

April 14, 2026

Ms. Vanessa A. Countryman, Secretary
U. S. Securities and Exchange Commission
100 F Street, NE
Washington, DC 20549-1090

Re: File No. 4-887; Roundtable on Options Market Structure Reform

Dear Secretary Countryman:

We appreciate the opportunity to provide feedback and comment regarding the Securities and Exchange Commission's Roundtable on Options Market Structure Reform. Option markets are an extremely important component of our financial system with respect to such features as price formation, price discovery, liquidity, as well as risk management, and hedging.

By way of background, the two authors of this comment letter are professors who have been studying the structure of option trading and are continuing to do so. Chester Spatt served as Chief Economist of the Commission (2004- 2007) during the adoption and implementation of Regulation NMS and served as a member of the Commission's Equity Market Structure Advisory Committee (EMSAC) from 2015 through 2018. Thomas Ernst and Chester Spatt also have examined in various studies a range of regulatory and market design issues involving the equity and option markets, including latency and high-frequency trading, order-by-order competition, payment for order flow, order routing as well as crypto trading, and Spatt also has studied the interaction between the order book and order flow, pre-opening trading, and competition among markets.¹

¹ Spatt was one of the founders in the mid-1980s of the *Review of Financial Studies* (which quickly emerged as among the three leading journals in finance) and its second executive editor and served as President of both the Society for Financial Society and the Western Finance Association. Besides the EMSAC, he also has served as a member of both the Model Validation Council of the Federal Reserve System and the Advisory Committee of the Office of Financial Research as well as various non-governmental groups, such as the Systemic Risk Council, the Shadow Financial Regulatory Committee, and the Financial Economists Roundtable.

While there has been considerable attention to potential reforms and innovations in equity market structure and trading, the option markets have not attracted the same degree of interest from the Securities and Exchange Commission (SEC). In that spirit this roundtable is a very welcome development. One justification for the attention to equity trading is the misplaced criticism of equity markets as having almost 50% of it trading “off-exchange” and “in the dark,” suggesting that aspect of the equity market structure is nefarious and such trade is problematic. In contrast, option trades occur only “on exchange,” suggesting to some that such trading requires less attention by regulators. Yet the structure of equity trading leads to considerable direct competition among wholesalers with legitimate potential for entry rather than special privileges being assigned by exchanges to specific wholesalers. Reflecting this, as well as both the relative costs of market marketing and the underlying nature of equity vs. option exposures, equity bid-ask spreads are much smaller than option bid-ask spreads in absolute and relative terms and the structure of the option market is much more arcane. This does not necessarily imply that the option market structure design is inferior, but it certainly suggests that the option markets deserve more attention as compared to the almost exclusive high-level regulatory focus on the equity markets. The importance of increasing attention to the option markets is further motivated by the dramatic increase in interest in option trading by retail investors in recent years. Of course, central to the mission of the SEC is the protection of (retail) investors.

As academic researchers we have been studying the options markets in considerable detail. Many of our findings are reflected in our paper, “Payment for Order Flow and Option Internalization,” forthcoming, *Review of Financial Studies*. There are several important facets of the markets that we should highlight. Many options exchanges appoint a single Designated Market Maker (DMM) to each symbol. This DMM has enhanced quoting obligations but receives certain trading privileges. One of the key privileges is the right to internalize orders for five contracts or less without sharing these orders with other market makers quoting at the same price. While DMMs would normally obtain more orders by quoting a narrower spread, the ability to internalize orders via self-routing limits the incentives of the DMM and other market makers to narrow the bid-ask spread. In fact, the results in our paper highlight the differences in execution quality between five-contract and six-contract trades. While there may be several exchanges which each assign a unique local DMM for each symbol, the vast majority of DMM seats are held by a small number of firms. [Assignments, once made, are rarely reassigned; in the event a firm with DMM seats is sold, the acquirer also obtains the DMM seats held by the target firm.]

When wholesalers compete for order flow from retail brokers, wholesalers with many DMM seats have flexibility in methods for internalizing order flow which wholesalers with few DMM seats do not have access. Controlling the routing of retail order flow is critical, both because of the ability to internalize via the DMM route, and via alternative routes. Price improvement auctions provide another example, as the initiator of a price improvement auction is granted the right to match incoming bids in an otherwise blind auction. As a result, there is a winner’s curse faced by other bidders, and our paper highlights that this winner’s curse is especially severe for single-

contract trades [where the contract cannot be split, and therefore the auction initiator will always win if they elect to auto-match competing bids]. We find that single-contract orders pay larger effective spreads than similar two, three, or four-contract trades, consistent with this winner's curse preventing competition.

While option order flow executes almost entirely on-exchange, rather than off-exchange, outcomes are not inherently more competitive. To the contrary, our paper finds that auction initiators and DMMs have powerful advantages in internalizing retail order flow, and the largest option wholesalers, who are also the largest DMMs, have advantages which may serve as a barrier to competition from new entrants to option wholesaling.

Finally, we should note that much more information is available for equity execution quality than option execution quality and indeed, recent SEC rule-making further enhanced the equity disclosures under Rule 605. Both relative and absolute spreads in options are substantially higher than equity. Some of this variation is no doubt due to differences in instruments (such as lower option price levels and greater inherent private information), yet the room for potential spread improvement, or the consequences for an investor deciding between a market or limit order are substantially higher with larger spreads. While investors enjoy substantial information about the performance of equity orders under 605, no similar data exists for option orders. This suggests the potential scope for an enhanced look at option market disclosures, though we fully recognize that this is not a straightforward issue.

We very much appreciate the opportunity to share our perspectives and views about option market structure with the Commission, the SEC staff, and roundtable participants. To facilitate review of our more detailed analysis, we have appended to this comment letter our underlying academic paper, "Payment for Order Flow and Option Internalization," *Review of Financial Studies*, forthcoming.

Best,

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Payment for Order Flow and Option Internalization

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Option wholesalers specialize in purchasing and executing against retail option order flow. Orders are internalized via auctions (which provide price improvement) and the limit order book. Designated market makers (DMMs) have a key advantage in internalizing limit order book trades: they obtain the first five contracts of any order they bring to an exchange where they are a DMM. We exploit variation in DMM assignments and allocation rules to highlight how these rules create a barrier to entry in option wholesaling that does not exist for equity wholesaling, protecting wholesaler profits and high option PFOF. (*JEL* G13, G14, G23)

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Financial technology has drastically reduced trading expenses, and falling costs have led many brokers to abandon fixed commissions for alternative revenue schemes, such as payment for order flow (PFOF).¹ This practice has raised a series of concerns from both market participants and the U.S.

First Draft: October 2021. For helpful comments, we are thankful to Robert Battalio, Svetlana Bryzgalova, Zhi Da, Anne Haubo Dyhrberg, Brian Hatch, Terrence Hendershott, Steve Heston, Saad Ali Khan, Pete Kyle, Craig Lewis, Stewart Mayhew, Dmitriy Muravyev, Bernt Arne Odegaard, Anna Pavlova, Neil Pearson, John Shim, Andriy Shkilko, and Robert Van Ness; several anonymous industry participants; and seminar participants at Carnegie Mellon University, the University of Cincinnati, Hofstra University, the University of Maryland, the Microstructure Exchange, the University of Mississippi, the SFS Cavalcade, the Econometric Society, FMA Europe, FMA Derivatives and Volatility, Eastern Finance Association, European Finance Association, Midwestern Finance Association, Tepper-LAEF, NBER Big Data meeting, and the University of Washington, and for financial support we gratefully acknowledge the Block Center at Carnegie Mellon. The paper was previously circulated under the title "Payment for Order Flow and Asset Choice." Send correspondence to Chester Spatt, cs patt@andrew.cmu.edu.

¹ Payment for order flow involves payments from wholesalers (such as "Citadel") to brokers (such as "Robinhood"), made on the condition that a broker privately routes orders to the wholesaler rather than to the public markets.

Securities and Exchange Commission (SEC). The first concern is that these trades may not receive the best prices. The second is that the practice of routing customer orders to wholesalers—market makers who specialize in executing retail orders—may lead to wider bid-ask spreads on exchanges. The third is that retail brokerages have incentives to encourage excess trading.

Although the SEC has focused on equity regulation, our article highlights the critical role of option trading in these concerns. Two-thirds of total PFOF payments are paid to brokers routing option orders. Because of clearing considerations, option markets do not provide off-exchange internalization. Instead, all trades occur on-exchange, with exchange-provided methods for internalizing trades. We contribute an analysis of two key methods of internalizing retail option trades: designated market maker (DMM) assignments and price improvement mechanism (PIM) auctions. DMM assignments provide a powerful method of internalizing trades, and the top three wholesalers (Citadel, SIG, and Wolverine) control 74% of all DMM seats. This gives these firms an advantage in internalizing retail trades, and the fact that DMM seats are rarely reassigned creates a barrier to entry by natural competitors, like other option market makers or equity wholesalers. The lack of competition for option wholesaling protects the revenues of option wholesalers and enables option wholesalers to pay high prices for the flow of option orders.

Wholesalers compete for order flow on the basis of aggregate price improvement (filling retail orders at prices better than the NBBO). Brokers periodically measure aggregate price improvement obtained from each wholesaler and adjust the future order flow accordingly, routing more orders to wholesalers who offer more price improvement. On every order, wholesalers face a trade-off between charging a wider spread (earning profit today) and charging a narrower spread (receiving more future order flow). Option markets have the added complexity that all trades must be executed on exchange, which adds a further goal for wholesalers: to ensure that they trade against the purchased order flow and not a competitor.

Most U.S. option exchanges have designated market makers (DMMs), who are market makers with both a special obligation to quote securities and special privileges in trading. Market makers compete for incoming marketable orders by quoting at the top of the NBBO, but DMMs can bypass the NBBO queue and route up to five contracts directly to their own quote, regardless of their position in time priority or *pro rata* share of the NBBO. This reduces their incentives to improve upon the NBBO, as the benefit of additional marketable order flow must be weighed against decreased spread earned on any self-routed marketable order flow. Consistent with this trade-off, we show that among symbols with just one DMM, DMMs who purchase order flow are associated with wider quoted and effective spreads compared to DMMs who do not purchase order flow.

Most stock symbols have multiple DMMs, so for generalizable analysis we turn to analyzing how patterns of DMM trading behavior change with contract

size.² We find that PFOF-paying DMMs are associated with higher volume than non-PFOF-paying DMMs: when a DMM on an exchange pays for PFOF, that exchange has an additional \$406,000 in monthly trading volume and an additional market share of 1.1% (measured as market share of all exchanges using DMM). The self-routing ability of a DMM, however, is limited to the first 5 contracts of orders they bring to the exchange: if a DMM brings an order for 6 or more contracts, the first 5 will be allocated to the DMM while the remaining contract(s) will be allocated according to the NBBO priority rules. Consistent with PFOF-paying DMMs purchasing retail order flow and routing it to exchanges where they are DMMs, the volume-share increases we observe are concentrated in contract sizes below 10 contracts. We then examine the usage of auctions at an exchange where the DMM pays for PFOF, and the exchange is quoting at the NBBO. Under these conditions, the internalization route of the DMM is likely available to a DMM,³ but the DMM can select the auction to provide price improvement (which is monitored by brokers and used to allocate future order flow). Larger quoted spreads are associated with a greater likelihood that a trade enters an auction, consistent with wholesalers seeking to provide price improvement when exchange spreads are wide. This likelihood is much greater for larger trades and smaller for trades of five contracts or fewer. As wholesalers have discretion over which trades to provide price improvement, these results are consistent with wholesalers rationally responding to their incentives, prioritizing providing price improvement for trades which they could not fully internalize via the DMM allocation, and prioritizing internalizing at the NBBO spread for smaller orders which can be fully internalized via the DMM allocation.

Market makers can also internalize retail trades in a PIM auction, whereby a market maker brings a retail trade and proposes a price, after which other participants can enter the auction and propose better prices. These auctions are commonplace, consisting of 16% of all single-leg trades and 18% of the dollar volume of single-leg trades, generating apparent savings of \$150 million to \$650 million per month.⁴ The bar for an improvement in options is much lower, however, as option bid-ask spreads can be quite wide, particularly for thinly traded contracts. Although option market making costs are higher, as shown in [Battalio and Schultz \(2011\)](#), the preponderance of price improvement

² All but the lowest volume of symbols have more than one DMM. Although DMM assignment will be unique on a specific exchange, 11 exchanges assign DMMs, leading to an overlap in coverage. As an example, at CBOE, Global Trading Systems is the DMM in Coca-Cola, while Citadel is the DMM in Walgreens. At the Miami Options Exchange, Global Trading Systems is the DMM in Walgreens, while Citadel is the DMM in Coca-Cola. Comparing option trades in Coca-Cola at CBOE versus Miami against option trades in Walgreens at CBOE versus Miami allows us to fit fixed effects for both symbols and exchanges, and isolate the role of PFOF, as Citadel pays for order flow while Global Trading Systems does not pay for order flow.

³ OPRA data are anonymous, but DMMs typically have an obligation to quote at the NBBO at least 90% of the trading day; consequently, if an exchange is at the NBBO and has an appointed DMM, it is highly likely the DMM is at the NBBO.

⁴ These savings are measured relative to the option NBBO.

auctions in options raises the question of whether retail trades get as much price improvement as possible.

To test the competitiveness of PIM trades, we examine the winner's curse in auctions, where the market maker who initiates an auction has the right to auto-match competing bids. When there are competing bids, auto-matching leads to a tie, and the initiator and competing bidder split the order. The exception is for trades of a single contract, which cannot be split; as a result, any competing bidders receive the order *only if the initiator declines to auto-match*. We compare execution quality on 1-contract and 2-, 3-, and 4-contract trades. Trades for just one contract pay higher effective spreads than these larger contract sizes, consistent with a winner's curse preventing competing bids in PIM auctions.

In principle, any option market maker could obtain the PIM auction initiator privileges by directly purchasing order flow, but option market makers are evaluated by brokers on the total execution quality that they provide. DMM positions offer better profit on individual trades, while PIM auctions offer price improvement, which guides future allocation decisions by brokers. Market makers who can use both DMM allocations and PIM auctions will be better positioned to extract value from retail trades than market makers who only have access to PIM auctions. Consequently, DMM allocations can serve as a barrier to entry in the retail option market making, particularly in the first stage, where wholesalers compete in aggregate to obtain retail order flow. We contrast this with equities, where any firm can trade off-exchange and internalize trades. The two firms, Citadel and Susquehanna, which buy over 70% of retail option order flow also control 60% of DMM positions. Any entrant into retail option market making will have far less access to the DMM internalization privilege, if any, compared to the current top two retail option market makers, imposing a barrier to competition.

Routing option order flow pays substantially better than routing equity order flow.⁵ When PFOF is the only source of broker income, this discrepancy in PFOF per asset creates a powerful potential incentive misalignment for brokers, with option trades producing substantially more marginal income per trade for the broker than equity trades. Brokers have not only a duty of best execution but also a duty to act placing their clients' interests alongside their own. Our work highlights the market structures that give rise to high option PFOF, and

⁵ From SEC rule 606 reports, we estimate that the typical PFOF paid to a broker for routing a 100-share option trade is around 40 cents, while the typical payment for routing a 100-share equity trade is around 20 cents. In an era of \$5 commissions, an option trade would give a market maker 4% more revenue than an equity trade. With \$0 commissions, an option trade would give a market maker 100% more revenue than an equity trade. Differences in prices between stocks and options provide further amplification. The average retail stock trade is in a \$25 stock, while the average retail option trade is in a \$5 option. A nominal investment of \$1,000 in a \$25 stock would generate a 40-share equity order worth 8 cents in equity PFOF, while a nominal investment of \$1,000 in a \$5 option would generate a 200-share option order worth 80 cents in option PFOF. In other words, the same nominal investment in options will generate 10 times as much PFOF as the investment in equity.

we note that the equity-option differences in PFOFs shape brokers' incentives to guide or direct retail trading and investment.

I. Contribution and Literature Review

While the role of option designated market makers has been studied ([Mayhew \(2002\)](#)), we add novel analysis on the DMM's ability to internalize retail trades, as well as the differences in outcome depending on whether option DMMs are also wholesalers who pay for retail order flow. This dual role in option markets, theoretically modeled in a theoretical setting by [Yueshen and Van Kervel \(2023\)](#), distinguishes option wholesalers from other option DMMs or from equity DMMs, where their role is studied only as a liquidity provider.⁶

The importance of our results is magnified by the boom in retail option trading. [Bryzgalova, Pavlova, and Sikorskaya \(2023\)](#) use price-improvement auction trades to track the volume of retail option trading and document a massive increase in retail option trading. We highlight that PIM auctions are just one method of internalizing trades, with DMM assignments providing an alternative. We show that around the time stocks are added or dropped from the penny pilot program, there are large changes in the share of trades that enter auctions. On the broader topic of retail option trading, [Eaton et al. \(2022\)](#) suggest retail traders increase volatility, while [Bogousslavsky and Muravyev \(2024\)](#) use trade journal data to track option positions taken by a series of fairly sophisticated option traders. Our focus is on trade-level execution quality for single-leg option trades, while [Li, Musto, and Pearson \(2023\)](#) examine complex multileg options.

Our paper introduces an analysis of how DMM assignments affect competition in retail wholesaling. [Hendershott, Khan, and Riordan \(2025\)](#) also analyze wholesaling, including how wholesalers use auctions to obtain order flow from brokers. Despite most auctions failing to attract multiple bidders, they argue option auctions provide more competition than nonoption trades in terms of lower trading costs and market maker revenues.⁷ [Anand and Muravyev \(2024\)](#) examine the relationship between auctions and prevailing quotes, showing that auctions are much more likely when an exchange is

⁶ For example, [Bessembinder, Hao, and Zheng \(2020\)](#), [Venkataraman and Waisburd \(2007\)](#), [Foley et al. \(2020\)](#), and [Clark-Joseph, Ye, and Zi \(2017\)](#) analyze DMMs, while [Madhavan and Smidt \(1993\)](#) examine the related specialist system.

⁷ Following our paper, they also examine how DMM assignments influence quoted spreads and transaction costs. They show that wholesaler DMMs offer more price improvement later in the month, consistent with competitive pressures to obtain order flow from brokers. Complementary to their analysis, we show that wholesaler DMM auction use depends on trade size; wholesalers do not obtain their DMM allocation benefit if they submit a trade to an auction, so they use auctions more readily for larger trades, where the DMM allocation benefit is a smaller share of the order. While [Hendershott, Khan, and Riordan \(2025\)](#) analyze all auctions, we use DMM allocation rules based on trade size to show how these affect order routing, auction use, price improvement, and trading costs.

not at the NBBO.⁸ While [Anand and Muravyev \(2024\)](#) focus on auctions when a market maker does not have a quote at the NBBO, we examine the market maker's use of auctions when the market maker is at the NBBO. This voluntary auction usage is consistent with option wholesalers competing for order flow from retail brokers, particularly for larger orders that they cannot fully internalize. Subsequent work to our paper by [Schwarz, Huang, and Jorion \(2024\)](#) tracks routing and execution for a sample of self-placed option trades. They confirm our results on the importance of DMMs, noting that DMMs are 70% more likely to route limit order book trades to an exchange where they are a DMM.

Option markets typically have higher trading costs than equity markets, in part due to the greater difficulty market makers face in hedging, as in [Battalio and Schultz \(2011\)](#). This gamma hedging, in turn, may affect equity markets, analyzed by [Ni et al. \(2021\)](#), though [Hu et al. \(2023\)](#) suggest option market makers rarely hedge. Although option spreads are wide, investors can time their trades, as shown by [Muravyev and Pearson \(2020\)](#), or route to exchanges with particular make-take pricing models as analyzed by [Battalio, Shkilko, and Van Ness \(2016\)](#). [Battalio, Griffith, and Van Ness \(2021\)](#) examine the switch of the PHLX option exchange from make-take to PFOF pricing model. Our paper focuses not on the PFOF model of exchange-trade pricing but instead focuses on the PFOF paid from wholesalers to brokers. Wholesalers may internalize trades on both PFOF-pricing model exchanges, but also on traditional make-take exchanges or fee-free exchanges, with retail trades occurring on all platforms.

Payment for order flow has a long history,⁹ yet zero-commission trading, with PFOF as their primary revenue source, is fairly new.¹⁰ Our paper highlights cross-asset differences, which results in a new incentive conflict arising from the combination of PFOF with zero-commission trading.¹¹ We note that PFOF gives brokers a powerful financial incentive to encourage not

⁸ [Anand and Muravyev \(2024\)](#) also show that auctions when an exchange is not at the NBBO are less likely to provide price improvement, with these auctions matching only the NBBO. The ability to use auctions in this manner reduces the incentives for market makers to quote competitively. After an exogenous rule change that restricted auctions when the NBBO is a penny, they establish a causal link between overall spreads in the market and auctions; they also find that quoted spreads are affected more than effective spreads which can lead to misleading inferences if EQ ratios are examined in isolation.

⁹ [Chordia and Subrahmanyam \(1995\)](#) and [Battalio, Shkilko, and Van Ness \(2016\)](#) examine exchanges, [Easley, Kiefer, and O'Hara \(1996\)](#), [Baldauf, Mollner, and Yueshen \(2024\)](#), [Parlour and Rajan \(2003\)](#), and [Battalio and Holden \(2001\)](#) examine brokers. [Dyhrberg, Shkilko, and Werner \(2025\)](#) and [Battalio, Griffith, and Van Ness \(2021\)](#) examine wholesaling, while [Ernst et al. \(2024\)](#) examine broker routing practices.

¹⁰ [Adams, Kasten, and Kelley \(2024\)](#), [Jain et al. \(2024\)](#), and [Kothari, Johnson, and So \(2021\)](#) examine the switch to zero-commission trading.

¹¹ Typical payment for a 100-share trade is 40 cents in option markets and 20 cents in equity markets. On a fixed \$5 commission, the option trade earns brokers 4% more than the stock. With a \$0 commission, the option pays a broker 100% more than the stock. These differences are per share, so if the investment is in nominal terms, these price differences can be further amplified by the lower nominal price of options.

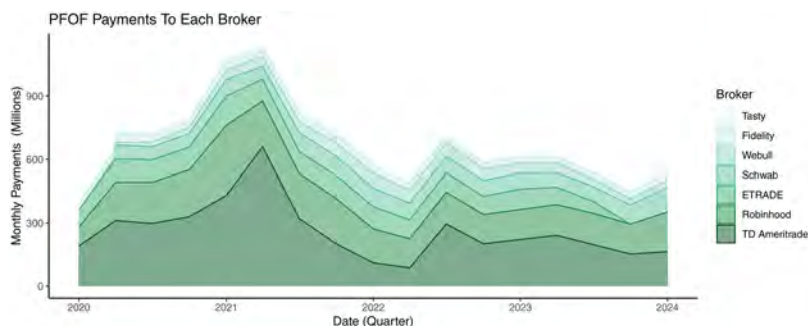


Figure 1
PFOF by broker.

Payment for order flow has increased over time. For our 606 data from January 1, 2020, to December 2023, we document \$10 billion in total payments for order flow across the major brokerages.

just more trading of all assets, but especially trading of options due to their higher payment for order flow.

II. Market Structure, Revenue, and Payments

We begin our analysis with a brief description of option markets. In Section A, we describe the major brokers and wholesalers. We then discuss how brokers route to wholesalers in Section B, and briefly summarize the two main methods by which wholesalers internalize retail trades: DMM assignments and PIM auctions. In Section C, we note how DMM assignments form an entry barrier in retail option wholesaling. Finally, in Section D, we describe the incentives that PFOF offers brokers and provide a discussion of how the SEC proposals affect equity markets, while similar issues in option markets go unaddressed.

A. Routing and payments

Any brokers who take PFOF must report aggregate monthly statistics on where they route orders and how much payment they receive from wholesalers under SEC rule 606. Using these data, we track the total payments made to each broker in Figure 1.¹² Payments vary considerably by asset class. Figure 2 plots the payment for each type of asset. Options are by far the largest share of PFOF, paying around 65% of all PFOF, and the remaining 35% comes from equity. These percentages are based on the total value of the payments, but the payment rate per order is also unequal. Averaged across the main brokerages, options pay an average of 40 cents per 100 shares, while stocks pay an average of 20 cents per 100 shares. Routing is concentrated among a small number of

¹² We use SEC 606 reports for brief motivation and descriptive statistics. Bryzgalova, Pavlova, and Sikorskaya (2023) provide a detailed analysis of SEC 606, including using them to verify measured levels of retail option trading.

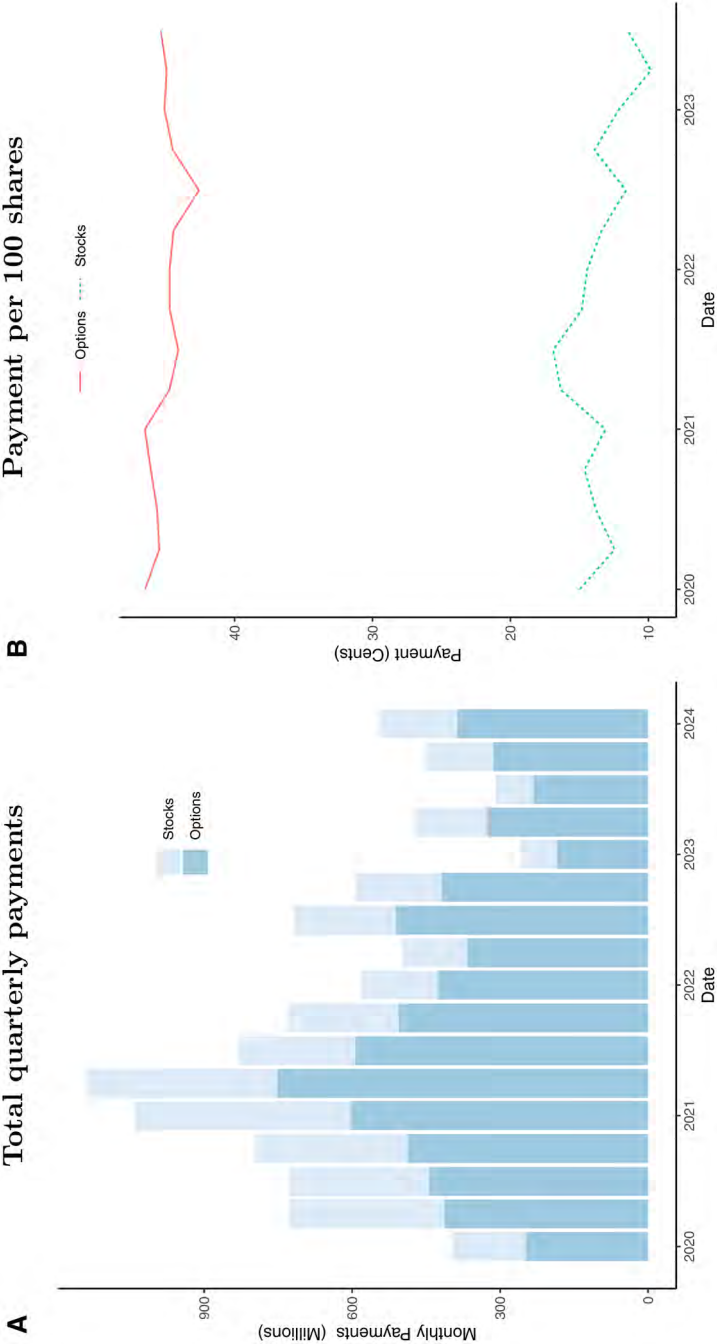


Figure 2

PFOF by asset class.

There are large differences in payments across assets, both in total value and in the payment per share. Panel A presents total payments. Most payment for order flow (65%) comes from option markets. The remainder comes from stocks (35%). Panel B presents the payment rate per 100 shares traded. Options are consistently the highest in payments, averaging over 40 cents per 100 shares traded.

wholesalers. Table 5 in Appendix I documents the routing behavior between asset classes. In each asset class, the top two firms receive 70% of all broker orders. The top 4 firms receive over 90% of all broker routing in each asset class.

B. Competition for retail trades

Retail brokers have a best-execution duty and will route orders to wholesalers based on past price improvement.¹³ Wholesalers want to internalize (trade against) retail trades, and offering more price improvement in one month can lead to obtaining a larger fraction of a broker's retail trades in a future month. However, offering price improvement reduces wholesaler profits, as offering price improvement reduces the amount of revenue they collect from internalizing orders. Wholesalers face a trade-off between maximizing profit on an individual trade (by charging a wide effective spread) and maximizing order flow (by offering better price improvement).¹⁴

Wholesalers are evaluated by brokers on the resultant effective spread of each order they receive. Their goal is to internalize (trade against) the order, so that they earn the effective spread.¹⁵ Internalizing a trade in options is not straightforward, as all orders must execute on exchange due to clearing requirements. Market makers who pay for order flow from brokers control the routing of that flow; they can route to exchanges to try to internalize the order. Option exchanges offer trading procedures that facilitate the internalization process, and we highlight two particular procedures. Designated market maker assignments and Price Improvement Mechanism (PIM) auctions.

A designated market maker (DMM) position provides one advantage for internalizing a trade. For any order that the DMM routes to an exchange, the DMM obtains the first five contracts of the order, provided that the DMM is quoting at the NBBO. As an example, Citadel is the DMM in American Airlines at CBOE; If Citadel is quoting at the NBBO at CBOE and routes a marketable retail order in American Airlines, Citadel receives the first five contracts of the order, regardless of whether other market makers are quoting at the NBBO at

¹³ Ernst et al. (2024) provide a detailed examination of broker routing in the equity market. FINRA rule 5310 mandates that if a broker accepts PFOF, they must justify why it does not shape their routing behavior; to comply with this regulation, all brokers who accept PFOF set a single rate across all wholesalers. If a broker receives 20 cents per 100 shares sent to a wholesaler, it will obtain that same rate from each wholesaler. Note that some brokers use a percentage of the spread payment rather than a fixed rate; under this alternative, the same percentage must be applied equally to all wholesalers.

¹⁴ This trade-off is analogous to that faced by a classic market maker. A market maker has a choice between quoting narrowly (and potentially attracting order flow) and quoting widely (offering more profit). Decisions with a traditional market maker are made based on the quoted spreads for each individual trade, while a broker evaluates wholesalers on the basis of aggregate historical price improvement to route the next day or month of order flow.

¹⁵ Wholesalers may also receive orders for which they perceive a high adverse selection risk or inventory cost; for these orders, they may send the order to another market maker for execution, in a practice known as "externalizing" or "exhaust."

CBOE, even if those brokers have time priority or are quoting a larger depth than Citadel.¹⁶

Price Improvement Mechanism (PIM) auctions provide a second possible method to internalize a trade. Continuing the same example, Citadel could initiate an auction for the retail order with an opening bid. Citadel will fully internalize the order, provided that there are no competing bidders. If there are competing bidders, the order will be split, but rules in the auction favor the auction initiator. As the initiator of this auction example, Citadel has a unique ability to match competing bids (in an otherwise sealed-bid process) and obtains a superior fractional allocation of the order in the case of matching bids.

Wholesalers have a choice of which method to use when internalizing a trade.¹⁷ The DMM method maximizes profit on an individual trade, as the order is filled at the NBBO spread. The PIM mechanism, in contrast, offers price improvement, which is critical for obtaining future order flow from brokers. The method a wholesaler selects can depend on several factors, including market conditions, trade size, and their perceived standing against competing wholesalers.

As a simple example of how size can matter, consider two trades for 5 contracts each, and one trade for 10 contracts. A wholesaler could send all three orders to an auction with 1 cent of price improvement each; alternatively, a wholesaler could send both 5-contract trades to a place where they hold a DMM seat, and send the 10-contract trade to an auction with 3 cents of price improvement. If there are no other bidders, both approaches offer the same price improvement and effective spreads. The latter approach, however, provides better competition against competing bidders: for orders sent through the DMM route, a competitor has no way to win the order, while for the auction trade, there are three cents of improvement relative to the NBBO, meaning a competing bidder would need to offer substantial improvement.¹⁸ We empirically analyze auction usage with market conditions in [Section III C](#), and the nonlinearity around the 5-contract size.¹⁹

¹⁶ For orders larger than 5 contracts, the first 5 contracts are allocated to the DMM. For the remaining contracts, they are assigned to all market makers (including the DMM) at the NBBO according to the priority rules.

¹⁷ They also may not use either method. If, for example, a wholesaler routes to an exchange where they happen to be at the front of the NBBO queue at an exchange with price-time priority, they could route the order to that exchange and obtain the entire order (provided they are quoting sufficient depth).

¹⁸ If it does, the aggregate statistics of the wholesaler will be further improved.

¹⁹ If an order doubles from 2 contracts to 4 contracts, the impact on the wholesaler's order statistics doubles (as the order is twice as big) and the impact on the wholesaler's revenue doubles (assuming the wholesaler obtains the entire order through a DMM allocation). If the contract doubles again to 8 contracts, the impact on the wholesaler's order statistics doubles (as the order is twice as big), but the impact on the wholesaler's revenue does not double (assuming they use a DMM allocation for the first 5 contracts, but the remaining 3 contracts of the order are split among market makers at the NBBO). For orders larger than five contracts, a wholesaler is not guaranteed to obtain the full order; increases in contract size may lead to only small (or no) increase in revenue if the wholesaler fails to trade against the full contract size.

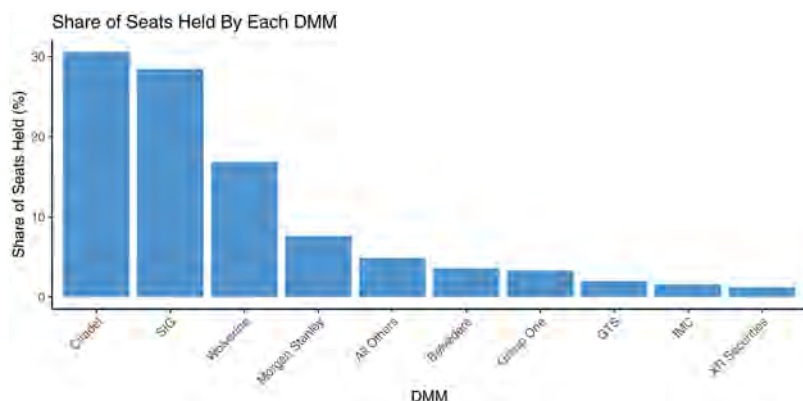


Figure 3

Share of DMM seats by DMM.

We plot the number of DMM seats held by each firm, as a percentage of the total number of seats assigned by all exchanges. Citadel holds 30.5% of all seats; Susquehanna International Group (SIG) holds 28.5% of all seats; Wolverine Execution Services holds 16.8% of all seats; and Morgan Stanley holds 7.6% of all seats.

C. DMM assignments as an entry barrier

Designated market makers (DMMs) are assigned at the exchange-symbol level; exchanges that use DMMs will assign a single market maker as the DMM for each symbol. Option DMM assignment information can almost universally be obtained from the exchange websites. CBOE and EDGX lists are available on the CBOE website.²⁰ AMEX and NYSE ARCA lists are available on the NYSE website.²¹ MIAX and MIAX EMLD are available on the MIAX website.²² Our option DMM assignment data were originally obtained from an anonymous option industry firm and have been verified against the option DMM lists posted by exchanges.²³

DMM assignments are highly concentrated. Figure 3 plots the share of DMM seats held by each DMM. The four largest PFOF-paying wholesalers (Citadel, SIG, Wolverine, and Morgan Stanley) are also the four largest holders of DMM seats, collectively holding 83% of the DMM assignments. The top two firms alone, Citadel and SIG, hold 59% of DMM seats.

²⁰ See https://www.cboe.com/us/options/symboldir/equity_index_options/ and https://www.cboe.com/us/options/symboldir/edgx_equity_index_options/

²¹ See <https://www.nyse.com/publicdocs/nyse/markets/arca-options/EligibleOptionsArca.xls.txt> and <https://www.nyse.com/publicdocs/nyse/markets/american-options/EligibleOptionsAmex.xls.txt>

²² See <https://www.miaxglobal.com/markets/us-options/miax-options/listings> and <https://www.miaxglobal.com/markets/us-options/emerald-options/listings>

²³ In cases in which the DMM list was not posted by an exchange on its website, we sent an email request for the official DMM assignment list to the exchange.



Figure 4
Order flow competition.

Order flow competition occurs in two stages. At stage one, brokers route orders to wholesalers on the basis of best execution, routing more orders to wholesalers offering better average prices. Once an order is allocated to a wholesaler, they must fill the order, which forms stage two of the competition. The wholesaler can send the order to the limit order book (2A), where the order goes through quote competition but the routing wholesaler will have a guaranteed allocation whenever they are a DMM, or through an auction (2B), where competitors can bid but the wholesaler has an advantage as the auction initiator.

DMM seats are a valuable asset, and when one trading firm buys another firm, they also acquire the DMM seats.²⁴ Acquiring DMM seats can be a powerful motivation in mergers or buyouts of trading firms.²⁵ Both equity and option DMM positions can offer reduced trading fees, but option DMM positions confer an additional benefit in enabling internalizing retail option orders. Consequently, the assignment of DMM seats forms a barrier to entry in the retail option wholesaling business, since most exchanges have already assigned their DMM seats in all of the more actively traded symbols.

Competition between wholesalers for retail order flow has two stages. Figure 4 highlights the two-stage nature of this competition. In the first stage, wholesalers compete for the order flow from brokers. In the second stage, wholesalers must execute retail orders through the limit order book or through an auction. Wholesalers may route the trade as a regular limit order book trade (point 2A of Figure 4), in which case there is competition via quotes, but if they are a DMM they have a guaranteed allocation. Wholesalers can route the trade as an auction trade (point 2B of Figure 4), in which anyone can bid for the order, but the initiator has an advantage.

Any market maker could obtain auction initiator rights for themselves by buying order flow directly from a retail broker, and routing these orders to an auction.²⁶ Wholesalers must balance execution quality with gaining spread on internalized orders, however, and wholesalers with DMM seats will have

²⁴ Susquehanna International Group (SIG), for example, acquired Beartooth Capital in 2001, when Beartooth was the DMM on CBOE for Home Depot and Hewlett Packard (Capital (2001)). On acquiring Beartooth, SIG gained those DMM positions, and 20 years later SIG is still the DMM for Home Depot and Hewlett-Packard Enterprise at CBOE. GTS gained many DMM seats by buying the DMM business of Barclays (Parsons (2016)); Barclays, in turn, acquired some of its DMM business from Lehman Brothers' 2008 bankruptcy, which acquired some of its DMM positions from Van der Moolen's bankruptcy in 2007.

²⁵ In several recent instances in equity markets, firms have bought businesses of competitors explicitly with the primary purpose of gaining the DMM seats of their competitor (e.g., Reuters (2020); McDowell (2020)).

²⁶ As we note in Section III.F, the initiator of the auction gains a reduced trading fee, an outsize allocation, and a right to auto-match competing bids.

additional flexibility in internalizing orders than wholesalers that rely on auctions alone.²⁷ For any bundle of retail orders sent by a broker, a market maker with many DMM seats will be able to extract a higher value from internalizing than a DMM without those seats. To obtain a larger bundle of orders for future months, the market maker with many DMM seats will be more economically motivated, as well as able, to provide a higher amount of PFOF and price improvement than a competing market maker with few DMM seats.

D. PFOF and option market regulation

The SEC has recently proposed a substantial overhaul of the U.S. market structure, with a release of four simultaneous proposals on equity markets. Speeches by the SEC Chairman have focused on equity markets, with 3 of the 4 proposals explicitly dealing with equity markets, and none of them explicitly dealing with the option markets.

According to existing SEC rule 605, equity market centers must provide monthly statistics on the execution quality of orders they receive.²⁸ As part of its recent equity market reforms, the SEC recently expanded the required data disclosures for equity, but there is no comparable data set for options. Retail investors, academics, and other market participants are left with much less data on the execution quality that different market centers provide in the options market.

The SEC has recently adopted a rule that reduces access fees permitted under rule 610 in equity markets, but the rule does not apply to option markets. The access fees that traders must pay to an exchange to access liquidity typically differ depending on the volume of the market maker.²⁹ SEC Commissioner Crenshaw, in a 2023 speech, has raised the possibility of a renewed focus on the benefits of access fees in option markets, extending to option markets similar protections to that experienced by equity investors (Crenshaw (2023)). Reductions in access fees would decrease the advantages of DMMs, who currently can internalize order flow with lower take fees. Reducing the advantage of incumbent DMMs, who hold most seats, would help allow competing market makers to enter the business and offer retail clients lower effective spreads on their trades.

²⁷ Anand and Muravyev (2024) examine a rule change which prevented the use of auctions when the NBBO is only one penny wide; this reduces the flexibility of option DMMs to use auctions (stage 2B), and forces them to compete more vigorously on quotes (stage 2A).

²⁸ Dyhrberg, Shkilko, and Werner (2025) use these order statistics to study the execution quality. SEC rule 605 reports allow studying the nature of how brokers route to wholesalers, and the authors are able to characterize the competitiveness of equity wholesaling.

²⁹ Option markets have much higher access fees than equity markets, and option DMMs often have reductions in access fees (or profit-sharing agreements where the exchange shares a portion of access fees collected with a DMM). Ernst and Spatt (2023) propose an access-fee cap apply to PFOF.

The SEC has proposed that retail equity orders each execute in order-by-order auctions as a potential method to increase competition (e.g., [Gensler \(2022\)](#)). Auctions in option markets exist currently, but under a different set of rules than the proposal, with auctions having a guaranteed fill (as the initiator starts with a firm bid), but rules that advantage the initiator and potentially discourage competing bidders.³⁰ While the SEC has proposed auctions with no advantage to the initiator in equity markets, it has not proposed any similar change to option markets.

PFOF payments from wholesalers to brokers are much higher in options than equities, both in aggregate and on a per-share basis.³¹ Under the SEC's Regulation Best Interest, brokers have a mandate to "Act in the best interest of the retail customer at the time the recommendation is made, without placing the financial or other interest of the broker-dealer ahead of the interests of the retail customer." While a broker's financial incentives from PFOF may reward having clients trade options, it is difficult to determine where, exactly, a broker oversteps its bounds, if at all, in offering or promoting option trading. [Bryzgalova, Pavlova, and Sikorskaya \(2025\)](#) show that retail traders often fail to optimally exercise call options before dividend dates, raising questions about the suitability of these options for investors.³²

III. Internalization in Options Markets

As described in [Section II B](#), option wholesalers must take all trades to an option exchange. Wholesalers purchase order flow from retail brokers with the intent of trading against it, and the requirement to bring an order to an exchange presents a challenge in ensuring that they trade against the order and not a competing market maker at the NBBO. In this section, we analyze in depth two methods for internalizing option trades on exchanges, designated market maker (DMM) assignments, and price improvement mechanism (PIM) auctions.

We analyze the use of DMM assignments in two ways. In [Section D](#), we look at the cases in which, across all exchanges, at most one DMM is assigned to the symbol. While this offers a clean differentiation between DMMs who purchase retail order flow and those who do not, it restricts our analysis to symbols with at most one assigned DMM, which tend to be smaller, less liquid

³⁰ From a theoretical standpoint, a winner's curse in auctions can decrease competition for retail order flow, as shown by [Ernst, Spatt, and Sun \(2025\)](#).

³¹ For example, an equally priced \$1,000 investment in a stock with a share price of \$100 would give 20 cents worth of payment for order flow. In contrast, an equally priced \$1,000 investment in an equity option with a price of \$10 would give approximately \$4.00 worth of payment for order flow. Thus a \$1,000 nominal investment in options generates a far larger share volume than an investment in equities; consequently, the option investment also generates a far larger per-dollar-traded payment than an investment in equities.

³² Users have agency in picking assets, however, and have agency in following or rejecting broker recommendations as well as in choosing a brokerage firm. Although 606 reports show that customers of some brokers trade options much more frequently than customers of other brokers, the customer choice of broker is endogenous.

symbols. In subsection B, we focus on the broad cross-section of symbols, and use differences in contract size to study the impact of the DMM's ability to internalize retail option trades when multiple DMMs are assigned to a given symbol across exchanges.

Price Improvement Mechanism (PIM) trades offer a second method for market makers to internalize trades. [Section III.E](#) provides an overview of these trades, which allow a market maker to start an auction to internalize a trade. Although competing market makers can bid, the initiator of the auction has several advantages, and in subsection F we highlight how this can limit competition for orders in auctions.

A. Data

We obtain all U.S. equity options trades reported by the Options Price Reporting Authority (OPRA) from November 4, 2019, to December 31, 2023, through SpiderRock.³³ From SpiderRock, we also obtain matching quotes for the option as well as the underlying asset, and the option Greek values. For matching quotes, we obtain both the best bid and the best ask at the exchange where a trade occurs, and the national best bid and ask across all exchanges.

Our focus is on single-leg option trades. We sign these trades according to [Lee and Ready \(1991\)](#). When analyzing "auto-electronic trades" (OPRA code 73), which trade in a regular limit order book, we use the local best bid or offer at the exchange where the trade occurs, both to sign trades and to calculate effective spreads, as this is more accurate than the National Best Bid or Offer (NBBO).³⁴ When analyzing "Single Leg Auction Non-ISO" trades (OPRA code 97), we use the NBBO, as these trades frequently occur at exchanges where the local exchange's best bid or offer is inferior to the NBBO. [Table 7](#) in [Appendix I](#) presents summary statistics on orders. The average quoted and effective spreads are much higher than for equity trades. We separately report summary statistics for single-leg trades that are executed in a PIM auction and single-leg trades which execute in a limit order book. [Bryzgalova, Pavlova, and Sikorskaya \(2023\)](#) argue that these PIM auctions are primarily retail, but we note that retail trades can also be internalized via other methods, so we analyze both auctions and other methods of internalizing trades, such as the DMM allocation. [Table 1](#) presents summary statistics for each option exchange, as well as key rules.³⁵ As we describe in [Section II C](#), our list of DMMs was

³³ SpiderRock Holdings, LLC is a Chicago-based market data vendor and offers SpiderRock EXS, an agency broker-dealer.

³⁴ Our trade data are prematched to the NBBO by our data provider, SpiderRock. The trade we observe is matched by SpiderRock with the local exchange best bid and offer prevailing before the trade, and with the NBBO as recorded at its data center.

³⁵ We note the substantial cross-exchange variation in quoted and effective spreads, in part driven by differences in the pricing method, queue priority, or the use of DMMs. [Battalio, Shkilko, and Van Ness \(2016\)](#), for example, show that exchanges with a payment-for-order flow model typically have higher effective spreads than those with a maker-taker pricing model. Consequently, in all analyses we fit a fixed effect for each exchange to control for different exchange rules, particularly fee structures.

Table 1
Summary statistics on exchanges.

Exchange	Quoted half spread	Effective spread	Total volume	PIM share	LOB share	DMM	Pricing	Queue priority
AMEX	8.18	2.90	16.63	10.8	10.7	X	PFOF	<i>Pro rata</i>
ARCA	7.01	4.36	19.6		69.8	X	mix	Time
BATS	7.92	3.10	14.3		68.1		MT	Time
BOX	9.74	3.95	10.6	10.60	29.4		MT	Time
C2	7.26	2.04	8.2		31.20		MT	<i>Pro rata</i>
CBOE	10.24	2.72	108.2	3.00	6.7	X	PFOF	<i>Pro rata</i>
EDGX	8.25	2.35	8.6	5.10	16.6	X	PFOF	<i>Pro rata</i>
EMLD	12.85	4.96	10.1	0.00	27.1	X	MT	<i>Pro rata</i>
GMNI	7.69	3.71	7.0	2.30	42.1	X	MT	<i>Pro rata</i>
ISE	11.80	3.35	17.6	1.70	6.4	X	PFOF	<i>Pro rata</i>
MIAx	8.78	2.49	16.3	10.30	8.6	X	PFOF	<i>Pro rata</i>
MPRL	5.70	3.47	9.8		59.40		MT	Time
MRX	8.68	3.42	5.9	19.90	4.3	X	PFOF	<i>Pro rata</i>
NQBX	8.56	2.97	4.9	0.30	20.6	X	Fee-Fee	mix
NSDQ	6.69	3.37	14.5		71.0		MT	Time
PHLX	9.04	3.13	25.2	29.5	9.9	X	mix	<i>Pro rata</i>

This table presents mean, standard deviation, and quantile summary statistics for single-leg trades reported in OPRA for the 30 trading days starting on July 1, 2020. Quoted Half-Spreads and Effective Spreads are measured in cents. Total Volume is measured in billions of dollars. PIM Share measures the share of dollar volume executing in single-leg auctions. Limit Order Book Share measures the percentage of dollar volume executing as auto-electronic orders. DMM is an indicator for whether the exchange has a DMM with a five-lot allocation privilege. Pricing highlights the main pricing system of the exchange (MT stands for maker-taker), and queue priority highlights the main priority system for limit order allocations. Note that Nasdaq's MRX exchange was formerly ISE's Mercury Exchange.

initially obtained from an anonymous industry participant, and subsequently verified against DMM lists on exchange websites. Most exchanges provide DMM information on their website; for those which do not, we requested the official DMM list via email.

B. Designated market maker internalization

Designated market maker (DMM) assignments provide a powerful method of internalizing trades. Exchanges appoint DMMs, also called specialists, at the stock-specific level. Eleven exchanges use a DMM system³⁶ and assign DMMs to stocks, creating stock-exchange-level variation in DMM assignments. These DMM assignments grant special rights and obligations to the holder. One particularly strong advantage for internalizing trades is that if a DMM has a quote at the NBBO, the DMM obtains the first five contracts of any order they route to the exchange, regardless of their position in the NBBO queue.³⁷

³⁶ By DMM, we refer to the ability of designated market makers to internalize orders for five or fewer contracts. Some exchanges may use different names for this position, including "Designated Primary Market Maker."

³⁷ For an order of 6 or more contracts, the DMM will obtain the first 5 contracts. See, for example, NYSE American 964 NYP (h)(1)(b), NYSE ARCA 6.76AP-O(a)(B), CBOE 5.32(c), EDGX 21.8(g)(2), MIAx EMLD 514 (g)(2), Nasdaq GEMX Options (3) 10(c)(1)(D), NASDAQ ISE (3) 10 (c)(1)(D), MIAx 514 (g)(2), NASDAQ MRX Options (3) 10 (c)(1)(D), NASDAQ BX Options (3) 10 (a)(1)(C)(c), and NASDAQ PHLX Options (3) 10 (a)(1)(D). Any remaining contract(s) will be allocated in accordance with the priority rules of the NBBO at that exchange.

The allocation right of the DMM allows the DMM to internalize orders that it routes to the exchange regardless of its position in the price-time or *pro rata* queue at the NBBO.³⁸ This is a powerful advantage for internalization: If market makers wish to internalize order flow, they can use a DMM seat to guarantee their ability to do so, and do not need to offer a superior quote over competitors to internalize the trade. Competing market makers, in turn, will not be able to trade against this internalized flow, regardless of their *pro rata* depth or time priority at the NBBO.

From SEC 606 reports, we identify five key PFOF DMMs in the options space: Citadel, Wolverine Execution Services, Susquehanna International Group, Morgan Stanley, and Dash IMC. Together, these DMM firms account for approximately 98% of the total PFOF in options trades, as noted in [Table 5](#) in [Appendix I](#). We compare these firms with the following DMM firms, which pay nothing or very little for order flow: Belvedere, Two Sigma, GTS, XR Securities, Cutler, Simplex, Hudson River Trading, and Optiver. We also note the considerable activity across both groups. Optiver, for example, is one of the largest option market makers, comparable in size to Citadel and Susquehanna International Group.

We use PFOF as an indicator that takes the value 1 if the exchange's DMM assignment for the option is a DMM that is a major provider of PFOF (Citadel, Wolverine, Susquehanna, Morgan Stanley, and Dash IMC). This indicator takes the value zero for other DMMs. For this section, we restrict our analysis to regular limit order book trades on exchanges which use a DMM.

We first examine whether, at a fundamental level, having an assigned DMM who pays PFOF is associated with additional exchange volume. The major DMMs who pay PFOF receive orders from retail brokers and have flexibility to route them to any exchange; if they route them to an exchange where they have a DMM seat, they would obtain their allocation advantage. Consequently, we expect volume to be higher at exchanges where the DMM is a PFOF payer, even after controlling for exchange and symbol or date fixed effects. To estimate this, we run the following regression.

REGRESSION 1. *For each security j on exchange k in month t :*

$$\text{Volume}_{jkt} = \alpha_0 + \alpha_1 \text{PFOF}_{jk} + X_{jk} + \epsilon_{jkt}.$$

The results of the estimation of [Regression 1](#) are presented in [Table 2](#), where we estimate using monthly observations of trading volume, aggregated over

³⁸ As an example, suppose two market makers have quotes at the best ask at the CBOE exchange: one from Citadel, for 5 contracts, and one from Belvedere, for 20 contracts. CBOE uses a *pro rata* model, so an incoming order would normally be split according to how much depth each market maker displays; for example, an incoming market order for 5 contracts would be allocated with 1 contract to Citadel and 4 to Belvedere. Citadel is, however, the DMM in Walgreens options at the CBOE exchange. Consequently, if Citadel routes a customer order for 5 contracts to the exchange, Citadel has a right to claim an allocation of all 5 contracts, thanks to its DMM status.

Table 2
Estimation of regression 1: Trading volume.
A. Exchange dollar volume

	<i>Dependent variable: Monthly volume (thousands)</i>			
	All symbols		High-volume symbols	
	(1)	(2)	(3)	(4)
PFOF	406.631*** (144.540)	744.119** (348.842)	6,213.921*** (805.977)	3,081.449** (1,531.381)
Exchange FE		X		X
Symbol FE		X		X
Observations	670,065	670,065	108,125	108,125
R ²	.00001	.499	.001	.496

B. Exchange volume share

	<i>Dependent variable: Monthly volume share (%)</i>			
	All symbols		High-volume symbols	
	(1)	(2)	(3)	(4)
PFOF	1.198*** (0.071)	1.185*** (0.070)	0.494*** (0.087)	0.361*** (0.064)
Exchange FE		X		X
Observations	670,065	670,065	108,125	108,125
R ²	.0004	.196	.0003	.569

We present results of the estimation of [Regression 1](#), which examines the relationship between PFOF-paying DMMs and exchange trading volume. Observations are at the monthly level, where we aggregate over all trades for 10 contracts or fewer. PFOF takes the value 1 when an exchange's designated-market-maker pays for order flow, and 0 otherwise. Panel A presents results with monthly trading volume (in thousands of dollars), while panel B presents results with exchange volume share (as a percentage of all electronic trading volume at exchanges which use designated market makers). Columns 1 and 2 present results for all symbols, while columns 3 and 4 present results for the 500 symbols with the highest trading volume. * $p < .1$; ** $p < .05$; *** $p < .01$.

all trades for 10 or fewer contracts.³⁹ In panel A of [Table 2](#), we use trading volume in thousands of dollars, and fit a fixed effect (X_{jk}) for each exchange and trading symbol. PFOF-paying DMMs are associated with an additional \$744,000 trading volume per month across all symbols, and an additional \$3 million in trading volume when we restrict ourselves to the 500 symbols with the highest total trading volume during our sample period. For reference, the average exchange-level trading volume is \$1.2 million across all symbols, and \$7.7 million across the most liquid symbols.

We also estimate [Regression 1](#) using exchange volume shares (as a percentage of all regular trading volume at exchanges that use DMMs), rather than as a raw dollar volume. The results are presented in panel B of [Table 2](#). We fit a fixed effect for each exchange (to account for different trading rules at each exchange that uses DMMs), but not for each symbol (as all symbol trading volumes must individually sum to 100%).⁴⁰ PFOF-paying DMMs are associated with an additional 1.2% volume share compared to non-PFOF-paying DMMs when we estimate using all symbols, and an additional

³⁹ Note that our results in [Table 2](#) are similar to the [Hendershott, Khan, and Riordan \(2025\)](#) results in [Table 7](#).

⁴⁰ In the appendix, we also fit a version with month fixed effects.

0.36% volume share within the most liquid symbols. We explore alternative specifications of [Regression 1](#) in [Appendix II](#).

The advantage of a DMM in internalizing a trade varies with contract size. Provided they are quoting at the NBBO, DMMs obtain the first five contracts of any order they bring to an exchange where they are the DMM, regardless of their position in the NBBO queue. For orders of 5 or fewer contracts, DMMs will therefore obtain the entire order, while for larger orders, they will obtain the first 5 contracts while the remaining contracts will be allocated according to NBBO queue rules (e.g., time priority or *pro rata*). The DMM advantage is therefore extremely strong for small trades (where the DMM is guaranteed to obtain almost all the orders), and less strong for larger trades (where the DMM is only guaranteed the first five contracts of the order). We therefore reestimate [Regression 1](#) for each individual contract size, from 1 contract trades up to 21 contract trades. We anticipate that DMMs will be strongly associated with an increase in volume for the smallest contracts, and less strongly associated or possibly not associated at all for the larger contract sizes.⁴¹

Results of this estimation are presented in [Figure 5](#).⁴² At the individual exchange-symbol-contract-size level, many symbols have very few observations across some contracts, so we estimate [Regression 1](#) at the exchange-symbol-contract-size level.⁴³ This procedure has the advantage of identifying a more detailed estimation of the effects at each individual contract size, but comes with the drawback that many symbols will have little activity in some contract sizes, even over the entire sample period. Panel A of [Figure 5](#) presents the results for all symbols, with DMMs that pay for the order flow associated with a 0.5% to 2% larger exchange volume share than symbols with DMMs that do not pay for the order flow. As a reasonable refinement, we also consider the estimation of the top 500 symbols, by total dollar volume, in panel B of [Figure 5](#). In this panel, a slightly different pattern emerges: PFOF-paying DMMs are strongly associated with more volume for orders between 2 and 5 contracts, mildly associated with more volume for 6 to 9 contracts. For larger contract sizes, PFOF-paying DMMs are associated with smaller increases in volume, but this is not statistically significant.

C. Auction trade usage

Option market makers compete for aggregate order flow. In each individual trade, option market makers have the option of providing price improvement via a price improvement auction. Doing so reduces the profit they make on the

⁴¹ The DMM 5-contract advantage is a smaller portion of the order for larger contract sizes. As a result, DMMs can use other routes, such as auction trades, to internalize the trade, which we explore in [Section III C](#). Furthermore, retail investors may use more small-contract trades than large-contract trades.

⁴² For orders of at least 22 contracts, we estimate all orders as one size category (i.e., 22 contracts refers to 22 and more).

⁴³ We also present estimates at the exchange-symbol-contract-size level by year in [Appendix II](#).

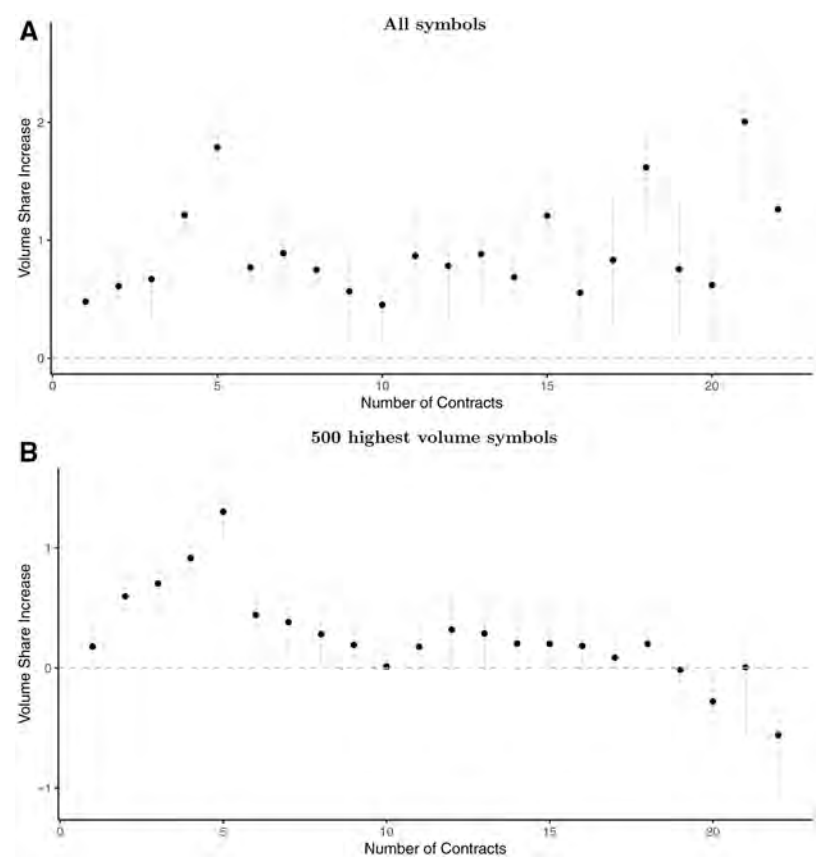


Figure 5
Volume increase from PFOF-paying DMMs.
We estimate [Regression 1](#) for each individual contract size and plot the coefficient estimate on PFOF. Regression observations are at the stock-exchange level for each contract size. The dependent variable is the volume share of the exchange out of all volume in that contract size, while PFOF is an indicator which takes the value 1 if the DMM at that exchange is a major PFOF-paying firm, and 0 if it is not. Blue lines represent a 95% confidence interval for the parameter estimate. Panel A presents results for all stocks, while panel B presents results for the 500 symbols with the highest dollar volume across all contracts. Note that we estimate all contracts of size 22 or more as a single point at 22.

individual trade, but may improve their aggregate order flow statistics and earn them additional order flow in future months. In this section, we investigate evidence for when auctions occur and evaluate whether it is consistent with market maker’s conflicting desires between profit on individual trades and providing broader price improvement.

The designated market maker benefit, whereby a DMM obtains the first five contracts of any order they bring to an exchange regardless of their position in the NBBO queue, requires that DMMs quote at the NBBO, as this advantage applies to regular trades and not auction trades. If a DMM is not

actively quoting at the NBBO, they do not receive an allocation advantage. On the importance of this rule, [Anand and Muravyev \(2024\)](#) show that auction trades are less likely when an exchange is actively quoting at the national best bid or offer.⁴⁴ Although lack of a local bid or offer at the NBBO strongly predicts auctions, auction trades can occur even when an exchange is at the NBBO. As we note in Section B, wholesalers compete for order flow from brokers. Sending an order to an auction (even when a DMM is quoting at the NBBO) reduces the potential profit on that trade, but it does improve the average order statistics of the wholesaler. When brokers route to wholesalers, the primary variation across wholesalers is the effective-over-quoted spread. When a wholesaler receives a trade for which the NBBO spread is large, filling this order at the NBBO spread will cause their order execution statistics to deteriorate, while entering the trade into an auction will maintain their order execution statistics. Consistent with this intuition, in [Table 11](#) in Appendix III we find that larger quoted spreads are associated with a higher likelihood of entering an auction.

To better understand how the DMM advantage for internalizing small-contract trades influences this trade off, we estimate the following trade-level regression.

REGRESSION 2. *For each trade i in security j on exchange k :*

$$\text{Auction}_{ijkt} = \alpha_0 + \alpha_1 \text{Quoted Spread}_{ijk} + X_{ijk} + \epsilon_{jkt}.$$

We restrict ourselves to trades that occur when the local exchange is at the NBBO. With this restriction, we focus on trades in which a DMM could have potentially routed the trade to their own quote⁴⁵ (and obtained the full spread), but instead opted for an auction trade. Our coefficient of interest is α_1 , the coefficient on the NBBO quoted spread and how it changes with contract size. The quoted spread is the NBBO across all exchanges at the time of trade. Controls X_{ijk} include the option Greeks, option price, and fixed effects for each exchange and either a symbol or date fixed effect, with standard errors clustered by either each symbol or date.

We estimate [Regression 2](#) separately for each possible contract size, and present coefficient estimates for α_1 for each contract size in [Figure 6](#). Across all contract sizes, larger quoted spreads are associated with a higher probability

⁴⁴ We confirm the findings of their paper hold in our sample in [Table 11](#) in [Appendix III](#). Trades are considerably less likely to be auction trades when an exchange is at the NBBO, even after controlling for other features of the trade.

⁴⁵ OPRA data are anonymous, and we do not observe the participant identity of any individual trade or quote. However, a key requirement for a designated market maker is to quote at the NBBO for 90% of the trading day. As a result, if we observe an exchange that uses DMMs at the NBBO, there is an extremely high likelihood that the DMM is among those quoting at the NBBO.

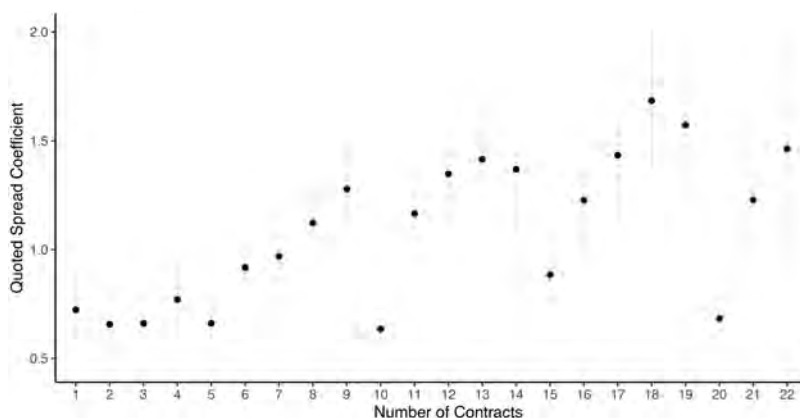


Figure 6
Auction probability and quoted spreads.

We estimate [Regression 2](#) for each individual contract size. Each coefficient estimate on Quoted Spreads is plotted by a black dot with a light blue bar indicating the 95% confidence interval. We restrict our analysis to trades where trades happen at an exchange which matches the national best bid (for a buy order) or ask (for a sell order). The dependent variable *Auction* is an indicator for whether a trade is an auction or a regular limit order book trade. Quoted Spread is the NBBO half-spread, in dollars. Controls include the option Greeks, a fixed effect for each exchange and symbol, and standard errors are clustered by exchange. Blue lines represent a 95% confidence interval for the parameter estimate. Note that we estimate all contracts of size 22 or more as a single point at 22.

that a trade is an auction; this is consistent with market makers using auctions for trades when the NBBO is wide.⁴⁶

Coefficient estimates are consistently between 0.5 and 0.75 for trades between 1 and 5 contracts. The coefficient estimates increase for trades between 6 and 9 contracts and are consistently high for contracts between 11 and 22 or more.⁴⁷ This pattern in quoted spreads is consistent with wholesalers strategically using auctions. If a wholesaler routes a large order to an exchange where they are the DMM, they will obtain the first five contracts, but the remainder will be split, typically with a *pro rata* formula with the other market makers quoting at the NBBO. When brokers score wholesalers, the entire order will count on the wholesaler's statistics, even though the wholesaler may have had to share the order with other market makers. For an order of five contracts or fewer, in contrast, the entire order will still count on the wholesaler's statistics, but the wholesaler will also be able to trade against the entire order. In the trade-off between offering price improvement (via an auction) and maximizing profit

⁴⁶ Note that we examine auctions at the same exchange. When a wholesaler who is a DMM initiates an auction, they do not obtain a DMM 5-contract allocation guarantee, but they will still obtain DMM-based fee advantages; as such, the incentive for a DMM to initiate auctions at exchanges where they have the DMM position is less strong than for regular trades, but still present. [Anand and Muravyev \(2024\)](#) provide additional information on these fee differences.

⁴⁷ There are two discontinuities at the round sizes of 10 and 20 contracts. Different compositions of round-lot trades may explain these discontinuities.

(avoiding an auction and filling the order at the NBBO), wholesalers can better maximize profits on trades for five contracts or fewer and accordingly focus their attention on price improvement for larger trades.

D. Single DMM stock analysis

To analyze how PFOF affects execution quality, we consider a simple question: do markets appear worse when the assigned DMM pays for retail order flow relative to when the assigned DMM does not pay for retail order flow? In this section, we test the impact of DMM-PFOF payments on option transaction costs, restricted to the case in which, across all exchanges, a single firm is assigned as a DMM. Although this restricts our analysis to a set of less liquid symbols, it offers a particularly sharp, clear distinction between securities where the only assigned DMM pays PFOF and securities where the only assigned DMM does not pay PFOF. In both cases, a DMM is assigned; we are not comparing stocks with a DMM to stocks without one.⁴⁸ Our focus is not on the effectiveness of the quoting obligation of market makers, but rather on whether designated market makers who have substantial purchased retail order flow behave differently than designated market makers without purchased retail order flow.

For each individual trade, we do not observe the individual brokers routing the trade, but we do observe which DMMs pay PFOF from SEC 605 reports. Our identification strategy is at the symbol level, based on the identity of the sole DMM assigned to that symbol. To control for any observable differences in the assignments of DMMs to symbols, we used a propensity score match. For each symbol with a non-PFOF-paying DMM, we match it with a symbol with a PFOF paying DMM, with a closest match on the median daily dollar volume in the symbol.⁴⁹

DMMs are important in determining the costs of liquidity, with a series of exchange privileges and obligations. However, unlike the pre-Reg NMS Specialist at NYSE, all option DMMs face competitive pressures and will set quotes in competition with other market makers. Setting a narrower quote will reduce their profits but allow them to gain more orders. DMMs who purchase retail order flow face a reduced incentive to quote narrow spreads. So long as these DMMs match, but do not narrow, the NBBO, they can internalize their purchased retail order flow at the NBBO. Indeed, quoting a narrower NBBO would reduce the profits they earn on any purchased order flow. Consequently,

⁴⁸ Anand and Venkataraman (2016) and Clark-Joseph, Ye, and Zi (2017), for example, highlight how DMMs can play a key role in liquidity provision.

⁴⁹ The major PFOF-paying DMMs control more DMM seats in symbols of all liquidity levels. Consequently, we match non-PFOF symbols to the closest PFOF-paying symbol, rather than the other way around. We also note that conversations with U.S. industry participants suggest that when competing market makers apply to be a DMM, an element of randomization is used to assign seats. We present results for the unmatched symbols, as well as alternative match criteria, in [Appendix IV](#), which are very similar to the results for the propensity-score matched tests.

we estimate [Regression 3](#) to analyze the impact on option transaction costs for trades depending on whether the single assigned DMM either does or does not purchase order flow.

REGRESSION 3. *For each option trade i in security j on exchange k on date t :*

$$\text{Spread}_{ijkt} = \alpha_0 + \alpha_1 \text{PFOF}_j + X_{ijkt} + \epsilon_{ijkt}.$$

The indicator PFOF_j takes the value 1 whenever the DMM assigned in symbol j is a DMM that buys retail order flow, and takes the value 0 whenever the DMM assigned in symbol j does not buy retail order flow. As controls, we include the option Greeks vega, gamma, theta, and the absolute value of delta, as well as the price and size of each option, and the total dollar volume of option volume traded in that symbol during our sample period. Because of the small volume in some of the symbols, we also use a weighted ordinary least squares (OLS), with the total dollar value traded in each option as the weight in the regression. To control for differences in exchange pricing, we fit a fixed effect for each exchange and date, and cluster standard errors by exchange.

Estimates of [Regression 3](#) are presented in [Table 3](#).⁵⁰ When the sole DMM is a PFOF-paying firm, we find that across all auto-electronic option trades, effective spreads are a statistically significant 5.7 cents higher, quoted half-spreads a statistically significant 9.6 cents higher. The impacts of PFOF and internalization on bid-ask spreads are a key concern for regulators. In the words of (former) SEC Chairman Gensler: “Under the segmentation of the current market, nearly half of the trading, along with a significant portion of retail market orders, happens away from the lit markets. I believe this may affect the width of the bid-ask spread.” [Gensler \(2021\)](#). While the reference to off-exchange trading implicitly ties this quote to the market for U.S. equities, the market for U.S. option trades, instead, has created a system where market makers who buy order flow direct that flow either to themselves for the DMM allocation or to auctions (where we show, in the next section, that they have an advantage as the auction initiator), with the result that they are incentivized to quote a wider spread.

We also separately estimate [Regression 3](#) for auction trades, with results reported in column 4 of [Table 3](#). We find that while auction trades obtain around 5.2 cents more price improvement, they also pay around 5.3 cents more in effective spreads. Although we do not observe which trades a DMM internalizes or routes to an auction, these results are consistent with DMMs selectively routing trades to a PIM auction when the spreads are wide and the price improvement relative to the wide spread is high. Our results provide

⁵⁰ While our focus is on single-DMM stocks for identification, [Hendershott, Khan, and Riordan \(2025\)](#) examine the relationship between quoted spreads and PFOF-DMMs using all trades in table six of their paper.

Table 3
Option spreads with a single DMM.

	<i>All trades</i>		<i>LOB trades</i>	<i>PIM trades</i>	
	Effective spread (1)	Quoted half spread (2)	Effective spread (3)	Price improvement (4)	Effective spread (5)
PFOF	5.741*** (1.876)	9.611*** (2.336)	6.700*** (2.172)	5.204*** (1.232)	5.344*** (1.207)
Price	0.564*** (0.062)	0.889*** (0.089)	0.680*** (0.036)	1.679*** (0.160)	0.246*** (0.058)
Abs. delta	1.499* (0.845)	13.015*** (0.984)	5.276*** (0.782)	1.536 (1.788)	1.826 (1.814)
Vega	64.601*** (1.921)	96.803*** (5.713)	66.115*** (2.399)	77.840*** (6.440)	43.883*** (3.771)
Gamma	-12.992*** (1.969)	-34.478*** (3.004)	-21.124*** (2.091)	-8.260** (3.634)	-8.774*** (1.630)
Theta	-13.821*** (1.926)	-25.863*** (2.071)	-14.169*** (2.278)	-32.298*** (2.513)	-8.706** (3.272)
Size	-0.00001** (0.00000)	0.00000 (0.00000)	-0.00003** (0.00002)	-0.00002 (0.00001)	0.00001 (0.00001)
Symbol volume	0.005 (0.006)	0.016** (0.007)	0.007 (0.007)	0.009* (0.005)	0.004 (0.004)
Observations	556,706	556,706	334,650	99,212	99,212
R ²	.349	.414	.422	.513	.317

This table estimates [Regression 3](#). Dependent variables are the effective spread, quoted spread, or price improvement (relative to the NBBO), all measured in cents. Analysis is restricted to the subset of options which have a single DMM across all exchanges. We conduct a propensity score match: for each symbol with a non-PFOF DMM we match to a symbol with a PFOF-DMM closest in volume. Columns 1, 2, and 3 are for all auto-electronic trades, while column 4 is restricted to PIM trades. PFOF is an indicator for whether the single DMM in that stock is one of the major PFOF-paying firms. Estimates are weighted-least-squares regression, using the total traded value of each security as the weight. There is a fixed effect for each exchange and date, and standard errors are clustered by exchange. * $p < .1$; ** $p < .05$; *** $p < .01$.

empirical support for the model of [Yueshen and Van Kervel \(2023\)](#), where the ability to internalize trades at a reference price (in this case, the ability of DMMs to internalize at the NBBO) leads to wider spreads.

E. Price improvement mechanism trades

Price improvement mechanisms (PIM) trades provide a second method of internalizing a trade. Any market maker or broker routing an order can initiate an auction, which begins with a proposed auction bid at which the order would be filled. In single-leg auction trades, regular trade execution stops and the proposed trade goes through a two-sided auction mechanism with an exposure period where competing market makers have 100 milliseconds in which to place bids.⁵¹ The decision by a wholesaler to internalize a trade is endogenous, and many retail option trades do not receive improvement and do not execute in an auction. Although DMM assignments may influence the decision of a

⁵¹ In the OPRA datafeed, these trades are formally defined as “Single Leg Auction Non ISO,” and coded as order type 97. Exchanges may refer to these trades as “Price Improvement Mechanism,” “Customer Best Execution (CUBE),” or an “Automated Improvement Mechanism.” The improved trade price is a benefit that the customers receive, and the PIM trades are overwhelmingly retail trades; [Bryzgalova, Pavlova, and Sikorskaya \(2023\)](#) show correlations between the volume of retail option trade and the volume of the PIM auction.

market maker to use or not use a PIM auction, they do not play a direct role in the PIM trading rules.

Any market maker can initiate a PIM auction and any market maker can ostensibly participate in the auction by submitting a competing bid, but the exchanges often adopt rules that discourage anyone other than the market maker initiating the auction from participating in the trade. As an example, the NASDAQ PHLX exchange allows a market maker who proposes internalizing a trade in a Price Improvement Mechanism to choose, upon initiating the auction, whether to auto-match any competing bids in the auction.⁵² This gives the market maker a powerful first-mover advantage and a winner's curse: a competing market maker will win the auction outright only if the initiator (who is better informed about the source of the order) decides not to match at that price. When there are multiple bids at a price level, market makers also receive a guaranteed fill of at least one contract or 40% of the original size of the order, whichever is higher.⁵³ Both rules decrease the potential competition for PIM auctions.

Suppose a retail customer wishes to buy a call option for 500 underlying shares in Amazon, and the current price for the national best ask for this option is \$2.50. If Morgan Stanley receives this order from the retail customer's broker, Morgan Stanley will be unable to use a DMM allocation, as they do not have any DMM seats in Amazon. An alternative method of internalizing the order would be to use a price improvement mechanism trade. Morgan Stanley could go to an exchange that offers this type of order and start an auction at \$2.49. Competing market makers could place bids to fill the order at a price even lower than \$2.49; if they do, Morgan Stanley can choose to automatically match competing bids. This auto-match right is given to Morgan Stanley as the initiator of the auction. If there are no competing offers, Morgan Stanley will directly trade with the customer for \$2.49. If Morgan Stanley does not elect to auto-match bids and is outbid, the competitor will win the auction and trade against the retail customer. If there is a competing bid and Morgan Stanley elects to auto-match bids, the allocation will be *pro rata* but with Morgan Stanley, as the initiator, receiving an outsize share as a bonus for initiating the auction.

Price improvement mechanisms generally offer an improvement against the bid-ask spread.⁵⁴ Just as in equity, the NBBO provides an ultimate lower bound on the execution quality of retail traders, and price improvement offers

⁵² The initiator can specify auto-matching orders up to any specific price. Once selected, this selection cannot be modified.

⁵³ At the time an auction starts, an initiator can also select to "surrender" an order. This gives the auction initiator the option to decline their allocation priority in the event of a competing bid.

⁵⁴ There is one notable exception: size improvement. Some auctions offer an auction option to provide a size improvement. These auctions are allowed to match, rather than improve, the NBBO price, provided that the order size meets a certain threshold (often 50 contracts, i.e., 5,000 shares). Flash orders, which are coded as regular electronic trades in the OPRA data feeds, also typically offer a size improvement.

potentially better prices to customers. However, the extent to which this is a meaningful improvement is partially dependent on the competitiveness of the quotes.

Figure 7 plots the total improvement by trading month, with the total aggregate monthly improvement varying between \$150 and \$650 million per month. The total effective spreads paid on these trades vary between \$100 and \$400 million per month. In our sample, 18% of the total single-leg dollar volume is executed through a single-leg auction. Figure 7 breaks down the price improvement by the NBBO spread at the time of auction. The tick size in options markets can vary with the option symbol: some have a 1-penny bid-ask spread, some have a 5-penny bid-ask spread, and some have a 10-penny bid-ask spread. However, in these definitions, most of the aggregate price improvement comes from trades when the bid-ask spread is wider than two ticks. This price improvement can reflect savings for retail traders over the NBBO, but to some extent it also depends on the competitiveness of the bid-ask spread. Brokers use quoted spreads as a benchmark when evaluating wholesaler performance, typically measuring “effective-over-quoted” spreads for each customer trade routed to a wholesaler. In thinly traded symbols or strike prices, these quoted spreads may be very wide and quite divergent from the prices realized in an auction. When this divergence is very large, as Figure 7 shows, quoted spreads may cease to be a very accurate benchmark for the prices retail traders should expect to obtain in an auction, and savings in price improvement auctions will reflect this divergence rather than true savings. In the next section, we examine the competitiveness of PIM auctions.

A wholesaler is not allowed to communicate any information about forthcoming trades to the affiliated market maker.⁵⁵ Signaling an affiliate market maker to quote at the NBBO in anticipation of an imminent order arrival, for example, is prohibited as an internalization strategy.⁵⁶ When a wholesaling unit routes an order to an exchange for execution where their affiliate market making unit is a DMM, the market making unit will have no advance notice of the trade, but will receive the DMM allocation as the trade is executed. For PIM Auctions, the wholesaling unit selects the use of auction, bid, and auto-match or surrender options.⁵⁷ The market-making unit will receive the same auction notice that is sent to all market participants, but

⁵⁵ All exchanges must adhere to “just and equitable principles of trade.” If a wholesaler were to communicate information about forthcoming trades, that would give their affiliate market-making unit an advantage over others, so exchanges prohibit this information sharing. For details, see CBOE rule 8.1, and Regulatory Circular 22-014, or NASDAQ rule General 9, section 1 General Standards and Regulatory Alert 2022-22. Wholesalers also have a best-execution obligation, which FINRA Regulatory Notice 15-46 details.

⁵⁶ Simplex Trading, LLC, a market maker with few option DMM positions, briefly entered the retail option wholesaling business, allegedly using a strategy of presignaling to internalize trades: <https://www.wsj.com/articles/high-speed-trader-simplex-warned-about-potentially-abusive-options-strategy-11667391891>

⁵⁷ Auto-matching includes the right to auto-match only to a specified price (specified by the wholesaling unit). Some exchanges allow an option to surrender, that is, the auction initiator would obtain a lower or no allocation if there are any competing bids; this choice would also be made by the wholesaling unit.

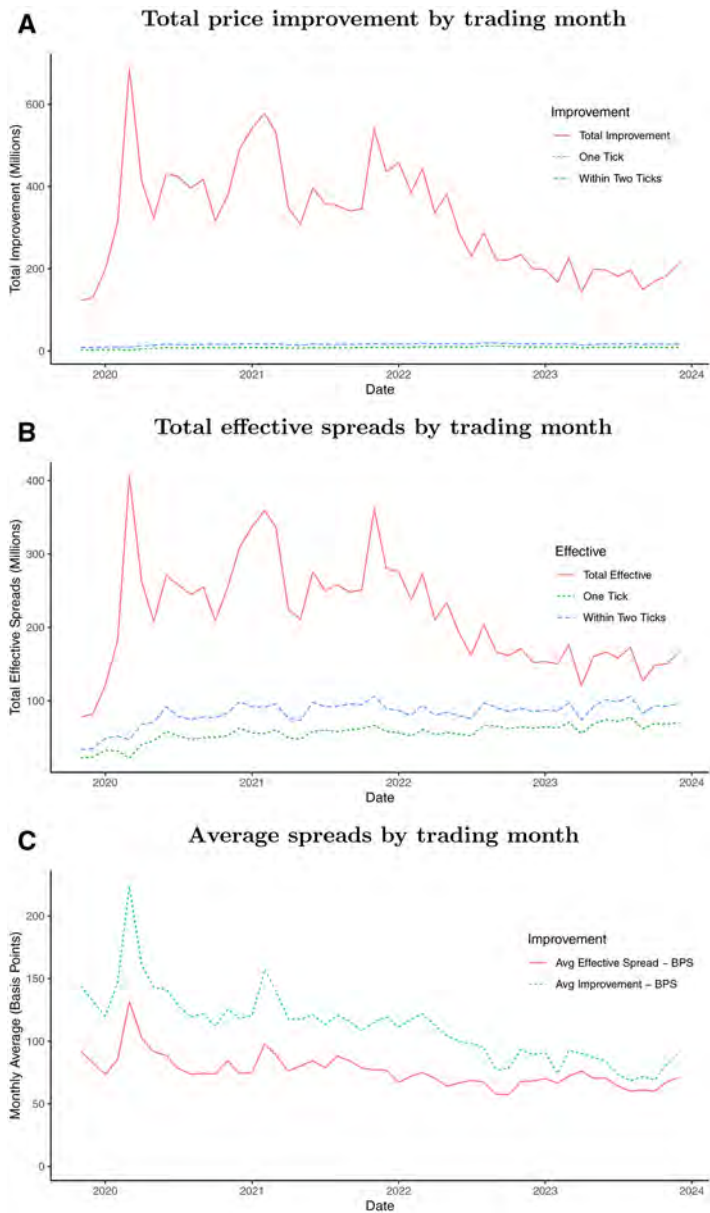


Figure 7
Option price improvement by month.

We plot total price improvement (panel A), total effective spreads (panel B), and average spreads (panel C) across all price improvement mechanism (PIM) single leg auction trades in our sample. For panels A and B, we plot the relevant total measure with the solid red line, and then separately plot the total for when spreads are less than or equal to 5 cents (one tick for most option series) with the green dashed line, and when spreads are less than or equal to 10 cents (two ticks for most option series) with the blue dashed line. For panel C, we plot average effective spread with a red solid line, and average improvement with the blue dashed line.

will not discover that the trade is from their affiliate wholesaling unit until after the auction is over.

F. Competition in PIM trades

OPPRA flags PIM trades as type 97, “single-leg non-ISO auction,” but there is no information in either the consolidated OPRA feed or the individual exchange feeds about the bidding activity in the auctions. While printing on the passive side allows us to infer cases of multiple bidders sharing an allocation, we only observe the outcome price and quantities; we do not observe the individual bidders, their bids, nor their identities. To explore the competitiveness of these option auctions, we examine differences in price improvement around the size of an order.

Our size-based cutoff is guided by the initiator allocation advantage in PIM trades. For single-contract trades, a market maker who initiates and auto-matches competing bids always wins the entire allocation. In contrast, for two or more contracts, a market maker who initiates and faces competing bids will receive less than the full allocation.⁵⁸ As a result, single-contract trades experience a powerful winner’s curse: competing bidders will win an allocation only if the initiating market maker, who is best informed about the source of the trade, declines to auto-match their bid.

Motivated by this problem, we define NotSplittable to take the value of 1 if a trade is for exactly 1 contract, and 0 otherwise, and estimate the following regression, which compares the effective spreads paid by single-contract trades in auctions against the spreads paid by 2-, 3-, or 4-contract trades (for which a competing bidder could obtain some allocation at a price where the initiator auto-matches):

REGRESSION 4. *For each option trade i in security j on exchange k on date t :*

$$\text{Spread}_{ijkt} = \alpha_0 + \alpha_1 \text{Exact_Size}_{ijkt} + X_{ijkt} + \epsilon_{ijkt}.$$

Results of [Regression 4](#) are presented in [Table 4](#). Auctions for exactly 1 contract pay higher effective spreads than other small contracts; against a baseline of 4 contract orders, 1-contract orders pay effective spreads which are 0.85 cents higher, while 2 and 3 contract trades pay effective spreads which are only

⁵⁸ See, for example, AMEX 971.NYP (c)(4)(D)(ii)(b) or NASDAQ PHLX section 13 (b) (5)(B)(ii) in conjunction with NASDAQ PHLX section 13 (b) (5)(B)(vi), or Nasdaq ISE section 13 (d)(3) in conjunction with Nasdaq ISE Supplementary Material to Options 3 section 13.10, MIA rule 515A(a)(2)(iii)(I) in conjunction with MIA rule 515A Interpretations and Policies .10, MIA EMLD rule 515A(a)(2)(iii)(I) in conjunction with MIA EMLD rule 515A Interpretations and Policies .10, Nasdaq MRX Options 3 section 11 (b)(4)(iii) in conjunction with Nasdaq Options 3 section 11 Supplementary Material .09, EDGX rule 21.19 (c)(3) in conjunction with EDGX rule 21.3, Box 7150 (h)(2) in conjunction with BOX 7150 (h)(4), CBOE 5.37 (e)(3) in conjunction with CBOE Trading Manual 1.9 “Matching and Allocation”, NASDAQ Gemini Options 3 section 11(b)(4)(iii) in conjunction with NASDAQ Gemini Options 3 section Supplementary Material .08, or NASDAQ BX section 13 (ii)(E)(2)(b) and NASDAQ BX section 13 (ii)(F)(2)(b) in conjunction with NASDAQ BX section 13 (ii)(G).

Table 4
Price improvement and nonsplittable trade cutoff.

	Dependent variable:		
	Effective spread (1)	Quoted spread (2)	EFQ (3)
1 contract	0.849*** (0.025)	1.716*** (0.028)	-0.743*** (0.234)
2 contracts	0.382*** (0.027)	0.681*** (0.031)	0.479* (0.256)
3 contracts	0.243*** (0.030)	0.394*** (0.035)	-0.093 (0.287)
Abs. delta	-3.082*** (0.028)	6.692*** (0.032)	-122.950*** (0.266)
Vega	0.552*** (0.021)	20.628*** (0.023)	-24.377*** (0.197)
Gamma	-8.809*** (0.050)	-10.621*** (0.057)	56.874*** (0.474)
Theta	-0.738*** (0.003)	-0.623*** (0.003)	2.721*** (0.024)
Price	-0.058*** (0.0004)	0.804*** (0.0004)	0.408*** (0.004)
Quoted half spread	0.210*** (0.0002)		-0.448*** (0.002)
Observations	13,775,072	13,774,979	
R ²	.194	.132	
Residual std. error	22.813	213.839	

This table estimates [Regression 4](#) for PIM trades occurring in the 30 trading days starting on July 1, 2020. We take trades for 1, 2, 3, and 4 contracts. The variable *1 contract* is an indicator which takes the value 1 for trades of exactly 1 contract; trades for 4 contracts form the omitted group. Effective and quoted spreads are in cents, while EFQ refers to the effective-over-quoted spread ratio. We include the option Greek values, a fixed effect for each stock, and a fixed effect for each exchange. * $p < .1$; ** $p < .05$; *** $p < .01$.

0.38 and 0.24 cents higher. This is consistent with a strong winner’s curse that prevents competition to narrow effective spreads in one-contract auctions. We also note that the EFQ ratios⁵⁹ are lower, consistent with market makers selecting trades for PIM auctions versus DMM internalization based on how the trade would affect their EFQ scores. We note that smaller trades may carry lower adverse selection risk; this would lead to smaller trades paying smaller effective spreads. We find the opposite: smaller trades pay higher effective spreads.

IV. Conclusion

Wholesalers compete for order flow from retail brokers on the basis of payment for order flow (PFOF) paid to brokers, and price improvement offered to retail orders. Option markets present a special challenge to wholesalers in comparison to equity markets, as all trades must go through an exchange. For an option wholesaler seeking to internalize a trade, they must ensure that they trade against the trade on exchange, and not a competitor.

⁵⁹ We use the NBBO spread for PIM trades as the exchange holding a price-improvement auction does not have to have a quoted spread at the NBBO, and frequently has a bid-ask spread worse than the NBBO.

Designated market makers (DMMs) have a strong advantage in internalizing trades: provided they are quoting at the NBBO, DMMs obtain the first five contracts of any order they bring to an exchange, regardless of their position in the NBBO queue. In our single-DMM analysis, we show that DMMs that pay for the order flow are associated with wider quoted spreads in the symbol, consistent with the conflicting incentives between competing for the order flow and internalizing trades modeled in the theoretical work of [Yueshen and Van Kervel \(2023\)](#). Across all symbols, we show that PFOF-paying DMMs are associated with volume increases in limit order book volume, consistent with utilizing their advantage in internalizing trades.

Retail orders can also be internalized through auctions. In these auctions, however, the wholesaler who initiates the auction has specific advantages, such as the ability to auto-match competing bids. Consistent with a winner's curse, we show that single-contract auction trades pay higher effective spreads than 2-, 3-, or 4-contract auction trades, and the results hold across different price levels or quoted spread levels.

Wholesalers use both methods to internalize trades, with the DMM route allowing internalization at the NBBO spread, while the auction route offers price improvement. When we restrict to conditions under which auction usage is voluntary, auction trades are more likely when quoted spreads are larger, but this effect is much less pronounced for orders of five contracts or fewer, consistent with PFOF-paying DMMs using auctions less frequently on the trades they could fully internalize via the DMM route.

When wholesalers compete for the flow of orders from brokers, they use both the DMM route and the auction route ([Figure 4](#)). However, option wholesalers with more DMM positions will have more flexibility in how they internalize flow. As DMM positions are rarely reassigned, these positions serve as a barrier to entry in option wholesaling and can prevent competition from entry by either non-DMM option market makers or equity wholesalers.

Limits to competition in option wholesaling protect option wholesaler profits and support high PFOF, with option PFOF much higher than equity PFOF. The resultant cross-asset variation in payments gives rise to substantially different financial rewards to brokers based on the types of assets their clients trade. Although PFOF has brought about zero-commission trading, the PFOF-only business model pays brokers far more when their clients trade options than when their clients trade stocks. Brokers do have suitability standards around the assets they can offer clients. However, distinguishing between a broker who pushes high-variance securities to gain higher PFOF, and a broker who merely satisfies client demands for high-variance securities is a difficult task. In comparison, measuring execution quality against posted spreads is much easier. Developing more competitive option markets, including by eliminating the retail self-route ability of DMMs, has the potential to reduce the profitability—and the associated PFOF—surrounding internalizing option trades and potentially turn broker incentives to a more equal level between equity and options.

Appendix I

Additional Summary Statistics

We present additional summary statistics on our data in this Appendix. Table 5 summarizes payments and order share of major option wholesalers. Table 6 presents summary statistics on the volume share of DMM exchanges, with DMM exchanges capturing approximately 60% of the order flow for limit order book trading and 90% of the order flow for auctions. Table 7 presents summary statistics on orders. Table 8 presents summary statistics on the share of trades executing as auctions for each contract size. Figure 8 plots the share of auction volume executing with single versus multiple participants.

Table 5
Options wholesalers that pay for order flow.

Firm	Total payments (millions \$)	Order share (%)
Citadel	2,858	39.6
Susquehanna International Group (SIG)	1,822	25.3
Wolverine	1,082	15.0
Dash	960	13.3
MorganStanley	372	5.2
All others	118	1.6

Nearly all options PFOF payments are made by just five wholesalers: Citadel, Global Execution Brokers, Wolverine, Morgan Stanley, and Dash IMC. *Source:* SEC 606 Filings.

Table 6
Specialist exchange volume shares.

A. Regular trades

Symbol volume	1_to_5	6_to_9	10_to_20	20+	All
Over 1 billion:	60.9	61.6	62.1	59.8	60.8
100 million - 1B:	62.2	56.6	60.9	60.4	60.7
5 million - 100M:	66.1	60.4	63.9	63.3	64.0
Under 5 million:	70.6	66.5	68.0	65.8	67.7

B. Auction trades

Symbol volume	1_to_5	6_to_9	10_to_20	20+	All
Over 1 billion:	94.9	94.1	19.3	36.6	94.1
100 million - 1B:	86.4	83.3	83.2	81.4	83.3
5 million - 100M:	86.3	83.1	83.0	81.5	83.1
Under 5 million:	92.1	90.1	90.3	88.7	90.1

We present the volume share of the exchanges which use designated market makers, out of all exchange volume. We consider order share across four different contract size categories, and further divide volume across 4 separate symbol volume categories. Panel A presents volume shares for limit order book trades, while panel B presents volume shares for auction trades.

Table 7
Summary statistics on orders.

A. All single-leg trades

Group	Mean	SD	5%	25%	50%	75%	95%
Quoted half spread	8.43	13.58	0.50	1.00	2.50	7.50	52.50
Effective spread	3.26	5.01	0.00	0.50	1.00	3.00	20.00
Price	6.19	32.51	0.06	0.48	1.42	4.08	22.15
Order Size	753	9976	100	100	200	500	2500
EFQ	59.83	40.04	0.0	20	61.54	100	100
Days to maturity	36	83	0.0	2	8	35	191
Absolute delta	0.36	0.23	0.03	0.17	0.34	0.50	0.80

(Continued)

Table 7
(Continued)*B. PIM auction single-leg trades only*

Group	Mean	SD	5%	25%	50%	75%	95%
Quoted half spread	7.21	11.68	0.50	1.00	2.50	7.50	35.00
Effective spread	2.34	4.00	0.00	0.50	1.00	2.50	11.00
Price	4.49	15.41	0.08	0.48	1.35	3.65	17.42
Order size	722	4706	100	100	200	500	2800
EFQ (%)	44	36	0.0	12.5	33	73	100
Days to maturity	30	73	0.0	2	7	25	164
Absolute delta	0.38	0.22	0.04	0.20	0.38	0.51	0.78

C. Limit order book single-leg trades only

Group	Mean	SD	5%	25%	50%	75%	95%
Quoted half spread	8.18	13.53	0.50	1.00	2.50	7.50	52.50
Effective spread	3.77	5.37	0.00	0.50	1.50	5.00	20.00
Price	5.32	23.60	0.07	0.50	1.42	3.87	19.70
Order size	603	2,370	100	100	100	500	2,100
EFQ (%)	68	38	0.00	33	100	100	100
Days to maturity	37	85	0.00	2.00	8.0	35	192
Absolute delta	0.36	0.22	0.03	0.18	0.35	0.50	0.78

This table presents mean, standard deviation, and quantile summary statistics on OPRA data for the 30 trading days starting on July 1, 2020. Quoted Half-Spreads and Effective Spreads are measured in cents. Price is measured in dollars. Order Size is measured in shares (where 1 contract is equivalent to 100 shares) and we combine multiple simultaneous passive prints into a single market order. Effective-Over-Quoted (EFQ) is the ratio of effective spread to the NBBO quoted half-spread. Absolute Delta is the absolute value of the option delta.

Table 8
Auction share by contract size.

Contract size	Auction share
1	20.25
2	22.36
3	21.32
4	21.14
5	25.17
6	18.42
7	16.13
8	19.08
9	19.11
10	29.79
11	12.13
12	17.98
13	15.56
14	14.33
15	24.67
16	15.16
17	12.45
18	24.13
19	12.49
20	24.38

Across all symbols from November 4, 2019, and December 2023, we calculate the share of volume which executes through auctions, out of the total share of auction and regular limit order book trade.

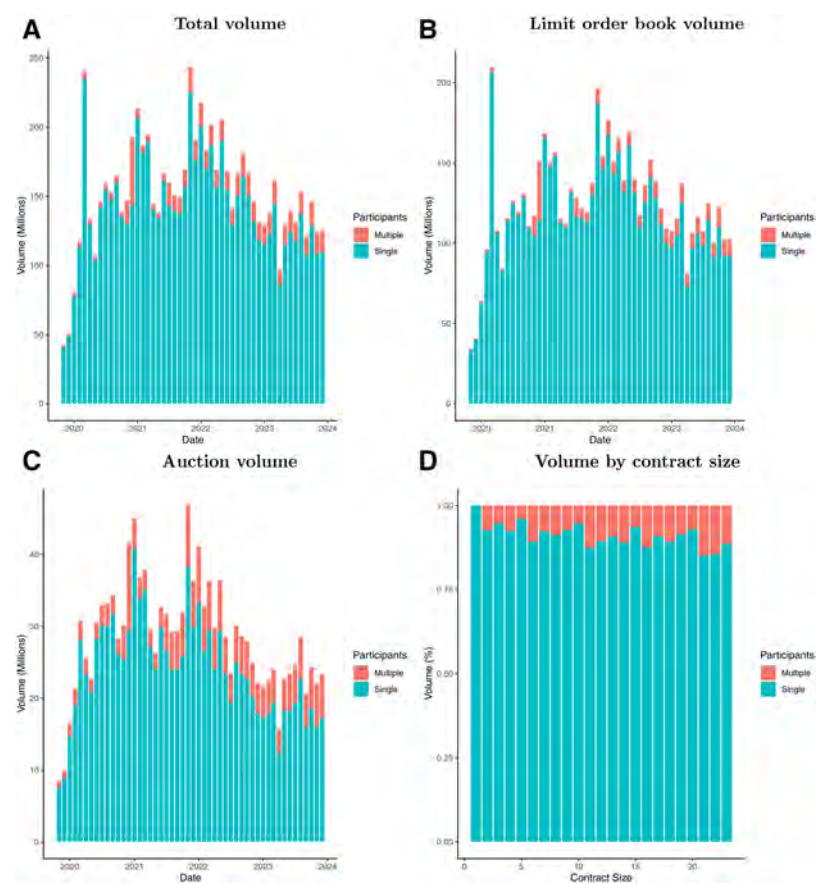


Figure 8
Single versus multiple participants in auctions.
Most option trades involve a single passive limit order (or quote). Panel A presents total dollar volume over time, split between orders which contain either a single participant (blue) or multiple participants (red), as identified by printing on the passive side (multiple trade records with the same exact timestamp). There are fewer multiparticipant trades in limit order book trades (panel B) than auction trades (panel C). Multiparticipant trades are slightly more common in larger trade sizes (panel D).

Appendix II
Trade Volume Alternative Specifications

In this appendix, we present robustness checks and alternative specifications to our main results on trade volume and auction usage. In [Table 9](#), we estimate [Regression 1](#) with fixed date effects, and standard errors clustered by date, rather than fixed symbol effects.

In [Table 10](#), we estimate [Regression 1](#) with a different set of wholesalers. In this specification, we compare the top two wholesalers, Citadel and SIG, against the rest of the major wholesalers. Citadel and SIG lead to an additional 0.5% in exchange volume in liquid symbols, but -0.7% in exchange volume in all symbols. Although Citadel and SIG are the largest wholesalers (and would presumably bring in the most PFOF-related volume), they also control the largest number of DMM seats. Once we control for the number of seats held by each firm (Columns 3 and 4 of [Table 10](#)),

Table 9**Estimation of regression 1: Trading volume with date fixed effect.**

	<i>Dependent variable</i>			
	Dollar volume		Volume share	
	(1)	(2)	(3)	(4)
PFOF	509.026*** (84.849)	8,845.776*** (608.709)	1.162*** (0.088)	0.368*** (0.067)
Exchange FE	X	X	X	X
Date FE	X	X	X	X
Observations	670,065	108,125	670,065	108,125
R^2	.001	.007	.198	.571

We present results of the estimation of [Regression 1](#). In contrast with [Table 2](#), we estimate using fixed effects for each date (and cluster standard errors by date), rather than for each trading symbol. Observations are at the monthly level, where we aggregate over all trades for 10 contracts or fewer. PFOF takes the value 1 when an exchange's designated-market-maker pays for order flow, and 0 otherwise. Panel A presents results with monthly trading volume (in thousands of dollars), while panel B presents results with exchange volume share (as a percentage of all electronic trading volume at exchanges which use designated market makers). Columns 1 and 2 present results for all symbols, while columns 3 and 4 present results for the 500 symbols with the highest trading volume. * $p < .1$; ** $p < .05$; *** $p < .01$.

Table 10**Estimation of regression 1: Trading volume with specific wholesalers.**

	<i>Dependent variable: Volume share</i>			
	All symbols (1)	Liquid only (2)	All symbols (3)	Liquid only (4)
Top_PFOF	-0.733*** (0.060)	0.556*** (0.064)	1.747*** (0.062)	0.634*** (0.070)
Number of seats			-0.068*** (0.001)	-0.002*** (0.001)
Exchange FE	X	X	X	X
Observations	555,033	84,020	555,033	84,020
R^2	.209	.585	.234	.585

We present results of the estimation of [Regression 1](#). In contrast with [Table 2](#), here we restrict our estimation to the top two option wholesalers, Citadel and SIG, indicated by *Top_PFOF*. Observations are at the monthly level, where we aggregate over all trades for 10 contracts or fewer. Number of Seats refers to the number of DMM seats held in the symbol by the DMM of the local exchange. PFOF takes the value 1 when an exchange's designated-market-maker pays for order flow, and 0 otherwise. Panel A presents results with monthly trading volume (in thousands of dollars), while panel B presents results with exchange volume share (as a percentage of all electronic trading volume at exchanges which use designated market makers). Columns 1 and 3 present results for all symbols, while columns 2 and 4 present results for the 500 symbols with the highest trading volume. * $p < .1$; ** $p < .05$; *** $p < .01$.

Citadel and SIG are associated with a 1.7% (all symbols) to 0.6% (most liquid symbols) volume increase relative to the other, smaller PFOF-paying DMMs.

Appendix III

Auction Usage Alternative Specifications

We explore several alternative specifications to Section III C. Table 11 confirms that larger quoted spreads are associated with a higher likelihood of entering an auction. Figure 9 estimates Regression 2 utilizing only exchanges at the NBBO. Figure 11 presents results with date-fixed effects and results with a restriction to the most liquid symbols. Table 13 presents estimates for separate price categories. Figure 10 estimates the regression 2 over time and plots the spread coefficient quoted for different time periods. Although the propensity for auction usage increases for all contract sizes in the later years of the sample, the pattern of lower usage is present in each sample for trades of five contracts compared to trades of more than 10 contracts.

To examine, at a higher level, how auction usage varies with the assignment of DMMs, we estimate Regression 5:

REGRESSION 5. For each security i :

$$PIM_share_i = \alpha_0 + \alpha_1 Non_PFOF_Seats_Assigned + X_i + \epsilon_i.$$

PIM share is the volume share that is executed in the PIM auctions. Non-PFOF Seats Assigned is the quantity of DMM seats, across all exchanges, assigned to non-PFOF-paying firms. X is a vector of controls that includes the market cap and the average daily volume of stock of each symbol. Results of Regression 5 are presented in Table 12. The assignment of a non-PFOF specialist is associated with a 0.42% to 1.12% higher total volume executed in auction for orders of up to 9 contracts, consistent with the assignment of DMM seats to non-PFOF-paying firms, leaving the PFOF-paying specialists with less flexibility in how they internalize orders and increased utilization of auctions.

Table 11
Estimation of auction usage.

	Dependent variable: AuctionTrade	
	(1)	(2)
At NBBO	-0.55*** (0.08)	-0.56*** (0.01)
Abs. delta	0.61*** (0.10)	0.59*** (0.01)
Vega	0.10 (0.10)	0.22*** (0.02)
Gamma	-0.07 (0.06)	-0.19*** (0.03)
Theta	-0.01 (0.01)	-0.02*** (0.00)
Price	-0.01*** (0.00)	-0.01*** (0.00)
Quoted half spread	0.30 (0.15)	0.19*** (0.03)
Stock FE	X	
Date FE		X
Exchange FE	X	X
Num. obs.	34,641,506	34,647,220

This table replicates the main finding of Anand and Muravyev (2024), that auctions are less likely when an exchange is at the NBBO. We estimate Regression 2 with trade-level data for the 30 trading days starting on July 1, 2020, for trades between 1 and 10 contracts. Our dependent variable *AuctionTrade* takes the value 1 when a trade is an auction and 0 when a trade is a regular limit order book trade. *AtNBBO* is an indicator which takes the value 1 if the local exchange bid (for a buy order) or ask (for a sell order) is at the NBBO at the exchange where trade occurs. Controls include the absolute value of delta, as well as vega, gamma, theta, price, and the half-quoted spread. We include a fixed effect for each exchange as well as each symbol (1) or date (2) and cluster standard errors by symbol (1) or date (2). * $p < .1$; ** $p < .05$; *** $p < .01$.

Table 12
Option auction usage and non-PFOF DMM assignments.

Number contracts:	Dependent variable: PIM auction volume share						
	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 to 9 (6)	10+ (7)
Seats assigned to Non-PFOF	0.42*** (0.15)	0.68*** (0.20)	0.45* (0.23)	1.12*** (0.26)	0.67** (0.27)	0.05 (0.24)	-0.97*** (0.23)
Market cap	-0.00*** (0.00)	0.00*** (0.00)	0.00*** (0.00)	0.00*** (0.00)	0.00*** (0.00)	0.00*** (0.00)	0.00*** (0.00)
Symbol daily Equity volume	0.00*** (0.00)	-0.00*** (0.00)	0.00*** (0.00)	0.00*** (0.00)	0.00** (0.00)	0.00 (0.00)	-0.00*** (0.00)
Constant	17.70*** (0.34)	19.67*** (0.45)	20.09*** (0.54)	16.49*** (0.61)	22.13*** (0.62)	17.04*** (0.56)	23.91*** (0.54)
Observations	2,192	1,908	1,725	1,602	1,811	1,668	1,933
R ²	.01	.13	.12	.14	.09	.16	.17

We present results of the estimation of [Regression 5](#). PIM Auction Volume Share is the percentage of auction volume which occurs, at a symbol level, in auctions. Seats Assigned to Non-PFOF measures the number of specialist seats assigned to non-PFOF-paying DMMs, across all exchanges. We restrict our analysis to symbols where at least eight specialists have been assigned, and observations are weighted by symbol volume. * $p < .1$; ** $p < .05$; *** $p < .01$.

Table 13
Auction usage price controls.

Price:	Dependent variable: Auction			
	Below \$1 (1)	(\$1 to \$3) (2)	(3, 10) (3)	(10,50) (4)
Abs. delta	0.47*** (0.13)	0.54*** (0.05)	0.55*** (0.05)	0.38*** (0.07)
Vega	5.44* (2.12)	0.92*** (0.24)	0.20 (0.12)	0.11 (0.08)
Gamma	-0.07 (0.05)	0.11 (0.18)	-0.66 (0.52)	2.16 (2.30)
Theta	0.12* (0.05)	0.02 (0.02)	0.01 (0.01)	-0.01 (0.00)
Price	-0.24 (0.13)	-0.01 (0.01)	-0.04*** (0.00)	-0.01*** (0.00)
NBBO quoted spread	1.33*** (0.14)	0.95*** (0.06)	0.69*** (0.07)	0.88*** (0.11)
Num. obs.	5,964,681	3,964,566	3,812,764	1,307,726
Num. groups: SYM_ROOT	3,331	3,088	2,397	1,182

This table estimates [Regression 2](#), conditional on trades at the NBBO, for different option prices. Column 1 for trades priced between 0 and \$1, column 2 for trades priced between (\$1 and \$3), column 3 for trades priced between (\$3 and \$10), and column 4 for trades priced between (\$10 and \$50). * $p < .1$; ** $p < .05$; *** $p < .01$.

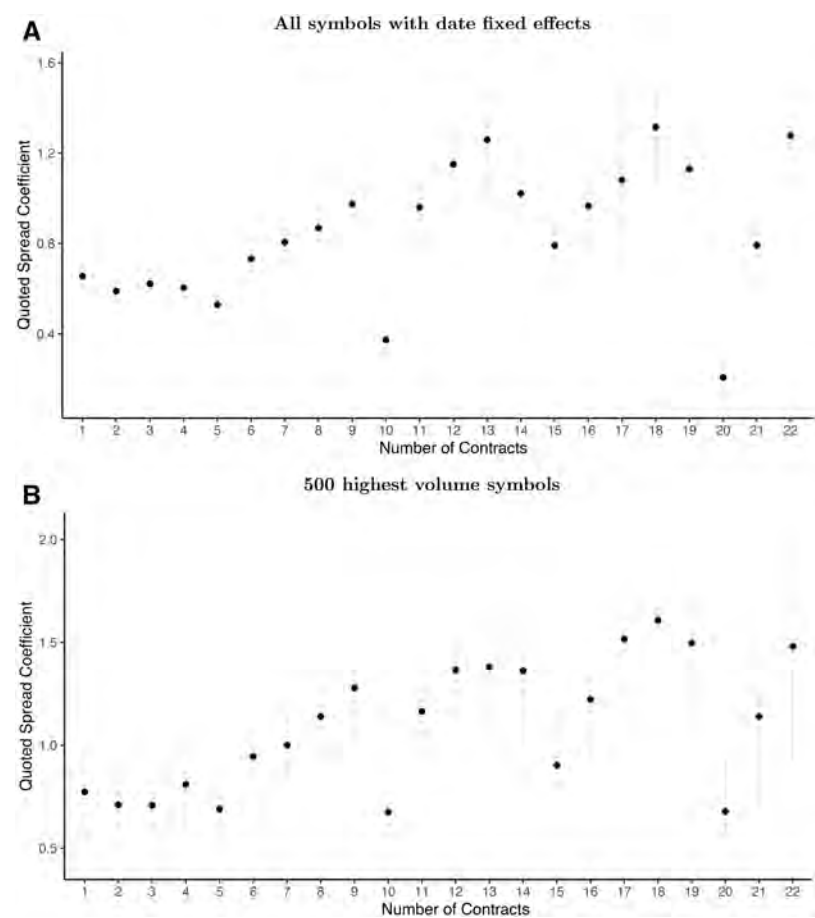


Figure 9
Auction probability and quoted spreads: Alternatives.
We estimate Regression 2 for each individual contract size. Each coefficient estimate on Quoted Spreads is plotted by a black dot with a light blue bar indicating the 95% confidence interval. We restrict our analysis to trades where trades happen at an exchange which matches the national best bid (for a buy order) or ask (for a sell order). The dependent variable *Auction* is an indicator for whether a trade is an auction or a regular limit order book trade. Quoted Spread is the NBBO half-spread, in dollars. Controls include the option Greeks, a fixed effect for each exchange and symbol, and standard errors are clustered by exchange. Panel A presents estimation with all symbols, but with date and exchange fixed effects (and standard errors clustered by date). Panel B presents fixed effects for each symbol and exchange, with standard errors clustered by symbol, but restricted to the 500 symbols with the highest trading volume. Note that we estimate all contracts of size 22 or more as a single point at 22.

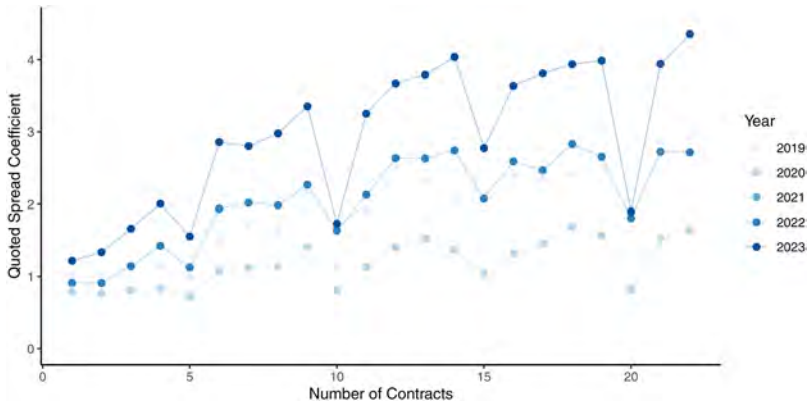


Figure 10

Auction probability and quoted spreads through time.

We estimate [Regression 2](#) for each individual contract size. We restrict our analysis to exchanges with a PFOF-paying DMM assigned and trades which occur when the exchange matches the national best bid (for a buy order) or ask (for a sell order). The dependent variable *Auction* is an indicator for whether a trade is an auction or a regular limit order book trade. Quoted Spread is the NBBO half-spread, in dollars. Controls include the option Greeks, a fixed effect for each exchange and symbol, and standard errors are clustered by exchange.

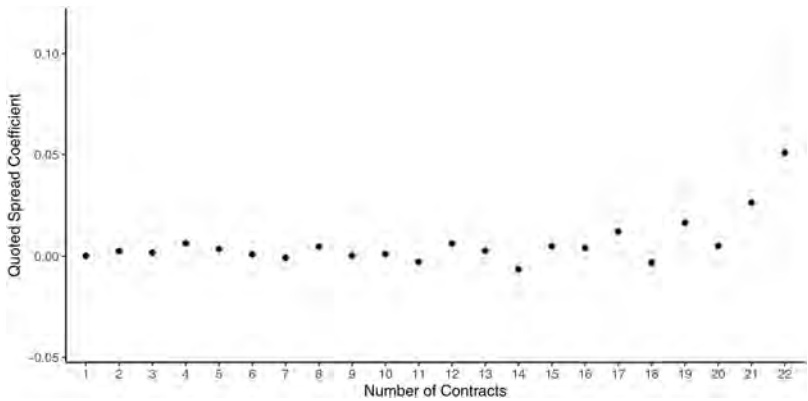


Figure 11

Auction probability and quoted spreads: Single DMM.

We estimate [Regression 2](#) for each individual contract size for single-DMM securities. We restrict our analysis to trades where trades happen at an exchange which matches the national best bid (for a buy order) or ask (for a sell order). The dependent variable *Auction* is an indicator for whether a trade is an auction or a regular limit order book trade. Quoted Spread is the NBBO half-spread, in dollars. Controls include the option Greeks, a fixed effect for each exchange and date, and standard errors are clustered by exchange and date. Note that we estimate all contracts of size 22 or more as a single point at 22.

Appendix IV

Single-DMM Analysis: Alternative Specifications

We present additional analysis of Section III D, and reestimation of Regression 3 under various alternatives specifications. We present estimates with fixed effect of date and exchange with standard errors clustered by symbol in Table 14. We present summary statistics on the propensity score match in Table 15. For each symbol with a non-PFOF-assigned DMM, we match to a symbol with a PFOF-paying DMM based on median daily dollar volume of the symbol.

In addition to the propensity score match, we estimate Regression 3 using all symbols, rather than just the matched sample based on volume. Results are presented in Table 16. When the sole DMM is a PFOF-paying firm, we find that across all auto-electronic option trades, effective spreads are a statistically significant 2.0 cents higher, quoted half-spreads a statistically significant 3.0 cents higher.

We also separately estimate Regression 3 for auction trades, with results reported in column 4 of Table 16. Auction trades obtain approximately no greater price improvement but pay 1.8 cents more in effective spreads.

As an alternative match, we consider matching jointly on volume and the share of auction volume that executes as Single Leg Non-ISO auction trades; Bryzgalova, Pavlova, and Sikorskaya (2023) present SLIM trades as a measure of retail trading. The summary statistics of the match are presented in Table 17 and the results of the estimation are presented in Table 18.

Next, we consider a version of our estimates with different price filters. We measure spreads in cents, but options can have radically different prices. In Table 19, we present coefficient estimates

Table 14
Option spreads with a single DMM.

	All trades		LOB trades	PIM trades	
	Effective spread (1)	Quoted half spread (2)	Effective spread (3)	Price improvement (4)	Effective spread (5)
PFOF	5.741** (2.638)	9.611** (3.797)	6.700** (3.027)	5.204** (2.265)	5.344*** (1.985)
Price	0.564*** (0.103)	0.889*** (0.221)	0.680*** (0.119)	1.679*** (0.193)	0.246 (0.173)
Abs. delta	1.499 (0.979)	13.015*** (3.856)	5.276*** (1.834)	1.536 (2.463)	1.826 (1.419)
Vega	64.601*** (2.065)	96.803*** (3.197)	66.115*** (2.140)	77.840*** (2.720)	43.883*** (2.739)
Gamma	-12.992*** (3.414)	-34.478*** (11.608)	-21.124*** (5.115)	-8.260** (3.697)	-8.774*** (3.361)
Theta	-13.821*** (4.033)	-25.863*** (6.222)	-14.169*** (3.816)	-32.298*** (8.404)	-8.706 (6.620)
Size	-0.00001*** (0.00000)	0.00000 (0.00000)	-0.00003*** (0.00001)	-0.00002*** (0.00000)	0.00001*** (0.00000)
SymbolVolume	0.005 (0.006)	0.016* (0.009)	0.007 (0.007)	0.009 (0.006)	0.004 (0.004)
Observations	556,706	556,706	334,650	99,212	99,212
R ²	.349	.414	.422	.513	.317

This table estimates Regression 3; in contrast to Table 3 we cluster standard errors by symbol, with exchange-date fixed effects. Dependent variables are the effective spread, quoted spread, or price improvement (relative to the NBBO), all measured in cents. We restrict analysis to the subset of options which have a single DMM across all exchanges; columns 1, 2, and 3 are for all auto-electronic trades, while column 4 is restricted to PIM trades. PFOF is an indicator for whether the single DMM in that stock is one of the major PFOF-paying firms. Estimates are weighted-least-squares regression, using the total traded value of each security as the weight.

* $p < .1$; ** $p < .05$; *** $p < .01$.

Table 15
Single DMM propensity score match.

DMM	Statistic	Mean	SD	5%	25%	50%	75%	95%
No PFOF	Median dollar volume	10.1	17.3	0.1	0.7	2.3	9.8	47.5
PFOF	Median dollar volume	6.9	7.4	0.1	1.5	4.3	10.6	20.4
No PFOF	Median spread	24.7	35.1	2.4	4.9	11.7	26.6	120.3
PFOF	Median spread	26.5	34.9	2.8	6.0	15.3	29.9	120.8
No PFOF	Market cap	1.8	2.9	0.0	0.1	0.5	2.6	7.3
PFOF	Market cap	1.8	2.2	0.1	0.4	1.1	2.5	5.8
No PFOF	Equity trades	1.8	2.9	0.0	0.1	0.5	2.6	7.3
PFOF	Equity trades	1.8	2.2	0.1	0.4	1.1	2.5	5.8
No PFOF	SLIM share	7.1	7.6	0.0	0.9	4.7	11.8	20.6
PFOF	SLIM share	8.9	6.8	0.7	3.0	7.3	13.4	20.2
Non-PFOF symbols								
ACWX	AIRR	ANGL	CAF	CPER	CQQQ	DDG	DEA	DLS
ECNS	EDOC	EMQQ	EURL	EYEN	FDLO	FFG	FGD	FNDE
FNDF	FNDX	FPXI	FTEC	FTXR	FVD	GEM	GLCN	GLIN
GLMD	GMF	GSIE	HDV	HEWG	HEZU	HOMZ	IDNA	IFGL
IGF	IWY	IXJ	IYC	IYK	JILL	JOET	KORU	KXIN
MAGA	MOAT	MSON	NETL	OUNZ	OUSA	PEJ	PFFA	PSCH
PSI	RETL	SDEM	SNSR	SPDN	SPDW	SPEM	SRET	TPOR
URNM	VIGI	VTIP	XAR	XT				
PFOF symbols								
ALE	BMTC	BUSE	CPK	CTT	DGRW	DLN	DWAS	EBF
ENZL	EWK	FBIZ	FENY	FMS	FXG	FXN	HBIO	HMN
HOPE	HYMB	HYS	IBTX	IFN	IHAK	INDY	IOO	IXC
JPUS	LFT	LTPZ	MGC	MGRG	MGV	NJR	NL	PATK
PCF	PRFZ	PSB	PSP	PZA	RWJ	RWK	RWL	RWX
SASR	SBCF	SBSI	SCHA	SCM	SJB	SJI	SNLN	SPHB
SPOK	SR	STCN	TFI	TRC	TRST	TSLX	ULBI	VDC
VIS	VONV	VOX	VSS	YCL				

This table presents the details of the propensity score match for [Regression 3](#). We match on the median daily trading volume of each symbol, in millions of dollars. We present summary statistics for the Median Dollar Volume (in millions), Median Spread (in Basis Points), Market Cap (in Billions), Equity Trades (in Thousands per Day), and SLIM Share (percentage of option trades which execute in a single-leg non-ISO auction, out of all option trading volume).

across four subgroupings of the data: trades for less than \$1, trades between \$1 and \$3, trades between \$3 and \$10, and trades above \$10. The results are very similar between option trades priced below \$1 and between \$3 and \$10. The results are similar in sign and magnitude for trades priced between \$3 and \$10, but with much lower statistical significance for all outcome variables, except for quoted half spreads. The results of trades priced above \$10 are similar in sign but lack statistical significance for all outcome variables except quoted spreads.

Finally, we consider a match only utilizing the smallest PFOF-paying DMMs (i.e., Wolverine, Morgan Stanley, and IMC but not Citadel and Virtu) in [Table 20](#) and present results of the estimation in [Table 21](#).

Table 16
Single DMM with all symbols.

	All trades		LOB trades	PIM trades	
	Effective spread (1)	Quoted half spread (2)	Effective spread (3)	Price improvement (4)	Effective spread (5)
PFOF	2.037** (0.914)	2.976*** (1.129)	2.559*** (0.859)	-0.404 (0.781)	1.827* (0.937)
Price	0.462*** (0.044)	0.460*** (0.066)	0.404*** (0.058)	0.810*** (0.258)	0.286*** (0.034)
Abs delta	7.171*** (2.182)	19.886*** (2.286)	12.768*** (2.582)	11.971*** (3.201)	2.023*** (0.422)
Vega	13.798*** (4.154)	32.447*** (4.316)	20.334*** (3.115)	25.928*** (6.514)	14.031** (6.646)
Gamma	-18.840*** (3.368)	-33.121*** (9.365)	-24.132*** (4.845)	-16.597*** (3.526)	-5.256 (3.930)
Theta	-11.017*** (2.190)	-14.963*** (2.785)	-9.917*** (2.918)	-18.223*** (2.035)	-3.557** (1.609)
Size	-0.00001** (0.00000)	0.00000** (0.00000)	-0.0001 (0.0001)	-0.00003 (0.00002)	0.00002 (0.00002)
Symbol volume	0.003*** (0.001)	0.011*** (0.002)	0.006*** (0.001)	0.007*** (0.003)	0.005*** (0.002)
Observations	1,553,433	1,553,433	961,031	258,564	258,564
R ²	.282	.372	.354	.462	.215

This table estimates [Regression 3](#) with data from November 4, 2019, to December 31, 2023. Dependent variables are the effective spread, quoted spread, or price improvement (relative to the NBBO), all measured in cents. We restrict analysis to the subset of options which have a single DMM across all exchanges; columns 1, 2, and 3 are for all auto-electronic trades, while column 4 is restricted to PIM trades. PFOF is an indicator for whether the single DMM in that stock is one of the major PFOF-paying firms. Estimates are weighted-least-squares regression, using the total traded value of each security as the weight. There is a fixed effect for each exchange and date, and standard errors are clustered by exchange. * $p < .1$; ** $p < .05$; *** $p < .01$.

Table 17
Single DMM propensity score match on volume and SLIM share.

DMM	Variable	Mean	SD	5%	25%	50%	75%	95%
No PFOF	Median dollar volume	10.1	17.3	0.1	0.7	2.3	9.8	47.5
PFOF	Median dollar volume	16.4	42.2	0.1	0.8	3.5	12.8	66.1
No PFOF	SLIM share	7.1	7.6	0.0	0.9	4.7	11.8	20.6
PFOF	SLIM share	7.1	7.3	0.1	0.8	4.7	12.0	20.7

This table presents the details of the propensity score match for [Regression 3](#). We match on the median daily trading volume of each symbol, in millions of dollars, as well as the median SLIM auction volume share, as a percentage of total dollar volume.

Table 18
Single DMM with SLIM match.

	<i>All trades</i>		<i>LOB trades</i>	<i>PIM trades</i>	
	Effective spread (1)	Quoted half spread (2)	Effective spread (3)	Price improvement (4)	Effective spread (5)
PFOF	2.171 (1.307)	0.725 (2.115)	2.120 (1.674)	-3.142 (3.046)	2.333 (1.660)
Price	0.439*** (0.024)	0.416*** (0.029)	0.371*** (0.024)	0.697*** (0.097)	0.208*** (0.059)
Abs. delta	8.198*** (2.191)	22.153*** (1.050)	14.574*** (1.645)	14.735*** (0.632)	2.798** (1.213)
Vega	12.349*** (3.676)	31.972*** (4.892)	18.610*** (3.341)	25.501*** (5.323)	18.778*** (3.445)
Gamma	-30.377*** (3.375)	-56.611*** (3.465)	-38.626*** (3.808)	-25.932*** (1.812)	-18.112*** (2.381)
Theta	-10.327*** (1.218)	-14.623*** (2.015)	-8.471*** (1.133)	-17.162*** (1.259)	-3.965 (2.427)
Size	-0.00001 (0.00001)	0.00000 (0.00001)	-0.0001 (0.00005)	-0.00003 (0.00002)	0.00002 (0.00002)
Symbol volume	0.003 (0.002)	0.015*** (0.003)	0.007** (0.002)	0.012** (0.005)	0.003 (0.002)
Observations	586,377	586,377	349,743	93,667	93,667
R ²	.292	.374	.362	.480	.236

This table estimates [Regression 3](#) with data from November 4, 2019, to December 31, 2023. Each symbol with a non-PFOF-paying DMM is matched to a symbol with a PFOF-paying DMM based on volume and SLIM (price improvement auction) volume share. Dependent variables are the effective spread, quoted spread, or price improvement (relative to the NBBO), all measured in cents. We restrict analysis to the subset of options which have a single DMM across all exchanges; columns 1, 2, and 3 are for all auto-electronic trades, while column 4 is restricted to PIM trades. PFOF is an indicator for whether the single DMM in that stock is one of the major PFOF-paying firms. Estimates are weighted-least-squares regression, using the total traded value of each security as the weight. There is a fixed effect for each exchange and date, and standard errors are clustered by exchange.

* $p < .1$; ** $p < .05$; *** $p < .01$.

Table 19
Single DMM with price restricted estimation.

	<i>All trades</i>		<i>LOB trades</i>	<i>PIM trades</i>	
	Effective spread (1)	Quoted half spread (2)	Effective spread (3)	Price improvement (4)	Effective spread (5)
PFOF coefficient estimate	5.496***	8.006***	5.214***	3.751***	6.213***
Trades priced less than \$1	(1.829)	(2.465)	(1.933)	(1.257)	(1.716)
PFOF coefficient estimate	5.832*	10.268**	7.369**	8.570***	4.164*
Trades priced \$1 to \$3	(3.049)	(4.325)	(3.430)	(3.209)	(2.132)
PFOF coefficient estimate	4.426	9.024**	6.126*	6.129	1.179
Trades priced \$3 to \$10	(3.445)	(4.333)	(3.610)	(4.098)	(2.340)
PFOF coefficient estimate	1.108	6.542**	0.697	5.806	0.891
Trades priced above \$10	(2.468)	(2.824)	(2.911)	(6.388)	(10.668)

This table estimates [Regression 3](#) according to the specifications of [Table 3](#), but for different price filters. In the interest of saving space, we present estimates only for the PFOF coefficient across four subgroupings of the data: trades for less than \$1, trades between \$1 and \$3, trades between \$3 and \$10, and trades above \$10. * $p < .1$;

** $p < .05$; *** $p < .01$.

Table 20
Single DMM propensity score match with smaller PFOF-paying DMMs.

DMM	Variable	Mean	SD	5%	25%	50%	75%	95%
No PFOF	Median dollar volume	10.1	17.3	0.1	0.7	2.3	9.8	47.5
PFOF	Median dollar volume	8.0	16.6	0.1	0.5	2.3	9.1	26.0

This table presents the details of the propensity score match for [Regression 3](#). We match on the median daily trading volume of each symbol, but we exclude Citadel and SIG from the DMMs, restricting the analysis of PFOF-paying DMMs to Wolverine Execution Services, Morgan Stanley, and IMC.

Table 21
Single DMM with smaller PFOF-paying DMMs.

	<i>All trades</i>		<i>LOB trades</i>	<i>PIM trades</i>	
	Effective spread (1)	Quoted half spread (2)	Effective spread (3)	Price improvement (4)	Effective spread (5)
PFOF	9.381*** (2.110)	14.001*** (2.543)	9.513*** (2.502)	8.752*** (1.767)	8.183*** (1.846)
Price	0.541*** (0.065)	0.849*** (0.084)	0.655*** (0.035)	1.649*** (0.166)	0.218*** (0.054)
Abs. delta	1.844** (0.863)	13.957*** (0.905)	5.901*** (0.837)	2.065 (1.866)	1.870 (1.806)
Vega	62.752*** (2.388)	91.951*** (5.168)	61.828*** (1.968)	78.025*** (6.488)	46.634*** (4.275)
Gamma	-15.399*** (2.088)	-38.399*** (2.952)	-24.541*** (2.138)	-8.733* (4.178)	-10.560*** (1.641)
Theta	-13.481*** (1.833)	-24.457*** (1.916)	-13.143*** (1.868)	-31.663*** (2.610)	-9.581** (3.240)
Size	-0.00001* (0.00000)	0.00000 (0.00000)	-0.00003** (0.00002)	-0.00002 (0.00001)	0.00001 (0.00001)
Symbol volume	0.005 (0.006)	0.016** (0.007)	0.007 (0.007)	0.010* (0.005)	0.004 (0.004)
Observations	517,144	517,144	312,584	91,793	91,793
R ²	.350	.413	.423	.510	.318

This table estimates [Regression 3](#) according to the specifications of [Table 3](#), but we exclude Citadel and SIG from the DMMs, restricting the analysis of PFOF-paying DMMs to Wolverine Execution Services, Morgan Stanley, and IMC. * $p < .1$; ** $p < .05$; *** $p < .01$.

Appendix V

Competition in PIM Trades: Alternatives

We examine alternative specifications for [Section III F](#), which looks at competition within PIM trades for small orders. We document that effective spreads for trades of exactly 1 contract (which cannot be divided and therefore accrue entirely to the initiator if the imitator decides to auto-match competing bids, and entirely to the competitor only when the initiator decides not to auto-match competing bids) are larger than for trades of 2, 3, or 4 contracts. This is consistent with a winner's curse, whereby competing bids only obtain any order if the initiator decides not to auto-match that price. Although we cannot identify any possible sources of fixed costs in the all-electronic options market, to control for the possibility that fixed costs contribute to our results, we divide

Table 22
PIM auctions and spread tiers.

A. Effective spread with spread divisions

Spread:	<i>Dependent variable: Effective spread (cents)</i>		
	< 5 cents	[5 cents, 10 cents]	(10 cents, 50 cents)
Size100	0.359*** (0.026)	0.550*** (0.057)	-0.111 (0.079)
Size200	0.159*** (0.029)	0.371*** (0.062)	0.097 (0.086)
Size300	0.093*** (0.032)	0.259*** (0.069)	0.076 (0.096)
Observations	8,646,419	3,092,360	2,429,793
R ²	.144	.131	.121

B. Quoted spread with spread divisions

Spread:	<i>Dependent variable: Quoted spread (cents)</i>		
	< 5 cents	[5 cents, 10 cents]	(10 cents, 50 cents)
Size100	0.107*** (0.001)	0.163*** (0.005)	0.272*** (0.029)
Size200	0.031*** (0.002)	0.064*** (0.005)	0.219*** (0.031)
Size300	0.020*** (0.002)	0.049*** (0.006)	0.154*** (0.035)
Observations	8,646,419	3,092,360	2,369,618
R ²	.216	.058	.199

C. EFQ with spread divisions

Spread:	<i>Dependent variable: EFQ (%)</i>		
	< 5 cents	[5 cents, 10 cents]	(10 cents, 50 cents)
Size100	3.563*** (0.327)	5.118*** (0.488)	0.717* (0.419)
Size200	1.713*** (0.357)	3.020*** (0.532)	0.772* (0.455)
Size300	0.787** (0.401)	2.275*** (0.594)	0.883* (0.508)
Observations	8,646,419	3,092,360	2,429,793
R ²	.130	.135	.138

This table estimates [Regression 4](#) for PIM trades occurring in the 30 trading days starting on July 1, 2020. We take trades for 1, 2, 3, and 4 contracts. Effective and quoted spreads are in cents, while EFQ refers to the effective-over-quoted spread ratio. We include the option Greek values, a fixed effect for each stock, and a fixed effect for each exchange. Column 1 presents coefficient estimates for trades with a quoted spread less than 5 cents, column 2 for a quoted spread between 5 and 10 cents (inclusive), and column 3 for trades between 10 and 50 cents.

Table 23
PIM auctions and price tiers.

A. Effective spread with price divisions

Price:	Dependent variable: <i>Effective spread (cents)</i>			
	< \$1	(\$1, \$3)	(\$3, \$10)	> \$10
Size100	0.486*** (0.037)	0.546*** (0.041)	0.369*** (0.055)	−0.165 (0.102)
Size200	0.163*** (0.040)	0.189*** (0.044)	0.355*** (0.060)	0.113 (0.111)
Size300	0.104** (0.045)	0.200*** (0.050)	0.170** (0.067)	−0.044 (0.125)
Observations	5,232,063	4,679,868	3,429,944	1,667,344
R ²	.109	.191	.194	.219

B. Quoted spread with price divisions

Price:	Dependent variable: <i>Quoted spread (cents)</i>			
	< \$1	(\$1, \$3)	(\$3, \$10)	> \$10
Size100	0.979*** (0.015)	0.957*** (0.024)	1.377*** (0.050)	4.866*** (0.234)
Size200	0.229*** (0.016)	0.352*** (0.026)	0.821*** (0.054)	2.619*** (0.255)
Size300	0.174*** (0.018)	0.306*** (0.029)	0.624*** (0.060)	0.862*** (0.285)
Observations	5,232,063	4,679,868	3,429,944	1,667,344
R ²	.020	.042	.063	.498

C. EFQ with price divisions

Price:	Dependent variable: <i>EFQ (%)</i>			
	< \$1	(\$1, \$3)	(\$3, \$10)	> \$10
Size100	−1.876*** (0.425)	2.330*** (0.431)	1.651*** (0.439)	−1.003** (0.392)
Size200	0.111 (0.465)	0.903* (0.470)	1.679*** (0.477)	−0.094 (0.427)
Size300	−0.284 (0.522)	0.966* (0.528)	1.103** (0.533)	−0.259 (0.478)
Observations	5,231,990	4,679,833	3,429,935	1,667,342
R ²	.080	.168	.180	.092

This table estimates [Regression 4](#) for PIM trades occurring in the 30 trading days starting on July 1, 2020. We take trades for 1, 2, 3, and 4 contracts. Effective and quoted spreads are in cents, while EFQ refers to the effective-over-quoted spread ratio. We include the option Greek values, a fixed effect for each stock, and a fixed effect for each exchange. Column 1 presents coefficient estimates for trades less than \$1; column 2 for trades between \$1 and \$3; column 3 for trades between \$3 and \$10; and column 4 for trades greater than \$10.

trades by prevailing NBBO quoted spreads at the time of trade. In [Table 22](#), we note that the results for trades with a quoted spread between 5 and 10 cents are even stronger than for trades with a quoted spread less than 5 cents, suggesting that fixed costs of trade cannot play an important role (since fixed costs are easier to cover when the quoted spread is larger). In [Table 23](#), we divide our analysis into several tiers based on the traded price of the option. We find consistent results in options priced below \$1, between \$1 and \$3, and between \$3 and \$10. In [Figure 12](#), we extend our estimates to a series of rolling windows that cover our entire sample period. Our results on quoted and effective spreads are robust in all periods, while our results on effective-over-quoted spreads turn positive in the last months of 2023.

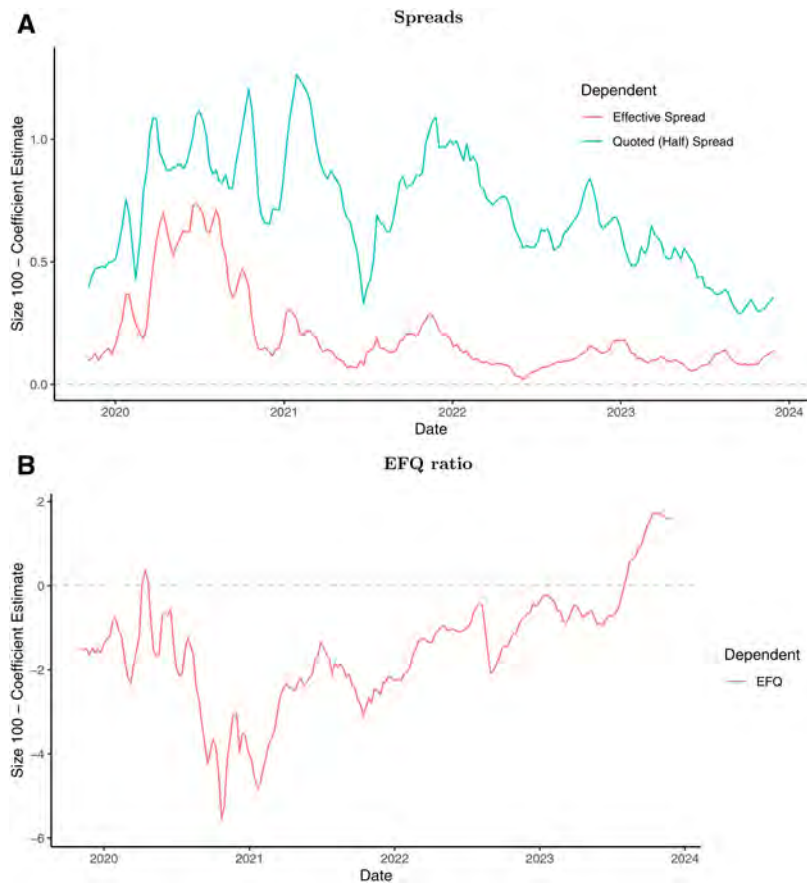


Figure 12
PIM auctions: Through time.

We estimate [Regression 4](#) over a series of trading windows. In panel A, we present the size-100 coefficient estimate when the dependent variable is either effective spread (in cents) or quoted spread (in cents). In panel B, we present the size-100 coefficient estimate when the dependent variable is EFQ, the effective-over-quoted spread ratio.

Appendix VI

PIM Auction Use and the Option Penny Program

Broker routing is competitive, with brokers routing more order flow to market makers that offer superior execution quality. As a measure of execution quality, brokers often track “effective-over-quoted” spreads, which is the ratio of the effective spread their clients pay divided by the NBBO quoted half-spread.⁶⁰ As an example, suppose that a broker initially splits orders equally among Citadel, Susquehanna and Wolverine; if Citadel provides a better EFQ ratio, then in subsequent months, the broker can change the allocation to route a larger fraction of orders to Citadel, and a smaller fraction of orders to Susquehanna and Wolverine.

Market makers who internalize order flow therefore face a trade-off between profit on the individual trade and how the trade will affect execution quality statistics, which would influence future order flow. Internalizing a trade with no price improvement (such as through a DMM position) will maximize profit on that trade but offer no improvement relative to quoted spreads. Internalizing the trade through a PIM auction will reduce profits on the individual trade, particularly if there are competing bidders, but will also improve the price relative to quoted spreads.

Initially a pilot program and now converted to be permanent, the Option Penny Program changes the tick size for a set of symbols. For symbols added to the program, their tick size is reduced from 5 cents to 1 cent for options priced below \$3.00. As symbols are frequently added and removed from the program, we are able to test the effect of a change in tick size on the results in auctions.

We examine the July 1, 2020, change, when the Option Penny Pilot became the Option Penny Program. At this time, the program changed to formally have the 363 most actively traded listed options trade in pennies, with updates made every six months. Our treatment group consists of 106 symbols added to the Option Penny Program on July 1, 2020. We consider two possible control groups: the set of 39 symbols added to the Option Penny Program in December 2020, and the set of 105 symbols removed from the Option Penny Program on July 1, 2020. The former set is our main control group and is motivated by a regression discontinuity design, as these symbols are similarly liquid and meet the definition of being in the top 363 symbols in December, but not July. The latter set creates a stronger treatment effect, as these symbols go from a 1-cent to 5-cent tick size while the treatment group goes from a 5-cent to 1-cent tick size. We estimate the following regression.

REGRESSION 6. For each security j on date t :

$$\text{PIM_Share}_{jt} = \alpha_0 + \alpha_1 \text{Post}_t + \alpha_2 \text{SmallerTick}_j + \alpha_3 \text{Post}_t * \text{SmallerTick}_j + \epsilon_{jt}.$$

PIM share measures the share of dollar volume executed through PIM auctions. *SmallerTick* refers to the set of securities added to the Option Penny Program on July 1, 2020. The results of the estimation of [Regression 6](#) are presented in [Table 24](#). When we estimate results only for the treatment group, the dollar volume share of PIM auctions drops by 3.5% after the addition to the Option Penny Program. We also estimate the drop in volume using two control groups. Compared to the control group of symbols added to the program in December 2020, the PIM share in the treatment group drops by 6.2%. Compared to the control group of the set of symbols removed from the program, the PIM auction share in the treatment group drops by 9.7%.

For symbols added to the penny program, the share of trades that made up PIM auctions clearly drops. [Bryzgalova, Pavlova, and Sikorskaya \(2023\)](#) show how PIM auction volume is highly correlated with retail trading activity and offers a method for identifying a large number of retail trades. However, we highlight that these are only selecting marketable retail orders that market

⁶⁰ Best execution requires brokers to obtain the best possible price. Conversations with industry participants have highlighted EFQ ratios as a key metric on which market maker performance is evaluated.

Table 24
PIM share and spreads in option penny program.

Control:	Dependent variable: PIM_share			
	None (1)	December (2)	Dropped (3)	Joint (4)
Constant	25.354*** (0.305)	27.451*** (0.519)	20.057*** (0.389)	21.993*** (0.331)
Post	-3.425*** (0.439)	2.774*** (0.741)	6.245*** (0.559)	5.245*** (0.475)
SmallerTick		-2.097*** (0.603)	5.298*** (0.540)	3.361*** (0.497)
Post*SmallerTick		-6.199*** (0.863)	-9.669*** (0.777)	-8.670*** (0.714)
Observations	3,276	4,439	6,317	7,387
R ²	.018	.046	.026	.022
Residual std. error	12.557	12.631	15.418	15.234

We estimate changes in the share of dollar volume executed through a PIM auction for options priced below \$3.00 when symbols enter the Option Penny Program for 15 trading days before and after July 1, 2020. Our treatment group is the set of symbols added to the penny program on July 1, 2020. Post is an indicator taking the value 1 following July 1. SmallerTick takes the value 1 for symbols added to the penny program, and zero for control symbols. We consider two possible controls: December, which refers to the set of securities added to the penny program in December 2020, and Dropped, which refers to the set of securities dropped from the penny program on July 1. Joint combines symbols from both control groups. * $p < .1$; ** $p < .05$; *** $p < .01$.

makers choose to send to a PIM auction. An interpretation of our results in Table 24 is that retail traders place fewer orders in symbols once they are added to the penny program; Given that the vast majority of retail traders are unaware of additions or deletions from the program, or even of the program itself, the idea that it would influence what symbols they trade seems unlikely. Two alternatives may explain the same result. First, at the moment retail traders place a trade, seeing a quoted spread in pennies or nickels may influence their choice of whether to use a market or limit order (and therefore whether their order executes in a PIM auction). Second, market makers may internalize a larger share of orders via DMM allocations rather than auctions depending on quotes. For further insight, we estimate the following regression.

REGRESSION 7. For each option trade i in security j on exchange k on date t :

$$\text{PIM_Share}_{ijkt} = \alpha_0 + \alpha \text{Post}_t * \text{Treatment}_j * \text{Auction}_{ijkt} + X_{ijkt} + \epsilon_{ijkt}.$$

We fit all interaction terms and are interested in the three-way interaction between Post, Treatment, and Auction. Post is an indicator that takes the value 1 starting on July 1, 2020, when changes to the Option Penny Program are implemented. Treatment is an indicator for the set of stocks added to the program (and takes the value 0 for control stocks). Auction is an indicator for trades that execute in a PIM auction (and takes the value 0 for regular limit order book trades). The results of the regression 7 are presented in Table 25. In the treatment-only estimation, we find that upon implementation of the Option Penny Program, quoted spreads on auction trades become 0.7 cents smaller relative to quoted spreads on limit-order book trades. Compared to the control group of stocks that are only added to the Penny Program in December, quoted spreads are 0.9 cents smaller relative to quoted spreads on limit order book trades. These results are consistent with incentives for market makers to change after the implementation of the penny program. Quoted spreads decrease for all trades; therefore, the contribution of these symbols to the market maker's overall effective-over-quoted ratio changes. We observe behavior consistent with market makers using PIM auction trades less, but in particular cases depending on spreads. These results warn of any potential analysis that uses PIM Auctions to track changes in retail investor behavior, as changes in the PIM share may not be due to changes in the behavior of retail investors, but rather due to the behavior of market makers who seek to internalize retail trades.

Table 25
Quoted spreads and penny program.

Control:	<i>Dependent variable: Quoted spreads</i>			
	None (1)	December (2)	Dropped (3)	Joint (4)
Post	-1.837*** (0.013)	-1.058*** (0.019)	0.549*** (0.040)	-0.862*** (0.017)
SmallerTick		-3.814*** (0.017)	-4.415*** (0.028)	-3.974*** (0.016)
Auction	-7.689*** (0.020)	-11.044*** (0.027)	-9.022*** (0.050)	-10.728*** (0.025)
Post*SmallerTick		-0.621*** (0.024)	-2.380*** (0.043)	-0.842*** (0.022)
Post*Auction	-0.718*** (0.026)	0.027 (0.034)	2.133*** (0.071)	0.371*** (0.031)
SmallerTick*Auction		2.800*** (0.030)	1.325*** (0.051)	2.541*** (0.028)
Post*SmallerTick*Auction		-0.894*** (0.043)	-2.878*** (0.076)	-1.248*** (0.041)
Observations	5,452,388	8,547,555	6,127,669	9,222,836
R ²	.207	.210	.205	.205
Residual std. error	13.067	13.726	13.444	13.937

We estimate quoted spreads around the inclusion of stocks in the penny program, for options priced below \$3.00 for the 15 trading days before and after July 1, 2020. Our treatment group is the set of symbols added to the Option Penny Program on July 1, 2020. Auction is an indicator which takes the value 1 for PIM Auction trades. Post is an indicator taking the value 1 after July 1. SmallerTick takes the value 1 for symbols added to the penny program, and zero for control symbols. We consider two possible controls: December, which refers to the set of securities added to the penny program in December 2020, and Dropped, which refers to the set of securities dropped from the penny program on July 1. Joint combines symbols from both control groups. We also include the option absolute delta, price, size, vega, gamma, and theta as control variables, and fit a fixed effect for each exchange.

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