Some Anonymous Options Trades Are More Equal than Others

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Abstract

We compare retail option trade execution by placing simultaneous market orders across six brokers. Although option trades are all anonymously executed on exchanges and therefore should be treated equally, we find that execution prices vary significantly: the average round-trip execution cost ranges from 0% to 7% across brokers. Wholesalers create differential pricing by not only systematically varying execution methods, but also the pricing *within* each method. A primary economic driver for differential pricing seems to be payment for order flow (PFOF). 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

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, driven by brokers eliminating fixed 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 (also called venues) for execution. These brokers can receive *payment for order flow* (PFOF) while retail investors can receive *price improvement* (i.e., 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 markets 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 (most still charge fees per contract, e.g., proportional fees 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]Indeed, retail orders sent to exchanges are simply labeled "Customer." Note that orders from hedge funds and other institutions are also labeled "Customer," which means that market participants on exchanges 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, routing them to exchanges where the wholesaler's firm operates as a Designated Market Maker (DMM, or specialist). Testing 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 paid by 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: two brokers

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

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

[6]The Options Price Reporting Authority (OPRA) database collects and disseminates quote and trade information for U.S. options, much like TAQ for equity trades.

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. For this trading, we selected 18 tickers, or symbols, that 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 through algorithms, which may introduce noise.[9]

Even though trades on exchanges are anonymous and therefore should be treated equally,[10] we find that price execution varies widely across brokers, as illustrated in Figure 1. Here, *price improvement* (PI) is measured by the trade price relative to the relevant NBBO quote, e.g., the ask price for buy orders.[11] Across our six brokerage accounts, the average price improvement

[7]However, one of these brokers is rebated a portion of the exchange 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 widely-used Lee and Ready (1991) method, which assigns buy (sell) signals from trades executed above (below) the midpoint. For our trades, average price improvement (PI%) estimated using the Lee-Ready method is 7% only, much lower than our actual price improvement of 27%. So, this method systematically understates price improvement because it erroneously assigns, for example, 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

[11]We use the NBBO at execution time because the time of order receipt by the broker was not available to us. We verified, however, that our results are not qualitatively affected when using our submission time, as will be explained later.

varied from 26 cents to 207 cents per contract, representing 7% to 52% of the NBBO. As a percentage of initial investment value, the average round trip execution cost varied from close to zero to around 700 basis points (bps).[12]

<Insert Figure 1 about here>

The dispersion is not only statistically significant but also economically important. The variation in option pricing across brokers exceeds the variation in equity trades documented by Schwarz et al. (2024). While the difference in best and worst price improvement across their brokers for equity trades is 28% of NBBO, the difference for our options is 45%.

Our findings indicate that the primary source of differential pricing is the wholesaler rather than choice of the exchange and its DMM. The wholesaler can achieve differential pricing in two ways. First, the wholesaler selects the trading mechanism, choosing between (1) *auto-execution trades* and (2) *Price Improvement Mechanism* (PIM) *auctions*.[13] Auto-execution trades are typically executed at NBBO, or with minimal price improvement. 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 we find 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

[12]Relative costs on options are much higher than equities due to the smaller size of initial investments. In our sample, the average option price is approximately one dollar, with spreads of several cents and a good fraction above ten cents. In any event, these numbers do not affect relative broker comparisons since we trade the same contracts across brokers.

[13]More specifically, "auto-execution" broadly describes electronic trades sent to one exchange. For these trades, the DMM has priority to execute any order of five contracts or fewer in full. 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.

prices.

Our results show that both these methods contribute to execution differences across brokers. The broker with best price execution 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 broker with worst price execution 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.

The remaining 8% is explained by price improvement in auto-execution trades. Brokers with the better overall execution also receive better execution on auto-execution trades. For example, the best (worst) overall broker receives 12% (2%) price improvement on these trades. Wholesalers obtain price improvement on these trades by converting our market orders into limit orders and posting them with a limit price inside the spread; these orders are then filled either by another market maker or by the wholesaler's affiliated market maker. Wholesalers go through this process more frequently for the best performing brokers.

We deepened our analysis by tracing the links between the broker, the routing venue, the execution exchange, and the venue-associated DMM. By invoking SEC Rule 606(b)(1), we obtained from our brokers the identity of the venues that received each of our trades.[14] Next, information about the identity of the exchanges where our trades took place was obtained by matching our trades with the OPRA transaction database. Finally, we compiled the list of

[14]This rule allows customers to request from their brokers information about the execution and routing of their orders.

DMM assignments for the 11 exchanges with a dedicated DMM per symbol. We therefore know the identity of the wholesaler that received the trade, the exchange where they routed the order, including the execution method, whether that exchange's DMM is affiliated with that wholesaler, as well as the PFOF to the originating broker.

Using this information, we show that broker pairwise execution differences are driven by wholesalers systematically providing different pricing for different brokers. Next, we perform multivariate regressions of price improvement on potential drivers. Broker fixed effects alone account for 16% of the variation in PI. Adding venue and symbol fixed effects, trade order, order imbalance, other pre-trade characteristics, and whether or not the wholesaler can internalize by routing to exchanges with an affiliated DMM, only increases the explained variation by 2%. Thus, the overwhelming determinant of price improvement is the broker.

Why do wholesalers provide different pricing to different brokers? One major economic driver appears to be PFOF. Unlike what has been documented for equity trades (e.g., Schwarz et al. (2024)), we observe that price improvement for option trades is strongly negatively correlated with PFOF, with a correlation of -0.91 across brokers. Our best execution 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. This negative correlation is evident across the selection of trading mechanisms as well as the price improvement achieved within both auction and auto-execution orders.

We discussion several implications of our result. The first is related to policy. Option execution is very complex as well as almost completely opaque. Unlike equities, there is no regulatory requirement for option execution disclosure, unlike the Form 605 that 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. However, we find that PFOF, which totaled $1.6 billion in 2023 alone, is likely a primary economic driver for execution. Thus, our findings suggest that an option equivalent of the newly finalized 605 rule is needed, both for wholesalers and brokers.[15]

Additionally, the SEC has proposed using auctions in equity markets. The SEC believes that using auctions will increase competition for these trades. However, our results suggest that auctions are not very competitive as auctions' final price improvement amounts appear strongly anchored to the initial amount. Bryzgalova et al. (2023) argue this is due to the high responder fee (i.e., break-up fee) that other market makers incur when responding to auctions. While we indeed do find limited competition, it is likely driven by factors beyond the responder fee. If the responder fee were the only friction limiting competition, we would expect the price improvement differences in the auctions across brokers to fall within that fee amount. Instead, we find differences that are much larger. Our findings suggest that either participation in auctions is low or the starting price is used as an information signal.[16] Under either scenario, it is unclear how much these types of auctions would increase competition in equity markets.[17]

Finally, while the focus of our paper is on execution costs rather than trading costs or brokers' business models, price execution quality is positively correlated with brokers' fixed per contract trading fees. The broker with the best price execution charges the highest fee whereas

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

[16] 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.

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

the worst price execution broker has the lowest. Total trading costs are a function of spreads, price improvement, and fees. Except for very low spread options, the highest-fee broker would have the lowest total trading costs due to lower execution costs. This is consistent with Parlour and Rajan (2003) who argue that the switch from commissions to PFOF would lead to higher total trading costs for some categories of investors. Additionally, the saliently of fees relative to execution costs may affect trading behavior.

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 used, as well as influencing pricing in these auctions, relative to auto-execution trades. In addition, we find that, unlike equity trades, the variation in option price execution is strongly and negatively correlated with PFOF.

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 what we find here. 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 for equities. Also, 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 price execution. In contrast, Eaton et al. (2024) show that trade toxicity across brokers is more homogeneous for options 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). In contrast, for options, the exchange trades do not carry client information. Still, the venue has tools to create differential pricing.

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 discuss the types of options that retail investors prefer to trade, mainly as short-term call options.[18] Ernst and Spatt (2022) use variation in DMM assignments to examine auto-execution trades by DMMs whose firms pay PFOF compared to those that do not, for the same symbol; they argue that these DMMs provide worse pricing. We provide more direct evidence that PFOF impacts pricing as well as the mechanisms for different pricing across brokers. Finally, Hendershott et al. (2024) suggest that auction are the primary mechanism for price improvement, which is used to offset wholesaler profits from auto-execution trades with their DMM. Our results show that, in the cross-section, the correlation of price improvement for these two trade types is 0.98. In other words, they are both used to enhance execution for the best execution brokers.[19]

Finally, we acknowledge that we only examined one specific aspect of brokerage trading. Our

[18] They identify retail trades as those executed in the single leg PIM auctions, even though they note that this method suffers from both Type I (i.e., non-retail identified) and Type II errors (i.e., retail not identified). Our trades suggest that the Type II error rate for this identification method is approximately 50%.

[19] Only 20% of our trades are executed on exchanges where the wholesalers' affiliated market makers are the DMMs. We will explore how brokers and wholesalers route our trades as well as retail trade identification and signing more thoroughly in future companion papers.

experiment was based solely on placing one contract market orders for call options during the day.[20] 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, such as the breadth of offerings; the ability to short; investment and margin fees; the quality of research and educational products; the 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 5.2 delves into the source for this variation, which we trace to how wholesalers route to exchanges and alter pricing within execution type. Section 6 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 equity and ETF option trading, and potential economic drivers of execution prices for retail clients.

[20]As a robustness check, we also placed a limited number of trades for put options as well as six contract orders, since these trades can be split and are not fully internalized. We find similar pricing across brokers in both cases.

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.[21] 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.)[22] Presumably, such broker fees cover some of the exchange fees, even though the amount charged is generally greater than this total.[23] The table also shows that

[21] 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.

[22] In this study, our focus is on execution costs. We have been told by venues that price execution is unrelated to brokers' fees. In Section 6, we discuss the impact of fees on total trading costs for investors. In addition to broker-listed fees, brokers separately pass along options regulatory fees, from $0.01 to $0.02 per contract, on both buys and sells, similarly to regulatory fees for equities.

[23] For example, for some index option trades, such as SPX(W) and NDX(P), which are traded on a single exchange, 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

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.[24] 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.[25] Note that, in these footnotes, some brokers explicitly downplay a connection between PFOF and price improvement.[26]

total fees on customer index options executions of $349,852 in January, $359,602 in February, and $449,754 in March." Because Robinhood does not charge any fees, this broker does not allow customers to place single index options trades.

[24]For example, E*Trade says that it receives a flat PFOF 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.

[25]Note that these PFOF amounts are an order magnitude greater than those for equities. We trade short-term options, with average spread of $0.04, or $4 per contract. So, for TD, for example, the average PFOF payment of $0.30 per contract translates into 7.6% of the spread. For equities, TD charges say $0.093 per 100 shares. Relative to an average spread of $17 per 100 shares, this translates into a ratio of 0.5% of the spread. So, the ratio of PFOF to spreads is 14 greater for options than equities. This ratio wold be even higher relative to initial investment.

[26]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*Trade 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, partly designed to minimize counter-party risk. An additional difference 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 U.S. options exchanges. Wholesalers have associated market makers 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 or equivalent assigned to each symbol; DMM assignments vary both across assets and 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, at NBBO or better.[27] However, DMMs also have additional obligations, such as being held to a higher mandatory percentage of quoting time. Importantly, all the large option venues' affiliated market makers are also DMMs.[28] 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," where the trade will most likely receive no price improvement, i.e., will sim-

[27] 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.

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

ply be executed at the NBBO;[29] alternatively, the venue can provide price improvement by converting the market order into a limit order inside the spread. The second is execution via a "Price Improvement Mechanism" (PIM) auction. Bryzgalova et al. (2023) identify retail trades using mainly PIM auctions, via a recently introduced OPRA flag.

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 routing the trade to an exchange where its affiliated market maker is the 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 price improvement can be zero when the spread is more than one cent.[30] 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.[31]

[29]We include intermarket sweep orders in this category. Trades could also be executed against a multi-leg order; we had very few of these, however.

[30]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, which on a round-trip trading basis is the entire one-cent spread, it would not be economically profitable for another market maker to breakup the auction and therefore the auctions would be uncompetitive.

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

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 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.[32]

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 can 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, would 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 venues 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.

[32] Anand and Muravyev (2023) find evidence that wholesalers may prefer auctions if their affiliated market maker is not at the NBBO. This would allow the wholesaler to still internalize the trade.

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, the 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., 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. We report our symbol list in Table 2.

<Insert Table 2 about here>

To examine the effect of venue-DMM linkages, we select one set of symbols where every venue's affiliated market maker is the DMM on at least one exchange that it can route the trade to. This includes TSLA, AAPL, and QQQ.[33] We then systematically select symbols where some venues' affiliated market makers are not the DMM on any exchange. For example, for RSP,[34] Citadel's and Dash/IMC's market maker is not the DMM at any exchange whereas the other three venues' market makers are. Thus, these two venues are unable to route to their firm's 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 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.[35]

3.2. Option Trading

We trade options at six different brokerages, namely E*Trade, Fidelity, Robinhood, Schwab, TD Ameritrade, and Vanguard.[36] 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:

- E*Trade, Robinhood, Schwab, and TD Ameritrade receive various amounts of PFOF.
- Fidelity states that it does not receive any PFOF; however, since its Form 606 reveals some PFOF payments, it must receive exchange fees generated from trades.

[33] QQQ is an exchange-traded fund that tracks the NASDAQ 100 Index.

[34] RSP is an exchange-traded fund that tracks the S&P 500 Equally-Weighted Index.

[35] 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.

[36] Our TD Ameritrade account was converted into a Schwab account on May 10, 2024 and thus was traded only until then.

- Vanguard receives no PFOF, as shown in its 606 Form.

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.[37]

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 each day 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.[38] On Fridays, rather than 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-

[37]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.

[38]For all trades in OPRA during our sample period, 50.6% of trades are for one contract, 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. 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.

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 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.[39] 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.

Instead, a better measure of *price improvement* is the average of cents-per-share differences

[39] We measure price improvement using execution time NBBO from OPRA. In 605 reports for equity trades, execution quality is measured relative to the broker's order receipt time. Between submission and execution time, spreads can move up or down, but the average move over many experiments should be close to zero for market orders. This is because our orders are at the NBBO size. Although we do not have the exact order time NBBO, we do record the bid/ask spread from the brokers right before we place our trade, which is a noisy proxy for the receipt time NBBO. In the end, our noisy submit-time price improvement, on average, is within 1.5 percentage points of our execution-time statistic and does not change the broker rankings.

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 execution 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):

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

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 price improvement above 50% of NBBO. 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 price improvement, the size of improvement, and the round-trip execution 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.

<Insert Table 3 about here>

In terms of frequency, 45% of our overall trades receive some amount of price improvement. The average price improvement is 27% relative to the NBBO spread, which is about halfway between NBBO and midpoint execution, or is equivalent to an E/Q of 0.46. Since option contracts are for 100 shares, the dollar spread is large, which results in a large amount of dollar price improvement, i.e., 108 cents on average. Finally, relative to the premium paid, our trades have an average round-trip execution cost of 392 basis points (bps).

The first observation is that execution costs for options are high, especially relative to equity trading. Round-trip execution 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.[40] It should be

[40] 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.

emphasized, however, that their cost estimates of 6.6% for call options that go through auctions are likely too high, reflecting the underestimation of price improvement from the Lee-Ready method. In addition, our calculation includes not only auctions but also auto-execution trades, which receive lower amounts of price improvement.[41]

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 execution broker has an average price improvement of 52% (E/Q of -0.04) while our worst execution broker has an average price improvement of just 7% (E/Q of 0.86),[42] resulting a maximum deviation of 45% (E/Q of 0.90). This translates into differences between the best and worst execution brokers in our sample that reach 181 cents per contract for the average price improvement and almost 700 bps for round-trip execution costs.

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

<Insert Figure 2 about here >

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 slightly less reliable than others. Although a majority of our trades overlap, to ensure that

[41] Our auction trades have round-trip execution 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 large difference. Auto-execution trading costs are much higher at close to 9%.

[42] During discussions with us, Robinhood indicated that their price improvement statistic was approximately 12% of NBBO, which is consistent with our estimate.

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>

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 5, we report the percentage of orders sent to each venue for each broker as well as the average across brokers.

<Insert Table 5 about here>

We see that Citadel is the dominant wholesaler for our sample, 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. At one end, Vanguard uses only three wholesalers; at 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 two groups, with results shown in Table 6.

<Insert Table 6 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, price improvement 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 groups lead to the same conclusions. Thus, the entirety of the observed average execution differences between brokers is due to different treatments by wholesalers.

Given the dispersion in execution across our brokers, we examine how much variation in price improvement can be explained by the clientele effect versus other factors. To do so, we run multivariate regressions where the dependent variable is the price improvement on each trade. In the first model, we simply regress PI against broker fixed effects, where the intercept represents Vanguard. In the second model, we add trade sequence order, plus symbol and venue fixed effects. Finally, the third model includes a wide range of order characteristics, i.e., 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 a dummy variable, *DMM Available*, that is one if the wholesalers' affiliated market maker is the DMM for that symbol on any exchange and zero otherwise. In each case, t-statistics use standard errors clustered by symbol. Results are reported in Table 7.

<Insert Table 7 about here>

In terms of the ability to explain price improvement, the broker effect is extremely large. In model one, it explains 16.5% of the PI variation across trades. In the second model, adding symbol and venue fixed effects only increases the R-squared by 1.3%. Finally, including all of the other trade characteristics only increases the R-squared by a meager 0.7%. In other words, broker fixed effects explain eight times more variation in the price improvement than all other variables combined. Outside broker information, spreads are the most significant variables, where values greater than one cent yield lower price improvement.[43] Finally, the availability of a DMM for the executing wholesaler has no significant impact on the price improvement of our trades.

5. Differential Pricing for Anonymous Trades

The prior section documents substantial variation in pricing across brokers. We were surprised to find such wide differences. Indeed, given that all trades are executed on exchanges where trades are anonymous, it would seem that such dispersion is not possible. In this section, we document the mechanism for creating differential pricing, as well as its primary economic driver.

5.1. Creation of Differential Pricing

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.

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

To examine whether or not venues are systematically altering these choices, for each of our brokers, Table 8 reports the fractions of our orders that are executed through PIM auctions. The remainder represents the percentage sent as auto-execution trades.[44] Next, we report our average price improvement for each trade type. We also report our overall price improvement from Table 3 in the first column for reference purposes.

<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,[45] using PIM auctions suffers from Type I and Type II errors. As expected, most price improvement comes through PIM auctions, with average price improvement of 45%, whereas auto-execution trades have average price improvement of only 5.6%.

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 price improvement, against 2.5% for Robinhood. The price improvement correlation across the two trade types is +0.98. The

[44] 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.

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

data are also shown in Figure 3, with confidence intervals.

<Insert Figure 3 about here>

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 shown in Figure 4. Of the overall execution differences, 41% is due to the execution method choice, versus 51% from auction pricing, and close to 8% from auto-execution pricing.

<Insert Figure 4 about here>

5.2. Major Economic Driver for Differential Pricing

Our results show that, beyond the identity of the broker, other factors do not seem to explain variations in the observed price improvement. These factors even include order imbalance, which has been found to have substantial explanatory power for equity trades. On the other hand, PFOF is a variable directly linked to the broker.

To assess the importance of PFOF, we report the PFOF amounts for our six brokers in the first column in Table 9, using data from their Form 606 during the experiment period. However, it is important to note that the PFOF amounts for most brokers are only estimates, as brokers' Form 606 filing usually does not provide the exact formulas that assign different payments to various bid/ask spread buckets.[46] Specifically, the numbers in the table are based on the per-share PFOF numbers reported in the forms. Potential measurement errors may arise because

[46]For example, Robinhood's Form 606 filing describes "for single leg orders, RHS received a per contract rate for orders of 1-100 contracts of \$0.30, \$0.38, \$0.56, \$0.70, \$0.90 or \$1.20 depending on the symbol's average spread."

our trading sample does not fully align with the actual trading patterns of brokers' clients during this period. These measurement errors likely attenuate the relationship between PFOF and price execution we could find. To examine the impact of PFOF on pricing, we report the correlation of our price improvement measures and execution type with PFOF across brokers in the last row.

<Insert Table 9 about here>

The dispersion we observe in overall price improvement is highly correlated with PFOF levels, with an average correlation coefficient of -0.90. As illustrated in Figure 5, which plots price improvement against PFOF, the relation between these two variables is nearly perfect. Only Schwab is slightly out of order.[47] This evidence suggests that PFOF directly affects execution pricing for options, even for anonymous trades on exchanges. The slope for retail *option* trades is strikingly different from the equivalent graph in Schwarz et al. (2024), which exhibits an almost negligible relationship between price improvement and PFOF for retail *equity* trades.

<Insert Figure 5 about here>

At the top end, Vanguard–which receives no PFOF–achieves price improvement above 50%, even better than the mid-point of the bid-ask spread. This is probably because wholesalers can take advantage of fee rebates without passing them through to Vanguard. In contrast, Fidelity recaptures at least some of these rebates,[48] which explains the lower price improvement of 41%.

[47] According to industry professionals, Schwab uses the same PFOF schedule as TD Ameritrade to avoid regulatory scrutiny, since both brokers are now owned by Schwab. In other words, other factors may affect the relation between price improvement and PFOF for Schwab. Excluding Schwab from the analysis results in a near-perfect correlation of -0.99 between price improvement and PFOF.

[48] Fidelity's Form 606 filing describes "FBS, through its affiliated broker-dealer NFS, does not negotiate, set rates for, or solicit payment for order flow on option orders. FBS does, however, receive compensation from options exchanges and/or brokers associated with the routing of options order flow."

As the size of the PFOF increases, the price improvement decreases monotonically. At the other end, when PFOF is large, the price improvement for Robinhood is only 7%.

We also find similarly strong correlations between PFOF and each component that contributes to the differential pricing. The use of auctions has a correlation of −0.83 with PFOF. The correlation between price improvement and PFOF with both auction and auto-execution trades is −0.93 and −0.91. To illustrate the strength of these relations, Figure 6 plots the link between PFOF and auction usage (Panel A), auction price improvement (Panel B), and auto-execution price improvement (Panel C), across brokers.

<Insert Figure 6 about here>

Overall, PFOF appears to be a major, if not the most important driver, of price improvement differences across brokers. In the next section, we discuss why the economic driver of price execution of retail trades in the option market differs from those in the equity markets.

6. 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 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. Next, we address the current state of disclosure in the options market and suggest potential improvements that could enhance market transparency and thus better inform retail investors. Finally, we discuss total trading costs, including fees and price improvement.

6.1. 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 direct control of pricing once the order is routed to them, though they are also required to fill 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 multiple times higher than in the equity market. Conversely, the literature has documented that the impact of order flow toxicity is much more homogeneous in the options market but highly heterogeneous in the equity market.[49] These differences may explain why PFOF plays a dominant role in driving variations in price execution in the options market, whereas order flow toxicity is the primary driver in the equity market.

6.2. *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, hoping to create 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 still present. First, the venue has discretion over whether or not a trade goes through the 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 price improvement varies from

[49] Various studies use 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)).

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.[50] 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 to PIM auctions will be forced to take 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, worse 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.

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

Finally, for auto-execution, as explained previously, wholesalers can choose to route our market orders as limit orders within the spread to create price improvement. By doing so, they can create price improvement across our brokers that varies from 2% to 12%, which is highly correlated by PFOF. This is a method the wholesalers can use to create price improvement without opening up the trade to competition as well.

6.3. 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.[51]

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 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

[51]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.

the percentage executed via PIM auction and their resulting price improvement.

Admittedly, option trades involve a broader range of contracts compared to single equities, varying by type, strike prices, and tenor, for the same underlying symbol. 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. In addition, brokers already receive detailed option execution statistics for their trades from external data providers.

Given the significant recent increase in option trade volumes and the execution differences 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.

6.4. Total Trading Costs

Unlike equities, where there are no commissions or fees, option trades incur broker fees on a per contract basis, implying that the total fee amounts scale with the size of the order.[52] These fees vary across brokers. Both fees and PFOF contribute to a broker's revenue, and appear to be negatively correlated.[53] In our sample, the broker with zero fees receives the highest PFOF payment, while the broker with highest fees receives zero PFOF payment. Other brokers fall somewhere in between.

[52]Some very small reporting fees are charged for equities but these are largely homogeneous across brokers. In this section, we are using broker-listed fees. Some brokers may have different fees depending on some trade characteristics, or capped fees.

[53]Fees generally are higher than necessary to cover the reporting and regulatory fees from trading. To generate revenue, a broker may replace or supplement fees with other sources, such as PFOF. Brokers could select different fee structures to support their overall business models.

At first glance, fees are paid by customers, whereas PFOF is paid by the venue. However, as our findings show that PFOF is a primary driver for the variation in price execution across brokers, the negative correlation between broker fees and PFOF creates a relation between broker fees and price execution, which both contribute to the overall trading costs incurred by retail investors. In our experiment, the broker with the highest fees tends to offer the best average price execution, whereas the broker with no fees provides the worst average price execution.[54] Ultimately, total trading costs for each broker depend on the relative magnitude of execution costs to fees.

To illustrate, for each broker, we compute the total round-trip trading costs in dollars including both the fees and execution costs across a range of increasing bid/ask spreads.[55] For each broker, the cost of a single trade is calculated by combining the listed fees and the execution cost, the latter derived from the price improvement applied to the dollar spread. This total is then multiplied by two to account for the round-trip transaction. We report results in Figure 7. The graph is split into sections listing the broker with the lowest trading costs for that range.

<Insert Figure 7 about here>

For one-cent spreads, Robinhood has the lowest total trade cost because it charges no fee. However, its fee advantage is offset by worse price execution with higher spreads. For two-cent spreads, Fidelity has slightly better total costs. Once spreads are above $0.03, Vanguard is

[54] As explained previously, because there is no fee to cover exchange costs, the broker with no fees also limits product choice by not allowing trading of single-exchange index options like SPX(W), which is the highest volume symbol in OPRA during our sample period.

[55] We use the spread instead of the price of the contract because the spread is the primary driver for dollar execution costs; indeed price execution tends to be consistent within a broker as a percentage of the NBBO spread.

always the lowest-cost broker. As a reference, 25% of trades in OPRA are one-cent spreads, and the median spread is $0.05.

While both fee and price execution affect the total trade transaction costs incurred by retail investors, fees are more transparent and salient while price execution is more opaque, akin to the contrast between the front-end loads and operating expenses in the mutual fund industry (e.g., Barber et al. (2005)). As a result, these two components may influence investor's trading behavior differently, implying that the fee structure may have significant wealth implications for retail investors. Given attention is a limited resource, retail investors are more likely to focus on the salient component (broker fees) but only partially process the opaque component (execution costs).[56] Therefore, lower broker fees might appear more attractive to retail investors and induce more option trades by their customers. Retail investors should be mindful of both fees and execution costs, which again justifies public disclosures of option execution costs across brokers.

7. 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 their execution quality across brokers. We find that price improvement, measured as a percent of NBBO, ranges from 7% to 52%. In terms of round-trip execution costs relative to notional, average costs across brokers range from around zero to 7%. Even at small quantities, these differences are economically large and, given the recent surge in retail option trading, such price execution

[56]For a summary of studies documenting evidence of limited attention and salience in various economic settings, see DellaVigna (2009). For example, individuals tend to be inattentive to shipping costs in eBay auctions (Hossain and Morgan (2006)) or to nontransparent taxes (Chetty et al. (2009)).

differences are economically important.

Venues are able to create differential pricing due to the option market structure. Notably, 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 better price improvement on auction trades as well. We also find that auto-execution trades have price improvement variation across brokers, albeit to a lesser extent.

Next, we find strong evidence that a primary economic driver of these differences is payment for order flow. The correlation between price improvement and PFOF is -0.91. PFOF is also strongly negatively correlated (-0.83) with the use of auctions. We also find similar correlations between price improvement and PFOF for auctions (-0.93) and auto-execution trades (-0.91). These results are markedly different from the relation between price improvement and PFOF observed for equity trades, where price improvement differs across brokers but does not seem related to PFOF and instead seems primarily driven by variation in broker order flow toxicity. In contrast, our option experiment suggests that the relation between price improvement and PFOF 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.

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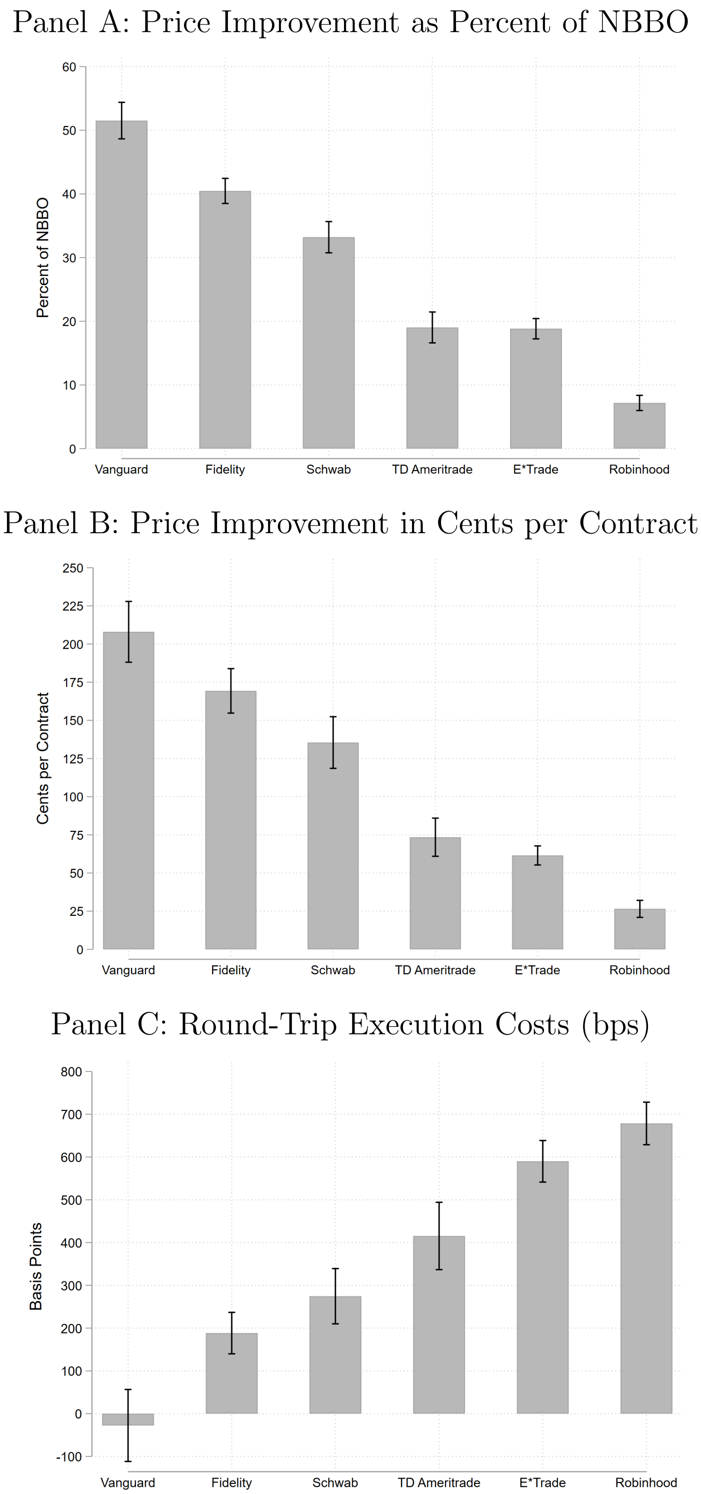


Figure 1: Price Improvement by Brokerage Account
This figure presents the average price improvement, measured relative to the National Best Bid and Offer (NBBO) in percent (Panel A) and cents per contract (Panel B). Panel C presents round-trip execution costs, relative to principal, for the purchase 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.

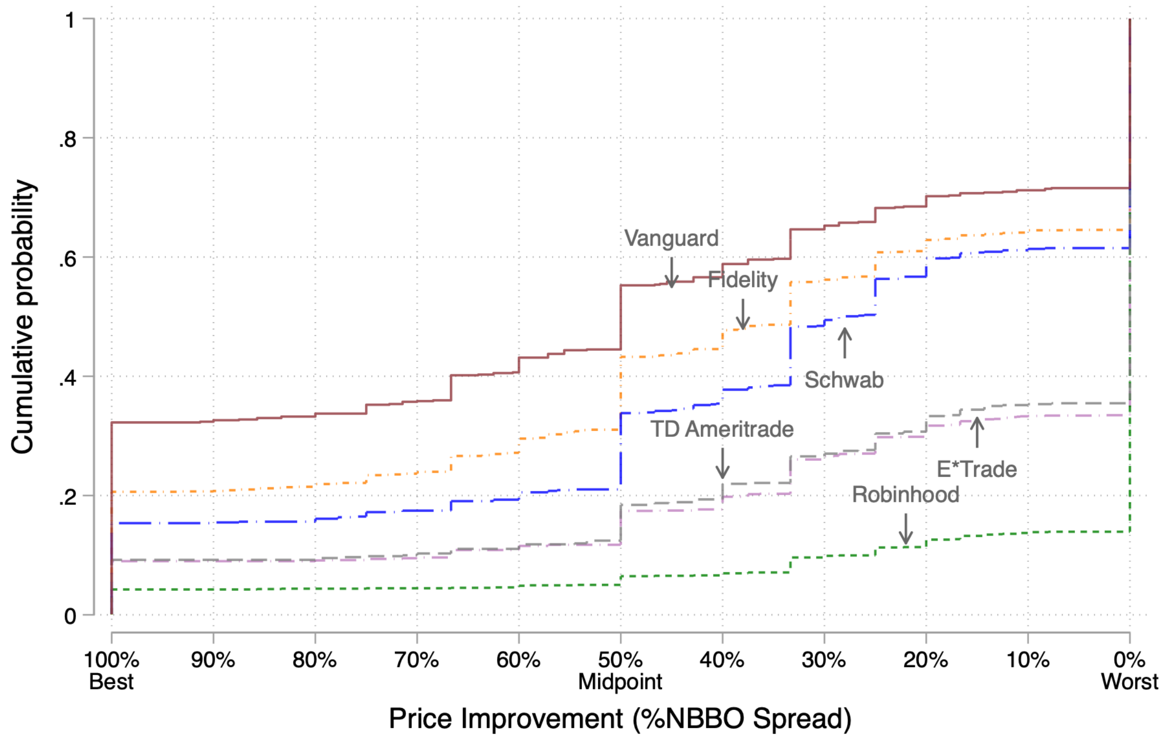


Figure 2: Cumulative Distribution of Price Improvement by Broker

The figure presents the cumulative distribution of price improvement (PI) as a percent of NBBO by broker. PI (%NBBO) 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.

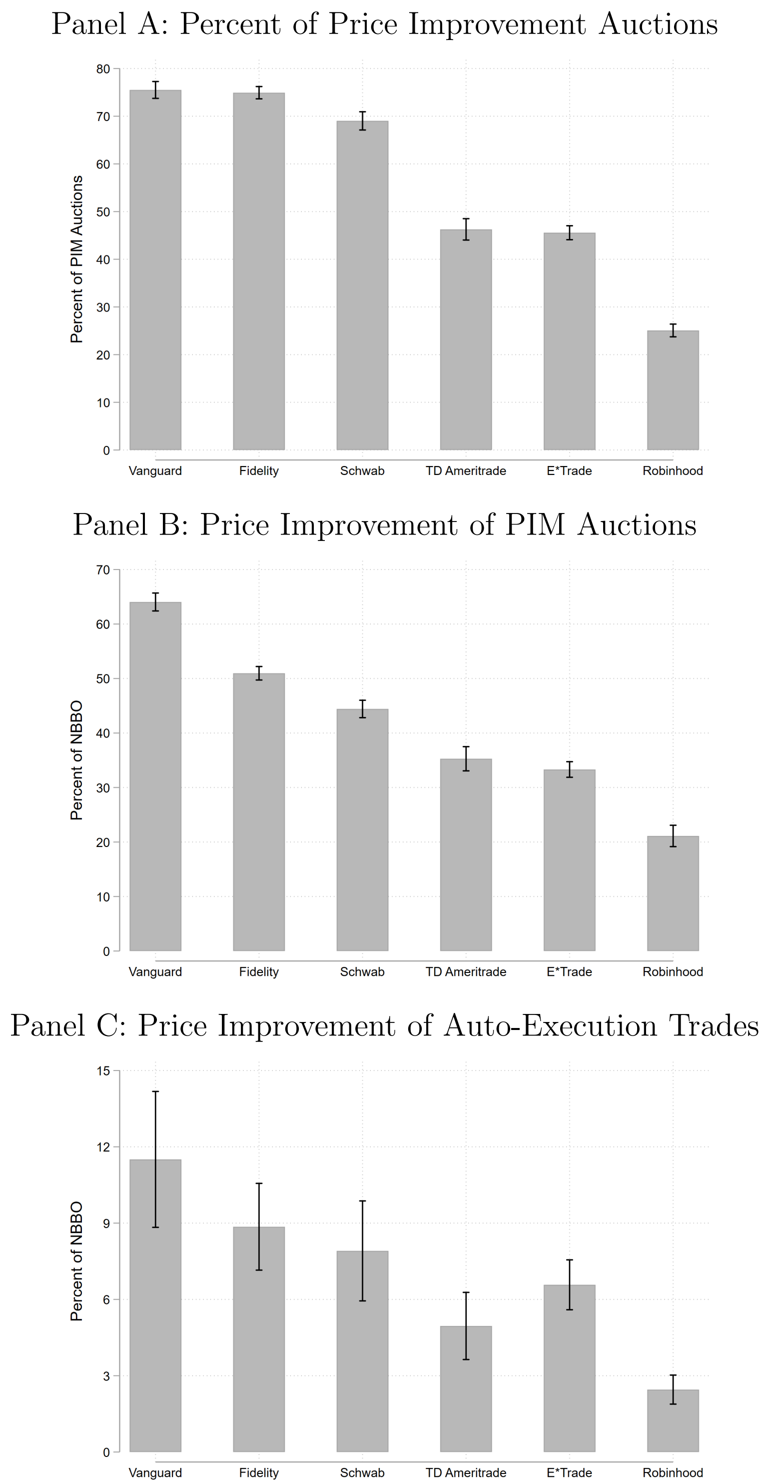


Figure 3: Auction Use and Price Improvement by Order Type and Broker
This figure presents the percentage of PIM Auctions used by broker (Panel A). It also shows the average price improvement, measured relative to the National Best Bid and Offer (NBBO) in percent, for PIM Auction trades (Panel B) and for auto-execution trades (Panel C) by broker. Whiskers represent 95% confidence intervals.

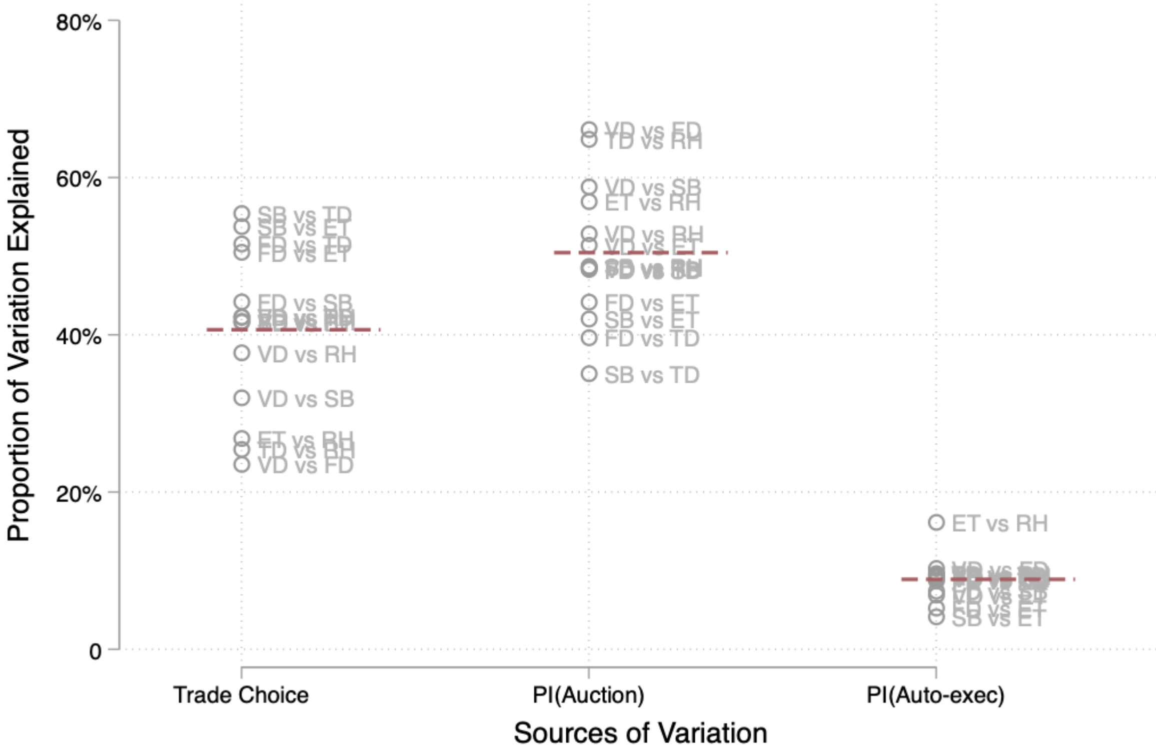


Figure 4: Breakdown of Differential Pricing

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.

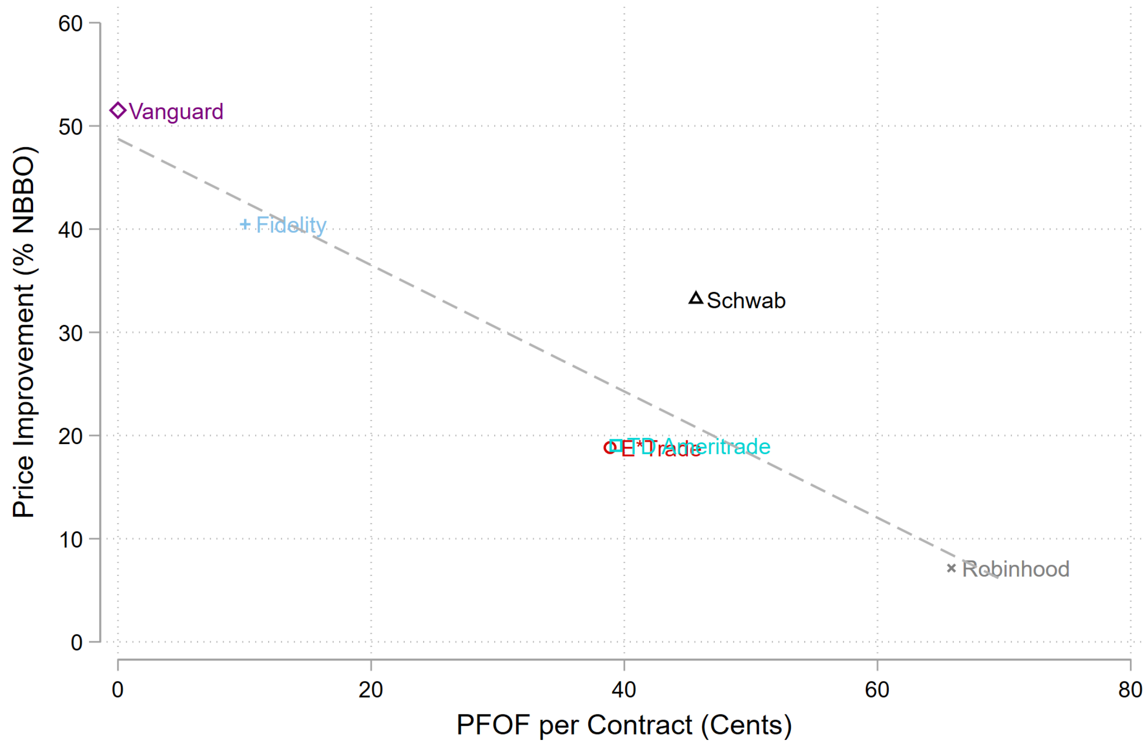
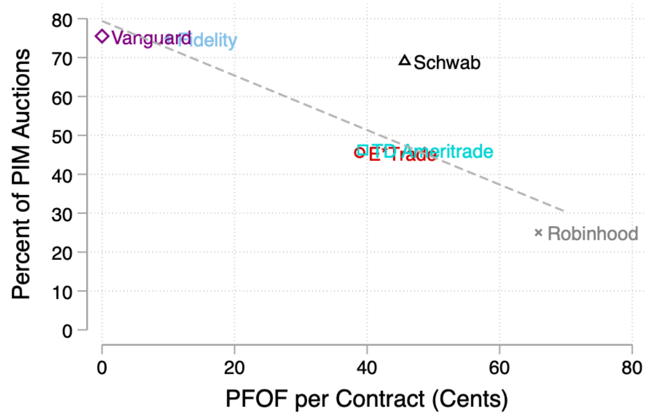
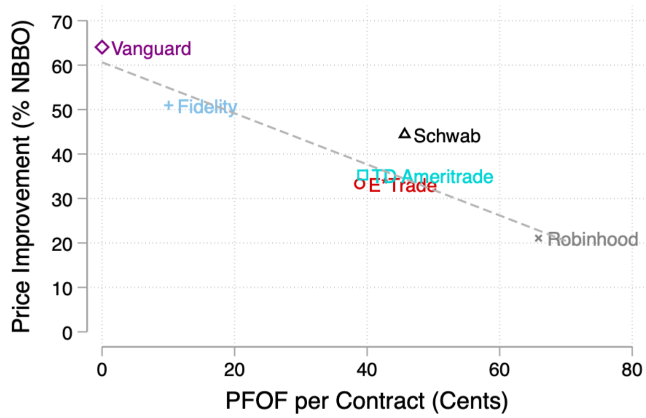


Figure 5: Price Improvement versus Payment for Order Flow
Price improvement is percent of the NBBO. Payment for order flow (PFOF) is in cents per contract based on broker filings (Form 606), using volume-weighted averages from April to June 2024.

Panel A: Percent of PIM Auctions



Panel B: Price Improvement of PIM Auctions



Panel C: Price Improvement of Auto-Execution Trades

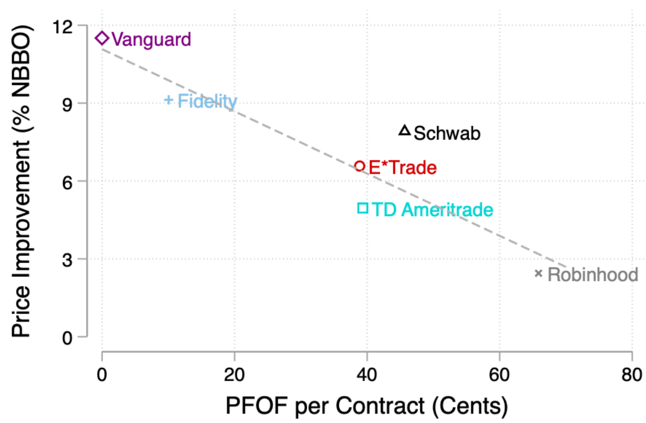


Figure 6: Auction Use and Price Improvement versus Payment for Order Flow
Percent of PIM Auctions reflects the frequency of PIM Auctions. Price improvement is in percent of the NBBO. Payment for order flow (PFOF) is in cents per contract based on broker filings (Form 606). Panel A reports results for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

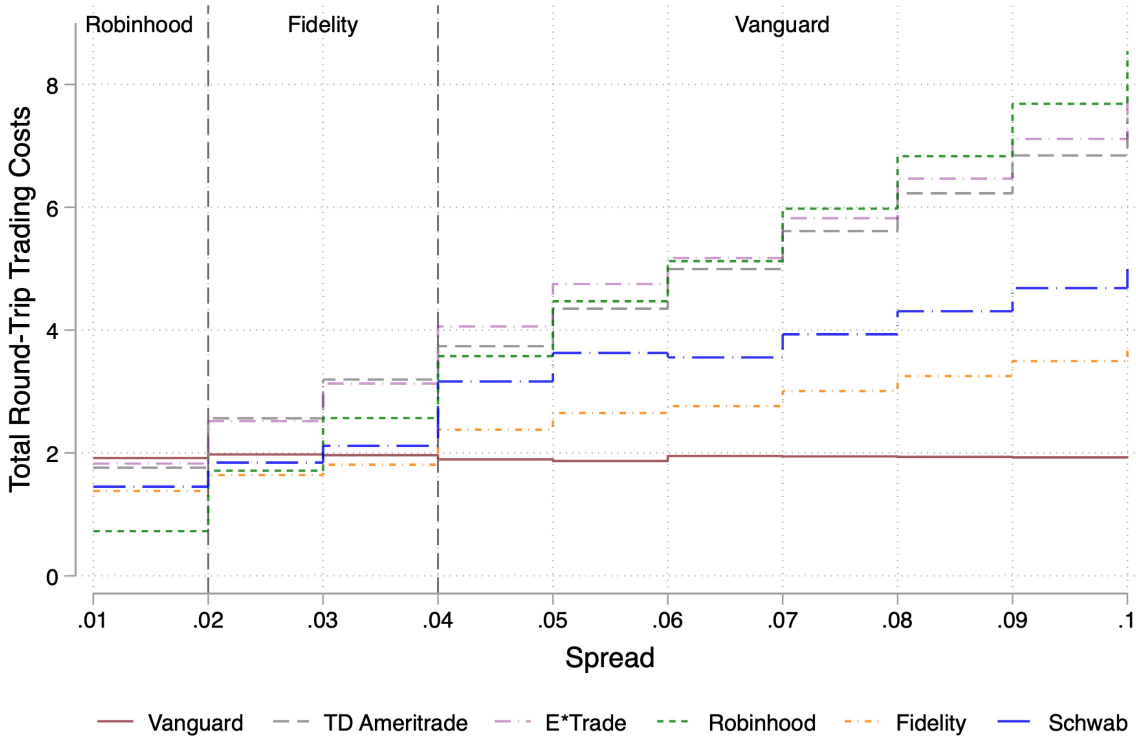


Figure 7: Total Round-trip Trading Costs by Broker and Spread
In this figure, we display the total round-trip trading costs per contract for each broker across bid/ask spreads. Total trading costs are calculated using the listed fee as well as execution costs, based on the price improvement (%NBBO) applied to the dollar spread, all multiplied by two. The graph is split into sections listing the broker with the lowest total trading cost for that range at the bottom

Table 1: Description of Retail Brokers in Experiment

For the six brokers used to trade options, Panel A gives the start date of 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 inferred payment per 100 shares, in addition to that actually 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 (cents) 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 their own venue-affiliated Designated Market Makers (DMM). We then select 15 more symbols where some venues are not be able to route all the trades to their own DMM. Venue codes are *CDRG* for Citadel, *WEXM* for Wolverine, *SIGQ* for Susquehanna/G1X, *DFIN* for Dash/IMC, and *MSCO* for Morgan Stanley. The "X" shows whether the venue could route the trade to an exchange with its own DMM. The table also 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
Panel A: 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
Panel B: 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) price improvement, the mean price improvement measured as a fraction of the NBBO spread and in cents per contract, and the mean round-trip execution cost in bps. 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.

	%Trades	Mean Price Improvement		Round-Trip
Execution at:	($PI > 0$)	%NBBO	(¢/contr.)	Execution Cost (bps)
All Brokers	44.6	26.8	107.87	392
Vanguard	71.7	51.5	207.99	-28
Fidelity	65.1	40.5	169.39	179
Schwab	60.8	33.2	135.48	275
TD Ameritrade	35.2	19.0	73.44	415
E*Trade	34.4	18.8	61.51	590
Robinhood	13.9	7.2	26.50	678
Benchmarks:				
Midpoint	100	50	207.53	0.0
NBBO	0	0	0	800

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). Positive values indicate that Broker A has greater price improvement. 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**	-27.5**	-12.1**	-10.8**	–
	(-26.11)	(-22.04)	(-12.94)	(-7.67)	(-11.86)	

Table 5: 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 of disclosures of venue routing for our trades 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 6: Pairwise Broker Differences in Price Improvement: Same versus Different Trading Venues

This table presents pairwise differences between price improvement (PI, 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 (%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 7: 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 as well as symbol and venue fixed effects. The third model includes other controls. 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. DMM Available is one if the wholesaler's affiliated market maker is the DMM for that symbol on at least one exchange. 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**	0.483	25.07**	0.687	8.38**
Fidelity	-0.110	-6.27**	-0.117	-5.90**	-0.115	-5.87**
Schwab	-0.183	-8.40**	-0.176	-7.52**	-0.172	-7.56**
TD Ameritrade	-0.325	-18.20**	-0.323	-14.98**	-0.316	-13.73**
E*Trade	-0.327	-22.35**	-0.336	-18.85**	-0.334	-18.93**
Robinhood	-0.443	-28.00**	-0.436	-24.13**	-0.443	-25.19**
2nd Trade			0.017	1.77	0.014	1.44
3rd Trade			0.007	0.76	0.002	0.25
4th or higher Trade			-0.018	-2.37*	-0.020	-2.49*
DMM Available (1/0)					-0.022	-1.27
Buy (1/0)					-0.003	-0.33
OIB					0.004	0.39
Log(Volume)					-0.015	-2.19*
2-3 Cent Spread (1/0)					-0.080	-2.46*
4-5 Cent Spread (1/0)					-0.131	-3.72**
6-10 Cent Spread (1/0)					-0.127	-3.17**
>10 Cent Spread (1/0)					-0.137	-3.04**
Trade Price					0.013	1.58
Days to Expiration					0.001	0.59
Implied Vol					-0.016	-0.94
Delta					0.030	1.30
Symbol Fixed Effects	N		Y		Y	
Venue Fixed Effects	N		Y		Y	
Observations	6,609		6,606		6,542	
Adj. R-squared	16.45%		17.80%		18.54%	

Table 8: Execution Method Allocation and Price Improvement by Broker
This table presents the allocation between two execution methods (auction and auto-execution), along with within method and overall price improvement by brokerage accounts. The first column reports overall mean price improvement as a percentage of the NBBO spread. The second column reports the percent of trades that are sent to exchanges as auction trades; the rest are sent as auto-execution trades. The table then report the mean price improvement for both auction and auto-execution of trades. Finally, we report the correlation between overall price improvement, auction usage, and within-method price improvements.

	Mean PI (%NBBO)	%Trades	Mean PI (%NBBO)	
Execution at:	Overall	Auction	Auction	Auto-exec.
All Brokers	26.8	54.2	44.5	5.6
Vanguard	51.5	75.5	64.0	11.5
Fidelity	40.5	74.9	51.0	9.1
Schwab	33.2	69.0	44.4	7.9
TD Ameritrade	19.0	46.3	35.3	5.0
E*Trade	18.8	45.6	33.3	6.6
Robinhood	7.2	25.1	21.1	2.5
Corr. with Overall PI:		0.96	0.99	0.98

Table 9: Payment for Order Flow and Price Improvement
This table compares different price improvement (PI) measures with PFOF by brokerage accounts. The first column shows the reported PFOF in cents per contract obtained from 606 reports. We then report different price improvement measures, both for overall trades and within each execution method, as well as the fraction of trades executed as auctions. The overall price improvement measures taken from Table 3 while the within-execution price improvement measures are taken from Table 8. Finally, we report the correlation between PFOF and various price improvement measures.

	PFOF (¢/contr.)	PI (¢/contr.)	PI (%NBBO)	% Trades	PI (%NBBO)	PI (%NBBO)
Execution at:		Overall	Overall	Auction	Auction	Auto-exec.
Vanguard	0.0	208.0	51.5	75.5	64.0	11.5
Fidelity	10.1	169.4	40.5	74.9	51.0	9.1
Schwab	45.7	135.5	33.2	69.0	44.4	7.9
TD Ameritrade	39.3	73.4	19.0	46.3	35.3	5.0
E*Trade	38.9	61.5	18.8	45.6	33.3	6.6
Robinhood	65.8	26.5	7.2	25.1	21.1	2.5
Corr. with PFOF:		-0.89	-0.91	-0.83	-0.93	-0.91