Some Anonymous Options Trades Are More Equal than Others

Christopher Schwarz, Xing Huang, and Philippe Jorion*,†

September 1, 2024

DRAFT: Please do not circulate or cite without permission of the authors

Abstract

We compare retail option trade execution by placing simultaneous market orders across six brokers. Although option trades are executed on exchanges, where they are anonymous and therefore should be treated equally, we find that execution prices vary significantly: the mean broker round-trip trading cost ranges from 0% to 7%, excluding any fees. Wholesalers create differential pricing by not only systematically varying the execution method, but also the pricing *within* execution method. Price improvement and PFOF are highly negatively correlated. However, wholesalers' ability to route to their firms' DMMs does not impact pricing. Our results have market design and disclosure implications.

JEL Classifications: G12, G14, G18, G50

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

---

*Christopher Schwarz (corresponding author, email: cschwarz@uci.edu) and Philippe Jorion are at the Paul Merage School of Business at the University of California at Irvine. Xing Huang is at the Olin Business School, Washington University in St. Louis. We thank Sanath Nair for research assistance. We also greatly appreciate many insightful conversations with industry participants.

†All brokerage accounts referenced were funded directly by the authors with personal money. No outside compensation was received from any broker or wholesaler for this study. This paper required no outside approval.

1. Introduction

Over the last several years, retail trading of U.S. equity options has grown sharply. From 2019 to 2023, total volume of U.S. equity options traded has increased from 4 billion to more than 10 billion contracts. Retail investors have been a significant driving force behind this increase, with the retail share rising from 35% to 42%.[1] The increase in retail trading can be attributed to greater access to option trading with brokers eliminating commissions, allowing option trading on cash accounts, and making option trading more prominent on their platforms.[2]

Similar to equity trades, option trades submitted to retail brokers are typically sent to wholesalers (venues) for execution. These brokers can receive payment for option order flow (PFOF) while retail investors can receive price improvement, with execution prices potentially better than the National Best Bid and Offer (NBBO). However, market structures for trading in equities and options differ significantly. For equities, wholesalers execute over 90% of marketable orders internally (i.e., off-exchange), where they have full control over pricing and know the originating broker. In contrast, due to clearinghouse requirements, option trades must be executed on exchanges where incoming trades are kept anonymous.[3] Unlike off-exchange where wholesalers can price discriminate across customers, public exchanges are required to treat identical orders equally.

[1]Sources: World Federation of Exchanges and NYSE (2023) for the fraction of retail option trading. Equity options include stocks and ETFs.

[2]All brokers largely eliminated fixed commissions per trade on options by 2019 (they may still charge fees per contract, e.g., reflecting exchange and regulatory costs.) Robinhood began allowing cash accounts to trade options starting in 2022. Robinhood also opened their "Option Trading Essentials" hub in 2021 to ".. provide education on the ins and outs of options trading."

[3]Retail orders sent to exchanges are simply labeled "Customer." Note that hedge fund and other institutional orders are also labeled "Customer," which means that market participants do not know whether an order is retail or not.

The potential advantage of the options market structure in fostering competition has been highlighted by policymakers. The Chair of the Securities and Exchange Commission (SEC), Gary Gensler, has praised the auction structure of options exchanges for opening individual orders to competition.[4] As a result, in 2022, the SEC proposed fundamental changes in the U.S. equity market structure that would convert it to an auction format, in order to "provide the best prices for retail investors."[5]

The academic literature, however, takes a different view. Bryzgalova et al. (2023), Ernst and Spatt (2022), and Hendershott et al. (2024) first note that retail brokers generate a majority of their total PFOF from option trades. These authors also argue that wholesalers that pay PFOF to brokers may provide worse execution by internalizing most option trades through routing them to exchanges where the wholesaler's firm operates as a Designated Market Maker (DMM, or specialist). Examining this hypothesis is challenging due to the limitations of the standard option database (OPRA),[6] which lacks information about the identity of the client, originating broker, and wholesaler. In addition, the hypothesis assumes that the associated DMM can tailor pricing to each client (e.g., adjusting for PFOF from its wholesaler), which contradicts the anonymity of trades inherent on exchanges.

To evaluate these two competing viewpoints and provide direct evidence of pricing practices for options, our research conducts a controlled experiment where we place market option orders at six different leading retail brokers. The brokers in our sample use some or all of the same five wholesalers, but the amount of PFOF that they receive varies significantly:

[4]See https://www.sec.gov/news/speech/gensler-remarks-piper-sandler-global-exchange-conference-060822

[5]SEC (2022), "Order Competition Rule."

[6]The The OPRA database collects and disseminates quote and trade information for U.S. options, much like TAQ for equity trades.

two brokers receive no PFOF,[7] while four other brokers all receive PFOF at various levels.

Our experiment generated approximately 7,000 trades from mid-March 2024 to the end of June 2024. We selected 18 symbols for trading, which represent approximately 45% of market volume; importantly, we also chose symbols where not all wholesalers could route a trade to an associated DMM. We placed intraday orders at our brokers that were identical in type (market orders), contract (symbol, strike, expiration), size (number of contracts), direction (buy or sell), and submission time.[8] We then compared execution prices across brokers and venues. Since we placed the trades ourselves, we know whether each trade is a purchase or sale, which is crucial to measure price improvement. In contrast, empirical studies based on the OPRA database must approximate the trade direction.[9]

Even though trades on exchanges are anonymous and therefore should be treated equally,[10] we find that price execution varies widely across brokers, which is illustrated in Figure 1. Across our six brokerage accounts, the average price improvement (PI) varied from 26 cents to 207 cents per contract, which corresponds to a range of between 7% and 52% of the NBBO. In percent of dollar value, the average round trip cost varied from close to zero to around 700 basis points (bps).

<Insert Figure 1 about here>

[7]However, one of these brokers is rebated a portion of the fees generated from client trades, e.g., from limit orders.

[8]Our experiment was also designed so that our results are not driven by any latency differences in our trades (i.e., systematic differences in execution times). This was ensured by randomizing submission orders across brokers.

[9]Indeed, approximately 22% of our trades are incorrectly signed using the Lee and Ready (1991) method, which assigns buy (sell) signals from trades executed above (below) the midpoint. So, this method systematically understates price improvement, e.g., because it erroneously assigns buy trades executed below the midpoint as sell orders.

[10]More specifically, exchanges are not allowed to discriminate across customers, unlike off-exchange markets. Under Section 6 of the National Securities Act, "The rules of the exchange are [...] not designed to permit unfair discrimination between customers, issuers, brokers, or dealers." See for instance https://www.nyse.com/publicdocs/nyse/regulation/nyse/sea34.pdf

The dispersion is not only statistically significant but also economically important. The variation in option pricing across brokers even exceeds the substantial variation in equity trades documented by Schwarz et al. (2024). While the difference in price improvement between the best and worst broker for equity trades is 28% of NBBO, the option difference is 44%. Broker fixed effects alone account for 16% of the variation in price improvement, which is 16 times as much of the variation as that explained by all other pre-trade order characteristics combined (1%), including spread, volume, symbol, and order imbalance.

Our findings indicate that the primary source of differential pricing is the wholesaler, who routes the retail trade to the exchange, rather than the DMM. The wholesaler can achieve differential pricing in two ways. First, the wholesaler selects the trading mechanism, choosing between "auto-execution" and Price Improvement Mechanism (PIM) auction.[11] Auto-execution trades are typically executed by the DMM at NBBO, with minimal price improvement on average. This is because the DMM has special priority as a market maker. In contrast, PIM auctions are the primary mechanism by which retail trades receive price improvement. Second, when a PIM auction is selected, the wholesaler sets the initial price improvement, which is an important determinant of the final execution price. Since wholesalers know the identity of the originating broker, they can systemically vary both the frequency of PIM auctions used as well as the initial price improvement in auctions across clients, resulting in different execution prices.

Our results show that both the choice of trading mechanism and the price improvements achieved in PIM auctions significantly contribute to the execution differences across brokers.

[11]More specifically, "auto-execution" broadly describes electronic trades sent to one exchange. We also include in this category "Intermarket Sweep Orders" (ISO) orders, electronic orders sent across market centers, which account for a small fraction of our trades.

The broker with higher overall price improvements has a larger proportion of trades executed through PIM auctions and receives greater price improvements within those auctions. Specifically, the best broker in our sample has 76% of trades executed via PIM auctions, yielding an average price improvement of 64% of NBBO in those auctions. In contrast, the worst broker in our sample only has 25% of orders executed in PIM auctions, with an average price improvement of 21% of NBBO in auctions. Together, these two factors account for the majority of the variation in overall price improvements across brokers, with 41% attributed to the selection of trading mechanism and 51% to the price improvements within auctions.[12]

A major economic driver of the differential pricing across brokers appears to be PFOF. Unlike what has been documented for equity trades (e.g., Schwarz et al. (2024)), price improvement for option trades appears strongly negatively correlated with PFOF, with a correlation of -0.91. Our best broker receives no PFOF while the second best receives no PFOF but some rebated fees. In contrast, the remaining brokers in our sample receive PFOF, which are associated with lower price improvement amounts. This negative correlation is evident across the selection of trading mechanisms as well as the price improvements achieved within both auctions and auto-execution orders.

Next, we examine the links between the routing venue, the execution exchange, and the venue-associated DMM. Using SEC Rule 606(b)(1), we obtained the identity of the venues that received each of our trades. Exchange information was obtained by matching our trades with the OPRA transaction database. Finally, we compiled the list of DMM assignments for the 11 exchanges with a dedicated DMM per symbol. We therefore know the wholesaler

[12] The remaining 8% is explained by price improvements in auto-execution trades. Interestingly, we also observe better execution in auto-execution trades for brokers with superior overall execution, as discussed later.

that received the trade, the exchange they routed the order to, including the order type, whether that exchange's DMM is affiliated with that wholesaler, as well as the PFOF to the originating broker.

A natural question is whether wholesalers systematically route more orders to exchanges where they have an affiliated DMM that might influence pricing. Our findings show that when wholesalers have this choice, they route only 24% of their trades to exchanges with an affiliated DMM, which is only slightly higher than the probability of random routing (19%).[13] However, we do find that routing to an exchange with an affiliated DMM is more likely within auto-execution trades. Specifically, wholesalers are 69% more likely to route to an exchange with an affiliated DMM than would occur with random routing. One possible reason is that, in auto-execution trades, the DMM can capture the spread, which can be strategically leveraged to consolidate profits within the organization. In contrast, for auction trades, where the DMM special status is not involved, wholesalers do not show a preference for exchanges with their firms' DMMs. Additionally, although wholesalers tend to route more auto-execution trades to exchanges with affliated DMMs, we find no evidence that these connections lead to worse execution.

This paper makes several contributions to the literature. We conduct a uniquely large and long-running experiment trading options simultaneously across multiple brokers to evaluate the execution of market orders. We document economically significant differences in price execution across brokers. We show that these differences are primarily driven by wholesalers varying the percentage of PIM auctions they use as well as influencing the pricing in

[13]More specifically, this percentage reflects the likelihood of *routing* to exchanges with an affiliated DMM, but does not necessarily mean the trade is *executed* by that DMM, as other market makers may execute the trade under various circumstances.

auctions. The remaining portion in the differences is explained by price execution within auto-execution trades. In addition, we find that, unlike equity trades, the variation in option price execution is strongly and negatively correlated with PFOF. Finally, we find that, while wholesalers show a preference to routing more orders to exchanges with affiliated DMMs within auto-execution trades, these wholesaler-DMM connections do not result in worse pricing.

Our paper extends the literature on differential pricing in financial markets. Schwarz et al. (2024) find no evidence that equity execution quality is related to PFOF, unlike the strong relation that we find for options. They document that execution differences are likely driven by variations in order flow toxicity across brokers. Indeed, Eaton et al. (2022) use broker outages to show evidence of differential toxicity across brokers. Both Schwarz et al. (2024) and Ernst and Spatt (2022) note that PFOF for equity trades is relatively low, relative to spreads. Thus, in the equity market, toxicity likely dominates PFOF in terms of economic drivers for differential price execution. In contrast, Eaton et al. (2024) show that option trades' toxicity across brokers is more homogeneous while, as noted earlier, option PFOF is large. Thus, in the options market, pricing is more affected by PFOF than toxicity. This is also consistent with the observation that trades on option exchanges are anonymous.

We also add to the literature on the execution of trades. We show that option trades can receive considerable price improvement, and that our execution is not related to order imbalance (e.g., Muravyev (2016), Muravyev and Pearson (2020)). Battalio et al. (2001) create a model to show that verifiable characteristics of orders can lead to differential pricing. Schwarz et al. (2024) and Levy (2022) document differential pricing in equities as venues know the client information (rather, the originating broker). Here, the exchange trades do not carry client information. Still, the venue has tools to create differential pricing. The starting price of auctions may also be used by other market makers as verifiable information. If so, this would explain why, on average, auction trades do not receive similar execution across all brokers. In addition, consistent with Battalio et al. (2016), our market orders get better pricing on DMM exchanges with marketing fees than the traditional maker-taker exchanges.

Our paper is also related to three other papers that discuss retail option trading. Bryzgalova et al. (2023) provide a method to identify retail option trades. They identify retail trades as those executed in the single leg PIM auctions, noting that this method suffers from both Type I (i.e non-retail identified) and II errors (i.e. retail not identified). Our trades suggest that the Type II error in this identification method is approximately 50%. They also argue that auctions are a method of internalization for wholesalers because of limited competition. While we do find limited competition, it is likely driven by other reasons.[14]

Ernst and Spatt (2022) and Hendershott et al. (2024) use variation in DMM assignments to examine the execution of DMMs whose firms pay PFOF compared to those that do not, for the same symbol. Our experiment, however, has the advantage of the full detail of execution choices and associated price improvement for our actual trades, which we can then tie to actual PFOF. We find that venues route a majority of their trades to exchanges without venue-affiliated DMMs; indeed only 20% of our trades have the venue-DMM firm

[14]Their main argument is based on the $0.50 per contract breakup fee other market makers incur to respond to the auction, which puts the wholesaler at an advantage. This, however, ignores the PFOF and other associated fees the wholesaler also faces, which diminishes the economic advantage provided by the breakup fee. Additionally, if the breakup fee were the only friction, we would expect the differences in auction price improvement across brokers to fall within the fee. However, we find differences that are much larger. As we discuss later, other frictions, such as information asymmetry, likely also contribute to these price differences.

connection. We also find no execution difference between PFOF and non-PFOF DMMs.

Our results have several policy implications. Option execution is very opaque, and complex, as we have seen. Unlike equities, there is no regulatory requirement for option execution disclosure (e.g., Form 605, which is required for equity trades). For brokers, the only comments related to option execution are in their Form 606 disclosures, usually stating that they do not negotiate PFOF in exchange for execution or that they do not expect PFOF to impact execution. Our findings suggest that an option equivalent of the newly finalized 605 rule is needed, both for wholesalers and brokers.[15]

Finally, the SEC has proposed using auctions in equity markets.[16] The SEC believes that using auctions will increase competition for these trades. However, that rule contains several features that are likely to result in similar results to our option trades. Venues have the choice whether to send a trade to auction or not. If they do use an auction, the venue sets the starting price. Thus, venues can use those same levers to create differential pricing. Additionally, our differential pricing within auctions suggests that either participation in auctions is low or the starting price is used as an information signal.[17] Under either scenario, it is unclear how much these types of auctions would increase competition.

Importantly, we only examined one specific aspect of brokerage trading. Our experiment was based solely on placing one contract market orders for call options during the day.[18]

[15] SEC (2024), "Disclosure of Order Execution Information," https://www.sec.gov/files/rules/final/2024/34-99679.pdf

[16] Ernst et al. (2024) use a model to show that these auctions may suffer from the winner's curse problem, as well as to failed auctions due to the inability to cross-subsidize.

[17] This is because any trade can be sent to an exchange as a PIM auction, even trades made by hedge funds and other potentially informed institutional investors. Thus, the starting prices on auctions may be viewed as revealing the informativeness of the trade. If so, that would explain why low starting price auctions do not generate strong counter-bids.

[18] We placed a limited number of trades for put options as well as six contract trades since these trades can be split and not fully internalized. We find similar pricing across brokers in both cases.

We do not evaluate other types of orders. 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, 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. So, variation in price execution is only one part of the mosaic of information available to evaluate brokerages.

The remainder of the paper is organized as follows. Section 2 provides institutional detail about brokers and option market structures. Section 3 then discusses the setup for our trading experiment. Section 4 presents our results, comparing price execution quality across brokers, which are found to vary widely. Section 5 delves into the source for this variation, which we trace to how wholesalers route to exchanges and altering pricing within execution type, instead of their routing. We discuss the impact of venues being able to route to their own DMMs in Section 6. Section 7 then discusses the implications of our results. The final section concludes and provides policy prescriptions.

2. Institutional Details

In this section, we discuss details about the brokers in our experiment, the market structure for single-name and ETF option trading, and potential economic drivers of execution prices for retail clients.

2.1. Broker Details

The market structure for retail option trading carries both similarities to and differences from retail equity trading. Like equities, almost all retail brokers route their customers' option trades to "venues," i.e., specialized brokers that direct trades for execution. The five main venues for option trading are Citadel, Susquehanna/G1X, Wolverine, Morgan Stanley, and Dash/IMC; only the first two are also major venues for equity trades. As with equity trades, most retail brokers receive payment for option order flow (PFOF) from the venues. Routing percentages and payment amounts are reported in SEC Form 606. PFOF amounts can implicitly include, for example, fees from exchanges that are rebated back for trades.[19] Table 1 describes information on brokers, including estimated options and equity volumes, as well as PFOF, in total amounts and per share or contract.

<Insert Table 1 about here>

As shown in Panel A, all major retail brokers abolished commissions, which are fixed costs per order, for option trading by late 2019. Still, most brokers continue to charge fees of approximately $0.65 per contract. (Robinhood is an exception to this, with no commissions and no fees on option trades.) Presumably this fee is to cover some of the regulatory, reporting, and exchange fees, even though the amount charged is generally greater than this total.[20] In this study, we do not account for the impact of such fees on trading costs, even

[19]For example, Fidelity notes that it receives no PFOF for option trading, but its Form 606 indicates net payments received for its options trades, e.g., marketing fees, rebate fees, and maker fees from exchanges, that are passed along by the venues.

[20]For example, for some index option trades, such as SPX(W) and NDX(P), brokers receive no PFOF. Instead, brokers must pay the venues for the fees they incur on these trades, which can be up to $0.55 per contract. For example, in its Q1 2024 Form 606, E*TRADE states that it: "... paid total fees on customer index options executions of $349,852 in January, $359,602 in February, and $449,754 in March." Because it does not charge any fees, Robinhood does not allow customers to place single index options trades.

though this is certainly an important factor for choosing a retail broker.[21] The table also shows that the volume of options trading is very large, which we estimate at four billion contracts traded on an annualized basis. As noted in previous research and confirmed in Panel B, retail brokers obtain a majority of their PFOF from options trades. This is due to the fact that option trades, even after controlling for contract size, have higher PFOF than equities, as shown in Panel C.

The actual formulae for PFOF per contract are described in the footnotes in Forms 606, and vary from simple to complex.[22] These are summarized in the last column of Panel C for 2023. In the more complex cases, average payments for venues will depend on the trade mix. We computed a volume-weighted average of reported PFOF, reported in the neighboring column. There is a wide dispersion in PFOF, ranging from zero to 50 cents per contract for market orders, which will prove useful for our empirical analysis. Note that, in these footnotes, some brokers explicitly downplay a connection between PFOF and price improvement.[23]

[21]Unlike equities whose trading costs are only due to the bid-ask spread, these fees are per contract and can be a substantial fraction of trading costs. For example, for a one-cent spread round-trip trade, the typical broker fees would add up to $1.30 whereas the maximum bid-ask cost would be $1.00. In this case, it would be better to execute at Robinhood regardless of its price improvement relative to other brokers. More generally, there is a trade-off between the fixed broker fee and the price improvement.

[22]For example, E*Trade says that it receives a flat rate of $0.43 per contract. In 2024, Robinhood states that, for orders up to 100 contracts, it receives a rate varying from $0.30 to $1.20 depending on the symbol's average spread. The descriptions for Schwab and TD Ameritrade are not very informative either, simply stating a maximum per contract.

[23]For instance, in a footnote to its Q1 2024 Form 606 disclosure, Robinhood states that "Non-exchange third party market centers compete for orders based on execution quality. The SEC Examination Staff has observed that there is a potential tradeoff between (i) payments received by brokers and (ii) price improvement and/or execution quality. RHS believes that the receipt of payment in the form of a portion of the spread earned by non-exchange third party market centers does not interfere with RHS' pursuit of best execution or the price improvement obtained on customer orders." Likewise, in its contemporaneous disclosure, E*Trades states that "the risk of overallocation to market maker profits at the expense of providing price improvement [...] is mitigated by competition [...] amongst MSSB's market makers."

2.2. *Market Structure and Price Execution Economics*

Unlike equity trades, option orders received by a venue must be executed on an exchange due to clearing considerations. An additional different from equity trades is that any price improvement must be in full cents as there is no subpenny pricing for option trades. Thus, if it occurs, price improvement is least one dollar per contract.

There are currently 17 options exchanges in the U.S. Wholesalers will have associated market makers (MM) that provide liquidity at many of these exchanges and post margins for open positions at the clearinghouse. Out of these 17 exchanges, 11 have a Designated Market Marker (DMM) or equivalent assigned to each symbol. DMM assignments vary both across assets and across exchanges. DMMs (formerly called specialists) have special privileges, including the ability to "internalize" any trade for five contracts or less without splitting it with other market makers.[24] However, DMMs also have additional obligations, such as being held to a higher mandatory percentage of quoting time. Importantly, all the large option venues have associated DMMs.[25] Therefore, in many cases, venues could route trades to associated DMMs. For the six remaining exchanges, five have no DMMs; the sixth, the Boston Exchange (BOX), has DMMs but not a dedicated one per symbol.

For single leg trades, the venue picks one of two execution methods. The first is electronic "auto-execution," in which case the trade will most likely receive no price improvement, i.e., will simply be executed at the NBBO.[26] The second is execution via a "Price Improvement

[24]For example, when the order is not directed to another participant when quoting at the NBBO on the local exchange, all orders of five contracts or less in that option class are allocated to the DMM. Even so, there are circumstances where the DMM cannot internalize a trade. For example, on a time-priority exchange, they may be behind a Priority Customer or another market maker. Also, DMMs are generally only allowed to handle at maximum 40% of total flow each day.

[25]Approximately 90% of all DMM assignments are to firms that also are venues for brokers.

[26]We include intermarket sweep orders in this category. Trades could also be executed against a multi-leg

Mechanism" (PIM) auction. Bryzgalova et al. (2023) identify retail trades using principally PIM auctions, using OPRA flags introduced recently.

If the venue decides to route the trade as a PIM auction, it engages its affiliated market maker, which must route the trade as a "paired" trade, i.e., with both the trade received from the retail broker and the opposite side ("contra"). For example, if the original customer trade involves buying a call option, it must be paired with the writing of the same option. The paired structure is necessary as PIM auctions have guaranteed execution. Therefore, the market maker needs to ensure that the trade will clear if it wins the auction, thus "internalizing" the order. Note that the DMM function is not relevant for PIM auctions; thus, there is no economic reason for a venue to favor its associated DMM, if there is one.

The venue also needs to set the "starting price" for the auction, i.e., lowest amount of price improvement it will provide. This starting PI can be zero when the spread is more than one cent.[27] The auction exposes the trade to competition as other market participants can bid on the auction and provide greater price improvement than the venue initially proposes. Such responders, however, would have to pay a fee of $0.50 per contract to the exchange to break up the two trades.[28]

Generally, the venue would prefer to route orders as auto-execution trades over PIM auctions. First, marketing fees from an auto-execution trade ($0.25 per contract plus any applicable tier-based rebates on traditional exchanges) are larger than the rebate fees for a

order; we had very few of these, however.

[27]For trades with one-cent spreads, the starting price needs to be on the near touch, i.e., at the bid for a buy and at the ask for a sell. This rule is in place because of the breakup fee in a PIM auction. At $0.50 per contract, anyone else interacting with the auction trade would essential lose all of their spread capture by just paying the fee.

[28]These responder fees are high because exchanges compete for order flows and incentivize wholesalers to bring orders to them.

PIM auction ($0.14 per contract maximum). Second, auto-execution trades give the venue the opportunity to capture the entire spread rather than likely less than the full spread for a PIM auction. If the venue has an associated DMM at an exchange, it could route the trade to that exchange to give its associated DMM the opportunity to capture the spread.

Importantly, in either execution method, the market maker has almost no control over pricing. It does not choose the execution method. For auto-execution orders, the DMM will execute at NBBO, which is set across all exchanges. For PIM auctions, the starting price is set by the venue and anyone can interact with the order, not just the market maker.

Finally, trades are anonymous when sent to an exchange. Retail trades are simply labeled as "Customer." Other trades, such as from hedge funds, could also be labeled as "Customer," thus, this label is not unique to retail trades. Only the venue knows the originating broker and therefore can treat trades differently across brokers. Although they would prefer to maximize profits by not using PIM auctions, they likely have E/Q targets for each broker since they compete with other venues for order flow. To meet these targets, they can vary the percentage of trades using PIM auctions as well as starting prices across brokers. Since venues have various ways to significantly influence price execution, their knowledge of the originating broker could lead to large differences in pricing across brokers. This is what we explore next.

3. Trading Experiment

The Options Price Reporting Authority (OPRA) is a securities information processor that collects and disseminates quote and trade information for options on U.S. exchange-traded securities. For each trade, OPRA reports transaction prices, the NBBO quote at the time of execution, the exchange, execution method, the "Greeks," and so forth. However, OPRA does not have any identifying information as to the customer, broker, venue, and trade direction, as is the case with TAQ for equity trades. This makes it very difficult, if not impossible, to pursue a direct analysis of potential determinants of prices, such as broker pricing effects, the impact of PFOF, and whether connections between venues and DMMs affect pricing.

To overcome these limitations, we place simultaneous identical trades (i.e., trades in the same contract for the same symbol 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 enter the order as well as the trade execution time provided by the broker. We use this latter time to match our trades to the OPRA database. Next, we describe our trading sample.

3.1. Symbol and Contract Selection

Because executing option trades is extremely costly, we could not trade the entire universe of symbols, which includes close to 6,000 symbols across all DMM exchanges as of January 2024. Instead, we created a representative sample by selecting some of the most popular symbols, both in terms of volumes and retail trading. In addition, to examine the effect of venue-DMM linkages, we selected a group of stocks such that venues are not always able to route trades to their affiliated DMM. We report our symbol list in Table 2.

<Insert Table 2 about here>

Specifically, we select one set of symbols where every venue has a firm-related DMM that it can route the trade to. This includes TSLA, AAPL, and QQQ.[29] We then systematically select symbols where some venues do not have a firm DMM on any exchange. For example, for RSP,[30] Citadel and Dash/IMC do not have a firm DMM at any exchange whereas the other three venues do. Thus, these two venues are unable to route to a firm DMM. We select symbols such that we have a few symbols for each venue without an associated DMM at any exchange. This will allow us to examine the impact of the venue-DMM firm connection on trade routing and execution quality. In total, we select 18 symbols that represent close to 45% of all trades and volume for single name equity and ETF listings.[31]

3.2. Option Trading

We trade options at six different brokerages, namely E*Trade, Fidelity, Robinhood, Schwab, TD Ameritrade, and Vanguard.[32] This sample covers all of the top market share retail brokers. As shown in Table 1, they all stopped charging fixed commissions per order, following Robinhood in 2017. Otherwise, our brokerage accounts can be split into four groups, sorted into varying levels of PFOFs and per contract fees:

- TD Ameritrade, E*Trade, and Schwab receive PFOF and charge a maximum fee of $0.65 per contract.
- Robinhood receives PFOF and does not charge any fee.
- Fidelity states that it does not receive any PFOF; however, since its Form 606 reveals

[29] QQQ is an exchange-traded fund that tracks the NASDAQ 100 Index.
[30] RSP is an exchange-traded fund that tracks the S&P 500 Equally-Weighted Index.
[31] Note that outside RSP, all of our symbols are part of the Penny Pilot (PP) program, which allowed options to be quoted with minimum price variations of $0.01 and $0.05 for premiums below and above $3, respectively.
[32] Our TD Ameritrade account was converted into a Schwab account on May 10, 2024 and thus was traded only until then.

some PFOF payments, it must receive fees generated from trades. It charges a $0.65 per contract fee.

- Vanguard receives no PFOF and no fee rebates, as shown in its 606 Form. It charges a $1.00 per contract fee.

Whenever possible, we use the Application Programming Interface (API) to automatically trade options. 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 approximately 300 per day. Unfortunately, some prominent brokers, including Schwab until recently, and Fidelity, do not offer general access to their API. We use alternative programming methods to execute these trades in an automated fashion. Thus, for all practical purposes, trades at these brokers were placed similarly to our API trades.[33]

Our program trades throughout the day, spacing trades out evenly. We placed one group of option purchases every 10 minutes. We randomized the ordering of symbols across trades to avoid any time-of-day effect (in addition to randomizing broker order). After purchase, we closed the position within five minutes to minimize directional exposure due to the high delta of options.

We use the results in Bryzgalova et al. (2023) to select contract types for our trades. They report that retail option trading is concentrated in call options that are at the money with less than a week to expiration; close to half of these trades are for one contract. Thus, our trades are for single contracts that meet these characteristics.[34] On Fridays, rather than

[33]These automation efforts were somewhat less reliable than the API method, however. Thus, our number of trades at these brokers was lower than for the API brokers. Even so, the missing trades from these brokers are random as the list was randomized each day. In additional analyses, we perform broker-pairwise comparisons using only overlapping trades, which show similar results to our uneven panel broker averages.

[34]For all trades in OPRA during our sample period, we find that 50.6% of trades are for one contract,

trade zero-day options, we roll our expiration date to the next Friday; thus, our expiration periods vary from one day to one week. Each day at approximately 10:15AM EST, we examine at-the-money contracts and select those with high volume and high open interest. Based on the consistency of our results across time, we do not believe that the exact contract specification has a significant impact on our findings.

To control the order submission times, our trading program is run as a single thread sequentially placing trades across all of our brokers. Even so, it cannot place orders at the same millisecond. To control for this issue, the program randomizes the order of the brokers on both the buy and sell trades to ensure that no broker has a systematic time advantage. We began option trading on March 12, 2024 for E*TRADE, Fidelity, Robinhood, and TD Ameritrade. By early April, Schwab and Vanguard were added to our sample. In total, we made 6,926 trades that cover a three-and-a-half-month period, or 52 trading days (we did not trade every single day).

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

We now begin our examination of price execution across brokers. Formally, "Price Improvement" is measured against the NBBO. It occurs when the executed price is strictly below (above) the ask (bid) for buys (sells). When this is the case, we assign a variable of one to this trade, or zero otherwise. The average of this variable across trades reflects the fraction of trades with price improvement. This measure is not very informative, however, because it does not quantify the size of the improvement.

56.4% of trades had expiration dates of one week or less, 59.0% of trades are for call options, and 80.9% of trades have strike prices within 10% of the underlying price at the time of the trade. Also, 79.7% of trades are under the six-contract threshold and thus can be fully internalized. As a robustness check, we also place trades for puts and for six contract orders and find results consistent with our main sample.

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 (Eq. 1) or relative to the NBBO spread (Eq. 2):

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

$$\text{PI\%} = \frac{\text{PI\$}}{\text{NBBO Spread}} \tag{2}$$

Another way to calculate price execution is through the *effective spread*, which is twice the difference from the midpoint, either in dollars (Eq. 3), or relative to the NBBO (Eq. 4), which is also called E/Q:

$$\text{ES\$}_{\text{buy}} = 2 \times (P - P_{\text{mid}}) \qquad\qquad \text{ES\$}_{\text{sell}} = 2 \times (P_{\text{mid}} - P) \tag{3}$$

$$\text{E/Q} = \frac{\text{ES\$}}{\text{NBBO Spread}} \tag{4}$$

None of these measures scale by the initial investment. This is why we also report the *round-trip trade cost*, which is the difference between the sell and buy prices, scaled by the latter, adjusting for the relative move in the contemporaneous mid-price, or (Eq. 5):

$$\text{Round-trip Cost} = \frac{(P_{\text{sell}} - P_{\text{buy}})}{P_{\text{buy}}} - \frac{(P^S_{\text{mid}} - P^B_{\text{mid}})}{P^B_{\text{mid}}} \tag{5}$$

This is averaged over each buy/sell pair, so is comparable to an effective spread measured relative to the midpoint instead of NBBO, with the sign switched.

It should be noted that all these measures rely on knowing the actual trade direction.

Trade direction is not included in OPRA, however, so empirical research typically infers trade direction from the effective spread, labeling trades closer to the ask (bid) as buys (sells), which is known as the *Lee-Ready* algorithm (Lee and Ready (1991)). This technique, unfortunately, systematically understates the extent of price improvement because it assigns the incorrect sign to trades with PI% > 50%. In our sample, that technique would misidentify 22% of our trades.

Next, Table 3 provides statistics on our price improvement for all of our trades, sorted by price improvement. These include the fraction with PI improvement, the size of improvement, and the round-trip trade cost as a fraction of dollar value. For reference, we also show statistics on hypothetical midpoint execution, which implies zero bid-ask spread transactions cost, and on NBBO execution, which is the worst possible.

The last column also reports the PFOF for our six brokers using data from their Form 606 covering our experiment period. We note, however, that the number for Robinhood is only an estimate, as we do not have the exact formula that assigns different payments to various spread buckets. The number shown uses the unit PFOF reported in the forms, but our trading sample may not match actual trading flows for Robinhood over that period. Finally, we report the correlation of PI measures with PFOF across brokers in the last row.

<Insert Table 3 about here>

In terms of frequency, 45% of our overall trades receive some amount of price improvement. The average PI is 27% relative to the NBBO spread, which is about halfway between NBBO and midpoint execution, or is equivalent to an E/Q of 0.50. Since option contracts are for 100 shares, the dollar spread is large, which results in a large amount of dollar PI, i.e., 108 cents on average. Finally, relative to the premium paid, our trades have an average round-trip trading cost of 392 basis points (bps).

The first observation is that execution costs for options are high, especially relative to equity trading. Round-trip trade costs average 3.9% of principal value, against around 0.2% for equities (Schwarz et al. (2024)). Bryzgalova et al. (2023) make the same point.[35] It should be emphasized, however, that their cost estimates of 6.6% for call options that go through auctions are likely too high, reflecting the underestimation of PI from the Lee-Ready method. However, our calculation includes both auction and auto-execution trades, which receive lower amounts of price improvement.[36]

The second observation is that, even though trades are executed on exchanges where the client is unknown, these overall values hide wide variations across brokers. Our best broker has an average PI of 52% (E/Q of −0.04) while our worst broker has an average PI of just 7% (E/Q of 0.86), resulting a maximum deviation of 45% (E/Q of 0.90). This translates into differences between the best and worst brokers in our sample that reach 181 cents per contract for the average PI and almost 700 bps for round-trip trading costs.[37]

To provide a more complete picture of the differences in execution across brokers, we plot the cumulative frequency distribution of price improvement in percent of NBBO in Figure 2. For better intuition, we have inverted the horizontal axis and start on the left with 100%

[35] It should be noted, though, that these two markets are not directly comparable. Options are highly levered instruments. For instance, a 7-day option on an asset with price of \$100 and implied volatility of 50% should cost about \$3 only. With a delta of 0.5, this controls \$50 worth of stock, which is equivalent to leverage close to 20 times.

[36] Our auction trades have round-trip trading costs of 0.2%. Using Lee-Ready, those costs are 3.8%. Thus, the Lee-Ready method would overestimate our trading costs on auctions by 3.6%, which is a major difference. Auto-execution trading costs are much higher at close to 9%.

[37] As indicated previously, however, this ignores per typical contract fees of \$0.65, which add up to 130 bps round-trip relative to the average premium of \$1.

price improvement, which is least likely. The higher the curve, the better the price execution across brokers.

<Insert Figure 2 about here >

Furthermore, the dispersion we observe in PI is highly correlated with PFOF levels, with coefficients averaging −0.90. In fact, as shown in Figure 3, which plots PI against PFOF, the relation between these two variables is almost perfect. Only Schwab is slightly out of order.[38] So, it seems that PFOF directly affects execution pricing for options, even for anonymous trades on exchanges. The slope is strikingly different from the equivalent graph in Schwarz et al. (2024), which shows no relationship between PI and PFOF for retail equity trades.

<Insert Figure 3 about here>

At the top end, Vanguard has price improvement above 50%, which seems abnormally high, even better than the mid-point. This is probably because wholesalers can take advantage of fee rebates. In contrast, Fidelity recaptures at least some of these rebates, which explains the lower PI of 41%. As the size of the PFOF increases, PI decreases monotonically. At the other end, PI for Robinhood is 7% only. The rate of decrease is about 2.5 times the increase in PFOF. Even so, we should note that Vanguard has the highest contract fee of this group, and that Robinhood has zero fees.

As mentioned earlier, our panel of trades is not perfectly balanced. For example, our TD Ameritrade account was closed on May 10, 2024. Trades at the non-API brokers were

[38] However, we have told been by industry professionals that the schedule used to compute Schwab's PFOF is the same as for TD's, in order to avoid regulatory scrutiny since both brokers are now owned by Schwab. In other words, other factors may affect the PI-PFOF relation for Schwab. Removing Schwab leads to a near-perfect PI-PFOF correlation of -0.99.

slightly less reliable than others. Although a majority of our trades overlap, to ensure that the differences in Table 3 are not due to the unbalanced panel, we report pairwise differences for each of our brokers in Table 4. Positive values mean that "Broker A," shown in the rows, has higher price improvement than "Broker B." Most t-statistics, where standard errors are clustered by symbol, are highly significant. In summary, these results are consistent with those using the uneven panel.

<Insert Table 4 about here>

Given the dispersion in execution across our brokers, we examine how much the variation in price improvement can be explained by the clientele effect versus other factors. To do so, we run regressions where the dependent variable is the price improvement on each trade. In the first model, we simply regress price improvement against broker fixed effects, where the intercept represents Vanguard. The second model includes a wide range of order characteristics without broker fixed effects. The independent variables include the trade sequence order, whether the order was a buy or sell, the order imbalance during the same minute, the log of the volume for all contracts for that symbol, dummy variables representing various spreads, the trade price, days to expiration, and the option's implied volatility and delta. We also include symbol fixed effects. Finally, in the third model, we include all the independent variables from the first and second model. In each case, we compute t-statistics with standard errors clustered by symbol. Results are reported in Table 5.

<Insert Table 5 about here>

In terms of the ability to explain price improvement, the broker effect is extremely large. In model one, the broker effect explains 16.5% of the PI variation across trades. In the second model without broker dummies, we see that the raft of other trade factors only explains 0.9% of the variation. Spreads are the most significant variables, where values greater than one cent yield lower price improvement.[39] In the third model, the addition of all these variables only increases the adjusted R-squared by 0.6% relative to model one. In other words, broker fixed effects explain 16 times more variation in PI than all other variables combined.

Although all of our brokers largely use the same five venues, our execution differences could be driven by how the brokers route trades to venues. For example, E*Trade does not send orders to Morgan Stanley, its owner. Brokers could use some venues more than others. To determine whether our price differences are due to systematic price discrimination by venues, we used the venue routing information that we requested and received from each of our six brokers. In Table 6, we report the percentage of orders sent to each venue for each broker as well as the average across brokers.

<Insert Table 6 about here>

We see that Citadel is the dominant wholesaler, with an average of 42% of trades. The next one, Global Execution Brokers (G1X/Sus), averages a 21% share. However, there is some variation across brokers. On one end, Vanguard uses only three wholesalers; on the other end, Robinhood has a more balanced flow across the five wholesalers.

We next compare the execution of our parallel trades across two brokers, which we split into two groups. The first group is comprised of orders where the same parallel trade was sent to the same venue ("Same"), as opposed to the second group where this was sent to different venues ("Different"). We then compare price executions across two brokers for these

[39] Because there is no subpenny pricing, one-cent spread trades either have no price improvement or 100% of NBBO.

groups. Results are shown in Table 7.

<Insert Table 7 about here>

The table provides strong evidence that indeed different brokers receive systematically different executions at the same venue for exactly the same trade. For example, PI for Vanguard and Fidelity differs by $55.3\% - 42.3\% = 13.0\%$ when both trades go to the same venue and by 11.2% when executed at different venues. For each one of our broker pairs, the results for the two categories lead to the same conclusions. Thus, the entirety of the observed average execution differences between brokers is due to different treatments by wholesalers.

5. Creating Differential Pricing for Anonymous Trades

We were surprised to find that brokers are receiving such differential pricing. Given that all trades are executed on exchanges, where trades are anonymous, it would seem that such dispersion is impossible. However, as discussed earlier, the venue has levers to influence the pricing of trades. It determines whether or not the trade goes through a PIM auction and if so, the starting price. So, the venue can choose the execution method with full knowledge of the originating broker, and its PFOF.

To examine whether or not venues are systematically altering these choices, for each of our brokers, we compute the fractions of our orders that are executed through PIM auctions and auto-execution trades.[40] Next, we report our average price improvement for each trade type. Results are shown in Table 8. We also show the size of PFOF for each broker, and report correlations of each variable with PFOF.

[40] For simplicity, we label as an auto-execution trade anything that is not sent as a PIM auction. Approximately 5% of our trades were executed as inter-market sweeps (trade condition 95) and 0.3% of our trades interacted with multi-leg orders. Separating out these other trades does not alter our results.

<Insert Table 8 about here>

Across all brokers, we find that only approximately 50% of our orders are executed as PIM auctions. Bryzgalova et al. (2023) suggest using PIM auctions to identify option retail orders; however, this method would miss half our our trades. Additionally, as noted by those authors, this measure also includes false positives. Thus, like the BJZZ method used to identify equity retail trades,[41] using PIM auctions suffers from Type I and Type II errors. As expected, most price improvement comes through PIM auctions, with average PI of 45%, whereas auto-execution trades have average PI of only 5.6%. The data are also shown in Figure 4, with confidence intervals.

<Insert Figure 4 about here>

Our aggregate results hide wide variations across brokers. Three quarters of Vanguard orders are set to exchanges as PIM auctions, against only one quarter of Robinhood orders. However, broker price discrimination is not just caused by differential auction usage. Even conditioning on trade type, brokers are systematically getting different pricing. Vanguard trades executed through auctions receive on average 64% price improvement; for Robinhood, the number is 21%. For auto-execution trades, Vanguard receives 11.5% of average PI, against 2.5% for Robinhood. The PI correlation across the two trade types is +0.98.

To provide more insight, we can decompose variation in broker execution differences into its three components, i.e., the execution method choice and pricing within the two execution methods. We perform this calculation for each broker pair and then average across brokers, as

[41] See Boehmer et al. (2021), Battalio and Jennings (2023), and Barber et al. (2024).

shown in Figure 5. Of the overall execution differences, 40% is due to the execution method choice, versus 50% from auction pricing, and close to 10% from auto-execution pricing.

<Insert Figure 5 about here>

As with overall execution, the usage of PIM auctions and pricing within the two order types are highly, negative correlated with the PFOF level. Figure 6 illustrates the link between PFOF and auction usage (Panel A), auction PI (Panel B), and auto-execution PI (Panel C), across brokers.

<Insert Figure 6 about here>

Venues are able to create differential pricing in PIM auctions through the starting price, which must give them significant control over final pricing. However, it is less clear how auto-execution trades can have different pricing. These trades should have no client information. So, it is puzzling to observe that, while the PI range is more narrow, it is also close to perfectly negatively correlated with PFOF. Investigating this effect would require further analysis.

6. Impact of a Venue-DMM Firm Connection

In this section, we investigate how the connection between a venue and its associated DMM at an exchange can impact our orders. As explained previously, wholesalers will have associated market makers at most exchanges, through which their trades are routed. Only some of these will be DMMs, for specific symbols at specific exchanges, however. Ernst and Spatt (2022) use variation in DMM assignments to conduct a "test of the impact of PFOF on execution quality."

6.1. Order Routing

We first begin by looking at how trades are routed by venues, conditional on them being able to route to their DMM.[42] For each of our trades, we know which venue received the trade, which exchange the trade went to, and which firm is the DMM at that exchange for that symbol. Based on this information, we can compute the percent of our trades that venues route to an exchange where their firm is the DMM.

The question is whether these DMM routing assignments systematically differ from random ones. As a counterfactual, we compile the percent of all trades in OPRA for that symbol at each exchange; next, we use this information to compute the total market share handled by each DMM firm. This percentage represents the percent of trades we would expect a venue to randomly route to exchanges where their firm is the DMM without considering the firm connection. This "expected" fraction can be then compared to the "actual" fraction of routing to the venue's DMM.

We present results in Table 9, showing data for all trades across our brokers and for each individual broker. We also break down trades into auto-execution and auction trades. The incentives for a venue to route to its firm DMM are very different in these two cases. For auto-execution trades, routing to the exchange where its firm is the DMM gives the firm the opportunity to capture the spread. For auction trades, the DMM is not involved in the execution of the trade, thus there is no economic incentive for the venue to route to an exchange where its firm has a DMM.

[42] Venues may not be able to route to their own DMM if it has no symbol-specific DMM at any exchange. For our symbols that represent more than 40% of market volume, approximately 20% of the time this is the case.

We do find that venues are more likely to route to exchanges where their firm is the DMM. However, the difference is muted. Venues, when feasible, route to exchanges where their firm is the DMM 25% of the time. If they were not considering the connection, we would expect this ratio to be approximately 20% of the time, which means they route to themselves slightly more often than expected. Conversely, for 75% of the time, the venue routes the trade *away* from its DMM.

As expected based on economic incentives, this over-allocation is limited to auto-execution trades, for which actual routing is 27%, versus 16% expected. Thus our auto-execution trades are much more likely to be routed to exchanges where the venue's firm is the DMM. This is consistent across all of our brokers. On the other hand, we find that auction trades are essentially routed randomly with respect to firm DMM.

Finally, we can compute the fraction of so-called "internalized" trades, i.e., auto-execution trades routed to a exchange with venue DMM. As the table shows, this represents only 10% of our trades across brokers.[43]

An open question is then whether or not this connection leads to worse execution for customers. It is difficult for one DMM to control pricing on auto-execution trades. DMMs will likely execute at NBBO, or perhaps better. In theory, the DMM does not know the identity of the originating broker, hence the PFOF paid by its venue.[44] So it is not obvious how the venue-DMM connection could affect pricing across brokers.

To investigate such potential effects, we examine pricing improvement by leveraging the

[43]While DMMs have privileges, in some cases, they may not handle the trade even when it is for five contracts or less. For example, DMMs can only handle a maximum of 40% of exchange volume per day.

[44]There is a strict information wall between the venue and market-making units of each firm. Thus, the market maker should not know the identity of the customer. Nevertheless, the market maker could still use information in the market to make predictions about the client's identity.

design of our experiment. Table 10 show regressions of price improvement on dummy variables of interest.[45] As a first test, we separate trades into two groups, defining the "can route" dummy variable. The first group, which comprises 80% of our trades, are trades where the venue has an opportunity to route our trade to an exchange where its firm is the DMM. These are trades subject to the conflict. The second group, which represents the other 20%, are trades where the venue cannot route our trade to their own firm DMM. Ernst and Spatt (2022) note that DMM assignments are random; thus, the selection of trades into these two groups should be exogenous. We check whether PI is affected across these two groups.

As a second test, we create a dummy variable ("firm DMM") set to one if the venue does route to their own firm-DMM and zero otherwise. For our last test, we set the "PFOF DMM" variable to one if the trade is routed to any exchange where the DMM has a firm venue that pays PFOF, similar to the identification used in prior studies.

<Insert Table 10 about here>

Overall, we find no evidence that routing differences explain variation in price execution. Across all trades, there is no significant execution differences for any of our variables of interest.

7. Discussion

In this section, we delve into the broader implications of our findings. We compare our results with related studies on equity trades and highlight the unique features of the options

[45] Regressions use standard errors clustered by symbol. For the "all trades" model, we also include broker fixed effects.

market. We also discuss how current market structure facilitates internalization and enables differential pricing, even in environments where trades are expected to be treated equally. Finally, we address the current state of disclosure in the options market and suggest potential improvements that could enhance market transparency and better inform retail investors.

7.1. Comparison with Equity Trades

Although the market structures differ between the equity and options markets, substantial differential pricing exists across brokers in both. In the equity market, nearly all retail trades are executed off-exchanges where wholesalers have control of pricing once the order is routed to them, though they are also required to fulfill all trades. Schwarz et al. (2024) conducted a similar experiment with equity trades, and report that wholesalers systematically provide differential pricing across brokers.

In contrast, option trades are executed on exchanges, where one would expect trades to be treated equally. However, our findings show even greater differential pricing in the options market compared to equities. Specifically, while Schwarz et al. (2024) show a 28% difference in price improvement between highest and lowest brokers relative to the NBBO for equities, we find a range of nearly 45% of NBBO for options.

Despite similar evidence in pricing disparities, the economic driver underlying differential pricing in the options market, as identified in our results, likely differs from that in the equity market. For equity trades, Schwarz et al. (2024) find no evidence that the differential pricing is primarily driven by differences in PFOF levels; instead, it is potentially explained by order flow toxicity. As evidence, they report that variation in order imbalance around the trade times creates dispersion in execution quality similar to that observed across brokers. In contrast, for option trades, we find that price differences across brokers are highly correlated with the level of PFOF, while order imbalance around our trades offers little explanatory power for price improvement, suggesting that the impact of toxicity is minimal for option trades.

The dominance of an underlying economic driver may be linked to the degree of variation in that driver across brokers. In the options market, PFOF is significantly larger, being multiple times higher than in the equity market. Conversely, literature has documented the impact of order flow toxicity is much more homogenous in the options market but highly heterogenous in the equity market.[46] These differences may explain why PFOF plays a dominant role in driving price differences in the options market, whereas order flow toxicity is the primary driver in the equity market.

7.2. Exchanges, Voluntary Auctions, and Differential Pricing

One important implication of our results relates to the value of anonymity at exchanges, especially when the market structure includes voluntary auctions. The SEC has proposed using auctions to execute retail equity trades with the expectation of opening them to more competition, which in theory should achieve better pricing for retail customers. However, our results show potential drawbacks of these type of auctions where the venue has discretion over whether to use an auction and over its starting price. While the auction specification in the equity proposal differs from the existing option market structure, these two core components are present. First, the venue has discretion over whether or not a trade goes through the

[46] Eaton et al. (2022) and Eaton et al. (2024) study brokerage platform outages to examine the impact of retail order flow on equity and options markets. While outages at Robinhood have an opposite effect on the equity market compared to traditional brokers (Eaton et al. (2022)), their impact on the options market is largely similar (Eaton et al. (2024)).

auction. Second, the venue sets the starting price of the auction. Since the venue knows the identity of the customer, just like in the options market, the venue can create differential pricing by varying these parameters across customers.

More generally, we also find that auctions are insufficient to provide all clients, even when trades are anonymous, similar pricing. We find that the average PI varies from 21% to 64% across brokers, in decreasing PFOF levels. The only way anonymous trades can end up with systematically different prices across different clients is by venues systematically setting different starting prices.[47] While other market makers do not know the identity of the customer, which could be a retail investor or a hedge fund, potential bidders must certainly be worried about the level of toxicity of this order flow. Hence, the starting price must serve an important anchor point, which explains why auctions do not end up with the same price improvement.

There are two potential reasons for this outcome. The first is simply that auctions do not invite sufficient competition. In other words, not enough market makers participate in auctions. To support this argument, Bryzgalova et al. (2023) suggest that the break-up fee stifles competition. However, it seems that the economic advantage of the venue is low, especially for brokers that are getting the worse execution. For example, the PFOF paid to Robinhood is greater than the breakup fee; yet those trades end up with the worst pricing in auctions, with a shortfall that exceeds the breakup fee.

A second reason is that the market uses the starting price as a signal regarding the toxicity of the trade. A market maker routing trades as PIM auctions will be forced to take

[47]We do not observe the starting prices, but this is the only mechanism that can explain different trade pricing since trades are anonymous.

the other side of the trade if they are not outbid. Thus, toxicity will influence the amount of price improvement the market maker is willing to provide. Given that any trade can be routed to a PIM auction, low starting prices could be taken as a signal of toxicity. If so, then Robinhood trades could be seen as potential hedge fund trades, for example, which would explain muted bidding in those auctions.

Finally, for auto-execution, it is likely that venues can use similar techniques to create differential pricing. We also observe slight variations in price improvements across brokers that correlate with the size of PFOF. The average PI varies from 2% to 12% across brokers, in decreasing PFOF levels. Further work is required to ascertain the drivers of this effect.

7.3. Disclosure

Currently, option price execution lacks meaningful public disclosure. The information provided by brokers on their web sites is even less informative than for equity trades, and certainly non-comparable across brokers. More importantly, there is currently no mandate for market centers to disclose price execution information, as is required for equities through Form 605. While some indirect information on options is disclosed on Form 606, which requires brokers to detail routing venues with their PFOF in dollars and per contract, the accompanying footnotes are hardly informative.[48]

Based on our findings, it seems crucial to require execution quality disclosures for options. We suggest adopting the same requirements recently implemented for equities (i.e., SEC (2024)), as applied to market centers and now brokers. Specifically, both wholesalers

[48] For example, TD Ameritrade and Schwab state they can receive "up to" 67 cents per contract, but provide no further details. Robinhood offers more information on the PFOF rates across various spread bins, but does not disclose the size of these bins.

and brokers should be required to provide execution information on their options trades. These disclosures should mirror those for equities, including effective spreads, percent executed at NBBO, and percent with price improvement. The reports should include statistics for different size bins (e.g. 1 contract, 2-5 contracts, and so forth) and order types. Ideally, disclosures should also include the percentage executed via PIM auction and the price improvements involved in those auctions.

Admittedly, option trades involve a broader range of contracts compared to single equities, varying by type, strike prices, and tenor. To simplify the disclosure process, execution statistics could be organized into various strike buckets (e.g., out of the money, near the money, in the money) and tenor buckets (e.g., less than a week, week to a month, more than a month). This approach should be technically feasible, in the same way that OPRA provides detailed option data, as TAQ does for equities.

Given the significant recent increase in option trade volumes and the execution differences we have observed across brokers, the benefits of these disclosures are likely to far outweigh the costs. In addition to providing more informative data, such disclosures would put more pressure on market participants to provide more competitive prices, thereby benefiting retail investors.

8. Conclusion

Retail option trades are required to be executed on exchanges where they are anonymous and should be treated equally. Yet, surprisingly, we find a large dispersion in the execution quality across retail brokers. We find that price improvement, measured as a percent of NBBO, ranges from 6% to 52%. In terms of round-trip trade costs relative to notional, average costs for the best broker are close to zero against close to 7% for the worst broker. Even at small quantities, these differences are economically large and, given the recent surge in retail option trading, such price execution differences are economically important.

Venues are able to create differential pricing due to the option market structure. Importantly, they can choose whether to route a trade to an exchange as a price improvement auction or not. If so, the venue will also select the starting amount of price improvement for the auction. These choices drive differential pricing. Brokers with better price execution have a larger fraction of their trades sent to exchanges as auctions and, conditional on being sent as an auction trade, receive much higher price improvement on auction trades as well. We also find that auto-execution trades have much lower price improvement, although there is still surprising dispersion across brokers.

Next, we find strong evidence that these differences are related to payment for order flow. The correlation between price improvement and PFOF is −0.9. PFOF is also strongly negatively correlated (−0.83) with the use of auctions. We also find similar PI-PFOF correlations for auctions (−0.93) and auto-execution trades (−0.91). These results are markedly different from the relation between PI and PFOF observed for equity trades, where PI differs across brokers but does not seem related to PFOF and instead seems primarily driven by variation in broker order flow toxicity. Conversely, our option experiment suggests that the PI-PFOF relation is negative and very strong, reflecting the relative low toxicity of option trades and the relatively high levels of PFOF for options versus equities.

While our experiment is expansive and systematic, our conclusions should reflect the limitations of its design. We only placed option market orders; other orders such as limit orders may be treated differently. We also only focus on price execution for one contract call option trades (even though we find similar results for put options and six contract trades.) More generally, clients surely choose brokers using a variety of criteria, only one of which is price execution. Finally, the experiment does not cover all possible brokerage account types and only reflects the current U.S. options retail market structure.

Even with these limitations, our study has important implications. First, it demonstrates the need for a substantial expansion in disclosure requirements for option execution quality, justifying the need for regulations mirroring the newly adopted Rule 605 for equity trading. Indeed, it is highly unlikely that retail investors are currently aware of the substantial variation in price execution for option trading. Second, our study has implications for market design. We show how, even when trades are executed anonymously on exchanges, differential pricing can be created when venues have choices for the type of execution and can affect pricing within these execution methods. Finally, because these features are also part of the SEC's proposed Order Execution Rule for equity trades, our results have implications for the effectiveness of this rule.

References

Barber, B., X. Huang, P. Jorion, T. Odean, and C. Schwarz (2024). A (sub)penny for your thoughts: Tracking retail investor activity in TAQ. *Journal of Finance 79*, 2403–2427.

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

Battalio, R. and R. Jennings (2023). Retail option traders and the implied volatility surface. https://ssrn.com/abstract=4304124. Working Paper.

Battalio, R., R. Jennings, and J. Selway (2001). The potential for clientele pricing when making markets in financial securities. *Journal of Financial Markets 4*, 85–112.

Boehmer, E., C. Jones, X. Zhang, and X. Zhang (2021). Tracking retail investor activity. *Journal of Finance 76*, 2249–2305.

Bryzgalova, S., A. Pavlova, and T. Sikorskaya (2023). Retail trading in options and the rise of the big three wholesalers. *Journal of Finance 78*, 3465–3514.

Eaton, G. W., T. C. Green, B. S. Roseman, and Y. Wu (2022). Retail trader sophistication and stock market quality: Evidence from brokerage outages. *Journal of Financial Economics 146*(2), 502–528.

Eaton, G. W., T. C. Green, B. S. Roseman, and Y. Wu (2024). Retail option traders and the implied volatility surface. https://ssrn.com/abstract=4104788. Working Paper.

Ernst, T. and C. Spatt (2022). Payment for order flow and option internalization. https://ssrn.com/abstract=4056512. Working Paper.

Ernst, T., C. Spatt, and J. Sun (2024). Would order-by-order auctions be competitive? https://ssrn.com/abstract=4300505. Working Paper.

Hendershott, T., S. Khan, and R. Riordan (2024). Option auctions. https://ssrn.com/abstract=4110516. Working Paper.

Lee, C. and M. Ready (1991). Inferring investor behavior from intraday data. *Journal of Finance 46*, 733–746.

Levy, B. (2022). Price improvement and payment for order flow: Evidence from a randomized controlled trial. https://ssrn.com/abstract=4189658. Working Paper.

Muravyev, D. (2016). Order flow and expected option returns. *Journal of Finance 71*, 673–708.

Muravyev, D. and N. D. Pearson (2020). Options trading costs are lower than you think. *Review of Financial Studies 33*, 4973–5014.

NYSE (2023). Trends in option trading. https://www.nyse.com/data-insights/trends-in-options-trading.

Schwarz, C., B. Barber, X. Huang, P. Jorion, and T. Odean (2024). The 'actual retail price' of equity trades. https://ssrn.com/abstract=4189239. Working Paper.

SEC (2022). Order competition rule. https://www.sec.gov/rules/proposed/2022/34-96495.pdf. Securities and Exchange Commission Release No. 34-96495.

SEC (2024). Final rule: Disclosure of order execution information. https://www.sec.gov/rules/final/2024/34-99679.pdf. Securities and Exchange Commission Release No. 34-99679.

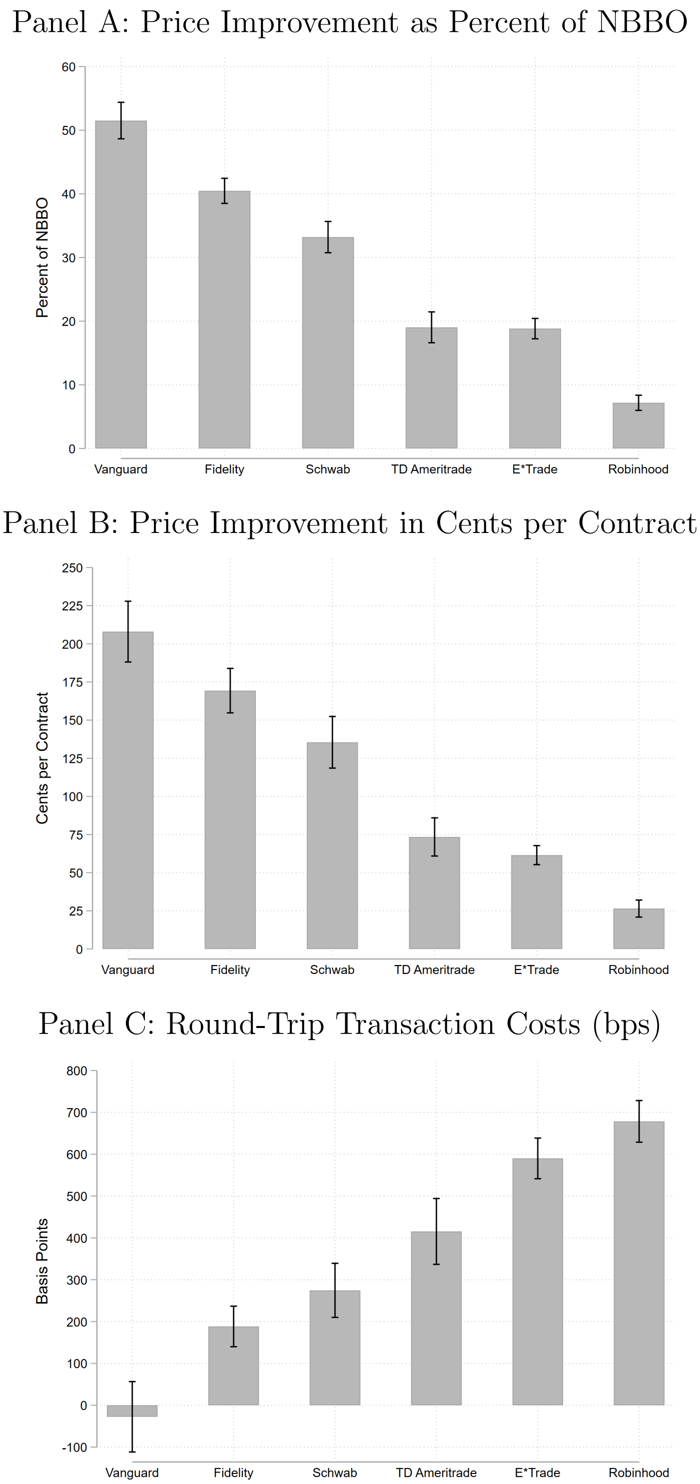

Figure 1: Price Improvement by Brokerage Account
This figure presents the average price improvement, measured relative to the National Best Bid and Offer (NBBO) in percent (Panel A) and cents per contract (Panel B). Panel C presents round-trip trading costs, relative to principal, for the purchase and sale of the same option contract within approximately 5 minutes, adjusting for the relative move in the contemporaneous mid-price. Whiskers represent 95% confidence intervals.

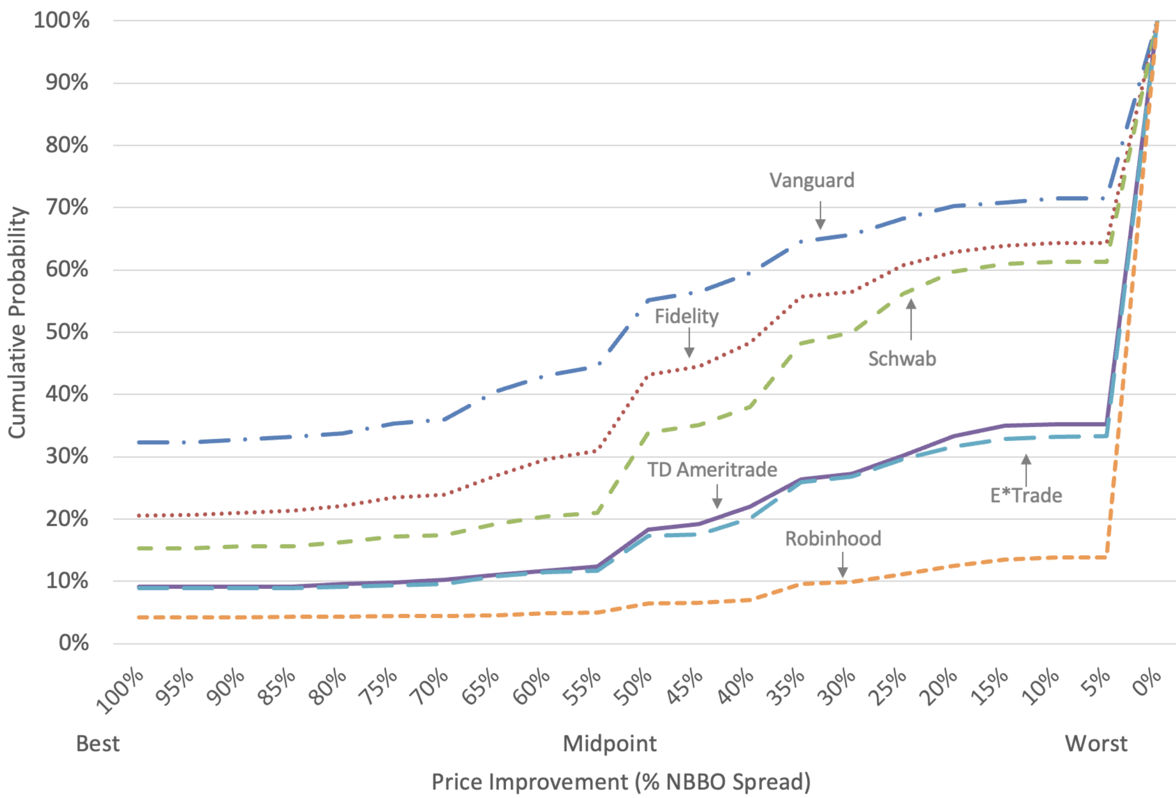

Figure 2: Cumulative Distribution of Price Improvement by Broker
The figure presents the cumulative distribution of price improvement (PI) as a percent of NBBO by broker. PI is the absolute value of the difference between the execution price and ask (bid) for buys (sells), divided by the NBBO spread. PI=0% indicates that a buy (sell) was executed at the NBBO ask (bid). PI=100% indicates that buys (sells) orders were executed at the bid (ask), which is the best possible pricing. PI=50% indicates that orders were executed at the mid-point, which would be "free" trading, not counting fees. We invert the x-axis so that topmost lines represent the best execution.

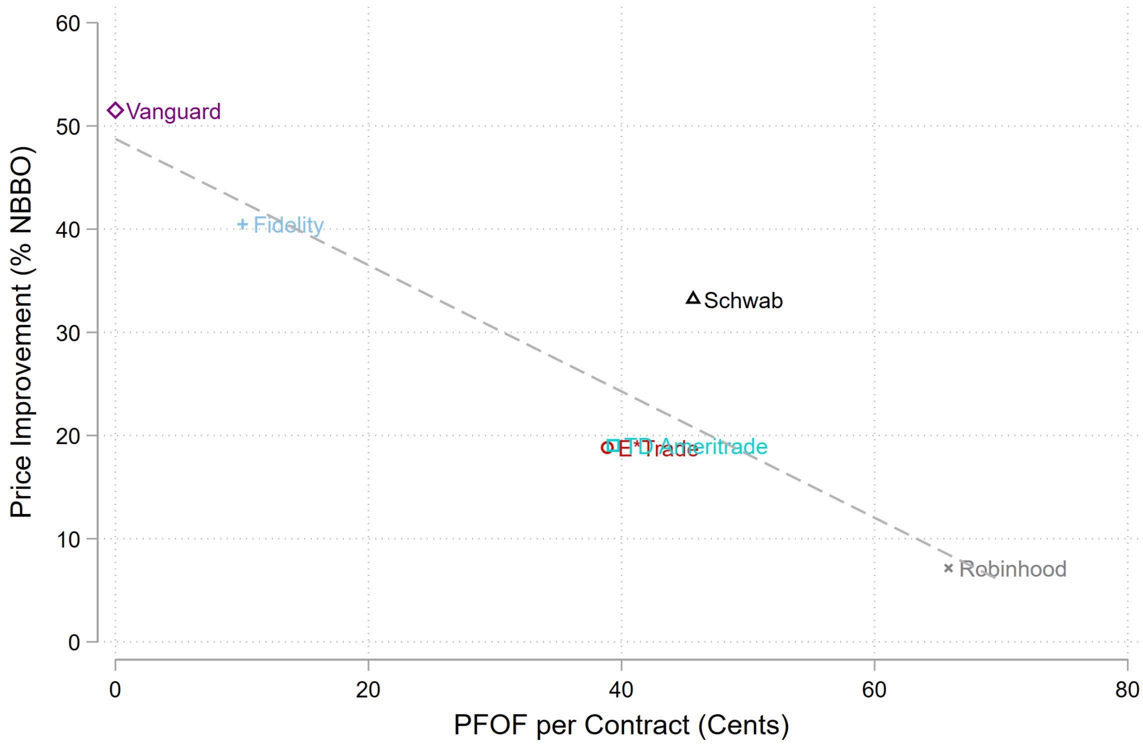

Figure 3: Price Improvement versus Payment for Order Flow
Price improvement is percent of the NBBO. Payment for order flow (PFOF) is in cents per contract based on broker filings (Form 606), using volume-weighted averages from April to June 2024.

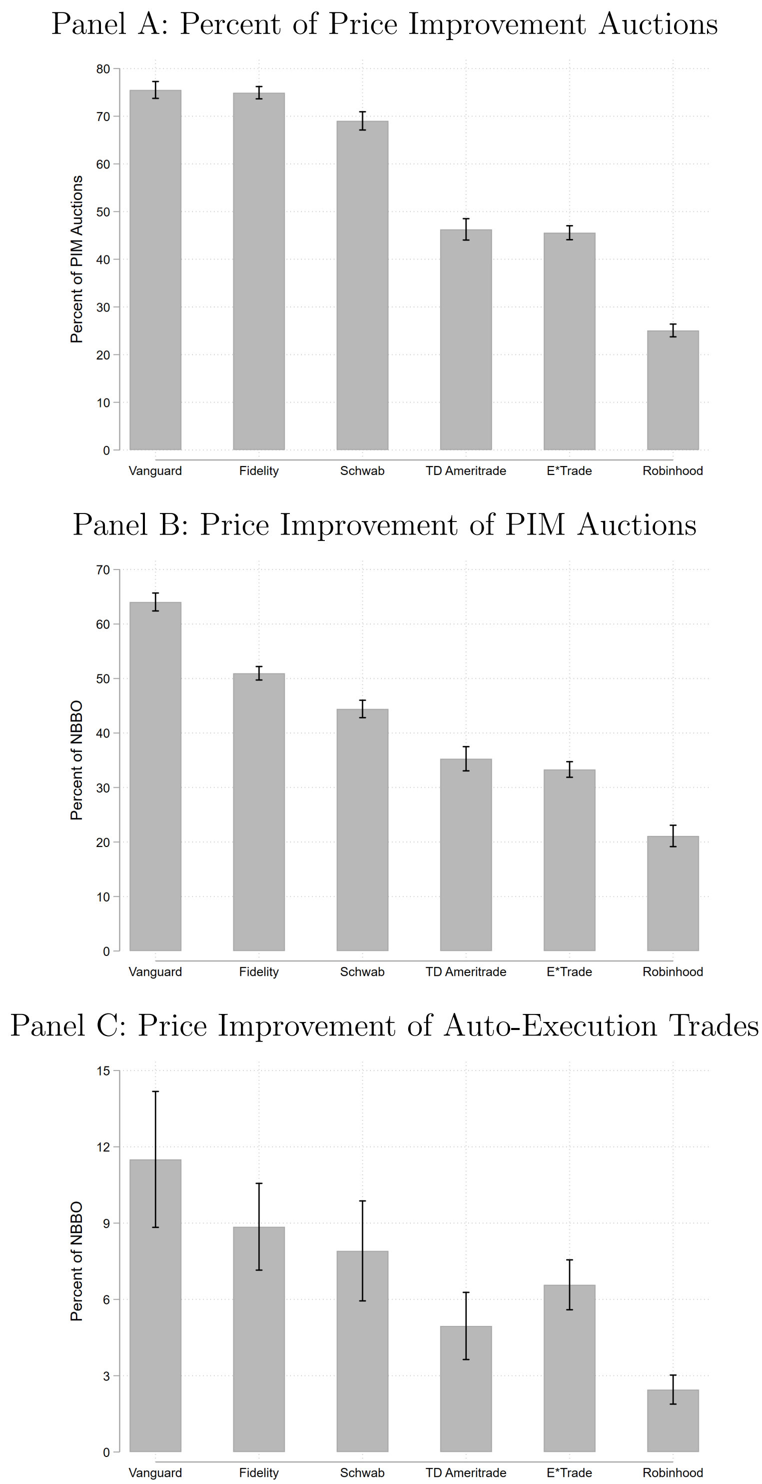

Figure 4: Auction Use and Price Improvement by Order Type and Broker
This figure presents the percentage of PIM Auctions used by broker (Panel A). It also shows the average price improvement, measured relative to the National Best Bid and Offer (NBBO) in percent, for PIM Auction trades (Panel B) and for auto-execution trades (Panel C) by broker. Whiskers represent 95% confidence intervals.

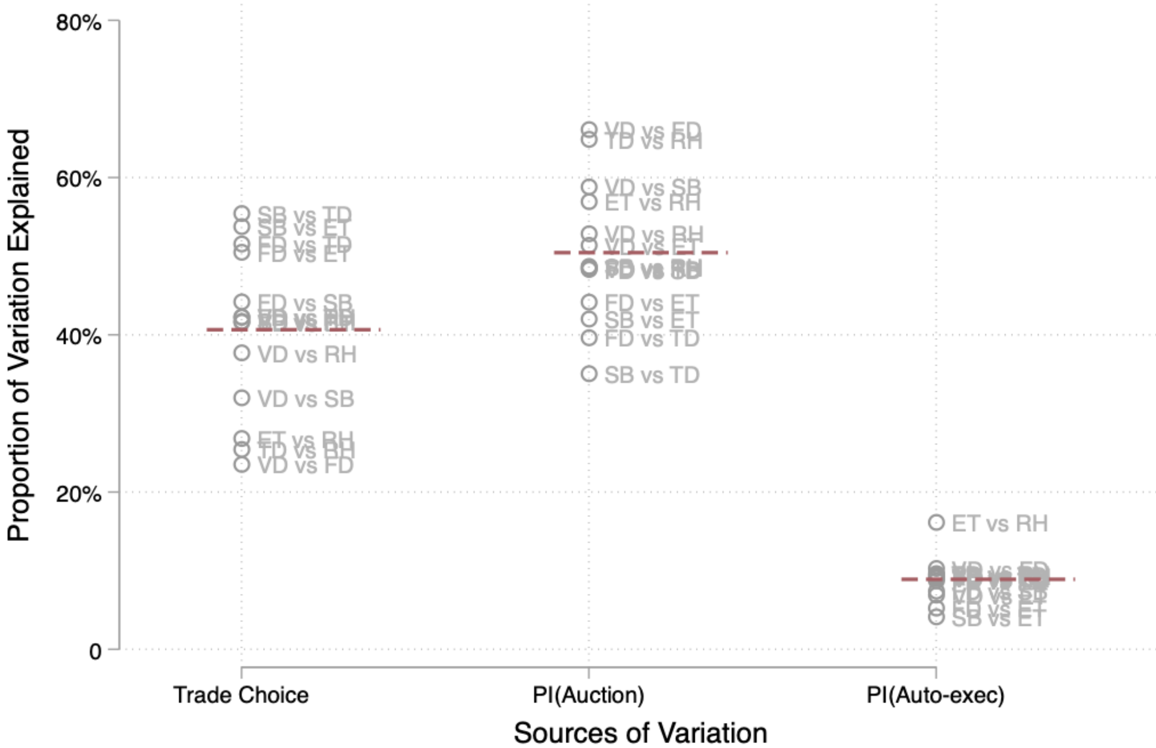

Figure 5: Breakdown of Differential Pricing

This figure shows the amount of our pricing differences that are driven by variation in execution method (*Trade Choice*) and from different pricing within execution method. *PI(Auction)* represents the amount from differential auction pricing, whereas *PI(Auto-exec)* is the amount from differential auto-execution pricing. We compute the breakdown for each broker pair and then compute averages, presented by the dashed line, across all pairs.

Panel A: Percent of PIM Auctions

Panel B: Price Improvement of PIM Auctions

Panel C: Price Improvement of Auto-Execution Trades

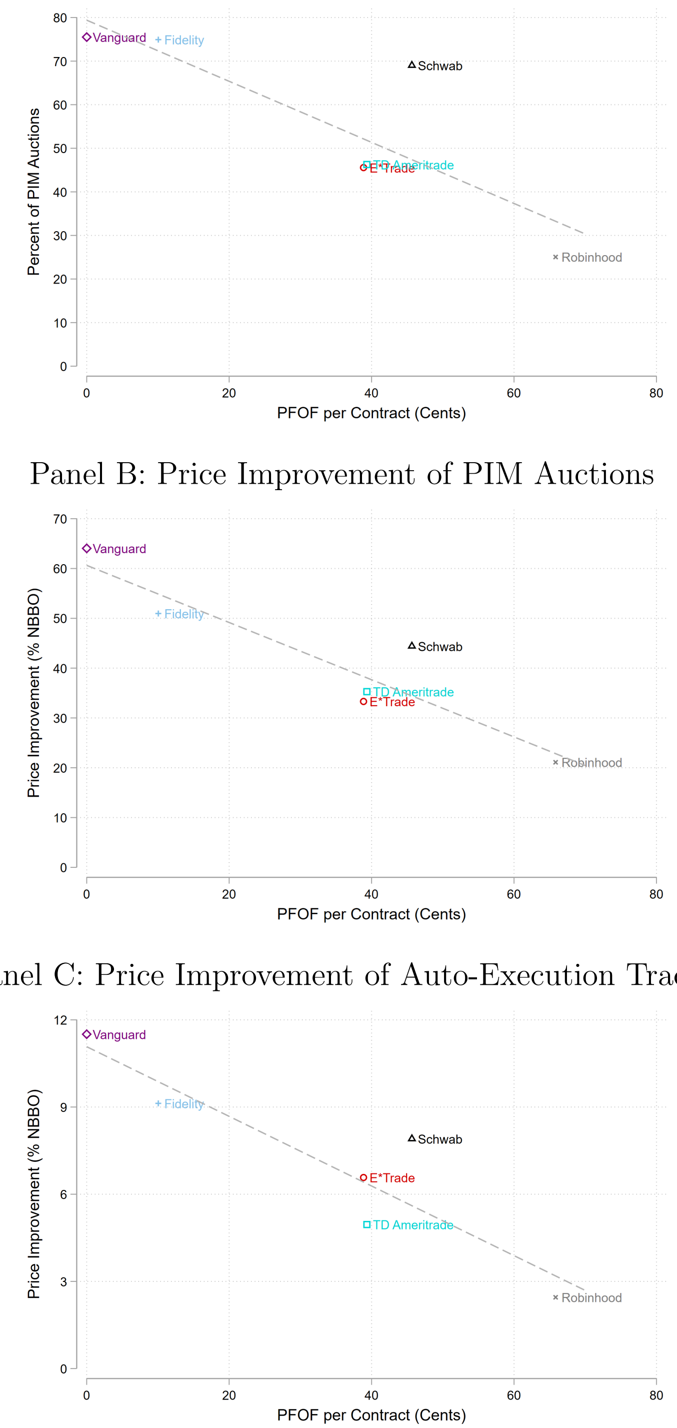

Figure 6: Auction Use and Price Improvement versus Payment for Order Flow Percent of PIM Auctions reflects the frequency of PIM Auctions. Price improvement is in percent of the NBBO. Payment for order flow (PFOF) is in cents per contract based on broker filings (Form 606). Panel A reports results for PIM Auction usage as compared to PFOF. Panels B and C compare price improvement for auction and auto-execution trades, respectively.

Table 1: Description of Retail Brokers in Experiment

For the six brokers used to trade options, Panel A summarizes the date the broker announced commission-free trading, the maximum fee charged for options trades per contract, and whether they accept payment for order flow (PFOF) from wholesalers for options trading. Panel A also shows the annualized option volume (in 100-share contracts) as well as stock volume, based on the SEC Form 606 disclosures for Q1 2024 (Vanguard has no PFOF, so volume cannot be inferred.) In Panel B, we report the total amount of PFOF in 2023 for each security type. In Panel C, we report the equivalent amount per 100 shares, in addition to the payment as described in the footnotes to Form 606 for options market orders.

Notes: E*Trade was transitioned to Morgan Stanley in September 2023. TD Ameritrade was acquired by Schwab in 2020, but maintained a distinct account until May 10, 2024.

Panel A: Broker Overview

Broker	Start of No Commission	Option Fee	PFOF	Options Contracts (mm)	Stocks Shares (mm)
E*Trade	10/2/2019	$0.65	Yes	589	75,534
Fidelity	10/10/2019	$0.65	Yes†	669	45,671
Robinhood	12/15/2017	$0.00	Yes	1,338	97,614
Schwab	10/7/2019	$0.65	Yes	663	144,345
TD Ameritrade	10/2/2019	$0.65	Yes	904	234,645
Vanguard	1/1/2020	$1.00	No	NA	NA
			Total:	4,163	597,809

†Fidelity only receives the rebates from exchanges.

Panel B: Total Payment for Order Flow ($ mm) in 2023

Broker	Stocks, S&P	Stocks, non-S&P	Options	Total	Option Share of Total
E*Trade	20	82	243	345	70.5%
Fidelity	6	23	84	112	74.5%
Robinhood	12	89	495	596	83.1%
Schwab	25	91	191	306	62.2%
TD Ameritrade	59	244	568	871	65.3%
Vanguard	0	0	0	0	N/A
Total:	122	528	1,581	2,230	70.9%

Panel C: Payment for Order Flow per 100 Shares in 2023

Broker	Stocks, S&P	Stocks, non-S&P	Options	Options, Mkt. Orders	Described, Options, Mkt.
E*Trade	18.2	9.2	38.7	40.8	43
Fidelity	0.0	0.0	14.7	9.6	N/A
Robinhood	47.0	6.9	41.9	50.4	30 to 110
Schwab	13.7	11.5	40.0	37.5	<67
TD Ameritrade	10.1	8.5	30.2	30.0	<67
Vanguard	0.0	0.0	0.0	0.0	N/A
Average:	17.8	7.2	27.6	28.0	

Table 2: Selection of Symbols by Venue for our Experiment
This table reports the symbols (tickers) used in our trading experiment. To select symbols, we first look at popular symbols as documented by Bryzgalova et al. (2023). We then selected three "placebo" symbols where all broker venues have the opportunity to route the trades to an exchange with its own venue-affiliated Designated Market Maker (DMM). We then select 15 more symbols where some venues are not be able to route all the trades to their own DMM. *CDRG* is Citadel, *WEXM* is Wolverine, *SIGQ* is Susquehanna/G1X, *DFIN* is Dash/IMC, and *MSCO* is Morgan Stanley. The "X" shows whether the venue could route the trade to an exchange with its own DMM. The next column shows whether the symbol is part of the Penny Pilot program (PP). For reference, we also report the percentage of all trades (contracts) and dollar volume in the OPRA database for each of our symbols during our trading period.

	Venue						%	%
Symbol	CDRG	WEXM	SIGQ	DFIN	MSCO	PP	Trades	Volume
Placebo Stocks								
TSLA	X	X	X	X	X	Y	6.1	4.6
AAPL	X	X	X	X	X	Y	3.0	2.7
QQQ	X	X	X	X	X	Y	7.3	8.2
Stocks without Some Venue-DMM Connections								
RSP		X	X		X	N	0.0	0.0
NVDA	X		X		X	Y	9.0	5.8
F	X		X	X	X	Y	0.2	0.3
JNJ	X		X	X		Y	0.1	0.1
MRNA	X		X	X		Y	0.2	0.1
SPY	X		X	X	X	Y	14.8	17.6
LUMN	X	X		X	X	Y	0.0	0.0
ARKK	X	X			X	Y	0.1	0.2
BX	X	X			X	Y	0.1	0.1
WBD	X	X	X		X	Y	0.1	0.1
MSFT	X	X	X		X	Y	1.1	0.6
TSM	X	X	X		X	Y	0.5	0.4
BABA	X	X	X	X		Y	0.4	0.5
SHOP	X	X	X	X		Y	0.3	0.2
AMZN	X	X	X	X		Y	1.8	1.4
						Total:	44.9	42.8

Table 3: Price Improvement by Broker Account for All Trades

This table compares the price improvement (PI) for our trades in different brokerage accounts. The columns report the percent of trades with any (positive) PI, the mean PI measured as a fraction of the NBBO spread and in cents per contract, the mean round-trip transaction cost in bps, and the reported PFOF in cents per contract. To account for market movements, trade costs are measured relative to the midpoint at the trade times. As benchmarks, we also report the values for each column if our trades were executed at the midpoint and NBBO. Finally, we report the correlation between our price execution and PFOF.

		Mean Price Improvement		Round-Trip	PFOF
Execution at:	Percent With PI	As Percent of NBBO	In Cents per Contract	Trade Cost (bps)	(Cents per Contract)
All Trades	44.6	26.8	107.87	392	
Vanguard	71.7	51.5	207.99	-28	0.00
Fidelity	65.1	40.5	169.39	179	10.05
Schwab	60.8	33.2	135.48	275	45.66
TD Ameritrade	35.2	19.0	73.44	415	39.34
E*Trade	34.4	18.8	61.51	590	38.87
Robinhood	13.9	7.2	26.50	678	65.83
Benchmarks:					
Midpoint	100	50	207.53	0.0	
NBBO	0	0	0	8.0	
Corr. with PFOF:	-0.84	-0.91	-0.89	0.88	

Table 4: Pairwise Broker Differences in Price Improvement for Parallel Trades For parallel trades in Broker A (in rows) and Broker B (in columns), the table summarizes the mean difference in percent price improvement (Broker A minus Broker B). t -values in parentheses (based on standard errors clustered by symbol) test the null hypothesis that the pairwise difference is zero. ** p<0.01, * p<0.05

Broker B:	Vanguard	Fidelity	Schwab	TD Amer.	E*Trade	Robinhood
Broker A:						
Vanguard	–	11.9**	21.2**	39.3**	31.7**	44.4**
		(6.05)	(7.66)	(12.19)	(19.55)	(26.11)
Fidelity	-11.9**	–	6.1**	19.2**	21.9**	32.4**
	(-6.05)		(3.20)	(9.65)	(17.31)	(22.04)
Schwab	-21.2**	-6.1**	–	13.9**	15.8**	27.5**
	(-7.66)	(-3.20)		(4.96)	(8.73)	(12.94)
TD Ameritrade	-39.3**	-19.2**	-13.9**	–	0.5	12.1**
	(-12.19)	(-9.65)	(-4.96)		(0.37)	(7.67)
E*Trade	-31.7**	-21.9**	-15.8**	-0.5	–	10.8**
	(-19.55)	(-17.31)	(-8.73)	(-0.37)		(11.86)
Robinhood	-44.4**	-32.4**	-15.8**	-12.1**	-10.8**	–
	(-26.11)	(-22.04)	(-12.94)	(-7.67)	(-11.86)	

Table 5: Multivariate Regressions of Price Improvement

This table presents regressions of price improvement in percent of NBBO spread against various variables. First, we include broker indicator variables where Vanguard is the omitted broker. Next, we use a number of trade order descriptors. The first group describes the trade order, i.e., whether the trade is the first, second, third, or later in our trade sequence. Buy indicates the trade direction. OIB represents the symbol's order imbalance the same minute as our trade. Log(Volume) is the volume across all contracts for that symbol on the date of our trade. Next are variables describing the quoted spread size, e.g. 2-3 cents and so on, where the missing bucket represents one-cent trades. Finally, we include the trade price, days to expiration, the implied volatility, and the option's delta. ** p<0.01, * p<0.05

	Model 1		Model 2		Model 3	
	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value
Intercept	0.515	35.79**	0.324	2.40*	0.590	7.67**
Fidelity	-0.110	-6.27**			-0.115	-6.57**
Schwab	-0.183	-8.40**			-0.186	-8.65**
TD Ameritrade	-0.325	-18.20**			-0.328	-17.63**
E*Trade	-0.327	-22.35**			-0.333	-21.18**
Robinhood	-0.443	-28.00**			-0.449	-27.46**
2nd Trade			0.005	0.35	0.014	1.52
3rd Trade			0.001	0.12	0.004	0.47
4th or higher Trade			-0.007	-0.66	-0.022	-2.56*
Buy (1/0)			-0.007	-0.66	-0.005	-0.53
OIB			0.011	1.05	0.010	0.95
Log(Volume)			0.002	0.16	0.001	0.27
2-3 Cent Spread (1/0)			-0.090	-2.68*	-0.063	-2.02
4-5 Cent Spread (1/0)			-0.131	-3.44**	-0.0100	-2.94**
6-10 Cent Spread (1/0)			-0.122	-2.96**	-0.081	-2.15*
>10 Cent Spread (1/0)			-0.118	-2.71*	-0.088	-2.07
Trade Price			0.000	0.00	0.014	2.25*
Days to Expiration			0.003	1.90	-0.001	-0.68
Implied Vol			-0.025	-1.90	-0.037	-2.48*
Delta			0.037	1.69	0.004	0.23
Symbol Fixed Effects	N		Y		N	
Observations	6,609		6,593		6,593	
R-squared	16.52%		1.42%		17.28%	
Adj. R-squared	16.45%		0.94%		17.04%	

Table 6: Percent of Brokerage Account Trades Executed by Venue
This table summarizes the percent of our trades in each brokerage account (columns) executed by each venue (rows). Brokerage accounts include Vanguard (VD), Fidelity (FD), Schwab (SB), TD Ameritrade (TD), E*Trade (ET), and Robinhood (RH). The information was obtained from direct requests to our brokers.

	Trade Order Submitted in Account at						
Venue Executing Trade	VD	FD	SB	TD	ET	RH	Row Average
Citadel	62.2	50.1	36.9	43.2	31.4	28.7	42.1
G1X/Sus	22.4	21.5	25.7	12.4	27.2	18.4	21.3
IMC/Dash	0.0	20.4	16.5	22.9	30.6	20.2	18.4
Wolverine	15.4	0.5	7.6	6.9	10.7	18.4	9.9
Morgan Stanley	0.0	7.5	13.3	14.7	0.0	14.4	8.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 7: Pairwise Broker PI Differences: Same vs. Different Trading Venues
This table presents pairwise differences between price improvement (as % of NBBO) of our parallel trades for six brokers: Vanguard (VD), Fidelity (FD), Schwab (SB), TD Ameritrade (TD), E*Trade (ET), and Robinhood (RH). "Same" means that the parallel trades were sent to the same venue (e.g., both to Citadel), whereas "Different" means that the parallel trades were sent to different venues (e.g., Citadel for Broker A and Wolverine for Broker B). t-statistics are computed using standard errors clustered by stock. ** $p<0.01$, * $p<0.05$

				Mean PI (% of NBBO) for:			
Broker A	Broker B	Venue	N	Broker A	Broker B	Diff	t-stat.
VD	FD	Same	294	55.3	42.3	13.0	5.21**
		Different	464	48.9	37.7	11.2	3.72**
VD	SB	Same	156	55.9	31.2	24.8	7.49**
		Different	354	51.6	32.1	19.6	5.38**
VD	TD	Same	79	60.7	14.9	45.8	7.07**
		Different	150	54.2	18.4	35.9	8.97**
VD	ET	Same	212	53.0	15.8	37.2	11.75**
		Different	557	50.8	21.1	29.6	14.21**
VD	RH	Same	190	48.0	8.5	39.5	13.87**
		Different	487	52.7	6.3	46.4	25.78**
FD	SB	Same	231	37.2	33.3	4.0	1.25
		Different	526	40.2	33.2	7.0	2.95**
FD	TD	Same	178	39.1	20.5	18.6	4.72**
		Different	458	38.2	18.7	19.5	9.29**
FD	ET	Same	422	40.7	18.0	22.7	7.36**
		Different	1065	39.9	18.7	21.3	15.48**
FD	RH	Same	317	37.6	9.3	28.3	11.69**
		Different	1017	40.3	6.6	33.7	19.32**
SB	TD	Same	98	30.8	18.9	11.9	2.79*
		Different	234	30.1	15.7	14.5	4.27**
SB	ET	Same	188	33.6	17.6	16.0	6.80**
		Different	576	33.3	17.6	15.7	7.41**
SB	RH	Same	134	32.5	7.9	24.6	8.97**
		Different	523	33.4	5.1	28.3	11.95**
TD	ET	Same	163	24.7	19.7	5.0	1.54
		Different	474	17.2	18.3	-1.1	-0.51
TD	RH	Same	150	20.3	6.3	14.0	3.41**
		Different	481	18.4	6.9	11.5	6.28**
ET	RH	Same	323	21.4	8.4	13.1	6.61**
		Different	1041	17.0	6.9	10.1	8.39**

Table 8: Trade Order Types: Usage and Price Improvement by Broker
This table compares the execution type and price improvement (PI) for our all our trades as well as by brokerage accounts. The columns first report the usage, i.e., the percent of trades that are sent to exchanges as two order types, auction trades or auto-execution trades. The table then report the mean PI, in percent of NBBO, for both groups of trades. Finally, we report the correlation between order type usage and price improvement for the two order types and PFOF.

	Percent of Trades		Mean PI (% NBBO)		PFOF
Execution at:	Auction	Auto-exec.	Auction	Auto-exec.	(¢/contr.)
All Trades	54.2	45.8	44.5	5.6	
Vanguard	75.5	24.5	64.0	11.5	0.00
Fidelity	74.9	25.1	51.0	9.1	10.05
Schwab	69.0	31.0	44.4	7.9	45.66
TD Ameritrade	46.3	53.7	35.3	5.0	39.34
E*TRADE	45.6	54.4	33.3	6.6	38.87
Robinhood	25.1	74.9	21.1	2.5	65.83
Correlation with PFOF:	-0.83	0.83	-0.93	-0.91	

Table 9: Impact of Venue-DMM Firm Connection on Order Routing

This table compares the frequency in which venues route orders to their associated DMM, or own firms. We report the percent of orders that venues route to their firms' DMMs. We then report the percent of orders their firms' DMMs should expect to randomly receive, based on exchange volumes report in OPRA. Next we report the ratio of actual over expected. For all orders, we also report the percentage of orders that are "internalized," i.e., when the firm sent orders to its own DMM as an auto-execution trade. Trades are separated into auction and auto-execution.

All Trades	Overall	VD	FD	SB	TD	ET	RH
Routed to Firm (%)	24.5	25.4	23.3	23.0	24.2	24.6	26.6
Expected (%)	19.9	22.7	22.8	20.4	18.9	19.7	14.9
Ratio of Actual vs. Expected	1.23	1.12	1.02	1.13	1.28	1.25	1.78
"Internalized"	10.0	5.0	4.6	7.4	12.8	12.7	16.0
Auto-Execution	**Overall**	**VD**	**FD**	**SB**	**TD**	**ET**	**RH**
Routed to Firm (%)	27.3	23.8	21.5	28.3	29.5	29.7	28.6
Expected (%)	16.3	16.1	18.0	17.0	17.1	17.4	13.8
Ratio of Actual vs. Expected	1.67	1.47	1.19	1.66	1.73	1.71	2.07
Auction	**Overall**	**VD**	**FD**	**SB**	**TD**	**ET**	**RH**
Routed to Firm (%)	22.1	25.9	23.9	20.4	17.6	18.5	21.2
Expected (%)	23.0	24.7	24.6	22.0	21.1	22.5	18.1
Ratio of Actual vs. Expected	0.96	1.05	0.97	0.93	0.84	0.82	1.17

Table 10: Impact of Venue-DMM Firm Connection on Price Execution
This tables reports differential price execution conditional on venue, PFOF, and firm relations. In each case, we regress price improvement as a percentage of NBBO against a dummy variable of interest, clustering standard errors by symbol. In the overall model, we also include broker fixed effects. "Can Route" is one if the venue has the opportunity to route to their own firm DMM and zero otherwise. "Firm DMM" is one if the venue routed the trade to its own firm DMM and zero otherwise. "PFOF DMM" is one if the trade was sent to an exchange with a DMM whose firm is also a venue and zero otherwise. ** $p<0.01$, * $p<0.05$

All Trades	Overall	VD	FD	SB	TD	ET	RH
Can Route	0.0	16.4	3.3	-2.8	-0.4	-4.9	-0.8
t-value	(0.00)	(1.82)	(0.80)	(-0.64)	(-1.12)	(-1.71)	(-0.38)
Firm DMM	1.4	7.3	8.2*	0.4	-0.4	-5.6*	-0.3
t-value	(0.63)	(1.16)	(2.59)	(0.10)	(-0.09)	(-2.33)	(-0.55)

Auto-exec.	Overall	VD	FD	SB	TD	ET	RH
Firm DMM	1.0	-7.9	3.7	-1.5	4.7	0.4	1.1
t-value	(0.47)	(-1.71)	(0.78)	(-0.43)	(1.21)	(0.15)	(0.47)
PFOF DMM	2.7	6.1	4.1	5.1	2.4	2.2	1.6
t-value	(1.68)	(1.73)	(1.57)	(1.09)	(0.77)	(0.88)	(1.51)