60% of all trades over the last 10 years. This reflects the greater retail activity, algorithmic trading, and high-priced stocks due to market appreciation and a decrease in stock splits over time.
[19] Bartlett et al. (2022) show that this "inside" market is very large and deep. For instance, Amazon, when priced around $3,100 had an NBBO spread of $3, but an inside, or "effective" spread based on actual trades of 60 cents only.

Instead, a better measure is the average of cents-per-share differences between the execution price *P* and the best bid or offer, either in dollars or relative to the NBBO spread:

$$PI\$_{buy} = NBO - P \qquad and \qquad PI\$_{sell} = P - NBB \tag{1a}$$

$$PI\% = \frac{PI\$}{NBBO\ Spread} \tag{1b}$$

Also useful is the "effective spread", which is the difference between the execution price and the midpoint of the NBBO spread, multiplied by twice the trading direction, either in dollars or relative to the NBBO:

$$ES\$_{buy} = 2 \times (P - P_{mid}) \qquad and \qquad ES\$_{sell} = 2 \times (P_{mid} - P) \tag{2a}$$

$$ES\% = \frac{ES\$}{NBBO\ Spread} \tag{2b}$$

Fidelity, for example, reports that it generally executes trades at effective spreads that are around 25% of dollar quoted spreads.[20] Assuming symmetry, this implies that the execution price represents a price improvement of 75%/2 = 37.5% of the quoted spread. Both *PI* and *ES* measures can also be converted in percent of investment by dividing by the midpoint.

C. Market Regulation and Payments for Order Flow

The legal framework for best execution is governed by Regulation National Market System (NMS), promulgated by the SEC in 2005 to foster competition in the national market for equity securities. While Reg NMS has boosted competition in equity trading and driven down trading

[20] Fidelity reports very detailed information about its execution. See https://www.fidelity.com/trading/execution-quality/overview

costs, it has also created a complex and fragmented market. One of its side effects has been the rapid growth of wholesalers and the attendant increase in payments for order flow. PFOF can potentially create conflicts of interests between brokers and investors. The particular concern is that the broker could decide to send more orders to venues that offer higher payments to the broker, despite worse execution for the client.[21] Appendix B reviews the controversy about PFOF, global regulatory developments, and summarizes the empirical evidence.

These concerns led Reg NMS to include "Rule 606," which requires broker-dealers to publish quarterly reports that provide a summary of their routing practices, including a breakdown of types of orders (e.g., market, limit, and so on), the venues to which orders are routed with their fraction, as well as the payments for order flows, both in total dollars and per share.[22] We will be using Rule 606 reports to analyze the routing and execution of our brokers. The Rule 606 reports were designed to "improve the ability of their customers to determine the quality of such broker-dealer services.".[23] Our trading experiment should help to assess whether these objectives are met.

In addition, under Rule 605, the SEC requires market centers to publish monthly reports that include information about the average quality of executions on a stock-by-stock basis.[24] This includes data on the fraction of trades with price improvement, the average amount of price improvement, the distribution of execution times, all reported for different types of trades and trade sizes. We will be using Rule 605 reports to analyze the execution of our trades by venues.

[21] For example, Battalio et al. (2016a) find that limit orders sent to exchanges with higher fees (accruing to the broker) have worse execution quality (for the client). On the other hand, Battalio et al. (2016b) report that, comparing execution prices for options across venues, PFOFs seem associated with better execution, concluding that "transparency and competition in equity options markets appear to have limited the potential agency problems."
[22] Enhanced disclosure requirements for Rule 606 were adopted in November 2018. For details, see C.F.R. 242.606, "Disclosure of order routing information".
[23] From SEC (2018).
[24] For details, see C.F.R. 242.605, "Disclosure of order execution information." Note that this only covers trades greater than 100 shares.

Table III compares PFOFs across six major retail brokers. Panel A shows that the total value of PFOF has sharply increased, more than three-fold since 2019, to $3.5 billion in 2021. This increase has coincided with an increase in retail trading volume. For TD Ameritrade and E*Trade, these payments accounted for a non-trivial fraction of their revenues, from 15 to 20%, before their acquisitions. The fraction is even greater for Robinhood, at 72%.

<Insert Table III about here>

The question is whether PFOF could affect the routing choices of brokers, possibly leading to worse price improvement. Even if this were the case, however, these payments are used to subsidize lower (or $0) retail trading commissions. Furthermore, trades routed to wholesalers may help retail traders avoid exchange fees. These fees are not negligible. For example, the NYSE charges a fee of $0.003 per share (i.e., 30 cents per 100 shares) for orders such as market orders that take liquidity. More generally, the broader issue, not directly addressed here, is whether the net of these effects is beneficial to the retail trader.

Panel B in Table III describes PFOFs during the first quarter of 2022, which overlaps with our trading experiment, between our brokers and the six major wholesalers. As a reference, it also breaks down PFOF by equities and options, with the latter accounting for the bulk of revenues. Panel B details PFOFs for equity market orders only. It shows that IBKR and Fidelity have no PFOF for this subgroup, even though they do receive payments for other equity trades and for options.

The table also shows the weighted average PFOF per share. For TD Ameritrade (and Schwab, not reported here), the price is about $0.001 cents per share, which is only a tiny fraction of transaction values, on average. That price is slightly higher, around $0.002 cents for E*Trade

and Robinhood.[25] It should be emphasized that for each broker these prices are basically the same across these venues. Thus, brokers should have no financial incentive to send orders to one market center or the other.

It is interesting to note that Fidelity takes no PFOF for equity trades but still sends nearly all these trades to the same six venues. Finally, Interactive Brokers routes orders to various "market centers," plus its own ATS for the Pro account.[26] For the commission-free Lite account, orders are generally sent to "OTC market makers," with the attendant PFOF. The venues listed in its 606 reports do not overlap with the six listed in the table.

II. Trading Experiment

To compare actual price executions, we implement an experiment in which we do our own trading at several brokerage houses. We place simultaneous identical trades (i.e., trades in the same stock of the same order size at the same time) across multiple brokerage accounts.

In addition to the execution prices of our trades, we also capture several other variables. We log the time we start entering orders, the time at which the order placement is complete, as well as the trade execution time provided by the broker. We use this latter time to match our trades to the TAQ database where we obtain the exchange code and the exact execution time on the exchange. We also capture the bid, ask, and quote prices immediately before and after the

[25] Unlike others, Robinhood indicates that the payments are a "fixed percentage of the [NBBO] spread" at the time of order execution. The 606 report still shows the average dollar price paid for each venue and order type but these now vary across venues depending on their spread mix. The weighted average price paid by Robinhood is higher than others, at about $0.0022 cents on average across S&P and non-S&P stocks.

[26] Anand et al. (2021) examine institutional brokers that route more orders to alternative trading systems that they own. They report such affiliated ATSs are associated with lower execution quality. For example, separating the sample into brokers with the most vs. the least of ATS transactions, effective spreads are higher by 4.4bp for the former.

trade is executed, from which we compute the National Best Bid (NBB) and National Best Offer (NBO). Finally, we record whether our trades are split into multiple orders. Next, we describe our trade sample.

A. Stock Selection

Because executing trades is costly, we were unable to trade the entire universe of stocks, which included 4,037 names on the CRSP database as of June 2021. Instead, we created a representative sample by stratifying the population into 128 bins. To be included, each stock was required to have a price greater than a dollar and a share code of either 10 or 11.[27]

The sorting proceeds as follows. First, stocks are split into four equal groups by market capitalization. Second, each of these groups is then split into four equal groups sorted by liquidity, which is taken from the median ratio of the percentage of shares outstanding traded daily, measured over the prior quarter. Third, each of these sixteen buckets is then split into four equal buckets sorted by volatility, which is taken from the median squared daily return, measured over the last quarter as well. Finally, these 64 buckets are split into equal halves by levels of the stock price.[28]

This classification generates a total of 128 bins, with an average of 32 stocks per bin in the population. One stock was selected randomly within each bin. If the share price of a stock drops below one dollar at the end of the week, that stock is replaced with another one from the same bucket using the latest quarterly version of the CRSP database. In addition, we included four

[27] Stocks less than one dollar are subject to different rules per Regulation NMS. Additionally, some of our brokers will not trade stocks less than one dollar without special approval. Share codes 10 and 11 identify U.S.-based common stocks.
[28] Since price and market capitalization are highly correlated, we only use two buckets for price.

stocks with high retail activity — AMC, Tesla, Nio, and Aurora Cannabis. We also include some mega-cap stocks in our sample — Apple, Bank of America, NVIDIA, Exxon Mobil, Google, and Visa. Finally, we also select the top four mover stocks each day according to Robinhood, which are included during the following week. Prior research has shown that these stocks see significant retail activity (see Barber et al. (2022)). A complete list of the stocks in our experiment is shown in Appendix A. Table AI compares the distribution of our stratified sample to that of the underlying population and confirms that the distribution statistics are similar.

B. Stock Trading

During the course of our experiment, we trade stocks at five different brokerages in six accounts. Our trades are executed through E*Trade, Fidelity, Interactive Brokers (IBKR) with both their Pro and Lite account types, Robinhood, and TD Ameritrade, which as noted previously is now owned by Schwab.[29] Our brokerage accounts can be split into three groups:

- E*Trade, IBKR Lite, Robinhood, and TD Ameritrade are commission-free and use payments for order flow (PFOF) to generate revenue from trading.
- Fidelity is commission-free and has no PFOF.
- IBKR Pro charges commissions and has no PFOF.[30]

Whenever possible, we use the Application Programming Interface (API) to automatically trade stocks each day. This allows us to process a large number of trades each day as well as to ensure that trades are executed at nearly identical times. At its peak, our trades numbered over

[29] As of June 2020, we cover all the top brokers, except for Schwab. (See https://inside.com/campaigns/inside-business-2020-08-11-24066/sections/202954)
[30] According to IBKR, the Pro account is for "… sophisticated investors and active traders…" while the Lite account type "… provides retail clients with $0 commissions …"

1,000 per day. Unfortunately, some prominent brokers, including IBKR Lite and Fidelity, do not offer general access to their API. We place trades at IBKR Lite and Fidelity by hand. The time period is shorter, but still long enough to draw general conclusions. Trade times are synced to match the trade times at other brokers.

We begin trading each day at 9:40 AM EST, shortly after the opening auction. Our program trades throughout the day, spacing trades out over the course of the day with the last trades ending at 3:50 PM EST shortly before the market close. We trade all the selected stocks each day on the brokers that allow API access, except for IBKR Pro, which has commissions and for which we trade only half the stocks per day. For the accounts without API capability, we place 26 roundtrip trades a day spread across the day. The time each stock is traded each the day changes in case there is any time of day effect. For each stock, the program records the current bid, ask, and quote for the stock that is about to trade. After purchase, the program sells the same number of shares within 30 minutes of the purchase. Thus, there is little directional exposure during the day and no open positions at the close.

Our order target size is $100. We trade full shares only, rounding the number to make the trade size closest to $100, with a minimum size of one share for higher priced stocks. In a robustness check, we find similar results for two smaller experiments using trades of about $1,000 and trades of about $5,000. Specifically, we traded 26 of our stocks each day with a target value of $1,000, again using the same logic to round to the nearest share; these stocks were rotated each day. For the 26 stocks traded each day with both $100 and $1000 targets, the two trades were placed at the same time with the order randomized. Because we found similar results for the $100 and $1,000 trades, we discontinued the $1,000 trades to reduce our transaction costs and

commissions. We also ran a second experiment with trade sizes up to $5,000. Again, we found similar execution to our $100 trades. Appendix A provides more detail for these comparisons.

To control the order submission times, our API program is run as a single thread sequentially across brokers for the same group of stocks. Even so, it cannot place orders at the same millisecond. To control for this issue, the program randomizes the order of the API calls on both the buy and sell trades to ensure that no broker has a systematic time advantage. We discuss this issue later in the experiment description.[31]

We began work on the API programming in October 2021 and started trading Robinhood as a test in November 2021. Next, we began trading Robinhood and TD Ameritrade in parallel on December 21, 2021. Over time, we expanded the number of brokers. IBKR Pro trading started on January 25, 2022. E*Trade was added on March 16, 2022. On April 8, 2022, IBKR Pro stopped trading so we could test IBKR Lite. On April 22, 2022, we started hand trading Fidelity and IBKR Lite. Finally, our experiment stopped on June 9, 2022. In total, our trades cover a five-and-a-half-month period, or 113 trading days.[32]

In total, we placed 85,417 trades equivalent to $15.4 million in notional. We applied some filters before the empirical analysis. First, we removed trades prior to December 21st when our trading started in parallel, as well as some test trades for brokers as they were added during the experiment. This reduced our sample to a total of 82,623. Next, we removed trades that we could not match to TAQ; these were almost exclusively trades in non-US stocks. We also removed trades where we did not have both the buy and sell on the same day, typically due to API issues.

[31] Although we randomize, we found that trading order has no impact on price execution. The first and second trades in a parallel sequence have the same amount of price improvement.
[32] As of this writing (September 2022), we continue to perform 26 roundtrip trades per day alternating stocks on E*Trade, Robinhood, and TD Ameritrade. We will use these data to monitor for any drastic changes in execution.

These two filters reduced our sample to 79,677. Finally, we imposed a maximum time difference of two seconds between paired trades. Overall, this left us with a sample of 75,936 trades. Finally, consistent with prior research, we removed trades with stock prices less than one dollar, leaving a final sample of 74,801.[33]

Given the importance of latency on our results, we examine the submission time differences as well as the execution time differences of our trades for each broker pair. Table AII in Appendix A describes the distributions of differences in submission and execution times for pairs of brokers. Each broker pair has trades in almost perfectly random order. Most of the trades are within one second of each other. Also, the median execution time differences are essentially zero. Thus, no broker has any systematic advantage in terms of submission and execution times. We discuss latency later in the paper as well.

Table IV displays summary statistics for our trade sample. The median share price is about $20, with a spread of $0.05, or about 25bp. We find our trades have, on average, a significant amount of price improvement. Our average price improvement is 33% of the average spread. We find a fair amount of dispersion across variables, which was expected since we stratified our sample across the range of CRSP stocks. The trade dollar size variation occurs because some stocks such as Google have high prices (e.g., close to $3,000) and we require a minimum of one share trade. The last row shows the commissions paid for IBKR Pro, which average $0.35 per trade. For our median trade size of 5 shares, this is also $0.07 per share or 35bp of notional.

[33] Results using all trades are similar to those using our filtered sample. We sometimes do not have both sides of the trade due to crashes with the API. When a crash occurred, we would manually sell the stocks held and then restart the program. Thus, we would have the buy trades recorded but not the sell trades. Submission differences of more than two seconds occurred when the program was held up submitting an order to one broker. This would then delay the submission to other brokers. These delays were not frequent, however. We also excluded trades when execution took more than two minutes.

<Insert Table IV about here>

III. Price Execution, or the "Actual Retail Price"

We now turn to the evidence on price execution across brokers, focusing on price improvement. Following Equation (1), price improvement can be measured by the price improvement in dollars or scaled by the NBBO spread (*PI%*). In terms of bounds, the best execution quality one could expect on average is a *PI%* of 50%. At this level, trading would indeed be "free." Assuming symmetry, all trades would occur at the midpoint, so buying and selling would incur zero transaction costs. A *PI%* greater than 50% should not occur systematically because it could generate trading profits. At the other extreme, the worst execution occurs when *PI%* is zero. This would indicate that sells were executed at the bid while buys were executed at the ask. This would be the worst possible execution that would conform to existing regulations.

We compare price execution across brokers by first sorting all their trades by their *PI%*. To compare brokers, Figure 1 plots the cumulative frequency distribution of *PI%* for our six brokerage accounts. For better intuition, we have inverted the horizontal axis and start on the left with 100% price improvement, which is least likely. The higher the cumulative curve, the better the price execution across brokers.

<Insert Figure 1 about here>

The six brokerage accounts have significantly different levels of price improvement. TD Ameritrade clearly has the most price improvement; 69% of our TD trades are executed at the

midpoint price or better. Below are the two curves for E*Trade and Fidelity, which are close to each other. Next comes Robinhood, with price improvement trailing those two brokerages. At the bottom are the two IBKR accounts. IBKR Pro has the lowest level of price improvement with only 16% of trades occurring at the midpoint price or better; IBKR Lite is slightly better, until *PI*=20%, at which point IBKR Pro has better performance.

Note that 10 to 20% of trades occur with a *PI%* better than 50%. These trades would be mis-classified under the Lee-Ready (1991) algorithm for attributing the direction of trade. Such misclassifications would result in understating the extent of price improvement, the estimation of which is our objective.

Table V more formally compares price improvement. In Panel A, we report the percentage of trades that have price improvement, the average percentage of the spread we receive as price improvement, and finally the average amount of price improvement in dollars. As before, we also report the best possible price improvement using the midpoint for each trade. Results are reported for our overall time period as well as the April-June subperiod, when we hand traded Fidelity and IBKR Lite. Next, Panel B displays the difference in the *PI%* for pairwise sets of brokers, using only matched trades. For the t-statistics, we cluster standard errors by stock. A negative value means that the brokerage listed in the column (row) has better (worse) execution.

Finally, in Panel C, we regress price improvement on broker dummies (Model 1) as well as dummies that represent the order of the parallel trade (Model 2). The intercept represents TD Ameritrade when its trades were executed first. We repeat these regressions using just our $1000 trades. If trade order were important, then the order dummies would be economically and statistically significant.

<Insert Table V about here>

Consistent with Figure 1, we find astonishingly large execution differences between brokers. TD has excellent price improvement, with 99.4% of its trades inside the NBBO and a price improvement of 47.2%. To put this in perspective, a roundtrip trade would pay only 2 × (50% – 47.2%) = 5.6% of the quoted spread. In dollar terms, TD averages 7.8 cents of price improvement, again close to the maximum amount of 8.4 cents. In contrast, IBKR Pro has price improvement on 76% of its trades, and average *PI%* of 18.8%. On a roundtrip trade, this translates into a cost of 62% of the spread. This is over 10 times more than TD. The average price improvement is 2.8 cents, without accounting for commissions.

In between these two brokers, we find that Fidelity and E*Trade have similar execution quality.[34] Robinhood is farther behind. Over the entire period, Robinhood has on average 26.8% price improvement, which translates into a roundtrip cost of 46% of the spread. The results are similar across the two periods. IBKR Lite, however, shows slightly worse price execution. Panel B shows similar results, using only paired trades. Given the very large number of observations, the differences are highly significant, both statistically and economically. Overall, we that find order execution varies significantly across brokers.

Finally, Panel C, we find that trade order, which is randomized in our experiment, does not impact price improvement for our trades and does not alter the key broker fixed effects. These results confirm that variation in price improvement across brokers is not driven by latency

[34] As an aside, our statistics for Fidelity match the advertised effective spread, which is around 25%. Translating into a one-way price improvement gives (100%-25%)/2 = 37.5%, very close to our number of 35.8%.

differences across brokers. We also find similar coefficient estimates for regressions using $100 trades (models (1)-(2)) and $1,000 trades (models (3)-(4)).

As an aside, Panel A also shows the fractions of our trades executed off-exchanges, as identified with the code "D" in TAQ. For commission-free accounts, this fraction ranges from 93% to 99%, so nearly all transactions occur off-exchange.

Another way to look at the execution differences is to compare returns on actual roundtrip trades. So, this is now scaled by initial stock prices. While in theory the return of a truly costless trade should be zero, in practice each trade is exposed to market movements during the approximately 30 minutes each position is long. To adjust for this effect, we compute price execution using midpoints as a benchmark, both at entry and exit. We then take our actual return and subtract this benchmark return to measure our estimated cost of the roundtrip trade. We also show the worst execution cost using NBBO instead of actual execution prices.

Table VI shows the results. Panel A reports roundtrip costs for all trades over our two time periods. Turning then to matched trades, Panel B shows pairwise costs comparisons while Panel C reports the fraction of time that a broker provides better execution.

< Insert Table VI about here>

Not surprisingly, we find similar results to those based on price improvement. TD provides the lowest round-trip cost, adjusted for midpoints, with a loss of 7.0bp. Again, we observe a very large dispersion in costs across brokers, with a highest round-trip cost of 46.2bp. The worst possible execution, going from the NBO to the NBB over the holding period, gives a cost of 61.9bp. Turning to comparisons of matched trades in Panels B and C leads to similar conclusions,

with differences in performance generally highly significant. For example, Robinhood has an average roundtrip cost that is 24bp higher than TD, which provides better execution 83% of time.

To highlight these execution differences, Figure 2 graphs cumulative returns across matched trades involving TD Ameritrade and each of the other three brokers with API-based trading. We assume a fixed size of $100 for all trades, which is close to the typical retail trade size, and add up the roundtrip return of all parallel trades for two brokers over the same period. This assumes that traders continuously trade the same amount of money and replenish their accounts for losses.[35] Panels A, B, and C compare TD Ameritrade to E*Trade, IBKR Pro, and Robinhood, respectively. Note that the returns should not be compared across panels because the number of trades, sample periods, and trade orders differ. Because costs are cumulative, a greater number of paired trades will lead to greater losses.

<Insert Figure 2 about here>

In each panel, the TD cumulative returns drift down, reflecting trading costs as well as the market downtrend during this period. Otherwise, the narrowest gap is with E*Trade. Trading with the other two brokers has been substantially more costly. For IBKR, including commissions would lead to a cumulative cost of about 2.5 times that indicated.

In terms of economic value of these differences, Table II indicates that our five brokers have daily trading volume of 14 million trades per day, or 3.6 billion per year. With an average retail trade of $8,000, this translates into $28 trillion worth of notional traded every year, as

[35] Due to minimum balance requirements for pattern day traders, this essentially mimics our behavior during the experiment. Using our average trade size of $160 and approximately 130 daily buys, this translates into a daily total notional exposure of about $21,000, but in our case only $1,700 of simultaneous long exposure at any time during the day. Typical minimum balances are $25,000, which we had to replenish after losses.

discussed before. So, for every 1 bp of price execution difference, the annual cost to retail traders is $2.8 billion. In that context, our observed execution differences are economically very large. For example, from Panel B in Table VI, half of the round-trip difference between TD and Robinhood is 12bp.

In summary, we find very significant execution differences, both statistically and economically, across our six brokerage accounts. In the next sections, we will examine systematically how much of this variation can be explained by payments for order flow, routing, and venue execution.

IV. Price Improvement and Payments for Order Flow

In view of the current debate on payment for order flow, the first hypothesis is that the variations we observed in execution prices are driven by PFOF. Indeed, the wholesalers that give money to brokers for their trades must still generate trading profits. Thus, the usual assumption is that greater payments to brokers must be systematically offset by worse execution prices.

To investigate the potential impact of PFOF, we use the brokers' Rule 606 reports, as described in a previous section. In Table III, we noted that Fidelity and Interactive Brokers do not receive PFOF for these trades. TD Ameritrade and E*Trade receive the same dollar payment per share across all venues, about $0.001 and $0.002, respectively. Robinhood receives a percentage of the bid-ask spread, so we derive an average price per share by weighting by volume, e.g., across venues.[36]

[36] Interactive Broker's Form 606 is difficult to interpret. The form shows mostly zero PFOF entries for equity market orders. Also, its reported trading venues have little overlap with those for other brokers.

This allows us to compare variations in price improvement with variations in PFOF, both per share. If PFOF explains the difference in our execution quality, we should see that a large percentage of the execution difference is explained by the PFOF difference. We report these results in Table VII. Panel A examines all stocks together. Panels B and C show S&P 500 stocks and non-S&P 500 stocks separately because they are also reported separately on Forms 606. The last column shows the ratio of the PFOF difference to the PI difference, using TD Ameritrade as the baseline broker.

<Insert Table VII about here>

Overall, we find that PFOF explains essentially none of the observed execution differences. The entries in the last column are very small. For example, the difference in average price improvement between TD and Robinhood is $0.0340 per share, for all stocks. The respective difference in PFOF is only $0.00116 per share. Thus, PFOF can only explain 3.4% of the difference in PI, which is not economically meaningful. Likewise for E*Trade. Across the column, the highest ratio is 18.6% for S&P 500 stocks traded on Robinhood; these stocks, however, account for only 5% of all Robinhood trades. In some cases, the PFOF relation to PI goes the wrong way. For example, TD Ameritrade does receive PFOF, unlike Fidelity, but still has better execution. In summary, we find that PFOF to brokers cannot explain the differences in price improvement. We then turn to the role of trading venues.

V. Price Improvement and Trading Venues

Since we find that PFOF cannot explain the differences in our execution, ultimately these must be due to trading venues, or market centers. For example, one potential explanation (venue choice) is that different brokers route orders to different venues or to the same venues with different allocations of orders. A second explanation (stock routing) is that, even if brokers used the same venues in the same proportions, routing differences across stocks could cause execution differences. Finally, a third explanation (broker execution) is that, even if brokers used the same venues with the same stock routing, specific venues could give different price executions to the same, parallel trades from different brokers. We examine these potential explanations next.

A. Venue Choice

The first line of explanation relies on different allocations across existing venues. This can be examined by using first, brokers' 606 reports, which indicate the fraction of equity market orders routed to different venues and second, the venues' 605 reports, which indicate the average execution quality on a stock-by-stock basis. For this, we choose the smallest category of trade order sizes, which ranges from 100 to 499 shares. Thus, one limitation of our study is that we assume that execution prices for smaller orders are similar to those in that bracket.

Table VIII displays in each column the fractions of orders for each broker that are sent to the six major venues, as well as the average across brokers. This is broken down into S&P 500 and non-S&P 500 stocks, respectively for Panels A and B. We then assume that the orders for our stock trades are sent to each venue in the same proportion as reported. Combining these weights with the 605 reports allows us to calculate the weighted average price improvement on each trade,

as well as the average across trades, which is reported as the "expected price improvement" for each broker.

<Insert Table VIII about here>

If routing across venues were the primary driver of our dispersion in execution, we would expect to see large differences in the expected PI between our brokers. Instead, we see minimal variations, which mean that venue routing is not a factor. This is not totally surprising, given that first, brokers are using the same six centers, with only slight variations in weights, and second, dispersion in price execution may be limited across venues.

B. Stock Routing to Trading Venues

Next, we investigate the potential impact of order routing at the stock level. We use our subset of 27 S&P 500 stocks, which is a limited sample for computational reasons, and combine it with the average stock-level execution statistics reported in the venue 605 filings. As shown in Table VII, we are attempting to explain price improvements ranging from $0.123 to $0.053 per share for S&P stocks, which is a difference of 7 cents. Fidelity is excluded from this analysis due to its much smaller sample size.

Results are shown in Table IX. First, we examine the extreme case where all orders are sent to one venue only, which is shown in Panel A. We see that there is some variation in the best and worst venues. Citadel on average provides the best execution while Two Sigma and UBS have the worst execution, with a maximum range around 3 cents. We need to consider the actual routing pattern across venues, however. For example, Fidelity sends almost no orders to Two Sigma and UBS (perhaps rationally due to their lower price execution quality).

<Insert Table IX about here>

Therefore, we design an experiment where we systematically route each of these 27 stocks to the worst of the six venues, while realistically constraining the total of orders within 5% of the actual percentages in the broker 606 filings. Results are reported in Panel B, where we show for each broker the actual price improvement received, the "minimum" price improvement expected with this worst possible routing, and the percentage of our stocks that receive worse actual price improvement than the worst market center for that stock.

If stock routing could explain our findings, we should observe that our actual price improvement is above the minimum amount and that very few of our stocks have execution worse than the worse market center. Instead, we see that the actual PI is worse than the minimum for both E*Trade and Robinhood. For the latter, the actual PI is $0.072, which is less than the worst-performing venue at $0.092. Many stocks have execution worse than at the worst venue. Thus, stock routing cannot explain either the observed dispersion in execution, which leads us to the only remaining explanation.

C. Broker Execution within Trading Venues

The final potential explanation for differences in execution is that the same, parallel, trades from different brokers receive different executions at the same market center. Unfortunately, such differences cannot be estimated from public disclosures in Rule 605 reports because these forms only show "average" execution, i.e., across all trades within a category.

Reg NMS, however, has a provision under Rule 606(b)(1) to "require a broker-dealer, upon request of a customer […] to provide customer-specific disclosures, for the prior six months,

regarding […] its routing of such orders to various trading centers".[37] As a result, we were able to receive a complete list of market centers from TD Ameritrade, E*Trade, Fidelity, and Robinhood for our trades. IBKR did not respond to our requests.

We first analyze the routing of our orders. Table X reports the percentage of our orders executed at different trading venues, which generally match those in the 606 reports.[38] Most of the orders go to four of our six market centers; UBS and Two Sigma receive significantly less orders than the others. We see that nearly all orders are routed to off-exchange venues.

<Insert Table X about here>

We further analyze stock routing patterns for each broker. Figure 3 displays the percentage of our orders that go to the largest venues, Citadel and Virtu, in Panels A and B, respectively. On the horizontal axis, stocks are sorted from the lowest to the highest percentage sent from that broker to that venue.

<Insert Figure 3 about here>

A horizontal line would mean that all stocks are sent by that broker the same percentage of time to that venue, in other words that stock routing is random. This seems to be largely the case with TD Ameritrade and E*Trade, for both Citadel and Virtu. However, orders for Robinhood and

[37] SEC (2018), p. 10.
[38] Interestingly, TD Ameritrade sends orders to CSTI as well. This market center is not listed on their 606 reports because it falls below the minimum required.

Fidelity appear to be routed in a non-random fashion. Some stocks are systematically routed more (and others less) frequently to some venues.

We now turn to the last explanation for executions differences, which consists of systematically different execution prices at the same venues for identical trades originating from different brokers. We consider only our group of parallel trades for two brokers, i.e., trades for the same stock sent at the same time (call this "Any"). This is split into two groups, the first with all parallel trades executed by the same venue ("Same"), and the second by different venues ("Different"). Next, we compare price executions across two brokers and these groups. This is measured by price improvement as a fraction of the quoted spread.

Results are shown in Table XI. Panel A describes overall results for all venues for broker pairs. Panel B gives more detail across venues. Consider for instance TD Ameritrade and Robinhood. From Table V, for all trades, matched or not, TD received an average price improvement of 47.2%, or $0.080 per share, vs. Robinhood with 26.8%, and $0.044. The question is whether we observe the same dispersion with the same exact trades at the same venue coming from different brokers.

<Insert Table XI about here>

The table provides strong evidence that indeed different brokers receive systematically different execution at the same venue. Panel A shows an average difference in price improvement of 46.7% – 24.2% = 22.5% between TD and Robinhood. For the subsample with the same venues, we observe the same difference of 22.5%, or $0.042. Thus, almost the entirety of the observed execution difference is due to different treatments by market centers, on average. A similar conclusion holds for the comparisons with Fidelity and E*Trade. Next, Panel B provides further

detail across venues. It shows that every single of the five venues provides better execution for TD Ameritrade

In summary, we find very strong evidence that our observed differences in price execution quality are due to different treatments of the same trades by market centers across brokers. This also confirms that PFOF is largely irrelevant for these pricing decisions, as Fidelity has worse order execution than TD Ameritrade even though even though it receives no PFOF.

VI. What Explains Variation in Price Improvement across Brokers?

In the prior section, we find that different brokers systematically receive difference price execution by the same market center. In this section, we discuss potential economic reasons for these differences. First, when thinking about the structure of the industry, there are three key players. They are the retail investor, retail brokers, and the market centers that execute retail trades (e.g., Citadel and Virtu).

Retail brokers are agents for retail investors. Thus, the key competition that occurs between market centers relies heavily on the routing decisions of retail brokers. Retail brokers set a PFOF level that is often quoted as a price per share, is the same for all market centers, and changes infrequently. There is no contractual agreement between brokers and market centers. Notably, any other agreement, e.g., with respect to volume or price improvement, would have to be disclosed in the 606 reports. Faced with this PFOF level, market centers decide whether to agree to execute trades that brokers route to them.

Once they know which market centers are willing to execute their trades, brokers decide how their orders are routed to market centers. Importantly, the broker routing decisions are a key component to the competition for flows across market centers. Different brokers may have different objective functions underlying their routing decisions. For example, some brokers might emphasize the resilience of a market center in times of market stress and other brokers might emphasize price improvement relative to the NBBO. Different brokers may also have different clienteles (e.g., high net worth individuals versus small individual retail traders) that cause the broker to emphasize different factors in their routing decisions. So, there may be other factors valued by brokers than price improvement.

Given this competitive landscape, we discuss factors that might explain the variation in price improvement that we document across brokers. We do not have a sufficiently powerful test to claim that any of these factors are the main drivers of the variation we document, but these issues provide a relevant starting point for future research.

A. PFOF as an explanation for variation in Price Execution

Brokers will cater to the demands of retail investors, but conflicts of interest might arise. For example, brokers have incentives to collect fees from PFOF. In theory, these payments might affect price execution. For example, market centers who pay an additional dollar in PFOF to a broker might offer a dollar less in price improvement to the broker.

Our analysis reveals current PFOF is too small to explain the variation in price improvement across brokers and, in the cross-section, is unrelated to the quality of price improvement across the brokers we analyze. This becomes obvious in Figure 4, which plots per

share PFOF (x axis) and per share price improvement (y axis) for the five brokers in our analysis that route to market centers. It is clear that the variation in PFOF cannot explain the magnitude of variation in price improvement. Notably, our best-performing broker in terms of price improvement does receive PFOF.

<Insert Figure 4 about here>

B. The Quality of Order Flow

Some brokers may have investors that generate order flow that is more attractive to market centers. For example, the broker's investor clientele may generate trades that are less correlated to each other, less concentrated, and/or less informed than its competitors. The classic Kyle (1985) model provides an example of how this variation in the quality of order flow can affect price improvement; a market with few informed trades should lead to lower transaction costs since the market maker does not need to worry as much about adverse selection.[39] Market centers might be willing to provide better price improvement for trades from brokers with better quality order flow (not highly correlated or uninformed).

C. Size of Order Flow

Market centers have large fixed costs that they must cover to become profitable so attracting some of the flow from large brokers is essential to becoming a profitable market center. Moreover, establishing and maintaining relationships and an order flow pipeline with a specific broker adds a layer of costs. To benefit from economies of scale, market centers might compete

[39] See also Benveniste, Marcus, and Wilhelm (1992), and Battalio, Jennings, and Selway (2001).

more aggressively for order flow from brokers with large aggregate order flows (e.g., TD Ameritrade has more than double the volume of other brokers in our analysis).

D. Differing Objective Function or Monitoring Quality of Brokers

As discussed above, different brokers might have different objective functions when routing order flow. Some brokers might be particularly sensitive to price improvements, others less so. Market centers will cater to these brokers objectives if doing so attracts more profitable order flow. In this setting, brokers who care about dimensions other than price improvement might receive systematically worse price improvement. For example, Robinhood and Interactive Brokers might value trade execution dimensions other than price improvement.

Taken together these economic explanations could explain the differences we observe across brokers. With that said, given that we have limited ability to test these hypotheses, there could be other reasons for the variation in price execution across brokers.

VII. Conclusions

Our trading experiment reveals an astonishing dispersion in the quality of price execution across our sample of six brokerage accounts. While we were aware that such trading would not be "free", we were surprised by the range of execution prices for our simultaneous identical trades. Indeed, we calculated that the average round trip cost ranged from –0.07% to –0.46% for the same trades at different brokerages, which is a substantial dispersion. Aggregated across all retail trades, a single basis point of cost (or savings) is equivalent to approximately $2 billion annually.

Our experiment allows us to conclude that payment for order flow (PFOF) is not the primary driver of differences in price execution. We used a sample of brokers with and without commissions, some accepting or not accepting PFOF, and some directing to the same wholesale venues. Differences in broker level PFOF do not explain differences in trade execution. Furthermore, the reported PFOF in dollars per share are rather small relative to the magnitude of price improvement.

Since PFOF does not explain our findings, we turn to market centers to try to unravel the drivers of variations in price execution. We find that the price differences we observe are due to different brokers getting different execution prices for the same trade, at the same time, at the same venue. We provide some potential economic reasons for the differences in price execution across brokers, including quality of order flow, size of order flow, and different broker objection functions.

While our experiment is expansive and systematic, our conclusions should reflect the limitations of our setup. We only placed market order for equities. Even though these are the most common retail trades, other orders such as limit orders may be treated differently. We also only focus on price execution for small, retail trades. Institutional clients with large trades have to manage price impact, as well as other execution features. More generally, clients choose brokers on a variety of criteria, only one of which is price execution. Finally, the experiment does not cover all possible brokerage account types and reflects the current U.S. equity market structure.

Even with these limitations, our results document clearly that the current disclosure environment under Reg NMS does not provide sufficient information for retail investors to identify such discrepancies. The Rule 606 broker reports, for example, were designed by the SEC "to improve the ability of their customers to determine the quality of such broker-dealer services."

Our trading experiment shows that the reports are woefully inadequate for that purpose. Instead, brokers make voluntarily disclosures that provide haphazard, inconsistent, and rarely useful information about the quality of their execution, all claiming high rates of price improvement over a benchmark, i.e., NBBO, that is easy to beat. Finally, while market centers do publish security-level price execution information in their Rule 605 reports, they do so averaged across trades from all brokerages. They do not report individual numbers for the different brokers from whom they receive order flow. Since there is substantial variation in price execution across retail brokers, the current disclosures are not informative to investors. We provide several suggestions for improvement, in particular expanding the scope of reports to display security-level execution statistics by brokers instead.

It should be noted that measuring price execution requires knowledge of the trade direction, which is a defining characteristic of our experiment. A broker can compare the price execution of market centers for orders they send. Aside from general information from public disclosures, brokers have no direct information about trade execution for other brokers. In our conversations with brokers, brokers indicated they could not have predicted their relative ranking in our study. If so, it must be impossible for retail investors to compare price execution across brokers. This points to the need for better disclosures of the "actual retail price" for equity trades.

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Figure 1. Price Improvement by Broker

This shows the cumulative distribution of price improvement (PI) by broker across their trades. PI is the difference between the execution price and bid (ask) for sells (buys) as positive values divided by the NBBO spread. PI=0% indicates that a buy (sell) was executed at the NBBO ask (bid), which is the worst possible pricing. PI=100% indicates that buys (sells) orders were executed at the bid (ask), which is the best possible pricing but unusual. PI=50% indicates that all orders were executed at the midpoint, which is excellent execution. We inverted the x-axis so that curves higher up represent better price improvement.

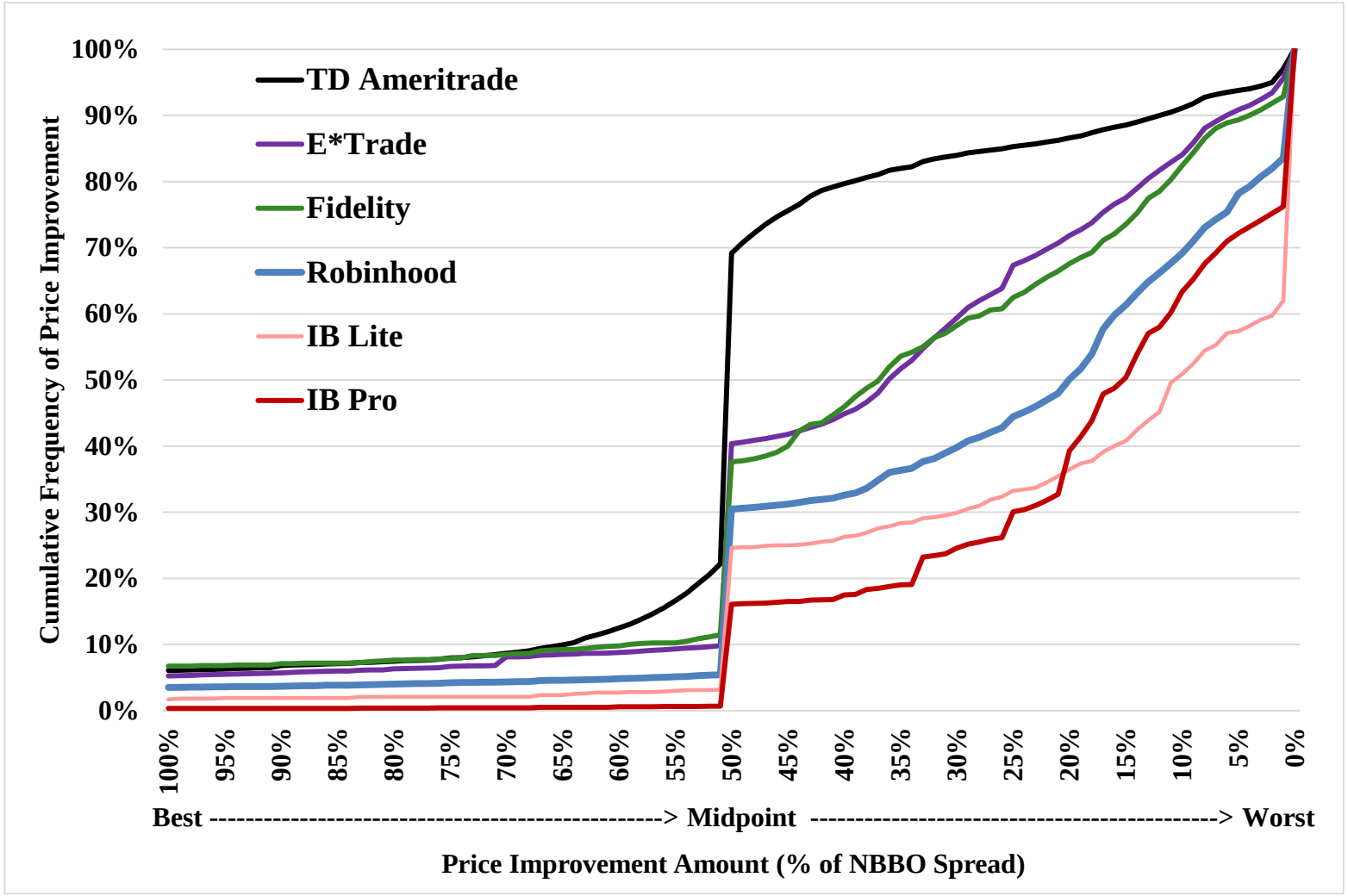


Figure 2. Cumulative Return Differences across Brokers

These graphs plot the cumulative round-trip losses between TD Ameritrade and three other brokers that we traded through their API. Panels A, B, and C compare matched trades between TD and E*Trade, IBKR Pro, and Robinhood, respectively. The panels are not comparable to each other, with different numbers and types of trades and time periods. We assume that investors continue to invest the same fixed amount of $100 for each trade.

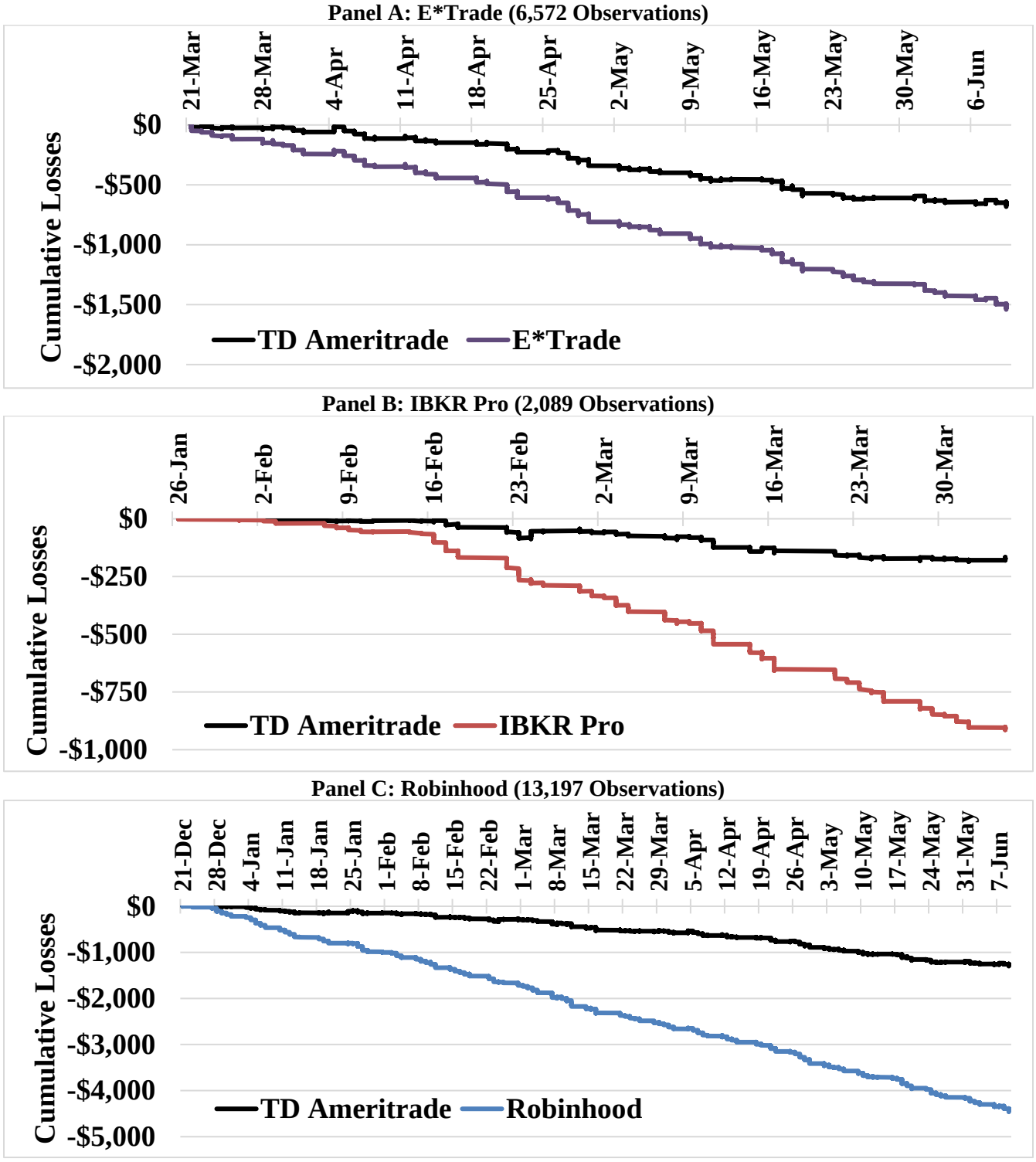
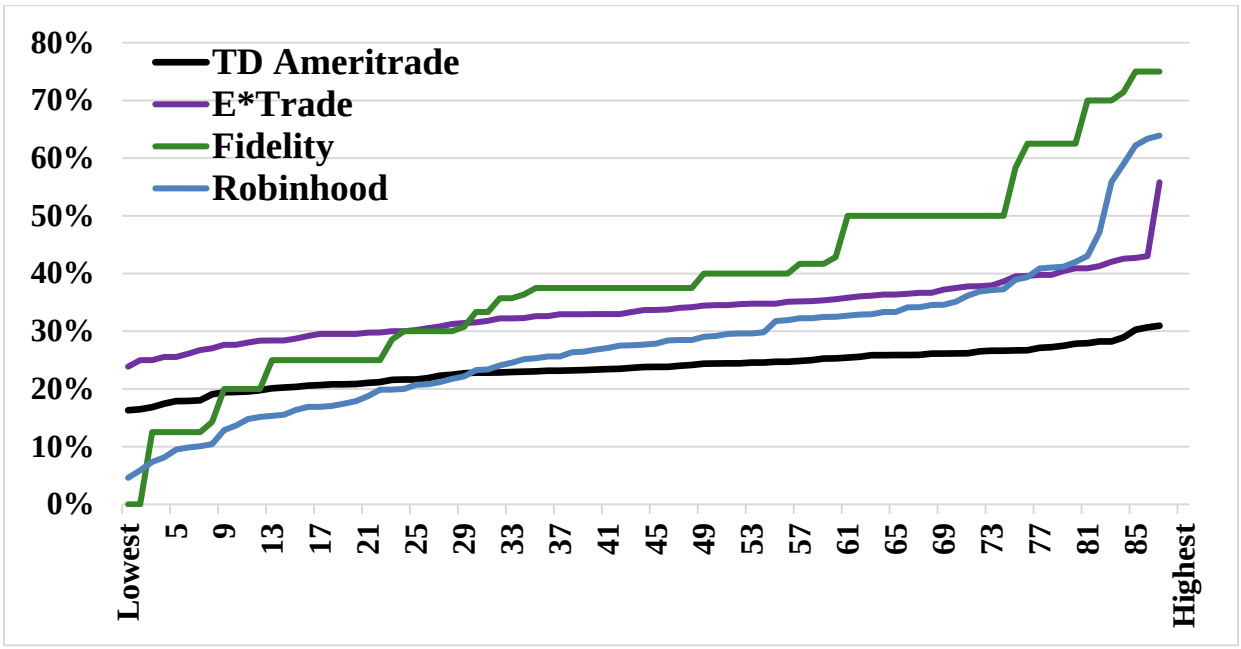


Figure 3. Routing by Stock

This figure reports the percentage of trades for each stock that are routed to various market centers. Panels A and B describe the percentages trades sent to Citadel and Virtu, respectively. For each broker, stocks are sorted from the lowest percentage to the highest. For a stock to be included in the analysis, it must have at least 100 trades for TD Ameritrade and Robinhood, 50 for E*Trade, and seven for Fidelity.

Panel A: Citadel



Panel B: Virtu

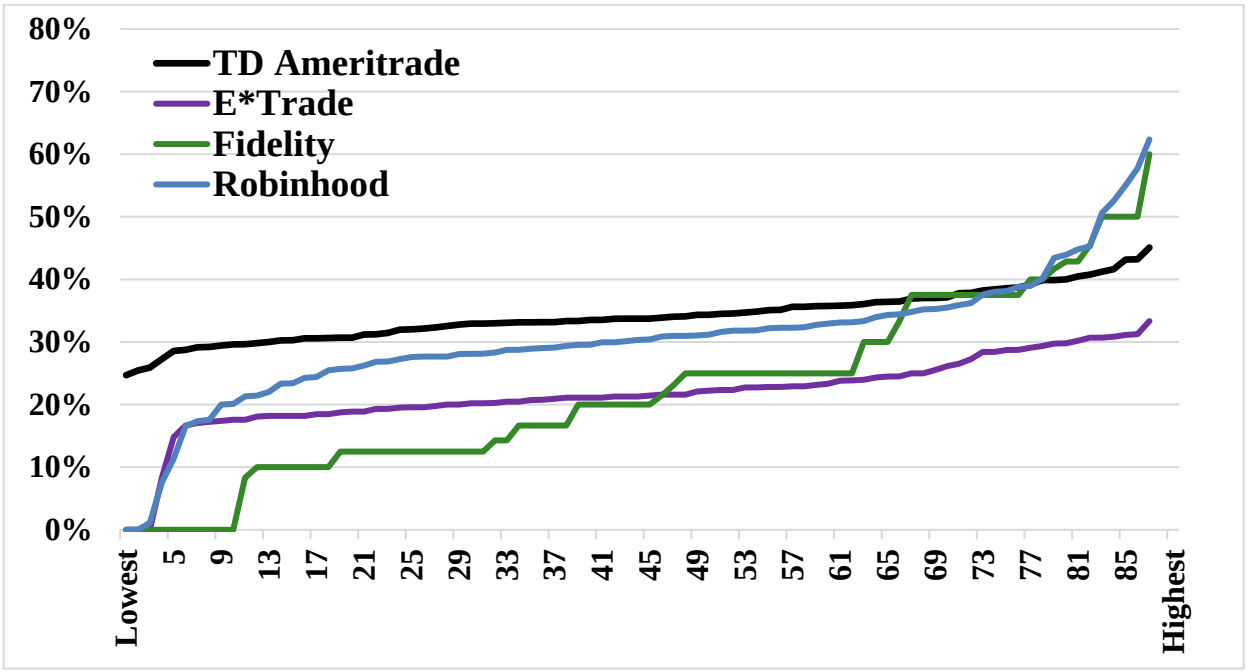


Figure 4. Price Improvement vs. Payment for Order Flow (PFOF)

This plots the price improvement (PI) for our trades versus the payment for order flow (PFOF) across brokers. PI is measured as the average dollar amount per share, from Panel A in Table V. PFOF payments per share are from brokers' Form 606 disclosures. The vertical and horizontal scales are kept the same to illustrate the much greater variation in PI than in PFOF.

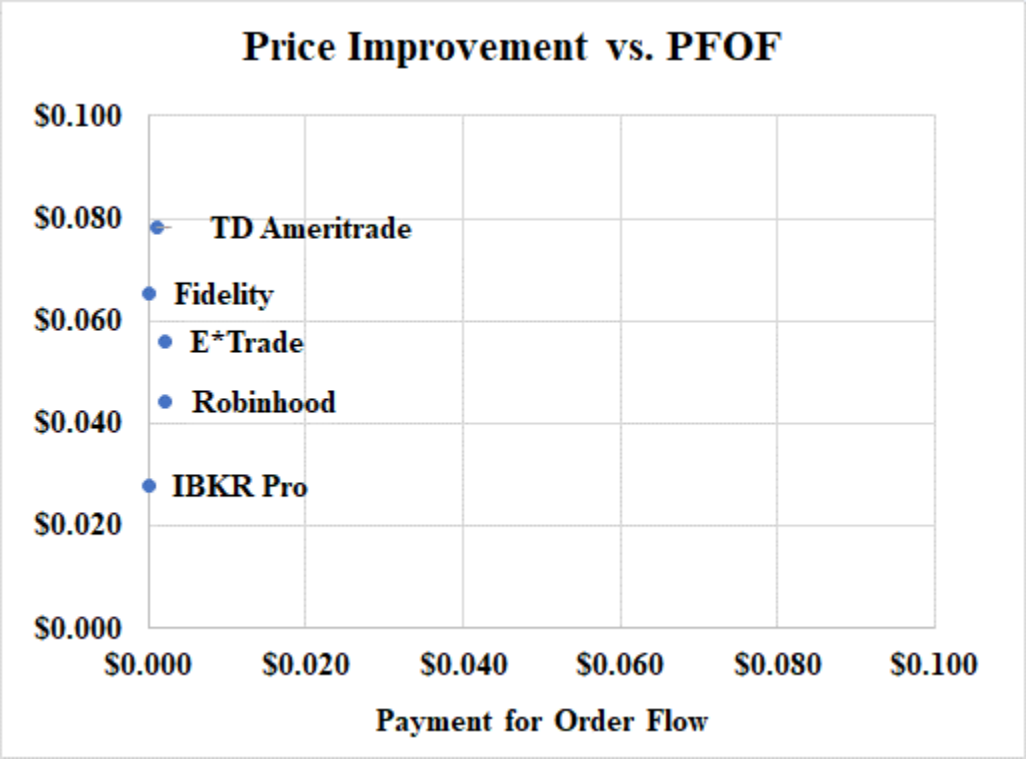


Table I
Comparison of Retail Broker-Dealers

This describes the environment for selected U.S. retail brokers, including the date they announced commission-free trading, whether they accept payment for order flow (PFOF) for equity trading, as well as information about their corporate structure. Interactive Brokers (IBKR) offers two account types, an IB Pro account with commissions and IB Lite with zero-commissions.

Broker:	Commission-Free Trading Date	PFOF Policy (Equities)	Ticker	Notes
E*Trade FinancialCorp.	10/2/2019	Yes	ETFC	Acquired in Oct 2020 by Morgan Stanley
Fidelity Investments, Inc.	10/10/2019	No		Private
Interactive Brokers Group, Inc.			IBKR	Public
IB Pro		No		
IB Lite	10/9/2019	Yes		
Robinhood Markets, Inc.	3/11/2015	Yes	HOOD	Public, IPO in July 2021
TD Ameritrade, Inc.	10/1/2019	Yes	AMTD	Acquired in Oct 2020 by Schwab

Table II
Volume of Trading by Selected Retail Brokers: First Quarter 2022

This describes the daily average trades (DAT) for the first quarter of 2022. DAT represents average trades per day that generate commissions, fees, or PFOF, and now also includes commission-free trades. DAT is widely used to compare retail trading activity across brokers.

Broker:	DAT
TD Ameritrade	5,118,000
Fidelity	3,100,000
Interactive Brokers	2,522,000
Robinhood	2,500,000
E*Trade	1,016,000
Total	14,256,000

Sources: Company financial reports and monthly statistics. For TD Ameritrade, DAT is taken from the current Schwab report, subtracting the Schwab DAT before acquisition, which was 1.460MM during the second quarter of 2020. Fidelity's DAT is for both retail and institutional clients, which are not provided separately. Interactive Brokers reports all electronic brokerage trading. For Robinhood, the reported DAT number includes equities and options but omits crypto. For E*Trade, DAT is taken from Morgan Stanley, which had insignificant DAT before its acquisition of E*Trade.

Table III
Comparison of PFOF across Brokers

This compares payments for order flows (PFOF) as reported in Rule 606 broker reports. Panel A describes the evolution of total PFOF, including both equities and options, from 2019 to 2021. Panel B shows the subset of PFOF for market orders for equities only, and the top 6 venues during the first quarter of 2022, for our five brokers. This includes the sum of all payments as well as the total fraction of such trades sent to these venues. The right side also shows the payment per 100 equity shares for market orders. For reference, the bottom lines show total PFOF broken down by equities and options across all venues and orders.

Panel A: Total PFOF over Time, Compared to Revenues

	PFOF ($ Million)			2020	
Broker:	**2019**	**2020**	**2021**	**Revenues**	**Ratio**
TD Ameritrade	$498	$1,149	$1,421	$5,811	19.8%
Robinhood	$68	$687	$974	$958	71.7%
E*Trade	$188	$402	$454	$2,846	14.1%
Schwab	$138	$245	$320	$11,691	
Fidelity		$134	$162	$21,000	
Interactive Brokers		$88	$137	$2,218	4.0%
Total		$2,706	$3,468		
Total, Top-4	$895	$2,484	$3,170		

Panel B: Detail of PFOF for First Quarter 2022

	Payment for Order Flow ($ Million), First Quarter 2022							PFOF per 100 shares		
	Broker					Total		Broker		
	E*Trade	**Robinh.**	**IBRK**	**Fidelity**	**TD Am.**	**Brokers**	**Pct**	**E*Trade**	**Robinh.**	**TD Am.**
Venue:	**Total for Equity only, Market Orders, Six Venues**									
Citadel	$5.7	$5.5	$0	$0	$10.8	$22.0	31%	18.0 ¢	20.8 ¢	9.9 ¢
Virtu	$3.2	$3.7	$0	$0	$14.8	$21.8	31%	18.3 ¢	23.9 ¢	9.9 ¢
G1X	$3.1	$2.8	$0	$0	$10.0	$15.9	22%	17.8 ¢	26.8 ¢	10.0 ¢
Two Sigma	$0.8	$1.8	$0	$0	$0.2	$2.8	4%	17.2 ¢	18.3 ¢	9.9 ¢
Jane Street	$2.7	$1.8	$0	$0	$3.2	$7.7	11%	17.9 ¢	18.5 ¢	10.0 ¢
UBS	$0.5	$0.0	$0	$0	$0.3	$0.9	1%	17.8 ¢		9.9 ¢
Sum of above	$16.2	$15.5	$0.0	$0.0	$39.4	$71.1	100%	Average:		
Frac trades sent	100%	99%	0%	97%	100%			17.9 ¢	21.7 ¢	9.9 ¢
Type:	**Total for Equity and Options, All Orders, All Venues**									
All Equity	$33.4	$35.0	$5.8	$8.9	$101.5	$184.7	28%			
Options	$71.0	$126.6	$32.9	$26.5	$208.1	$465.2	72%			
Total	$104.4	$161.6	$38.8	$35.4	$309.6	$649.9	100%			

Sources: Rule 606 broker reports and financial reports. Data for TD Ameritrade include both the parent company and TD Ameritrade Clearing. Fidelity data is for Fidelity Brokerage Services. In Panel A, revenues for acquired firms (TD Ameritrade and E*Trade) are from the first half of the 2020 year and annualized; others are for the full year. For Panel B, most brokers report a fixed dollar payment per share that is basically the same across trading venues. In contrast, Robinhood receives payments based on a fixed percentage of the NBBO spread. The payments in cents reported in the table are weighted averages, over three months and over S&P and no-S&P equities, which explains the slight variations across venues for each broker.

Table IV
Trade Summary Statistics

This table reports summary statistics for our 74,801 trades. Price is the execution price. Price improvement is the difference between the execution price and the bid for sell trades, and the ask and execution price for buy trades. Bid-Ask spread is the quoted NBBO spread just prior to trading in both dollars and percent. Dollar size is the amount traded whereas trade size is the number of shares traded. The split trades indicator is set at one if our order was split into multiple trades. Panel A reports data for all stocks. Panel B (C) reports results for S&P 500 (non-S&P 500) stocks, respectively.

Panel A: All Stocks

	Mean	Std. Dev.	10%	Q1	Median	Q3	90%
Price, execution	$73.64	$217.11	$2.36	$6.14	$17.98	$61.88	$179.49
Price Improvement ($)	$0.0581	$0.1727	$0.0010	$0.0047	$0.0125	$0.0450	$0.1250
Bid-Ask Spread ($)	$0.17	$0.40	$0.01	$0.02	$0.05	$0.15	$0.35
Bid-Ask Spread (%)	0.64%	1.06%	0.03%	0.11%	0.28%	0.68%	1.66%
Trade Dollar Size	$157.03	$271.09	$85.60	$97.10	$100.20	$109.50	$207.30
Trade Size (Shares)	15.72	29.01	1	2	5	17	47
Split Trades (%)	1.93%	13.77%					
Commissions	$0.35	$0.06	$0.35	$0.35	$0.35	$0.36	$0.37

Panel B: S&P 500 Stocks

	Mean	Std. Dev.	10%	Q1	Median	Q3	90%
Price, execution	$267.59	$448.83	$37.42	$69.42	$164.29	$239.68	$601.79
Price Improvement ($)	$0.0930	$0.2242	$0.0080	$0.0050	$0.0200	$0.0819	$0.2100
Bid-Ask Spread ($)	$0.26	$0.52	$0.01	$0.02	$0.08	$0.26	$0.53
Bid-Ask Spread (%)	0.08%	0.07%	0.02%	0.03%	0.06%	0.11%	0.17%
Trade Dollar Size	$296.94	$466.86	$76.70	$98.54	$167.80	$244.60	$630.50
Trade Size (Shares)	1.64	3.96	1	1	1	1	3
Split Trades (%)	0.26%	5.13%					

Panel C: Non-S&P 500 Stocks

	Mean	Std. Dev.	10%	Q1	Median	Q3	90%
Price, execution	$31.72	$62.47	$2.00	$4.45	$12.33	$34.16	$74.34
Price Improvement ($)	$0.0505	$0.1584	$0.0001	$0.0038	$0.0109	$0.0400	$0.1052
Bid-Ask Spread ($)	$0.15	$0.37	$0.01	$0.02	$0.04	$0.13	$0.30
Bid-Ask Spread (%)	0.77%	1.13%	0.10%	0.19%	0.37%	0.83%	1.96%
Trade Dollar Size	$127.38	$193.18	$86.79	$97.06	$99.79	$103.35	$120.22
Trade Size (Shares)	18.76	31.11	1	3	8	23	53
Split Trades (%)	2.30%	14.98%					

Table V
Comparison of Price Improvement

This table compares the price improvement (PI) for our trades in different brokerage accounts. Panel A reports the fraction of trades with any PI and PI measured as a fraction of the spread and in dollar amounts. We report results for the entire period as well as from April 22 to June 9, 2022, when we traded Interactive Brokers' free account and Fidelity; we also separate this period due to significantly worse market returns. Panel A also shows the best possible economically feasible execution, with all trades at the midpoint. "Exch. D" reports the fraction of trades identified on TAQ as executed off-exchange. Panel B reports pairwise differences in PI, as a fraction of the spread between brokers for matched trades. A negative return means that the broker reported in the column (row) has better (worse) performance. IB Pro was not trading at the same time as Fidelity and IB Lite, which precludes their comparisons. Panel C reports results from a regression of price improvement (in % of NBBO) on dummy variables to measure broker and trade order fixed effects. The intercept represents trades when TD goes first. T-values are computed using standard errors clustered by stock. *, ** represents significance at the 5% and 1% levels respectively.

Panel A: Overall Comparison of Price Improvement

	Entire Period				April 22 – June 9		
	Exch. D	% of Trades	% of Spread	Dollar Amt.	% of Trades	% of Spread	Dollar Amt.
Benchmark:							
Midpoint (Best Possible)		100%	50%	$0.0836	100%	50%	$0.0816
Broker:							
TD Ameritrade	99%	99.4%	47.2%	$0.0784	99.5%	46.2%	$0.0764
Fidelity	97%	92.9%	35.8%	$0.0654	92.9%	35.8%	$0.0654
E*Trade	98%	96.2%	36.1%	$0.0560	96.3%	36.4%	$0.0581
Robinhood	93%	85.0%	26.8%	$0.0444	89.2%	30.8%	$0.0490
IBKR Lite	96%	63.4%	19.5%	$0.0356	63.4%	19.5%	$0.0356
IBKR Pro	83%	76.4%	18.8%	$0.0278			

Panel B: Pairwise Comparison of Price Improvement (% NBBO) with Matched Trades

	vs. TD Ameritrade		vs. Robinhood		vs. E*Trade		vs. Fidelity	
	Mean	t-value	Mean	t-value	Mean	t-value	Mean	t-value
Robinhood	-20.2%	-77.92**						
E*Trade	-10.8%	-30.19**	6.8%	17.29**				
IBKR Pro	-28.7%	-51.57**	-6.6%	-11.25**	-15.0%	-13.76**		
Fidelity	-12.4%	-8.45**	3.4%	2.18*	-0.9%	-0.63		
IBKR Lite	-27.9%	-19.79**	-12.0%	-7.65**	-17.1%	-11.98**	-15.4%	-10.52**

Panel C: Impact of Latency on Price Improvement (% NBBO)

Dependent Variable:	Price Improvement (% NBBO)							
	Trades of about $100				Trades of about $1,000			
	(1)		(2)		(3)		(4)	
	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value
Intercept (TD goes first)	0.472	141.55**	0.471	138.31**	0.457	18.33**	0.468	15.84**
E*Trade	-0.111	-38.23**	-0.111	-37.32**				
Fidelity	-0.114	-13.54**	-0.109	-12.5**				
Robinhood	-0.203	-61.28**	-0.203	-61.14**	-0.230	-6.30**	-0.236	-6.34**
IBKR Pro	-0.284	-56.10**	-0.284	-55.78**	-0.287	-8.98**	-0.288	-8.16**
IBKR Lite	-0.277	-32.63**	-0.273	-29.66**				
Trade order = 2			0.000	0.09			-0.012	-0.55
Trade order = 3			0.001	1.84			-0.044	-1.28
Trade order $\geq$ 4			-0.002	-1.31				
Observations	74,709		74,709		636		636	
Adj. R-Squared	15.6%		15.6%		20.7%		20.8%	

Table VI
Comparison of Roundtrip Trade Costs

This table compares the average round-trip trade costs of our trades across different brokerage accounts. Average returns are reported in Panel A across two periods, including April 22 to June 9, 2022, when we traded Interactive Brokers' free account and Fidelity. To account for market movements, costs are measured relative to the midpoint at the trade times. We also show the worst execution, where all buys would be executed at the NBO and subsequent sells at the NBB, adjusted for the midpoint. Panel B reports pairwise difference between brokers for matched trades. A negative return means that the broker reported in the column (row) has better (worse) performance. In both panels, t-values are computed using standard errors clustered by stock. Panel C reports the percentage of trades where the broker listed in the column has better execution than the broker listed in the row. *, ** represents significance at the 5% and 1% levels respectively.

Panel A: All trades

	Entire Period		April 22 – June 9	
	Mean	t-value	Mean	t-value
TD Ameritrade	-0.072%	-6.59**	-0.093%	-6.86**
E*Trade	-0.197%	-9.46**	-0.199%	-9.21**
Fidelity	-0.234%	-6.57**	-0.234%	-6.57**
Robinhood	-0.314%	-10.46**	-0.285%	-10.03**
IBKR PRO	-0.444%	-8.25**		
IBKR LITE	-0.462%	-7.91**	-0.462%	-7.91**
NBBO (Worst Possible)	-0.619%	-10.50**	-0.646%	-10.45**

Panel B: Pairwise Comparison with Matched Trades

	vs. TD Ameritrade		vs. Robinhood		vs. E*Trade		vs. Fidelity	
	Mean	t-value	Mean	t-value	Mean	t-value	Mean	t-value
Robinhood	-0.241%	-11.52**						
E*Trade	-0.130%	-10.16**	0.070%	7.75**				
IBKR Pro	-0.367%	-9.15**	-0.115%	-6.05**	-0.152%	-7.40**		
Fidelity	-0.169%	-4.66**	0.047%	1.77	-0.010%	-0.33		
IBKR Lite	-0.384%	-7.62**	-0.164%	-4.80**	-0.227%	-6.51**	-0.204%	-7.19**

Panel C: Percentage of Time Execution is Equal or Better

	vs. TD Ameritrade	vs. Robinhood	vs. E*Trade	vs. Fidelity
Robinhood	83%			
E*Trade	73%	39%		
IBKR Pro	93%	63%	77%	
Fidelity	64%	44%	51%	
IBKR Lite	78%	65%	71%	72%

Table VII
Payment for Order Flow and Price Improvement

The table compares price improvement (PI) for our trades with the payments for order flow (PFOF) to the brokers we used. Panel A shows results for all our trades; Panel B (C) shows results for S&P 500 (non-S&P 500) stocks. *Price Imp.* is the average price improvement received across all our trades. *PFOF* is the amount of price improvement received per share based on information in the brokers' SEC Form 606 disclosure. We report the difference in price improvement (*PI Diff*) relative to TD Ameritrade as well as the difference in PFOF (*PFOF Diff*). The last column then computes the percentage of the difference in PI explained by PFOF (*PFOF Diff / PI Diff*).

Panel A: All Stocks

	Price Imp.	PFOF	PI Diff	PFOF Diff	PFOF Diff / PI Diff
TD Ameritrade	$0.0784	$0.00099			
E*Trade	$0.0560	$0.00180	$0.0224	$0.00081	3.6%
Robinhood	$0.0444	$0.00215	$0.0340	$0.00116	3.4%
IBKR Pro	$0.0278	$0.00000	$0.0506	-$0.00099	-2.0%
Fidelity	$0.0654	$0.00000	$0.0130	-$0.00099	-7.6%
Avg.					-0.6%

Panel B: S&P 500 Stocks

	Price Imp.	PFOF	PI Diff	PFOF Diff	PFOF Diff / PI Diff
TD Ameritrade	$0.1227	$0.00099			
E*Trade	$0.0927	$0.00198	$0.0300	$0.00099	3.3%
Robinhood	$0.0717	$0.01046	$0.0510	$0.00947	18.6%
IBKR Pro	$0.0525	$0.00000	$0.0702	-$0.00099	-1.4%
Fidelity	$0.0999	$0.00000	$0.0228	-$0.00099	-4.3%
Avg.					4.0%

Panel C: Non-S&P 500 Stocks

	Price Imp.	PFOF	PI Diff	PFOF Diff	PFOF Diff / PI Diff
TD Ameritrade	$0.0691	$0.00100			
E*Trade	$0.0475	$0.00175	$0.0216	$0.00075	3.5%
Robinhood	$0.0387	$0.00188	$0.0304	$0.00088	2.9%
IBKR Pro	$0.0223	$0.00000	$0.0468	-$0.00100	-2.1%
Fidelity	$0.0570	$0.00000	$0.0121	-$0.00100	-8.3%
Avg.					-1.0%

Table VIII
Effect of Venue Choice on Price Improvement

This table summarizes routing information for brokers to trading venues as well as the expected price improvement (PI) at those venues. We use the Rule 606 broker reports to show the average fraction of equity market orders routed to the top six venues during the first quarter of 2022. Panels A and B report data for S&P 500 and non-S&P 500 stocks, respectively. The last column displays the average for each venue across the four relevant brokers. We then combine the weights in these columns with venue-level average order execution data on Form 605 (for market orders ranging from 100 to 199 shares) to compute the expected price improvement for each broker on our trades.

Panel A: S&P 500 Stocks

	Routing: Fractions of Trades by Broker (from Form 606)				
Venues:	TD Ameritrade	E*Trade	Robinhood	Fidelity	Average
Citadel	36.7%	35.1%	33.8%	39.6%	36.3%
Virtu	42.3%	20.9%	21.1%	23.7%	27.0%
G1X	13.8%	20.2%	23.3%	13.8%	17.8%
Jane Street	6.0%	15.8%	13.5%	21.0%	14.1%
Two Sigma	0.8%	4.6%	7.0%	1.4%	3.4%
UBS	0.4%	3.5%	0.0%	0.0%	1.0%
Expected PI	$0.1154	$0.1145	$0.1137	$0.1150	$0.1147
Actual PI	$0.1227	$0.0927	$0.0717	$0.0999	
Expected PI Diff (vs. TD)		-$0.0009	-$0.0017	-$0.0004	
Actual PI Diff (vs. TD)		-$0.0300	-$0.0510	-$0.0228	

Panel B: Non-S&P 500 Stocks

	Routing: Fractions of Trades by Broker (from Form 606)				
Venues:	TD Ameritrade	E*Trade	Robinhood	Fidelity	Average
Citadel	36.2%	35.1%	30.7%	39.9%	35.5%
Virtu	43.6%	20.9%	26.8%	23.8%	28.8%
G1X	13.7%	19.8%	12.6%	13.8%	15.0%
Jane Street	5.2%	16.0%	17.6%	21.2%	15.0%
Two Sigma	0.8%	4.7%	8.5%	0.3%	3.6%
UBS	0.4%	3.5%	0.0%	0.0%	1.0%
Expected PI	$0.0549	$0.0543	$0.0533	$0.0555	$0.0545
Actual PI	$0.0691	$0.0475	$0.0387	$0.0570	
Expected PI Diff (vs. TD)		-$0.0006	-$0.0016	$0.0006	
Actual PI Diff (vs. TD)		-$0.0216	-$0.0304	-$0.0121	

Table IX
Effect of Stock Routing on Price Improvement (S&P 500 Stocks)

This table presents data on the variation in execution quality across venues and its effect on brokers. Panel A shows the average price improvement in dollars for our 27 S&P 500 stocks at each venue for each month. Panel B shows, for each broker, the actual price improvement as well as the minimum expected price improvement that we would expect if individual stocks were sent to the worst execution venue for each stock, based on their 605 filings. To maintain reasonable allocations across venues, we allow the percentage of orders sent to each venue to deviate by a maximum of 5% from the actual percentages in the brokers' 606 filing. Panel B also reports the percent of our stocks whose execution was worse than the worst market center.

Panel A: Price Improvement by Venue

	Citadel	G1X	Jane Street	Virtu	Two Sigma	UBS
January	$0.1186	$0.1242	$0.1185	$0.1151	$0.0889	$0.0991
February	$0.1241	$0.1222	$0.1244	$0.1138	$0.0894	$0.0952
March	$0.1211	$0.1202	$0.1123	$0.1080	$0.0885	$0.0973
April	$0.1208	$0.1177	$0.1136	$0.1102	$0.0968	$0.0970
May	$0.1308	$0.1268	$0.1253	$0.1186	$0.0964	$0.1008
Average	$0.1231	$0.1222	$0.1188	$0.1131	$0.0920	$0.0979

Panel B: Price Improvement by Broker

	TD Ameritrade			E*Trade			Robinhood		
	Actual	Min	% Less	Actual	Min	% Less	Actual	Min	% Less
January	$0.119	$0.106	0%				$0.059	$0.107	90%
February	$0.117	$0.105	12%				$0.064	$0.094	73%
March	$0.125	$0.102	0%	$0.095	$0.099	39%	$0.069	$0.092	69%
April	$0.116	$0.109	0%	$0.084	$0.104	22%	$0.072	$0.101	78%
May	$0.149	$0.125	0%	$0.109	$0.107	4%	$0.098	$0.111	22%
Average	$0.125	$0.109	2%	$0.096	$0.103	22%	$0.072	$0.101	66%

Table X
Order Routing to Trading Venues

This table shows the distribution of trades sent by E*Trade, Fidelity, Robinhood, and TD Ameritrade various execution venues. We report the percent of trades sent to each venue. These data were obtained from direct requests to the brokers under SEC Rule 606(b).

Name	Symbol	E*Trade	Fidelity	Robinhood	TD Ameritrade
Citadel	CDRG	34%	39%	27%	24%
Canaccord	CSTI	0%	0%	0%	1%
G1X	ETMM	20%	18%	8%	27%
Jane Street	JNST	17%	19%	18%	12%
Nasdaq	NASD	0%	0%	1%	0%
Virtu	NITE	22%	22%	31%	34%
Two Sigma	SOHO	4%	1%	15%	1%
UBS	UBSS	3%	0%	0%	1%
Total		100%	100%	100%	100%

Table XI
Effect of Broker Execution on Price Improvement

This table compares differences between the broker executions of our parallel trades at TD Ameritrade, Robinhood (RH), E*Trade (ET), and Fidelity (FD). The trading venues for our trades are reported by four brokers under SEC Rule 606(b). We report the *Price Improvement (% NBBO)*, which is the dollar price improvement scaled by the bid-ask (NBBO) spread and compare differences for parallel trades across brokers and venues. Panel A reports overall results and Panel B provides the detail by venue. *Any* means that the trade goes to any of the venues. *Same* means that the parallel trades were sent to the same venue (i.e., both to Citadel), whereas *Different* means that the parallel trades were sent to different venues. T-values are computed using standard errors clustered by stock. *, ** represents significance at the 5% and 1% levels respectively.

Panel A: Comparison of Overall Price Improvement (% NBBO)

TD Ameritrade (TD) vs. Robinhood (RH)						
TD Venue	RH Venue	N	TD	RH	Diff.	t-value
Any	Any	21,092	46.7%	24.2%	22.5%	63.11**
Any	Same	4,635	47.4%	24.9%	22.5%	44.14**
	Different	16,457	46.4%	23.9%	22.5%	58.51**
TD Ameritrade (TD) vs. Fidelity (FD)						
TD Venue	FD Venue	N	TD	FD	Diff.	t-value
Any	Any	750	47.2%	36.3%	10.9%	8.77**
Any	Same	183	46.9%	36.5%	10.4%	4.73**
	Different	567	47.2%	36.2%	11.0%	7.53**
TD Ameritrade (TD) vs. E*Trade (ET)						
TD Venue	ET Venue	N	TD	ET	Diff.	t-value
Any	Any	11,199	46.6%	36.3%	10.3%	26.69**
Any	Same	2,640	46.5%	36.6%	9.9%	17.88**
	Different	8,559	46.7%	36.3%	10.4%	24.60**

Panel B: Comparison of Price Improvement (% NBBO) for Parallel Trades at the Same Venue

TD Ameritrade (TD) vs. Robinhood (RH)					
Venue	N	TD	RH	Diff	t-value
Citadel	1,449	49.0%	27.8%	21.2%	21.23**
G1X	470	48.0%	14.0%	34.0%	29.81**
Jane Street	416	44.0%	25.2%	18.8%	12.14**
Virtu	2,282	47.0%	25.4%	21.6%	31.33**
Two Sigma	18	45.5%	21.4%	24.1%	7.01**

TD Ameritrade (TD) vs. E*Trade (ET)					
Venue	N	TD	ET	Diff	t-value
Citadel	1,045	46.8%	35.6%	11.2%	11.29**
G1X	618	48.6%	32.1%	16.5%	30.29**
Jane Street	212	41.6%	32.0%	9.6%	3.96**
Virtu	759	45.8%	42.9%	2.8%	3.56**

Appendix A: Details of the Trading Experiment

In this appendix, we provide additional data on our sample, including how our randomly selected sample compares to the overall population (Section A), a more detailed description of potential latency issues, i.e., differences in the timing of execution (Section B), differences in trade sizes (Section C), and the complete list of stocks traded (Section D).

A. Stratified Sample vs. Population

The main portion of our trades come from a stratified sample of stocks based on price, market capitalization, liquidity, and volatility. We choose these stocks using second quarter 2021 data from CRSP for all stocks with share code 10 or 11. Liquidity is measured as the median ratio of the percentage of shares outstanding traded daily, measured over the prior quarter. Volatility is the median squared daily return during the same quarter. We sort into 128 bins as described in the main text. Table AI compares the characteristics of our selected stocks (Panel A) versus the entire population (Panel B.) Overall, there is little difference, as expected from our stratification and random selection process.

<Insert Table AI about here>

B. Latency Discussion

Given the potential importance of latency on our results, we examine in greater detail the submission time differences as well as the execution time differences of our trades by broker. We perform these analyses for each broker pair and show results in Table AII. Panel A reports the distribution of submission time differences, as well as the percentage of time each broker has the trade submitted first. Panel B reports the distribution of execution time differences, as well as the fraction of time that the broker whose trade is submitted first does execute first. Given that different

brokers may have different latency in their API interface, such analyses are important to make sure that each broker is given a fair comparison.

<Insert Table AII about here>

Panel A shows that each broker pair has trades submitted in almost perfectly random order. In the worst case, one broker is "only" first 42% of the time, but the median time difference is still zero. Nearly all trades are within two seconds of each other (except for one trade where the difference is 42 seconds.) In all cases, more than 50% of trades have submission time differences less than one second. Panel B shows that the trade that is submitted first to a broker is almost always executed first. We also find that, most of the time, execution times are also within one second of each other. In fact, looking at the median execution time, the difference between all the brokers is essentially zero. Thus, no broker has any systematic advantage in terms of submission and execution times.

C. Trade Size and Price Execution

Our main experiment relies mostly on $100 trades. Originally, the experiment involved making larger $1,000 trades in parallel with the $100 trades. However, after six weeks of trading, these trades were halted for two reasons. First, these trades caused the cost of the experiment to be very high, so capping this cost would have resulted in a significantly lower number of observations. Secondly and most importantly, we found almost no difference in the price execution of the $100 and $1000 trades. We report these data below.

From December 21, 2021, until the end of January 2022, we traded each day 26 of our stocks, in sizes of $100 and $1000 at the same time. To ensure that the order was not important, the trades were randomized across size. In the table below, we compare execution statistics for the two sets of trades (standard errors are clustered by stock.) In total, we have 1,137 matched trades. The table shows that there is no economic or statistical difference between price executions for the two trade sizes at the overall level or by broker. We present statistics on price improvement as a percentage of NBBO as well as roundtrip returns.

Price Improvement (% NBBO)

Trade	All Trades	IB	RH	TD
$100	33.1%	18.3%	20.5%	47.5%
$1000	33.3%	15.2%	20.0%	49.1%
Diff.	-0.2%	-3.2%	-0.5%	1.5%
t-value	-0.28	-1.69	-0.40	1.18

Roundtrip Return

Trade	All Trades	IB	RH	TD
$100	-0.271%	-0.576%	-0.442%	-0.081%
$1000	-0.295%	-0.568%	-0.463%	-0.100%
Diff.	-0.025%	0.007%	-0.021%	-0.018%
t-value	-1.15	0.11	-0.68	-0.74

Next, we also split these trades by price. For stocks priced $10 or less, the $1,000 trades will involve a share count above 100, greater than a round lot. Bartlett (2022) suggests that trades of 100 shares or more will have better execution because they are reported publicly on SEC Form 605 by market centers. We split the trades into three price groups, $10 and lower, from $10 to $20, and $20 or above. For trade sizes of $1000, the first group must involve round lots. Results are in the table

below. Again, there is no significant difference between the trades across sizes. The amount of price improvement in terms of NBBO is almost identical in the pairwise comparisons.

Trades with Prices $10 and under

Trade	Price Imp. (% NBBO)	Price Imp. ($)	Roundtrip Return
$100	30.8%	$0.0152	-0.375%
$1000	31.1%	$0.0133	-0.422%
Diff	-0.3%	$0.0019	-0.047%
t-value	-0.24	1.29	-0.85

Trades with Prices between $10 and $20

Trade	Price Imp. (% NBBO)	Price Imp. ($)	Roundtrip Return
$100	32.3%	$0.0386	-0.327%
$1000	33.1%	$0.0357	-0.368%
Diff	-0.7%	$0.0028	-0.040%
t-value	-0.38	0.53	-0.91

Trades with Prices of $20 and above

Trade	Price Imp. (% NBBO)	Price Imp. ($)	Roundtrip Return
$100	35.1%	$0.1275	-0.176%
$1000	35.1%	$0.1240	-0.179%
Diff	-0.0%	$0.0035	-0.003%
t-value	-0.05	0.50	-0.27

For robustness, we also performed an experiment that varied the number of shares directly. Specifically, for any stock with a price less than $50, we performed trades of one, two, five, 10, 25, 50, 70, and 100 shares from February 23, 2022, to March 11, 2022. We use stocks priced below $50 so as to limit transaction costs. This still allows us to have orders up to $5,000 per trade, however. Price execution is compared to our baseline trades of $100. We split the comparison between trades that are larger in size than the $100 baseline and those that are smaller.

Results are reported below. Again, there is nothing to suggest that our use of $100 trade impacts our findings. No differences are economically or statistically significant.

Trades Smaller than the $100 Baseline

Trade	Price Imp. (% NBBO)	Price Imp. ($)	Roundtrip Return
$100	36.1%	$0.0234	-0.332%
Size Specific	35.7%	$0.0264	-0.312%
Diff	0.3%	-$0.0030	-0.020%
t-value	0.33	-1.55	-0.62

Trades Larger than the $100 Baseline

Trade	Price Imp. (% NBBO)	Price Imp. ($)	Roundtrip Return
$100	37.8%	$0.0362	-0.279%
Size Specific	37.0%	$0.0334	-0.281%
Diff	0.7%	$0.0027	0.002%
t-value	0.57	1.67	0.07

D. List of Traded Stocks

Table AIII provides a list of the stocks traded, the number of trades, as well as the first and last date traded. We separate the list into the stratified sample, the retail darlings, the megacap stocks, and the top movers.

<Insert Table AIII about here>

Table AI
Comparative Statistics for our Sample vs. the Total Population

This table presents summary statistics for our sample of 128 stocks compared to the universe of stocks in the CRSP database as of June 30, 2021. For a stock to be included in the population, its share code needs to be 10 or 11 and the price must be greater than one dollar. Stocks are sorted into quartiles by market capitalization, then by liquidity, then by volatility, and finally into two groups by price, which gives 128 bins, from which we randomly select one sample stock. Liquidity is measured from the quarterly median of the percentage of shares outstanding traded daily. Volatility is measured from the median squared daily return, over the last quarter as well. Panel A and B report summary statistics for our sample and the population, respectively.

Panel A: Sample Statistics

	Mean	10%	Q1	Median	Q3	90%
Price	$50.94	$4.39	$9.75	$20.71	$55.36	$149.52
Market Cap ($B)	$6,082	$109	238	$862	$4,313	$21,602
Liquidity	0.79%	0.16%	0.31%	0.57%	0.98%	1.42%
Volatility	0.47%	0.03%	0.12%	0.29%	0.69%	1.14%

Panel B: Population Statistics

	Mean	10%	Q1	Median	Q3	90%
Price	$67.65	$4.63	$9.77	$23.37	$58.35	$130.02
Market Cap ($B)	$12,716	$94	$238	$940	$4,314	$17,915
Liquidity	0.99%	0.12%	0.32%	0.54%	0.97%	1.85%
Volatility	0.59%	0.05%	0.08%	0.29%	0.71%	1.28%

Table AII
Latency Comparisons Across Brokers

In this table, we compare the ordering as well as submission and execution times of trades across brokers. Panel A compares the ordering of submissions as well as the difference in submission times for each of our pairs of brokers that trade via the API. Broker 1 (2) is the first (second) broker listed in the header row. Differences in times are measured in seconds, taken as the first broker time minus second broker time; a positive difference means that the first broker trade was submitted later. Panel B compares execution times. We report the probability for a broker's trade to be executed first conditional on being submitted first, as well as the distribution of differences in execution times. Again, Broker 1 (2) is the first (second) broker listed. Differences in times are in seconds, taken as the first broker time minus second broker time. *RH* is Robinhood, *TD* is TD Ameritrade, *ET* is E*Trade, *IB* is IBKR PRO, *IF* is IBKR LITE, and *FD* is Fidelity.

Panel A: Submission Times

	Fraction of Time Trade is Submitted First					
	RH vs. TD	IB vs. TD	ET vs. TD	IB vs. RH	ET vs. RH	IB vs. ET
Broker 1 vs.	50%	45%	50%	42%	50%	47%
Broker 2	50%	55%	50%	58%	50%	53%

	Time Difference (Broker 1 minus Broker 2) (in seconds)					
	RH vs. TD	IB vs. TD	ET vs. TD	IB vs. RH	ET vs. RH	IB vs. ET
Maximum	1.95	1.79	1.99	2.02	2.19	42.28
99%	1.48	1.40	1.53	1.01	1.06	2.09
95%	1.36	0.72	1.39	0.69	0.92	1.65
90%	1.26	0.65	1.34	0.28	0.86	1.55
75%	0.65	0.00	0.73	0.00	0.73	0.94
Median	-0.12	-0.16	-0.12	0.00	0.04	0.00
25%	-0.17	-0.30	-0.18	-0.67	-0.68	0.00
10%	-0.77	-0.92	-0.81	-0.95	-0.81	-0.68
5%	-0.86	-1.03	-0.85	-1.39	-0.86	-0.90
1%	-1.00	-1.69	-0.98	-1.68	-0.99	-0.96
Minimum	-1.93	-1.94	-1.80	-2.39	-2.00	-2.09

Panel B: Execution Times

	Probability that Order is Executed First (Conditional on Submission being First)					
	RH vs. TD	IB vs. TD	ET vs. TD	IB vs. RH	ET vs. RH	IB vs. ET
Broker 1 vs.	97%	84%	87%	91%	98%	86%
Broker 2	99%	92%	97%	86%	96%	80%

	Time Difference (Broker 1 minus Broker 2) (in seconds)					
	RH vs. TD	IB vs. TD	ET vs. TD	IB vs. RH	ET vs. RH	IB vs. ET
Maximum	6.77	4.48	6.32	245.39	1566.52	2.17
99%	1.04	1.54	1.03	1.82	1.58	1.56
95%	0.86	0.85	0.83	1.20	0.88	1.06
90%	0.69	0.77	0.73	0.80	0.80	0.87
75%	0.17	0.18	0.15	0.54	0.65	0.34
Median	0.00	-0.10	-0.03	0.00	0.00	0.00
25%	-0.66	-0.63	-0.82	-0.33	-0.77	-0.68
10%	-1.26	-0.89	-1.37	-0.81	-0.94	-1.27
5%	-1.37	-1.44	-1.48	-1.10	-1.06	-1.54
1%	-1.70	-1.90	-1.78	-1.72	-1.46	-2.05
Minimum	-2211.65	-85.23	-6.25	-84.62	-6.42	-2.94

Table AIII
List of Traded Stocks

This table list the stocks used in our experiment. Panels A shows the stratified sample, Panel B shows the retail darlings and megacaps, and Panel C shows the top movers.

Panel A: Stratified Sample

Ticker	Nb. of Trades	Start Date	End Date
AAP	529	12/21/2021	6/9/2022
AAWW	549	12/21/2021	6/9/2022
AGL	629	12/21/2021	6/9/2022
AGX	593	12/21/2021	6/9/2022
AIRI	35	12/21/2021	1/3/2022
ALB	562	12/21/2021	6/9/2022
AMP	550	12/21/2021	6/9/2022
AMTB	572	12/21/2021	6/9/2022
ANIP	573	12/21/2021	6/9/2022
AP	4	5/11/2022	5/11/2022
APLS	538	12/21/2021	6/9/2022
APT	588	12/21/2021	6/9/2022
ARAV	602	12/21/2021	6/9/2022
ARDS	109	5/10/2022	6/9/2022
ASB	567	12/21/2021	6/9/2022
ATNX	199	12/21/2021	2/18/2022
ATRA	617	12/21/2021	6/9/2022
AVO	561	12/21/2021	6/9/2022
AWR	550	12/21/2021	6/9/2022
BATL	620	12/21/2021	6/9/2022
BCC	555	12/21/2021	6/9/2022
BOXL	435	12/21/2021	5/9/2022
BV	591	12/21/2021	6/9/2022
CAL	578	12/21/2021	6/9/2022
CAPR	591	12/21/2021	6/9/2022
CDNA	589	12/21/2021	6/9/2022
CLR	574	12/21/2021	6/9/2022
CPK	543	12/21/2021	6/9/2022
CRS	595	12/22/2021	6/9/2022
CSLT	150	12/21/2021	2/16/2022
CSX	569	12/21/2021	6/9/2022
CURI	566	12/21/2021	6/9/2022
CVCO	532	12/21/2021	6/9/2022
CVLT	540	12/21/2021	6/9/2022
CVLY	586	12/21/2021	6/9/2022
CYAN	614	12/21/2021	6/9/2022
DCTH	590	12/21/2021	6/9/2022
DHIL	537	12/21/2021	6/9/2022
DISH	576	12/21/2021	6/9/2022
DNZ	616	12/22/2021	6/9/2022
DTOC	660	12/21/2021	6/9/2022
DUNE	591	12/21/2021	6/9/2022
EBET	564	12/21/2021	6/9/2022
EBIX	589	12/21/2021	6/9/2022
EDUC	11	6/1/2022	6/1/2022
ENOB	623	12/21/2021	6/9/2022
ENVB	124	12/21/2021	1/25/2022
ERES	596	12/21/2021	6/9/2022
EW	555	12/21/2021	6/9/2022
EWTX	612	12/21/2021	6/9/2022
FFIV	556	12/21/2021	6/9/2022
FLOW	287	12/21/2021	4/4/2022
FRBA	606	12/21/2021	6/9/2022
FRW	628	12/21/2021	6/9/2022
GBCI	585	12/21/2021	6/9/2022
GENC	580	12/21/2021	6/9/2022
GEVO	629	12/21/2021	6/9/2022
GIS	577	12/21/2021	6/9/2022
GLT	574	12/21/2021	6/9/2022
GO	658	12/22/2021	6/9/2022
GOAC	568	12/21/2021	6/9/2022
GS	558	12/22/2021	6/9/2022
HCDI	120	5/10/2022	6/9/2022
HEI	547	12/21/2021	6/9/2022
HMHC	341	12/21/2021	4/4/2022
HONE	585	12/21/2021	6/9/2022
HTGM	474	12/21/2021	5/9/2022
ICCC	608	12/21/2021	6/9/2022
IFF	549	12/21/2021	6/9/2022
INBX	570	12/21/2021	6/9/2022
INZY	591	12/21/2021	6/9/2022
IO	51	12/21/2021	1/3/2022
KNBE	569	12/21/2021	6/9/2022
KNDI	604	12/21/2021	6/9/2022
KVSA	642	12/21/2021	6/9/2022
LUNG	587	12/21/2021	6/9/2022
LXRX	6	6/1/2022	6/1/2022
MBRX	610	1/5/2022	6/9/2022
MCW	552	12/21/2021	6/9/2022
MMI	589	12/22/2021	6/9/2022
MODN	587	12/21/2021	6/9/2022
MSI	565	12/21/2021	6/9/2022

NFLX	196	4/21/2022	6/9/2022
NGC	623	12/21/2021	6/9/2022
NNBR	584	12/21/2021	6/9/2022
NOV	593	12/22/2021	6/9/2022
NP	612	12/21/2021	6/9/2022
NRG	579	12/21/2021	6/9/2022
NTAP	565	12/21/2021	6/9/2022
NTIP	4	4/27/2022	4/27/2022
NUWE	328	1/26/2022	5/9/2022
ODFL	515	12/21/2021	6/9/2022
OKE	575	12/21/2021	6/9/2022
OLMA	137	5/11/2022	6/9/2022
OPK	563	12/21/2021	6/9/2022
OPRT	567	12/21/2021	6/9/2022
PANW	566	12/21/2021	6/9/2022
PCYG	597	12/21/2021	6/9/2022
PLPC	562	12/22/2021	6/9/2022
POWW	610	12/21/2021	6/9/2022
PROV	593	12/21/2021	6/9/2022
PRPO	123	5/10/2022	6/9/2022
PRTH	611	12/22/2021	6/9/2022
PRTK	629	12/21/2021	6/9/2022
PVH	583	12/21/2021	6/9/2022
PXLW	585	12/21/2021	6/9/2022
RAMP	617	12/21/2021	6/9/2022
RAPT	611	12/21/2021	6/9/2022
RDI	614	12/21/2021	6/9/2022
RDUS	588	12/21/2021	6/9/2022
RM	627	12/21/2021	6/9/2022
ROOT	135	5/10/2022	6/9/2022
SALM	623	12/21/2021	6/9/2022
SCHL	597	12/21/2021	6/9/2022
SCKT	600	12/21/2021	6/9/2022
SCPS	208	12/21/2021	2/18/2022
SEAH	104	12/21/2021	1/27/2022
SGRP	608	12/21/2021	6/9/2022
SGTX	606	12/21/2021	6/9/2022
SHLS	640	12/21/2021	6/9/2022
SLGG	617	12/21/2021	6/9/2022
SSNC	577	12/21/2021	6/9/2022
SUNW	571	12/21/2021	6/9/2022
TACT	566	12/21/2021	6/9/2022
TALK	585	12/21/2021	6/9/2022
TDG	551	12/21/2021	6/9/2022
TETC	596	12/21/2021	6/9/2022
TRV	561	12/21/2021	6/9/2022
UAVS	324	1/27/2022	5/9/2022
UNF	598	12/21/2021	6/9/2022
VAPO	610	12/21/2021	6/9/2022
VNDA	600	12/22/2021	6/9/2022
VTAQ	601	12/21/2021	6/9/2022
VTVT	104	12/21/2021	1/25/2022
W	552	12/21/2021	6/9/2022
WBS	587	12/21/2021	6/9/2022
WH	524	12/21/2021	6/9/2022
WMPN	550	12/21/2021	6/9/2022
WRB	582	12/21/2021	6/9/2022
WTFC	529	12/21/2021	6/9/2022
XSPA	510	1/4/2022	6/9/2022
ZUMZ	602	12/21/2021	6/9/2022
AAP	529	12/21/2021	6/9/2022

Panel B: Retail Darlings and Megacaps

AAPL	431	1/31/2022	6/9/2022
BAC	456	1/31/2022	6/9/2022
GOOG	454	2/3/2022	6/9/2022
NVDA	421	1/31/2022	6/9/2022
V	458	1/31/2022	6/9/2022
XOM	420	1/31/2022	6/9/2022
ACB	87	3/10/2022	4/1/2022
AMC	575	12/21/2021	6/9/2022
NIO	93	3/10/2022	4/1/2022
SNDL	39	12/21/2021	12/31/2021
TSLA	588	12/21/2021	6/9/2022

Panel C: Top Movers

AAL	30	4/21/2022	4/27/2022
ACC	24	4/19/2022	4/25/2022
ADGI	25	3/30/2022	4/4/2022
AFRM	24	5/13/2022	5/19/2022
AGYS	31	5/18/2022	5/24/2022
AHCO	18	5/10/2022	5/13/2022
AKAN	10	3/16/2022	3/21/2022
AMLX	30	6/3/2022	6/9/2022
AMRS	30	5/17/2022	5/23/2022
APLD	31	5/20/2022	5/26/2022
APP	21	5/12/2022	5/18/2022
APPN	15	5/10/2022	5/13/2022
ARHS	24	3/30/2022	4/4/2022
ARQQ	13	3/15/2022	3/21/2022
ASLE	10	3/16/2022	3/21/2022
ATEN	32	4/22/2022	4/28/2022
ATGE	21	5/6/2022	5/11/2022
ATKR	30	5/3/2022	5/9/2022
ATRS	30	4/13/2022	4/21/2022
AVDL	31	4/26/2022	5/2/2022
AXGN	24	5/5/2022	5/10/2022
AXSM	24	4/19/2022	4/25/2022
BASE	6	6/9/2022	6/9/2022
BBAI	30	4/6/2022	4/12/2022
BBIG	27	3/21/2022	5/11/2022
BEKE	35	3/16/2022	4/7/2022
BFLY	30	6/1/2022	6/7/2022
BHG	30	5/4/2022	5/10/2022
BHVN	15	5/10/2022	5/13/2022
BITF	30	3/28/2022	4/1/2022
BLFS	32	4/25/2022	4/29/2022
BLTE	31	5/24/2022	5/31/2022
BORR	30	4/1/2022	4/7/2022
BTMD	30	6/3/2022	6/9/2022
BTU	18	6/7/2022	6/9/2022
BZ	24	6/6/2022	6/9/2022
BZUN	3	3/22/2022	3/22/2022
CALT	31	5/19/2022	5/25/2022
CANG	30	4/25/2022	4/29/2022
CASA	30	4/18/2022	4/25/2022
CD	31	4/22/2022	4/28/2022
CEI	23	4/18/2022	4/25/2022
CELU	16	3/10/2022	3/15/2022
CGEM	21	5/12/2022	5/18/2022
CHWY	30	6/2/2022	6/8/2022
CLVS	27	3/31/2022	4/6/2022
CLW	24	4/29/2022	5/4/2022
CNDT	30	4/7/2022	4/13/2022
CRDO	30	6/2/2022	6/8/2022
CRM	30	6/1/2022	6/7/2022
CRMT	30	5/24/2022	5/31/2022
CRNX	27	3/31/2022	4/6/2022
CRWD	30	4/12/2022	4/19/2022
CTT	30	5/31/2022	6/6/2022
CTV	6	6/9/2022	6/9/2022
CVNA	57	5/16/2022	6/1/2022
CXM	30	4/7/2022	4/13/2022
CXW	30	4/14/2022	4/22/2022
DDL	27	4/5/2022	4/11/2022
DECK	30	5/20/2022	5/26/2022
DG	30	5/26/2022	6/2/2022
DIDI	66	3/16/2022	6/9/2022
DLO	31	5/18/2022	5/24/2022
DLTR	30	5/26/2022	6/2/2022
DRTS	45	3/25/2022	5/19/2022
DSP	27	5/16/2022	5/20/2022
DTC	28	5/27/2022	6/3/2022
ENR	18	5/9/2022	5/11/2022
ENVX	30	5/3/2022	5/9/2022
ETWO	30	4/21/2022	4/27/2022
EXAI	12	6/8/2022	6/9/2022
EXK	18	5/11/2022	5/17/2022
FFIE	27	5/16/2022	5/20/2022
FINV	30	6/1/2022	6/7/2022
FMAC	12	3/15/2022	3/21/2022
FNKO	21	5/6/2022	5/11/2022
FRGE	57	5/2/2022	5/27/2022
FTCH	30	5/27/2022	6/3/2022
FTCI	24	6/6/2022	6/9/2022
GATO	30	4/8/2022	4/14/2022

GDYN	51	3/29/2022	5/11/2022
GET	30	5/20/2022	5/26/2022
GGR	27	4/5/2022	4/11/2022
GOGO	30	4/6/2022	4/12/2022
GRNA	30	4/12/2022	4/19/2022
GSM	18	5/11/2022	5/17/2022
GTLB	28	3/16/2022	6/9/2022
GTYH	24	4/29/2022	5/4/2022
HDSN	24	5/5/2022	5/10/2022
HMLP	30	5/25/2022	6/1/2022
HOLI	10	3/16/2022	3/21/2022
HPK	30	4/13/2022	4/21/2022
HPQ	30	4/7/2022	4/13/2022
HRT	4	3/22/2022	3/22/2022
HTH	27	5/2/2022	5/6/2022
HYMC	25	5/5/2022	5/10/2022
IBA	30	3/28/2022	4/1/2022
IGMS	30	3/29/2022	4/4/2022
INO	31	5/19/2022	5/25/2022
ISPO	24	3/30/2022	4/4/2022
IXHL	13	3/15/2022	3/21/2022
JBT	30	4/27/2022	5/3/2022
JMIA	54	4/4/2022	5/23/2022
JOBY	30	3/25/2022	3/31/2022
LEJU	30	5/20/2022	5/26/2022
LILM	54	3/25/2022	4/14/2022
LMDX	44	4/18/2022	6/9/2022
LOVE	30	3/29/2022	4/4/2022
LTHM	30	5/4/2022	5/10/2022
MANT	27	5/16/2022	5/20/2022
METC	18	6/7/2022	6/9/2022
MF	27	4/5/2022	4/11/2022
MHK	24	4/29/2022	5/4/2022
MKTW	6	6/9/2022	6/9/2022
MLTX	32	5/31/2022	6/6/2022
MNTS	31	4/7/2022	4/13/2022
MOD	30	5/26/2022	6/2/2022
MORF	31	4/26/2022	5/2/2022
MRTX	18	6/7/2022	6/9/2022
MSC	31	4/27/2022	5/3/2022
MSP	30	4/11/2022	4/18/2022
MULN	30	5/31/2022	6/6/2022
MVST	30	5/17/2022	5/23/2022
MX	60	4/26/2022	5/24/2022
NEXT	21	3/25/2022	3/30/2022
NKTX	30	4/25/2022	4/29/2022
NLSN	30	3/29/2022	4/4/2022
NNOX	28	3/31/2022	4/6/2022
NOTV	24	5/13/2022	5/19/2022
NTNX	30	5/23/2022	5/27/2022
NTRA	16	3/10/2022	3/15/2022
NTUS	30	4/18/2022	4/25/2022
NUTX	30	4/27/2022	5/3/2022
PAYO	25	5/13/2022	5/19/2022
PBI	25	4/28/2022	5/4/2022
PCOM	18	5/9/2022	5/11/2022
PLAN	6	3/21/2022	3/21/2022
PMVP	30	5/27/2022	6/3/2022
PNTG	16	5/10/2022	5/13/2022
POLY	30	3/28/2022	4/1/2022
PRPL	18	5/11/2022	5/17/2022
PSB	30	4/25/2022	4/29/2022
PSFE	30	4/8/2022	4/14/2022
PSO	16	3/11/2022	3/16/2022
PSTG	30	6/2/2022	6/8/2022
PUYI	27	5/2/2022	5/6/2022
RAD	30	4/14/2022	4/22/2022
RADA	32	3/25/2022	3/31/2022
RDBX	69	5/2/2022	6/9/2022
RDVT	16	3/10/2022	3/15/2022
RENN	31	4/14/2022	4/22/2022
RGEN	30	4/27/2022	5/3/2022
RLX	30	4/22/2022	4/28/2022
RMNI	30	6/1/2022	6/7/2022
RPTX	30	6/2/2022	6/8/2022
RSKD	30	5/17/2022	5/23/2022
SAI	30	5/18/2022	5/24/2022
SAIL	30	4/11/2022	4/18/2022
SES	21	3/25/2022	3/30/2022
SEV	24	4/19/2022	4/25/2022

SIGA	30	5/27/2022	6/3/2022
SIMO	24	5/5/2022	5/10/2022
SIVB	30	4/22/2022	4/28/2022
SKYH	46	3/11/2022	5/2/2022
SKYX	24	5/12/2022	5/18/2022
SMCI	54	4/19/2022	5/10/2022
SPRC	65	3/25/2022	5/31/2022
SQSP	21	5/12/2022	5/18/2022
SRLP	30	6/3/2022	6/9/2022
SRRA	30	4/13/2022	4/21/2022
SST	27	4/5/2022	4/11/2022
SSU	24	4/4/2022	4/7/2022
STAA	30	3/28/2022	4/1/2022
STON	30	5/25/2022	6/1/2022
SYM	8	6/8/2022	6/9/2022
TELL	30	4/1/2022	4/7/2022
TKNO	36	3/21/2022	4/19/2022
TLRY	60	3/25/2022	4/12/2022
TNON	30	5/4/2022	5/10/2022
TNXP	30	5/23/2022	5/27/2022
TPTX	60	4/13/2022	6/9/2022
TRQ	12	3/15/2022	3/21/2022
TTI	30	5/3/2022	5/9/2022
TUFN	30	4/6/2022	4/12/2022
TUYA	33	3/22/2022	4/7/2022
TWTR	24	4/4/2022	4/7/2022
UAL	30	4/21/2022	4/27/2022
UIS	27	4/28/2022	5/4/2022
UVXY	12	5/9/2022	5/11/2022
VERU	30	4/11/2022	4/18/2022
VGR	27	3/31/2022	4/6/2022
VIR	24	3/30/2022	4/4/2022
VMW	30	5/23/2022	5/27/2022
VNET	30	4/11/2022	4/18/2022
VSEC	25	4/28/2022	5/4/2022
VSTA	30	5/24/2022	5/31/2022
VTRS	18	5/9/2022	5/11/2022
VXX	10	3/16/2022	3/21/2022
WDFC	30	4/8/2022	4/14/2022
WDH	30	5/31/2022	6/6/2022
WULF	16	3/11/2022	3/16/2022
Y	6	3/21/2022	3/21/2022
YMAB	27	4/28/2022	5/4/2022
ZEAL	31	5/19/2022	5/25/2022
ZGN	6	6/9/2022	6/9/2022
ZH	10	3/16/2022	3/21/2022
ZYME	26	4/29/2022	5/4/2022

Appendix B: Payments for Order Flow: Controversy and Evidence

Payment for Order Flow is a direct payment from the wholesaler to the broker-dealer in exchange for routing client orders to its venue instead of sending them to an exchange.[40] This made possible the zero-commission model that was pioneered by Robinhood. The PFOF practice has become controversial given the increase in retail trading volume, size of payments, and its increasingly widespread use.

A key issue for evaluating best execution is whether PFOF is in the best interest of retail clients. Specifically, the question is whether the client receives the best execution available, in particular price improvement, when the broker receives payment for the trade. The concern is that brokers may have an economic incentive to send retail orders to specific rebating market makers rather than, say, exchanges, possibly leading to worse price improvement. IOSCO (2017) provides a good overview of potential conflicts of interest with order routing incentives.[41]

PFOF is allowed in the U.S. Indeed, the SEC and FINRA are acutely aware of the potential for conflicts of interest and, as a result, have issued rules stating that broker-dealers "may not let payment for order flow interfere with their duty of best execution."[42] In addition, they require, under Rule 606, detailed information about PFOF made to brokers, expressed in total dollars and price per share. Interestingly, for our broker sample, these reports show that prices per share are basically the same across venues. This is important because it indicates that there should be no

[40] PFOF dates back to at least 1984, as noted by Roberts, Richard (1993), "Payment for Order Flow," SEC. It was also pioneered by Bernard Madoff, who ran an automated trading operation that paid retail brokers for order flow.
[41] IOSCO (2017) identifies three incentives that may influence broker behavior: monetary benefits received from third parties such as PFOF; bundling of other client services with executions; and affiliated venues that have benefits for brokers, such as Alternative Trading Systems.
[42] FINRA Regulatory Notice 21-23, "Best Execution and Payment for Order Flow" (June 23, 2021).

particular incentive to favor any one venue because of PFOF. What about other arrangements, however?

Rule 606 requires, in addition to the numerical information, "a description of any arrangement for [PFOF] and any profit-sharing relationship and a description of any terms of such arrangements, written or oral, that may influence a broker's or dealer's order routing decision."[43] For instance, TD Ameritrade Clearing indicates for each of its six listed equity venues that it

"receives payment for routing listed equity order flow to market makers. For marketable orders the payment rate is $0.001 per share or less, for non-marketable orders the rate is $0.0037 per share or less, and for extended hours orders the rate is $0.0006 per share or less. All market makers pay the same rate for each respective order flow type. TD Ameritrade does not negotiate payment as a condition for sending more order flow to a market maker."

This states explicitly that there is no other arrangement.

PFOF raises other concerns besides potential conflicts of interests.[44] One is whether PFOF creates incentives for the broker to increase trading volume unnecessarily, for instance by "gamification" of online trading.[45] On the other hand, more trading increases liquidity generally, and should generate economies of scale for all investors. Also, greater, and more efficient competition across trading venues could push down trading spreads.

In addition, a broader issue is whether the decentralization of markets, with retail traders moving from exchanges displaying NBBO to other venues, is causing secondary effects. Bid/ask spreads are wider in markets with more informed traders to protect the market maker from adverse

[43] See C.F.R. 242.606, "(A) Incentives for equaling or exceeding an agreed upon order flow volume threshold, such as additional payments or a higher rate of payment; (B) Disincentives for failing to meet an agreed upon minimum order flow threshold, such as lower payments or the requirement to pay a fee; (C) Volume-based tiered payment schedules; and (D) Agreements regarding the minimum amount of order flow that the broker-dealer would send to a venue."
[44] For a good overview, see BestEx Research (2021).
[45] The gamification of investing refers to the addition of features to investment apps that make the user experience more intuitive, exciting, or visually appealing. Their purpose is to make stock trading more fun for the average consumer, like playing a video game. The SEC (SEC, 2021a) recently requested comments on the implications of these so-called Digital Engagement Practices (DEPs). Barber and Odean (2000) argue that "Trading is Hazardous to Your Wealth."

selection. Retail traders are typically less informed, hence should face tighter bid/ask spreads. In turn, their shift toward wholesalers could increase spreads on exchanges because these are left with a greater proportion of institutional and informed investors. In practice, however, trading volumes on exchanges continue to go up substantially.

While PFOF is accepted in the U.S., other countries, however, have outright bans on PFOF, notably the United Kingdom, Canada, and Australia. Within the European Union (EU), the situation is still evolving, as part of the process to review the Markets in Financial Instruments Regulation (MiFIR). PFOF is currently banned in the Netherlands, and the European Commission has proposed a general EU ban in 2021.[46] In part, this reflects structural differences between U.S. and EU financial markets. The EU has more fragmentation of exchanges, and hence less competition, including across wholesalers. In addition, there is no consolidated trade and quote database, nor any clear path to do so.[47]

The empirical evidence on the effects of PFOF on execution is mixed. Adams, Kasten, and Kelley (2021) confirm that effective spreads for off-exchange retail trades are tighter than those for comparable exchange trades. This is consistent with the uninformed nature of retail trading, or also that wholesale market makers serve as efficient cost competitors, as suggested by Battalio (1997). In addition, they argue that, given an average half-spread of $1.76 for typical trade notionals, eliminating a typical commission of $5 per trade provides a substantial benefit. So, they conclude that PFOF is beneficial to retail investors.

[46] EC (2021), "Proposal for a Regulation of the European Parliament and of the Council amending Regulation (EU) No 600/2014 as regards enhancing market data transparency, removing obstacles to the emergence of a consolidated tape, optimising the trading obligations and prohibiting receiving payments for forwarding client orders." At https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021PC0727

[47] Financial Times (July 8, 2022), "EU securities regulator says it lacks the skills to run live databases."

Jain, Mishra, O'Donoghue, and Zhao (2020) report that trading volumes for commission-free brokers increased markedly, which reveals that investors prefer to pay trading costs indirectly.[48] They also report that market quality improves, with lower effective spreads and price impact. However, they do find a small decrease in price improvement, from 17.1 to 15.9 cents per 100 shares around 2019. This change is statistically significant but fairly small, at 1.2 cents per 100 shares.

On the other hand, the Dutch Authority for the Financial Markets (AFM, 2022) has released a study finding that neo-brokers using PFOF offer worse execution prices than other actual transactions in Dutch shares. Because European databases do not have pre-trade quotes, they compare execution prices to the best ones observed on any reference trading venues for the same security at the same second. The opportunity loss for the two PFOF brokers examined ranges from 4.8 to 11.5bp, versus only around 1bp for the other, non-PFOF institutions in the comparison set. Admittedly, these comparisons do not account for other costs such as differential commissions and exchange fees.

A similar analysis has been carried out by the Spanish regulator (CNMV, 2022). This compares execution prices for Spanish stocks from a PFOF broker to those observed in the most liquid trading venues. It reports a price deterioration of 11bp, similar in magnitude to the AFM study. This could be because of lack of competition across trading venues. Indeed, for the AFM study, both PFOF venues have each one market maker acting as the counterparty for nearly all retail orders, versus multiple market makers for the other two venues. So, one could argue that the issue is lack of competition across trading venues, as these brokers each route their trades to a single market maker. This example illustrates the difficulty of generalizing across different market structures.

[48] Bryzgalova et al. (2022) focus on options instead and also report that trading volumes have gone up sharply after the abolition of commissions, with most trades going to a few wholesalers, Citadel, Susquehanna, and Wolverine. The last two differ from the top equity wholesaler group.

Hence, our controlled experiment should help inform the PFOF debate, even though generalizations should account for the fact that our conclusions are predicated on the market structure of U.S. equities.

Appendix C: Public Reporting of Brokers in our Sample

In this appendix, we provide additional information on the public reporting of execution quality by the brokers in our sample. The left panel in Table CI displays the actual price improvement statistics for our trades, taken from Panel A in Table IV. The right panel shows the information in public disclosures, for all broker trades. One broker does not report any quantitative information.

<Insert Table CI about here>

Brokers report most systematically the fraction of trades at or better than the NBBO, or with strict price improvement. This gives no information on the size of the price improvement, however. The next group of statistics describes the effective spread in dollars, or as a fraction of NBBO. Some brokers also describe the dollar price improvement, either by share or for the typical order size. The latter is not comparable to the former.

Finally, coverage varies across brokers as well. Statistics are reported for various ranges of order size, or number of shares. The ranges are 1-99, 1-1,999, and 100-1,999, which are not directly comparable. The last column reports the latest reported period for calculating these statistics, generally quarterly with various lags.

Generally, it would be difficult to infer the actual price improvement numbers in our trading experiment from the public reporting by brokers. There is an attempt at standardization of retail execution quality disclosures by the Financial Information Forum (FIF), but apparently this is not widely used.

Table CI
Comparison of Broker Execution Disclosures with our Analysis

This summarizes execution statistics as reported by the brokers on their web sites. Brokers report the fraction of trades better than NBBO (i.e., %PI, price improvement), and/or "at or better" than NBBO. They can also report the effective spread in dollars, or as a fraction of the quoted spread. Brokers can also report the average price improvement in dollars per share, or per order. The table also shows the range of orders covered by the analysis as well as the latest period for the report, as of July 2022.

	Actual Price Improvement (Our Trades)			**Reported Execution by Broker (All Trades)**						
	% of Trades with PI	% of Spread	Dollar Amount	% with PI (Better)	% at or Better NBBO	Effective Spread, Dollar	Effective/ Quoted Spread	Dollar PI/ Share or *Order	Orders Covered (Shares)	Latest Report Period
TD Ameritrade	99.4%	47.2%	$0.0784	97.4%		N/A	N/A	$0.0180	1-1,999	Apr-Jun 2022
Fidelity	92.9%	35.8%	$0.0654	88.0%	98.2%	$0.0121	N/A	$0.0192	100-1,999	Jan-Mar 2022
E*Trade	96.2%	36.1%	$0.0560	77.8%	94.4%	N/A	56.7%	$7.29*	100-1,999	May-2022
Robinhood	85.0%	26.8%	$0.0444		95.5%	N/A	46.4%	$0.0193	1-99	Jan-Mar 2022
IBKR Lite	63.4%	19.5%	$0.0356	N/A		N/A	N/A	N/A		
IBKR Pro	76.4%	18.8%	$0.0278							