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Do (Should) Brokers Route Standing Limit Orders Seeking to Trade U.S. Equity Options to Wholesalers?

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Abstract:

Brokers who route both market and limit orders to wholesalers are generally paid less for their orders than brokers who bifurcate their order flow. Since nonmarketable limit orders have priority over wholesalers at a price, limit orders routed to wholesalers may experience enhanced execution quality by having the opportunity to provide liquidity to uninformed retail orders. We first present evidence that several national retail brokers bifurcate their options order flow: they route most of their market orders to wholesalers and most of their limit orders to exchanges with high take fees and liquidity rebates. Next, using a recent decision by the Philadelphia Stock Exchange to alter the manner in which options trades are arranged, we provide empirical evidence that brokers can enhance limit order execution quality by routing all of their customer orders to wholesalers.

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Wholesalers like Citadel, KCG, and UBS profit by selectively purchasing and providing liquidity to marketable orders submitted by uninformed retail investors. The Manning Rule, which prohibits market makers from trading at prices which are equal or inferior to the prices of limit orders resting in their order books, limits the ability of wholesalers to interact with purchased order flow.[1,2] As a result, wholesalers who do not accept nonmarketable limit orders are generally able to pay retail brokers more for their marketable orders than those that accept both marketable and nonmarketable orders.[3] Thus, brokers who route marketable orders to wholesalers who do not accept standing limit orders and route nonmarketable orders to venues that offer large liquidity rebates are able to increase the revenue associated with their order flow.[4]

Battalio, Corwin and Jennings (2016) demonstrate that routing customer orders in a manner that maximizes order flow payments can, in certain circumstances, result in diminished limit order execution quality (e.g., lower fill rates and higher adverse selection costs). They show that in certain market conditions, brokers can enhance limit order execution quality by displaying orders on venues that offer less aggressive liquidity rebates.[5] Data limitations prevent Battalio et al. from examining whether or not limit order execution quality can be further enhanced by routing standing limit orders to wholesalers who purchase order flow. As a result, they could not evaluate whether the apparent decision of some retail brokers to take lower order flow payments and route all orders in a given stock to wholesalers results in improved limit order execution quality.

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[1] See Finra Regulatory notice 11-24, May 2011.
[2] See Parlour and Rajan (2003).
[3] Charles Schwab appears to route orders on a stock by stock basis while Ameritrade bifurcates its order flow. In 2013, Ameritrade earned $213 million in order flow payments while Charles Schwab earned around $100 million from its order flow.
[4] Interative Brokers notes that "the charges imposed or rebates offered by these exchanges [exchanges utilizing make/take fee schedules] affect the total cost of execution and IB's Smart Routing System may take this into account in determining where and how to route options orders."
[5] For an excellent discussion of the history and the economics of make/take pricing, see the SEC's Division of Trading and Markets' October 20, 2015 memorandum to the SEC's Market Structure Advisory Committee. The memorandum can be downloaded at: https://www.sec.gov/spotlight/emsac/memo-maker-taker-fees-on-equities-exchanges.pdf. Also see "How Maker Taker Impacts Market Makers," by Phil Mackintosh and Rachel Liang at: https://ptportal.kcg.com/kresearch/do/research/getDownload?attachmentId=4074&username=8FEW5ecT13JTdHAY7Qm0TA==.

To empirically examine this question in equity markets, one must obtain proprietary order data either from wholesalers or from the brokers that route to wholesalers.[6] Conversely, as discussed in Battalio, Shkilko, and Van Ness (2016) and SEC (2004), purchased orders in equity options must execute on an options exchange.[7] We take advantage of the Philadelphia Stock Exchange's 2012 decision to begin migrating option classes from their maker/taker (MT) pricing model to a payment for order flow (PFOF) pricing model to examine how allowing nonmarketable limit orders to interact with purchased order flow impacts limit order execution quality.

We begin by documenting the fees/rebates associated with demanding/providing liquidity on the different options exchanges. Liquidity seeking customer orders routed to options exchanges utilizing the PFOF pricing model generated payments or rebates of between \$0.18 and \$0.40 per contract in 2012.[8] Across the exchanges utilizing the MT model, the International Securities Exchange's (ISE's) take fee for customer orders of \$0.15 per contract was the lowest while the take fee of \$0.45 per contract, utilized by both the NASDAQ Options Market (NOM) and Archipelago Exchange (ARCA), was the highest.[9] During the period of time when the PHLX was transitioning sample option classes from the MT model to the PFOF model, only the ISE charged customers a take fee that was lower than the take fee charged by the PHLX. After option classes were migrated to the PFOF model, PHLX customer orders paid no take fee and, depending upon the agreement between the designated market maker (e.g., wholesaler) and the retail

[6] Rule 605 data cannot be used to evaluate relative limit order execution quality because the limit orders directed to different venues are not placed in similar market conditions.
[7] See footnote 16 of for an excellent discussion of the history and the economics of make/take pricing, see the SEC's Division of Trading and Markets' October 20, 2015 memorandum to the SEC's Market Structure Advisory Committee. The memorandum can be downloaded at: https://www.sec.gov/spotlight/emsac/memo-maker-taker-fees-on-equities-exchanges.pdf.
[8] An examination of Rule 606 filings made by brokers in the 4th quarter of 2012 reveals that Ameritrade received an average of \$0.34 per contract, E*Trade received less than \$0.35 per contract, Fidelity received a blended average of \$0.18 per contract, and Scottrade received less than \$0.40 per contract for their retail option order flow.
[9] In general, the difference between the take fee (rebate) and the liquidity rebate (fee) is an important source of revenue for options exchanges. Competition amongst options exchanges ensures there is a close association between an exchange's fee and rebate. As a result, liquidity rebates are generally increasing in the size of an exchange's take fee.

broker, generated competitive rebates. Thus, from a fee perspective, the migration of option classes to the PFOF model made the PHLX a more attractive destination for customer orders.[10,11]

We next document heterogeneity in option order routing strategies across large retail brokerages in the United States. In the fourth quarter of 2012 (4Q2012), two retail options brokers route all of their market and all of their limit orders to wholesalers. Limit orders placed with these brokers have the possibility of interacting with retail market orders. Five of the eight retail brokers we examine route orders to venues utilizing the PFOF model and to venues using the MT model. For three of these brokers, the percentage of market orders routed to the MT venues is substantially smaller than the percentage of market orders routed to the PFOF venues. For example, just over 25% of Fidelity's retail option order flow in 4Q2012 were market orders. Although Fidelity routes more than 45% of its retail options orders to MT exchanges with high take fees, these exchanges receive less than 4% of Fidelity's market orders. Conversely, the percentage of market orders contained in the order flow routed to the four PFOF venues ranged from 20.9% to 75.2%.[12] Thus, as is the case in equity markets, it appears some retail brokers route option orders in 4Q2012 in a manner that increases the revenue generated by their order flow.[13]

After establishing that retail options brokers utilize divergent order routing strategies, we next examine how the migration to the PFOF model impacts the composition of customer orders routed to the PHLX. Relative to option classes trading on PHLX that continuously trade under the PFOF model, the median number of marketable customer orders routed to the PHLX increases and the median number of nonmarketable customer orders decreases after sample option classes migrate from the MT model to the

[10] As noted in Interactive Broker's 4th quarter 2012 Rule 606 filing, "IB may route a marketable option order to an exchange that is not currently posting the NBBO but which may be willing to "step up" and execute the order at the NBBO. Generally, IB will do this in order to avoid or reduce the applicable fee for executing the order, compared to routing to a different exchange. IB generally will share some portion of the economic benefit of routing orders in this manner with customers in the form of reduced execution fees, although IB is not required to and does not guarantee that it will share such benefit."
[11] Customer limit orders have priority at a price on the PHLX limit order book under both the MT and the PFOF pricing structures.
[12] As hypothesized in Battalio et al. (2016) and, for one broker, verified in Senate testimony, it is likely that a high percentage of the limit orders routed by these brokers to the PFOF venues are marketable.
[13] As we document in Appendix Table II, Rule 606 filings reveal that several brokers appear to be routing market orders to PFOF venues and limit orders to venues offering high liquidity rebates in the fourth quarter of 2016.

PFOF model. Given these results, it is not surprising that relative to control options classes, we find that both the percentage of marketable customer orders routed to the PHLX and the unconditional fill rates for nonmarketable customer orders displayed on the PHLX rise following the migration of sample option classes to the PFOF model. These results suggest that some retail brokers are altering their order routing strategies in response to the change in fee structure on the PHLX, which decreases the fees (rebates) associated with executing marketable (nonmarketable) customer orders.

As the take fee assessed by the NOM was the highest take fee across all options exchanges during our sample period, it provides a useful benchmark against which to evaluate how the change from the MT model to the PFOF model by the PHLX impacts relative limit order execution quality.[14] For this reason, we conduct 'horseraces' between the PHLX and NOM before and after the PHLX migration. We find that similarly priced limit orders seeking to trade the same option concurrently on the PHLX and the NOM execute more frequently and faster on the PHLX, independent of whether the option classes trade in the MT or in the PFOF model on the PHLX. This is not surprising since the fees for marketable customer option orders were lower on PHLX than they were on NOM before and after the migration. However, we find that the percentage of all horseraces won by the PHLX increases from 84.57% to 86.95% after options migrate to the PFOF model on PHLX. For more actively traded options, the percentage of horseraces won by the PHLX increases from 77.27% to 85.48% after the change. This suggests that there are market conditions in which limit order execution quality can be enhanced by routing orders to a wholesaler rather than to a venue with a relatively low take fee.

Despite these results, it is possible that the improvement in relative limit order execution quality on the PHLX is attributable to the fact that the ISE had a take fee that was lower than that charged by the PHLX before the migration and a take fee that was higher than the PHLX after migration. To explore this possibility, we examine how the PHLX migration impacted each exchange's market share of trades. Consistent with Battalio, Corwin and Jennings (2016), we document a negative relation between take fees

[14] At a price, customer limit orders have priority over limit orders placed by other market participants on the NOM.

and market share of trades execute when all venues are quoting the best price. More important, we find that when option classes migrate from the MT model to the PFOF model, the PHLX gains market share at the expense of the Chicago Board Options Exchange (the CBOE is a PFOF venue) and not the ISE. This suggests that the improvements in relative limit order execution quality on the PHLX are attributable to the fact that standing limit orders routed to the PHLX after the migration are exposed to marketable customer orders purchased from retail brokers.

Since exchanges cannot discriminate across different types of customers and option orders must be internalized on exchanges, our results suggest that retail brokers can improve execution quality for nonmarketable customer limit orders by routing those orders to venues that purchase order flow even if those brokers route their marketable orders elsewhere. In actively traded options for which the minimum variation is binding, routing customer orders to wholesalers and/or exchanges that purchase order flow will increase the frequency with which their standing limit orders execute and improve the conditions in which they execute. Our results suggest that brokers who choose to route customer limit orders to venues offering high liquidity rebates rather than to exchanges utilizing the PFOF model are more interested in maximizing rebate revenue than maximizing execution quality.

2. Related Literature.

Parlour and Rajan (2003) construct a dynamic model to evaluate the impact of allowing dealers to purchase order flow on market quality and social welfare. They model a trading environment in which dealers cannot refuse to accept limit orders, which is similar to the setting that we empirically examine. Parlour and Rajan note that because of the Manning Rule, customer limit orders have priority over dealers at a price. As a result, dealers cannot interact with purchased order flow when they possess at-the-quote limit orders.[15] Among other things, Parlour and Rajan show that in this environment, dealers must quote spreads that are wide enough to cover the losses incurred when purchased marketable orders execute against

[15] An at-the-quote limit order is a limit order seeking to buy (sell) shares at the National Best Bid (Offer).

standing limit orders. We are the first paper to empirically examine the relative benefit of routing nonmarketable limit orders to dealers that purchase order flow.

In the 1990s, Cincinnati Stock Exchange (CSE) introduced its Preferencing Program and the Boston Stock Exchange (BSE) introduced its Competitive Specialist Initiative. Each of these programs gave internalizing dealers the choice of displaying customer limit orders on the exchange's central limit order book or keeping customer limit orders on their internal limit order books and providing print protection.[16] Placing a customer limit order on the central limit order book provides the order with the opportunity to trade against the first marketable order routed to any of the exchange's internalizing dealers while keeping the order on the dealer's internal book only gives the order access to one of internalizing dealer's marketable orders. In order to maximize the percentage of marketable orders that could be internalized, dealers generally avoided placing limit orders on the exchange's central limit order book.[17] Battalio, Hatch and Jennings (2002) provide evidence suggesting limit orders routed to the CSE's preferencing dealers in January of 1996 would not experience better execution quality had they been routed to the primary market. Our setting differs from the settings on the CSE and the BSE because internalizers on option exchanges cannot prevent brokers from placing nonmarketable customer limit orders on their central limit order book.

Battalio, Corwin and Jennings (2016) note that for stocks trading in minimum variation markets, the exchange's relative fee structure can have an impact on limit order execution quality. When multiple markets are offering to buy (sell) stock at the National Best Bid (Offer), brokers and self-directed investors have an incentive to route marketable orders to the venue(s) with the lowest take fee. Thus, at-the-quote limit orders resting on venues with low take fees will tend to execute before similarly priced orders resting on venues with high fees. This implies that limit orders resting on low fee venues will have higher fill rates and will execute with more favorable market conditions than similarly priced orders resting on high fee

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[16] Print protection was a policy designed to ensure that limit orders resting on the internalizers' limit order books received timely executions relative to same-priced limit orders on the primary market for the security.

[17] As noted in the SEC's Preferencing Report, "the NYSE conducted its own analysis of trading on the CSE for five consecutive trading days in March 1995, and concluded that as a result of preferencing CSE members can internalize order flow with minimal probability of that order flow interacting with the orders of other CSE members." See https://www.sec.gov/news/studies/prefrep.htm.

venues. The authors present empirical evidence suggesting that for at-the-quote limit orders, limit order execution quality is decreasing in an exchange's relative take fee.

Battalio et al. also present evidence from Rule 606 filings that suggests four retail brokers sold their marketable orders to wholesalers and routed their standing limit orders to the venue(s) offering the highest liquidity rebates in 4Q2012. As these venues are the same venues that charge the highest take fee, the authors conclude that these brokers are not routing orders in a way that maximizes limit order execution quality. We present evidence that suggests several retail options brokers are making similar decisions when routing their customers' options orders.

Battalio et al. also document that five of the popular retail brokers they examine route all of their market and limit orders to wholesalers. They note that this type of order routing appears to ensure that customer limit orders are exposed to all of the marketable orders purchased by the wholesaler and they write that "whether this routing strategy is preferable to alternative strategies is a question that we cannot address with our data." In this paper, we examine whether routing both marketable and nonmarketable orders to wholesalers improves limit order execution quality.

Battalio, Shkilko and Van Ness (2016) examine the change in the percentage of customer orders routed to the PHLX when the PHLX migrated option classes from the PFOF model to the MT model in 2010. Using the publicly available PHOTO data set provided by NASDAQ, they examine the percentage of trading volume attributable to five different classes of traders around the PHLX migration: retail customers, broker-dealers, market makers, firm proprietary traders, and professional customers. They find that the percentage of volume attributable to retail customers falls by 29% when option classes migrate to the MT model and it became more costly for customers to consume liquidity on the PHLX. As order data are not available around these migrations, the authors are unable to determine whether this decline was primarily attributable to a reduction in marketable or nonmarketable customer orders. We utilize order data to more finely document how the move from the MT model to the PFOF model impacts the arrival rate of retail marketable and nonmarketable orders on the PHLX.

Anand, Hua and McCormick (2016) present evidence suggesting participants in equity option markets are sensitive to fees when deciding where to route marketable orders. Among other things, they find that approximately 84% of the trades executed when ARCA, a venue utilizing the MT model, and at least one of the exchanges utilizing the PFOF model are at the best quote take place on exchange(s) utilizing the PFOF model. They also find that a majority of the trades which execute on ARCA occur when ARCA is quoting a better price. The authors interpret their results as evidence that the introduction of the MT model "improves outcomes for investors in the options markets" (page 3274). Anand et al. also speculate "that conflicts of interest associated with broker routing of limit orders to venues with higher make rebates may be less relevant for options markets than equity markets since most liquidity in options is provided by exchange market makers" (page 3274). We empirically examine this conjecture and present evidence that suggests the limit order routing decision in equity options markets has a significant impact on execution quality.

3. Trading protocols on the PHLX.

In an attempt to increase liquidity and attract order flow, the PHLX migrated the trading of options on the S&P500 exchange traded fund (SPY) from the PFOF model to the MT model on January 4, 2010.[18] The exchange then added an additional 91 option classes over the period from February 1, 2010 to September 1, 2011. With the exception of SPY, these options classes were gradually migrated back to the PFOF model over the following months. Since the PHLX began offering order level data on September 1, 2010, we restrict our analysis to the migration of options classes from the MT model back to the PFOF model. As only the most liquid options were transitioned to the MT model, our sample only consists of option classes trading in the penny pilot program.

The PHLX operates as an order-driven market that uses a customer priority pro-rata algorithm to arrange trades. Customer limit orders resting on the PHLX limit order book have priority over limit orders placed by other market participants at a price. Limit orders placed by market makers, broker dealers,

[18] In the SEC Release No. 34-61480; File No. SR-PHLX-2010-14 under the purpose section it explicitly states the rule change is intended to increase liquidity and attract order flow.

proprietary traders, and professional traders are prioritized based on a pro-rata allocation. The pro-rata priority matches marketable orders with all limit orders in the top of the book queue simultaneously, but in proportion to order size. The pro-rata percentage is calculated by dividing the marketable order size by the total quantity limit order volume at a given price. Liquidity supplying (demanding) orders placed by customers seeking to buy or sell options that trade in the MT model generate liquidity rebates (fees) when they execute. Conversely, liquidity demanding orders submitted by retail customers seeking to buy or sell options that trade in the PFOF model generate rebates while liquidity supplying orders are handled at no cost.

In contrast to equity market makers, options market makers on the PHLX often do not execute all of the liquidity demanding orders they purchase. Under the Directed Order Flow Program, a purchasing market maker receives an enhanced participation allocation of up to 40% of a purchased order after customer interest at a given price is exhausted if the market maker's quote equals the NBBO when the order arrived at the PHLX. If the purchasing maker is quoting a size of less than 40% of the incoming order, she is allocated an amount of the incoming order that equals her quoted depth. The remaining portion of the purchased order, if there is any, is allocated to liquidity providers on a pro-rata basis.[19]

As suggested above, the pro-rata allocation algorithm allows other market participants to interact with purchased orders alongside the purchasing wholesaler. To prevent registered options traders (ROTs) from free riding, the PHLX charges them a fee when they interact with purchased order flow that is subsequently passed onto the wholesaler. For example, if the market maker has an arrangement with a retail broker to pay $0.50 per contract for its retail marketable order flow and the retail broker routes orders seeking to trade a total of 100,000 contracts to the exchange in one month in a given option class, the market maker would subsequently send a check for $50,000 to the retail broker for that month. If the market maker executed 40,000 of the contracts, other registered option traders (ROTs) executed 40,000, and the remaining 20,000 contracts traded against limit orders placed by proprietary traders, broker-dealers, and customers,

[19] See PHLX rules 1080 and 1014.

the market maker can request a reimbursement of 50% from the ROTs.[20,21] While ROTs are required to compensate wholesalers when they interact with purchased orders, customers are not. Moreover, unlike equity markets, purchasing market makers cannot refuse to accept customer limit orders.

4. Hypotheses.

Given the close association between the fee/rebate charged/offered by a trading venue to liquidity demanders and the rebate/fee offered/charged to liquidity suppliers by that same trading venue, it is generally the case that the venue offering the most lucrative liquidity rebates also charges the largest take fee. Conversely, venues that pay liquidity demanders typically charge liquidity suppliers a fee when their orders execute. Battalio et al. (2016), Angel et al. (2015), and others argue that these fees and rebates are typically not passed onto clients.

All else equal, one would expect fee-sensitive liquidity demanders to route their order to the venue with the lowest take fee. How might an SOR (Smart Order Routing) router, which ignores fees, route at-the-quote limit orders if its goal is to maximize execution quality? Battalio et al. (2016), Sofianos and Youseffi (2010), Pragma (2013) and others present empirical results suggesting limit orders routed to the venue with the lowest take fee (and hence, the lowest liquidity rebate) execute more frequently and in more favorable market conditions than limit orders routed to venues with high fees and rebates.

Suppose, for the sake of illustration, that the current national best bid (NBB) for a call option on ACME common stock is $3.00 and the current national best offer (NBO) is $3.02. Suppose that Broker A receives a limit order to buy 20 contracts at a price of $3.01. Where should Broker A route this order if Broker A would like to maximize the probability that the order executes (ignoring liquidity rebates)? In this situation, since the order will establish a new NBB, it doesn't matter which venue that the order is routed to as a liquidity demanding seller will route her order to the venue on which the limit buy order is displayed. There is no other option. In this instance, Broker A can route the order to a venue that charges the maximum

[20] 50% equals 40,000 ROTs contracts divided by the sum of the contracts executed by ROTs and the purchasing market maker.
[21] See https://www.sec.gov/rules/sro/phlx/34-51909.pdf.

permissible take fee in order to fund aggressive liquidity rebates without impacting the probability (or the conditions in which) the order executes. So, assume that Broker A routes the order to NOM, a venue with a take fee of $0.45 per contract.

For actively traded, low priced options, it is typically the case that investors place limit orders that join (rather than establish) a new NBB or NBO. Returning to our example, assume now that a different broker, Broker B, receives a client order to purchase 2,000 call options on ACME common stock at a price of $3.01. If Broker B's goal is to maximize the probability that the order executes before the market moves away from the client's limit price (e.g., in this example, before prices rise), Broker B needs to place the order on a venue that has a take fee which is lower than the venue on which Broker A's order rests. Although placing the order on a venue with a lower take fee will generally result in a lower liquidity rebate when the order executes, all else equal, it will ensure the order trades before similarly priced orders displayed on venues with higher take fees.

Now assume that Broker B routes the order to BATS, a venue with a take fee of $0.44 per contract. Since the cost of accessing displayed liquidity on BATS is lower than the cost of accessing displayed liquidity on NOM, an investor seeking immediacy would route her marketable sell order to BATS rather than NOM. Thus, the limit order routed by Broker B would execute before the limit order routed by Broker A despite the fact that it arrived in the market place after Broker A's order. One can extend this logic to show that all else equal, limit orders displayed on venues with lower (negative) take fees will execute before similarly priced limit orders displayed on venues with high take fees. This leads to our first hypothesis.

> **Hypothesis 1:** Similarly priced customer limit orders seeking to trade the same option that are concurrently displayed on the PHLX (low take fee) and on the NOM (high take fee) will execute more quickly and more frequently on the PHLX.

Exchanges must accept any orders they receive. However, market makers operating on options exchanges utilizing the PFOF model can offer retail brokers different rebates for their marketable orders. During our sample period, none of the options exchanges utilizing the MT model offer negative take fees and charge positive make rebates. Prior to order flow migration, the PHLX had the second lowest take fee across exchanges utilizing the MT model. Because options exchanges cannot refuse to accept customer orders, brokers could avoid paying a positive take fee by routing their marketable customer orders to one of the exchanges utilizing the PFOF model. If the broker had no arrangement with the exchange, the broker would not incur a fee for accessing liquidity on the exchange. If the broker did have an arrangement with the exchange, the broker would receive a rebate. This suggests that if an options exchange utilizing the PFOF model was at the best bid or offer, that exchange would be the preferred destination for marketable customer orders.

> **Hypothesis 2:** The relative difference in limit order execution quality for similarly priced customer limit orders seeking to trade the same option that are concurrently displayed on the PHLX and on the NOM will increase when PHLX migrates trading from the maker-taker model to the PFOF model.

We expect brokers and self-directed customers to route their marketable orders to the wholesaler that is willing to pay the most for the order.[22] Indeed, the primary purpose of moving option classes from the MT model to the PFOF model was to attract marketable retail order flow to the PHLX exchange.[23] For some customers, the move is associated with a reduction in the take fee for customer orders on the PHLX from + $0.39/contract to - $0.45/per contract.

> **Hypothesis 3**: Customer marketable order volume increases when the PHLX moves option classes from the maker-taker model to the PFOF model.

Theory suggests that for retail investors who are responsible for the fees/rebates generated by their orders, the MT model can be a more attractive venue on which to provide liquidity. The make take model incentivizes market participants to place passive orders through a subsidy provided by the takers of liquidity (Colliard and Foucault, 2012 and O'Donoghue, 2015).[24] Therefore, we might expect the MT model to be associated with increased nonmarketable limit order flow. Alternatively, depending upon the conditions in

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[22] See the SEC's March 8, 2007 report concerning examinations of options order routing and execution, which can be found here: https://www.sec.gov/news/studies/2007/optionsroutingreport.pdf.
[23] See the purpose sections in SEC release No.'s 34-66252, 34-66488, 34-66756, and 34-67439.
[24] The retail broker Lightspeed has the following example on its website. "If you send this 500 share order as a market or marketable limit (take liquidity) order to NASDAQ which charges a $.003 per share fee, your total commission will be $3.75. This charge is made up of the $2.25 commission paid to Lightspeed plus the $1.50 market center fee charged by NASDAQ for taking liquidity. However, if you send this 500 share order as a limit (adding liquidity) order to NASDAQ which pays a $.002 per share rebate, your total commission will only be $1.25. This charge is made up of the $2.25 commission paid to Lightspeed minus the $1.00 rebate passed on to you from NASDAQ for adding liquidity. See https://www.lightspeed.com/pricing/routing-fees/.

which a given option series trades (e.g., whether or not the minimum tick size is binding), more sophisticated retail investors and/or brokers seeking to maximize limit order execution quality may find it worthwhile to forgo liquidity rebates in order to give retail limit orders the opportunity to trade against uninformed order flow and execute in more frequently in favorable market conditions. Whether or not there is a net gain in the PHLX's market share of nonmarketable customer limit orders depends on the number of brokers that are more concerned with pursuing best execution rather than order flow rebates and on the frequency with which the limit order routing decision is relevant in equity option markets.

Hypothesis 4: Customer nonmarketable limit order volume remains the same when the PHLX moves option classes from the maker-taker model to the PFOF model.

If the PHLX's goal was to simply attract marketable orders away from the ISE, it could choose to offer a take fee for customer orders that was less than that charged by the ISE instead of moving from the MT model to the PFOF model. By migrating option classes to the PFOF model, the PHLX made it possible for wholesalers to selectively pay market rates for retail options order flow. This suggests increase in market share in migrated option classes realized by the PHLX will come primarily at the expense of the two other options exchanges utilizing the PFOF model throughout our sample period.

Hypothesis 5: Any gain in market share realized by the PHLX when option classes are migrated from the maker-taker model to the PFOF model will come primarily at the expense of the CBOE and/or the American Stock Exchange (AMEX).

5. Fee structures and routing choices in U.S. equity option markets.

The order routing decision became relevant in September of 1999, when many actively-traded option classes began trading on multiple exchanges for the first time.[25] The SEC (2000) notes that multiple listing increased competition for options order flow as option market participants began offering "direct and indirect economic inducements to brokers in return for brokers agreeing to route their customers' order flow to them."[26] The SEC also notes that "payment for order flow and internalization create conflicts of interest for brokers because of the tension between the firms' interests in maximizing payment for order

[25] See DeFontnouvelle, et al. (2003).
[26] See the SEC's "Special study: Payment for order flow and internalization in the options market," December 2000. The study can be downloaded at https://www.sec.gov/news/studies/ordpay.htm.

flow, or trading profits generated from internalizing their customers' orders, and their fiduciary obligation to route their customers' orders to the best markets.” As there were no exchanges utilizing the MT model prior to 2007, brokers typically routed all of the orders in a given option class to the same exchange after multiple listing.

During 2005 and 2006, staff from the SEC’s office of Compliance Inspections and Examinations investigated the routing practices of eight broker-dealers that had a significant amount of retail order flow to determine whether these broker-dealers were fulfilling their duty of best execution when handling customer options orders. The investigation found that many firms were using smart order routers to ensure that marketable orders were routed to the market displaying the best price. When the best price was displayed on multiple markets, the SEC found that marketable orders were routed to the market offering the largest inducement. Five of the eight broker-dealers were found to route a significant portion of their order flow to affiliated specialists or market makers, seven of the eight broker-dealers had an ownership interest in one or more options exchanges, and six of the eight broker-dealers explicitly accepted payment for their order flow.[27] The investigation also revealed that only one of the eight broker-dealers evaluated execution quality for customer options orders across all exchanges. The SEC’s report concludes that “while there has been improvement over the last six years in order routing firms’ processes to seek and obtain best execution for their retail customers’ options orders, factors such as payment for order flow and other inducements continue to play a substantial role in broker-dealers’ order routing decisions.”

Liquidity fees and rebates were introduced to equity options markets when the NYSE Archipelago Exchange (ARCA) began using the MT model to trade in the first thirteen option classes that began trading in pennies in January 2007.[28] As we discuss in Section 5b, the introduction of the MT model to equity option markets made it possible for brokers to send marketable orders to wholesalers and their

[27] The investigation revealed that a broker-dealer’s ownership interests “appear to influence where a firm routes customer orders.”

[28] See “Balancing the Options: Customer Priority versus Maker-Taker in the U.S. Equity Options Market,” by Sherree DeCovny, published in the March/April issue of Futures Industry. The article can be found at https://secure.fia.org/downloads/Mar-Apr_Maker-Taker.pdf .

nonmarketable order flow to venues that offer liquidity rebates. Why might this be appealing to brokers (and others responsible for the fees/rebates generated by their orders)? In 2008, Kevin Fischer, a manager at the option market maker Timber Hill, estimated that the cost per contract for Timber Hill's trades on maker-taker exchanges is roughly $0.70 lower than the cost on an exchange using the PFOF model. He attributed this cost advantage to the $0.30/contract liquidity rebate on ARCA and the avoidance of $0.20/contract in exchange fees and $0.20/contract in order flow payments that Timber Hill firm incurred when displaying liquidity on exchanges utilizing the PFOF model. As of February 10, 2017, there were fifteen different options exchanges listed on the Option Clearing Corporation (OCC) website, the majority of which utilize the MT model.

a. Cost of executing customer orders.

We obtain information regarding exchange fees and rebates as of the first of each month in 2012 and for January 1, 2017 from the Investment Technologies Group (ITG).[29] ITG is an independent broker that, among other things, offers clients a smart router that allows them to access a variety of options exchanges. Table I contains details on the fees/rebates encountered by ITG when routing orders in options classes trading in the penny pilot program that were placed by customers, broker dealers, market makers, professionals, and proprietary traders on January 1, 2012. ITG also provides data as to when the fees and rebates in place as of December 2012 were subsequently changed. From ITG's perspective, there were no substantive changes in relative fees across venues during the remainder of our sample period.

Six exchanges utilize the MT model to arrange trades in some of their option classes and five use the PFOF model. The four exchanges utilizing the MT model to arrange all trades account for 22% of trading volume in equity options in the first eight months of 2012. The CBOE and the AMEX, venues that only use the PFOF model during our sample period, respectively account for 24% and 16% of the trading volume in equity options over the same time period. The two exchanges that use both models to arrange trades, the ISE and the PHLX, respectively account for 18% and 16% of trading volume.[30] The Boston

[29] Appendix A contains fees for July 1, 2012, December 1, 2012, and January 2017.
[30] See http://ir.cboe.com/~/media/Files/C/CBOE-IR-V2/presentations/barclays-slides-final.pdf

Options Exchange (BOX) appears to utilize an inverted MT model (e.g., charge liquidity suppliers and offer rebates to liquidity demanders). However, as a result of quoting behavior, and the price improvement mechanism used to arrange trades, on the BOX, liquidity demanders effectively pay liquidity fees and liquidity suppliers effectively earn liquidity rebates.[31]

Exchanges utilizing the PFOF model charge nothing to arrange customer trades and they offer payment to retail brokers for their marketable orders. Payments made for retail orders seeking to buy or sell options that were (were not) trading in decimals were as high as $0.10 ($0.55) per contract.[32] The liquidity fee charged by exchanges in 2012 ranged from $0.15 per contract on the ISE to $0.45 per contract on the NOM and on ARCA. If we restrict attention to the exchanges that only use the MT model to arrange trades, the lowest take fee for customer options orders was $0.44 per contract, available on BATS and on C2OX.

Liquidity rebates are often broker/market participant specific as they are a function of the average liquidity provided on an exchange during the month. The rebates listed in Table I are the rebates that our data provider, ITG, expected to receive when providing liquidity on the different exchanges. An inspection of rule filings made by ARCA, BATS and NOM during 2012 reveals that the liquidity rebates listed in Table I are the rebates associated with the lowest volume tier of liquidity providing orders. Brokers qualifying for the highest liquidity rebates could receive $0.46 per contract on BATS and NOM and $0.44 per contract on ARCA. The C2OX had no volume tiers, thus the rebate paid to liquidity providing orders was independent of trading volume.[33] Of the four venues charging take fees of $0.44 per contract or higher for customer orders in penny pilot options in 2012, the C2OX offered the highest liquidity rebates. Indeed, the C2OX offered the highest liquidity rebates for all types of market participants. BATS offered customers a liquidity rebate of $0.44 per contract, the NOM offered a liquidity rebate of $0.26 per contract, and ARCA offered a liquidity rebate of $0.25 per contract.

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[31] See page 1465 of Battalio, Shkilko and Van Ness (2016).
[32] See Tradestation's 4th quarter 2012 Rule 606 filing.
[33] On January 24, 2014 the C2 Options Exchange (C2OX) began charging take fees and offering rebates that were a percentage of the width of the execution-time width of the best bid and offer on the C2OX. See https://www.sec.gov/rules/sro/c2/2013/34-68792-ex5.pdf

b. Broker routing in 4Q2012.

The evidence presented in the prior section suggests retail brokers seeking to maximize the rebate revenue generated by executed customer orders in 2012 would have routed their nonmarketable limit orders to the NOM, ARCA, and BATS and sold their marketable orders to a wholesaler operating on one of the exchanges utilizing the PFOF model to arrange trades. Assuming they were offering to provide liquidity at the national best price, the venues utilizing the PFOF model were also the cost minimizing destination for brokers possessing marketable customer orders that wholesalers would not purchase. If there were no PFOF venues offering to provide liquidity at the best quote, brokers seeking to minimize costs would check the venues using the MT model in the following order: ISE, PHLX, C2OX or BATS, and then ARCA or NOM. The data presented in Table I suggest that if multiple exchanges were at the best quote, the venues utilizing the PFOF model tended to have the lower take fee for market makers, professional traders, and proprietary traders. The NOM charges the highest take fee for each type of market participant throughout our sample period.

All else equal, the data presented in Table I suggests that similarly priced customer limit orders placed concurrently on all venues should tend to execute first on the venues utilizing the PFOF model. The relative fee structure across options exchanges implies that the NOM will only receive marketable orders when it is either alone at the inside quote or joined at the inside quote by an exchange charging the same take fee as NOM at some periods during our sample period.

Rule 606 requires brokers to report the percentage of market orders, the percentage of limit orders, and the percentage of other orders routed to different trading venues on a quarterly basis. Brokers are also required to provide details as to the nature of their relationships with each executing venue, including any payment for order flow or internalization arrangement that could represent a conflict of interest between brokers and their customers.[34] In 4Q2012, we examine the routing of non-directed options order flow by eight national brokers.[35]

Panel A of Table II contains the percentage of non-directed market and limit orders routed to the various options exchanges. Panel B of Table II describes the ratio of market to both market and limit orders for each of the eight brokers and provides details on how the mix of orders routed by each broker varies across venues.[36] Three brokers report the wholesaler, not the exchange, to which they route customer option orders. As purchased options orders must execute on an exchange, these orders execute on one or more of the five venues utilizing the PFOF model in 4Q2012. None of these three brokers reports routing orders to venues that utilize the MT model during this time period. The remaining brokers route anywhere from 35% to 71% of their options orders to venues that utilize the PFOF model and between 23% and 55% of their options orders to one of the three venues that charge liquidity fees to marketable customer orders of $0.44 per contract or higher.

For each of the eight retail brokers, the first row of Panel B contains the percentage of non-directed market orders seeking to trade options during the 4th quarter of 2012. As a percentage of market and limit orders, Ameritrade's options order flow contains the lowest percentage of market orders, 3.06%, while Trade King's options order flow contains the largest percentage of market orders, 48.98%.

In stark contrast to Battalio, et al. (2016), who document that four retail brokers route no market orders in NYSE-listed equities to the venue charging the maximum permissible take fee (and offering aggressive liquidity rebates), each of the brokers we examine report that they route market orders to options exchanges that charge high take fees. For example, Ameritrade routes 2% of its market orders to NOM and 4% to BATS, most likely in situations where those exchanges were the only venues at the inside quote.

[34] See SEC Release No. 34-43590, "Final Rule: Disclosure of Order Execution and Routing Practices," effective January 30, 2001. The release can be found at: https://www.sec.gov/rules/final/34-43590.htm.

[35] Retail brokers are only required to post their quarterly order routing disclosures for the most recent quarter. Recent web searches reveal that only a few brokers make historical filings available on the internet. We utilize several of the routing reports as were used by Battalio et al. (2016) and a few that we obtain via web searches to evaluate broker routing in equity markets during the fourth quarter of 2012.

[36] We are unable to determine the ratio of marketable to nonmarketable orders in a broker's options order flow because Rule 606 does not require brokers to separately report where they route marketable and nonmarketable limit orders.

However, consistent with Ameritrade's equity order routing, it appears that the options order flow Ameritrade routed to the exchanges utilizing the PFOF model contains a higher percentage of marketable orders than the order flow routed to the two venues utilizing the MT model. Similar conclusions are reached when examining the order mix routed by Fidelity and E*Trade to the different exchanges. Each of these brokers overweights market orders and underweights limit orders when routing customer options orders to wholesalers. The fourth retail broker, Scottrade, appears to route equity orders in a very different manner than it routes options orders. While Scottrade only routes limit orders to trade equities to venues with high take fees (and liquidity rebates) in 4Q2012, the broker routes market orders and limit orders in options to venues in roughly the same proportion as their overall order mix. The percentage of market orders in Scottrade's option order flow is 16.33% and the percentage of market orders in the options order flow routed to the options wholesalers ranges from 14.79% to 16.89%. This suggests that Scottrade routes options orders on a class-by-class basis rather than on an order type basis.

Interactive Brokers routes 47% of its limit orders to options exchanges that charge take fees of $0.44 per contract or higher. Consistent with the practice of routing marketable orders to the PFOF venues when they are willing to match the NBBO, the percentage of market orders routed by Interactive Brokers to the PFOF (the MT) venues tends to be higher (is lower) than the overall percentage of market orders in Interactive Brokers' aggregate order flow. Across all brokers, Schwab is the only broker who routes a higher percentage of market orders to a venue using the MT model than it does to wholesalers.

To summarize, it appears that brokers differ in their willingness to route customer limit orders to wholesalers operating on options exchanges utilizing the PFOF model. In 4Q2012 we document that two brokers only route limit orders to wholesalers.[37] The data are consistent with what one might observe if these brokers made order routing decisions on a class-by-class basis. With the exception of Schwab in the 4th quarter of 2012, the other brokers alter the mix of order flow routed to the PFOF (MT) venues so that they receive order flow that contains a higher (lower) percentage of market orders than the broker's overall

[37] We demonstrate in the Appendix that retail options brokers route options orders in a similar fashion in 3Q2016.

average. We next examine whether the brokers who route both marketable and nonmarketable options orders to wholesalers (presumably at the cost of receiving lower order flow payments) obtain superior execution quality for their nonmarketable limit orders than brokers who route nonmarketable orders to exchanges with high take fees and liquidity rebates.

6. Data Description.

The NASDAQ OMX PHLX Order data feed provides a real-time (nanosecond) view of simple and complex orders for equity options. This includes orders added and changes made to orders resting on the PHLX limit order book. The PHLX includes one simple order message with the following fields: a unique order id, time stamped to the millisecond, option expiration date, strike price, option type, underlying asset, side, order volume, executable order volume, order status (open, filled, or cancelled), limit price and a market participant indicator (e.g., broker-dealer, customer, firm, market maker, or professional).[38] As we are seeking to understand the economics of retail broker option order routing, we restrict our analysis of the PHLX migration to customer orders.[39] We identify customer limit orders as marketable if the order executes within 500 milliseconds (or 0.5 seconds) of submission. Our results are robust to different millisecond cutoff levels such as 50 and 1,000.

We eliminate orders received before 9:45 a.m. and after 3:50 p.m. from our sample because the opening and closing rotations impede option series from trading freely. Complex orders (e.g., spreads and straddles) are priced as a package, so we remove them when examining how the migration of option classes from the MT model to the PFOF model affects the types of customer orders routed to the PHLX. We merge these data with closing prices and shares outstanding obtained from the Center for Research in Security Prices (CRSP).

[38] The term option class refers to all options under the same underlying stock. An option series refers to a particular option characterized by the underlying stock, option type (put or call), strike price, and expiration date (see Battalio, Hatch, and Jennings, 2004).
[39] Lakonishok et al. (2006) note that customer orders include orders that originated from discount customers (e.g., E*Trade), full-service customers (e.g., Merrill Lynch), or other public customers.

Part of our analysis involves examining how the PHLX migration impacts limit order execution quality for customer orders on the PHLX relative to the limit order execution quality available on NOM, the venue charging the highest take fees (and offering aggressive rebates). NOM order data contain four different types of messages that are linked by a unique order reference number. “Add order” messages contain information for new orders added to the book, including order time (stamped to the nanosecond), option series (underlying asset, expiration date, strike price, and option type), order side, order size, and limit price. “Executed order” messages are time stamped records generated by (partial) executions and report execution quantity and execution price (if the execution price is different from the limit price). “Order cancel” messages are time stamped records that report the number of contracts that are cancelled and “Order delete” messages report when an order is deleted from the NASDAQ order book.

Because we wish to examine the effect of a payment structure change on select option classes, Panel A of Table III contains the filters used to arrive at our final sample of migrating option classes. During our sample period, 92 option classes were moved from the MT model and placed back into the PFOF model. Of these select option classes, 27 option classes did not have an average of at least one order execution per day on the PHLX and 28 were not options on common stock. Panel B of Table III contains a list of the sample option classes migrated to the PFOF model and the dates on which they were migrated. We use a 4-month event window centered on each migration date; therefore, our sample period ranges from December 2011 to September 2013.

Some of our analysis utilizes a set of control option classes for which the PFOF model is used to arrange trades both before and after our sample option classes migrate from the MT model to the PFOF model. The control stock sample is selected by matching each migrating option class with a non-migrating option class (without replacement) with the smallest sum of the squared percentage difference in sample average underlying stock price and the squared percentage difference in sample average underlying market capitalization.[40] We report the distribution of the price and capitalization for both fee change firms and their

[40] A similar matching method is used in Battalio and Schultz (2011) and Malinova and Park (2015).

controls in Panel C of Table III. The median market capitalization for migrating firms is \$61.4 billion, while the median capitalization for the matched control firms is \$61 billion. We test for the difference in size between the underlying migrating stocks and control stocks based on both means and medians and find them to be insignificant. The median stock prices for migrating and their matched control stocks are \$34.01 and \$54.39, respectively. These prices are not significantly different from one another. The differences between mean prices and capitalizations between the fee change stocks and their controls are largely driven by a few stocks in the sample, such as the matched pair of Google (GOOG) and Apple (AAPL). For instance, during the sample period, Google has an average closing price of \$738 and an average market capitalization of \$197 billion, while Apple has an average closing price of \$507 and an average market capitalization of \$471 billion.

Finally, to evaluate how the PHLX migration impacts the across-exchange market share of trades in sample and control option classes, we obtain trade and matched quote data for the 61 trading days centered on the day that an option class (or its matched option class) migrates to the PFOF model on the PHLX from LiveVol. LiveVol uses data obtained from the Options Price Reporting Authority (OPRA) to construct daily files that contain the following information for each option trade: the date and to-the-millisecond time of the trade, the option class, the strike price, the expiration date, a put/call indicator, the trade price, the trade size, the venue on which the trade is executed, a trade condition code, and the national best bid and offer price prevailing when the trade is executed. Conveniently, each trade record also reveals the best bid price, the size at the best bid price, the best offer price, and the size at the best offer price prevailing on each options exchange when the trade occurred.

We eliminate any trade that does not have a condition code of regular, auto ex, spread, or straddle. Together, these trades comprise just over 79% of all trades between 9:45am and 3:55pm.[41] We restrict our analysis to trades executed on the two exchanges that only utilize the PFOF model during our sample period, the PHLX, the ISE, and the three MT venues with the largest market share of trading volume during our

[41] We obtain similar results when we restrict our sample to trades with a condition code of regular and auto ex. During our sample period, no trade executed by the CBOE has a condition code of auto ex.

sample period. For reasons discussed on page 1645 of Battalio, Shkilko, and Van Ness (2016), we exclude the BOX. We also exclude NASDAQ BX, MIAX, CBOE2 from the analysis that follows as these venues have small market shares that are not impacted by the PHLX migrations.[42]

7. Results.

a. Customer order arrival rates.

Table IV presents univariate statistics that describe how the flow and composition of customer orders routed to the PHLX changes in sample (control) option classes after migration (pseudo-migration). We also present order fill rates, cancellation rates, and average time to execution for nonmarketable customer limit orders before and after the (pseudo) event date. The unit of observation is an option class-day.

The average volume of customer marketable orders routed to the PHLX in migrating option classes increases by 49 contracts per day after migration, while the average volume of marketable customer orders in control option classes increases by only 33 contracts across their pseudo-migration. The median number of marketable orders routed by customers to the PHLX in migrating option classes increases by one order per day after migration, while the median number of marketable customer orders in control option classes is unchanged across the same time period. Conversely, the average volume of nonmarketable customer limit orders routed to the PHLX in migrating (control) option classes decreases by 76 contracts (increases by 98 contracts) per class-day. The unconditional fill rate for customer limit orders placed in sample option classes increases by 2.57 percentage points after migration, while the fill rate for similar orders placed in control options is statistically unaffected by the pseudo-migration. The percent of marketable orders routed by customers to the PHLX in sample (control) option classes increases by 7.52 (only 3.44) percentage points after migration. Together, these results suggest retail brokers began routing more marketable orders and fewer nonmarketable limit orders to the PHLX after option classes were migrated from the MT model to the PFOF model.

[42] Results available upon request.

As many factors can influence order arrival rates, we next examine the impact that migrating sample option classes from the MT model to the PFOF model in a multivariate setting. More specifically, we estimate the following regression using our sample of migrating option classes and the matched, control option classes.

$$Order\ Flow\ Variable_{i,t} = \alpha + \beta_1 Post_t + \beta_2 Migrate_i + \beta_3 Post_t \times Migrate_i + \beta_4 Log(Underlying\ Trading\ Volume)_i + \beta_5 Underlying\ Pvolt_i + \beta_6 Underlying\ Market\ Capitalization_i + \beta_7 S/X_{i,t} + \beta_8\ (S/X)^2{}_{i,t} + \beta_9 Days\ Expiration_{i,t} + \beta_{10} Call_{i,t} + \varepsilon_{i,t}. \quad (1)$$

One of the option classes in the migrating sample, Apple, has over thirteen times the average daily trading volume of the next most actively traded migrating option class, Amazon. For this reason, we estimate quantile median regressions to estimate Equation 1 when the order flow variable is the median number of marketable orders, the median number of nonmarketable orders, the median marketable order volume, the median nonmarketable order volume, or the median time to complete execution.[43] We use OLS to estimate Equation 1 when the order flow variable is the % of marketable orders. We aggregate each order flow variable on a daily basis by option type (e.g., put or call) and option class. We include the following as independent variables. *Post* is an indicator measure set equal to one if the class/day occurs after the sample option class (or its matched sample option class) has migrated to the PFOF model on the PHLX and zero otherwise. *Migrate* is an indicator variable set equal to one for sample option classes and is set equal to zero for control option classes. *Log(Underlying Trading Volume)* is the log of the CRSP daily share volume in the underlying stock. *Underlying Pvolt* is the difference between the CRSP daily high and daily low prices, scaled by the daily high price.[44] *Underlying Market Capitalization* is the market capitalization of the underlying stock measured daily. *S/X* is the ratio of the underlying stock price to the strike price (which controls for the moneyness of the option) and S/X^2 is included to capture any non-linear relation

[43] We obtain qualitatively similar results when estimating Equation 1 using Ordinary Least Squares Regression.
[44] See Diether, Lee, and Werner (2009).

between the moneyness of an option series and execution quality (see Battalio and Schultz, 2010). Lastly, we include the number of days until expiration for each option and an indicator variable that equals one if the option is a call.[45]

Columns 1 and 2 of Table V describe how the median number of marketable and nonmarketable customer orders routed to the PHLX is affected by the migration of sample option classes to the PFOF model. The statistically significant positive coefficient on *Post* indicates that the median number of marketable and nonmarketable customer orders in both sample and control option classes increases following their respective migration and pseudo migration dates. The results also suggest the median number of marketable and nonmarketable customer orders routed to the PHLX is higher in migrating option classes than in control option classes. Consistent with Hypothesis 3, the results indicate that relative to control options, the median number of marketable customer orders in sample option classes increases after migration to the PFOF model. We also find that the median number of nonmarketable orders in sample option classes falls relative to control option classes. The results in columns 3 and 4 Table V show that the median marketable (nonmarketable) customer order volume in sample option classes increases (decreases) by 16 (42) contracts per option day, relative to control option classes, after migration to the PFOF model. This suggests that brokers are routing marketable orders to the PFOF venues and nonmarketable orders to MT venues that offer positive make rebates. This result also suggests customer limit order queues on the PHLX shortened after migration, which, when coupled with the increase in the number of marketable customer orders routed to the PHLX, suggests absolute limit order execution quality improved following migration to the PFOF model.

The results in column 5 of Table V show the median time-to-complete execution is significantly lower for nonmarketable customer limit orders seeking to trade sample option classes than it is for similar orders seeking to trade control option classes. The difference in the median time-to-complete execution does not significantly increase after sample option classes migrate to the PFOF model. Finally, the results

[45] We estimate Equation 1 with day fixed effects and the results are qualitatively the same.

in column 6 of Table V indicate the order flow routed to the PHLX in control option classes contains a higher percentage of marketable orders than the order flow in sample option classes prior to migration. Given the PHLX utilized the PFOF model to arrange trades in control option classes, this result is not surprising. After migration, the percentage of marketable orders in the order flow seeking to trade sample option classes increases significantly by four percentage points relative to the control options.

Together, the results presented in Table V suggest that the migration of sample option classes altered the mix of customer orders routed to the PHLX. The PHLX receives more marketable and fewer nonmarketable customer limit orders following migration. This suggests that some brokers altered their routing strategies in response to the PHLX migration. Furthermore, both the number and the percentage of marketable customer limit orders in sample option classes increases while the number of nonmarketable customer limit orders falls after sample option classes begin trading in the PFOF model. While these results suggest that absolute limit order execution quality improves on the PHLX following migration, we are unable to distinguish whether this improvement is due to the increase in the number of marketable orders or a fall in the number of nonmarketable orders routed to the PHLX.

b. Horseraces.

While the order flow results are suggestive of a positive relation between PFOF and limit order execution quality, they do not control for the many factors that may affect execution quality. For this reason, we next examine how the migration of option classes to the PFOF model impacts customer limit order execution quality on the PHLX relative to limit order execution quality on the NOM. As the NOM charges customers (and other types of market participants) the highest take fee of $0.45 per contract throughout our sample period, it is reasonable to assume that the NOM was a destination of last resort for marketable orders. That is, it is likely that the only instances in which the NOM receives marketable orders is when they are alone (or joined by other venues with high take fees) at the best quote. For this reason, we use the NOM as a benchmark against which to assess how the migration (pseudo-migration) of sample (control) option classes from the MT model to the PFOF model impacts relative limit order execution quality on the PHLX.

Following Sofianos and Yousefi (2010) and Battalio, Corwin, and Jennings (2016), we identify pairs of identically priced orders displayed concurrently on the PHLX and NOM. We require PHLX limit orders to have been placed by customers, but do not have sufficiently detailed data to impose this constraint on NOM limit orders. For each order pair, we begin a 'horserace' when the orders are first concurrently displayed on both venues. We identify orders with the same order date, options series (underlying symbol, put or call, strike, and expiration date), order side (buy or sell), and limit price and we require that the first order in the pair to still be active (not canceled nor filled) when the second order arrives. Therefore, the paired orders are placed in identical option series and market conditions, which allows us to attribute differences in outcomes to venue-specific characteristics. A given limit order is not used in multiple horseraces.

To crown a winner of a horserace, we require that at least one of the two orders fills. In the case when both orders fill, the venue wins if it fills the order at least 500,000ns (500μs) before the paired counterparty order fills on the competing venue. If both orders in a pair fill within 500,000ns of each other, then we classify the horserace as a tie. If one order fills and the other is canceled or replaced subsequent to the fill, then the venue filling the order is victorious.

We use nonmarketable limit orders placed in sample (control) option classes during the twenty one day window centered on the migration (pseudo-migration) date that are routed to the PHLX and the NOM to construct horseraces. Horseraces conducted using limit orders placed in sample option classes before they begin trading in the PFOF model are used to estimate the relative benefit of having limit orders displayed on a venue with the second lowest take fee as opposed to a venue with the largest take fee. Horseraces constructed using limit orders seeking to trade control option classes throughout our sample period and those seeking to trade sample option classes after they migrate to the PFOF model will illustrate the relative benefit of having limit orders displayed on a PFOF venue rather than a venue with the largest take fee. Differences in relative limit order execution quality between the PHLX and the NOM before and after option classes are migrated to the PFOF model provide an estimate as to the value of having limit orders displayed on a wholesaler's limit order book rather than on the order book of a venue that charges customers one of the lowest take fees.

The first row of Panel A in Table VI presents results for the 6,773 horseraces conducted using 'identical' nonmarketable limit orders in sample option classes trading under the MT model on both the PHLX and the NOM. Consistent with the hypothesis that fill rates are inversely related to liquidity rebates, the unconditional fill rate for orders involved in these horseraces is 93.61% on the PHLX and 36.42% on the NOM. In 30% of the horseraces, both orders execute. In these instances, the decision to route orders to the NOM rather than to the PHLX has no impact on limit order execution quality. However, for 57% of the horseraces, the limit order that is routed to the PHLX executes while the limit order routed to the NOM does not. The median time to execution on the PHLX is 183 seconds versus a median time to execution of 251 seconds on the NOM. Overall, the limit order resting on the PHLX (NOM) order book is executed first in 84.57% (11.03%) of the horseraces, while 4.40% of the horseraces result in ties.

The second row of Panel A presents results for the 2,218 horseraces conducted using nonmarketable limit orders seeking to trade sample option classes trading under the PFOF model on the PHLX and the MT on the NOM. The unconditional fill rates on the PHLX and the NOM are 93.66% and 35.28% respectively, and both orders in a horserace fill 28.94% of the time. These statistics are similar to those obtained for horseraces conducted when the PHLX used the MT model to trade sample option classes. The fill rates for orders participating in horseraces are much higher than the unconditional fill rates, suggesting these horseraces occur in more actively traded option series. The median time to execution on the PHLX falls from 183 seconds to 143 seconds after migration while the median time to execution on the NOM increases from 251 seconds to 421 seconds. The percentage of horseraces ending in a tie falls from 4.0% to 2.96% and the percentage of horseraces won by the NOM falls from 11.03% to 10.09% after option classes migrate to the PFOF model. As a result, the percentage of horseraces won by the PHLX increases from 84.57% to 86.95%. This 238 basis point increase in winning percentage is comparable to the change in the unconditional fill rate on the PHLX across migration, which is 230 basis points. Overall, the results of the horseraces suggest that relative to the NOM, limit order execution quality improves when the PHLX migrates option classes from the MT model to the PFOF model.

Finally, the third row of Panel A presents results for the 2,672 horseraces conducted using nonmarketable limit orders seeking to trade control option classes trading under the PFOF model on the PHLX and the MT model on the NOM. The fill rates for limit orders participating in this set of horseraces is 98.66% on the PHLX and 14.02% on the NOM. The PHLX (NOM) fill rate is 500 basis points larger (1,626 basis points higher) than the PHLX (NOM) fill rate for limit orders participating in the set of horseraces involving sample option classes after they begin trading under the PFOF model on the PHLX. These differences may be attributable to differences in the liquidity of the sample and the control option classes and/or the liquidity and volatility of the underlying equities. Overall, the PHLX wins 93.84% of the horseraces versus 4.54% for the NOM, and 1.62% of the horseraces end in ties.

As noted by Battalio, Corwin and Jennings (2016), the order routing decision has more of an impact on limit order execution quality in actively-traded securities. For this reason, in Panel B of Table VI we present results for horseraces involving the most actively-traded series within an option class (rather than all series within a given option class) each day. The imposition of this screen reduces the disparity in the results of horseraces conducted using orders in the control option classes and the horseraces conducted using orders in the sample option classes after they migrate to the PFOF model on the PHLX. The PHLX wins 77.27% of the horseraces when it operates as a MT venue, 85.48% of the horseraces when it moves to the PFOF model, and 83.30% of the horseraces involving control option classes (which trade in the PFOF model throughout our sample period). These results suggest the benefit of routing nonmarketable limit orders to wholesalers is greater when orders are exposed to a higher volume of purchased order flow.

In Panels C and D we present results for horseraces involving sample option classes conditional on the venue that receives the first order involved in a horserace. We present results for horseraces in which the PHLX (NOM) receives the first order in Panel C (Panel D). The PHLX receives the first order in just over 27% of the horseraces that utilize orders in sample option classes. Across this set of horseraces, the PHLX is victorious 79.08% of the time before migration and 81.24% after migration. In the set of horseraces where the NOM receives the first order, the PHLX is victorious 85.84% of the time before migration and 88.26% of the time after. Thus, in each set of horseraces, the PHLX's advantage over the NOM increases by over 200 basis points when option classes begin trading in the PFOF model.

The fill rates for the limit orders involved in horseraces are significantly higher than the unconditional fill rates for customer limit orders presented in Table IV. Moreover, the unconditional fill rates on the NOM for orders involved in horseraces is nearly twice as high when the PHLX receives the first order involved in a horserace (see Panels C and D of Table V). These results suggest that horseraces are likely conducted in selective market conditions. For these reasons, we estimate the following regression using the sample of orders involved in our horseraces.

$$\begin{aligned} PHLX\ Wins_{i,t} = {} & \alpha + \delta_t + \beta_1 Post\ Migration_t + \beta_2 PHLX\ Recieves\ Order\ First_{i,t} \\ & + \beta_3 PHLX\ Order\ Size_{i,t} + \beta_4 NOM\ Order\ Size_{i,t} + \beta_5 Limit\ Price_{i,t} \\ & + \beta_6 Underlying\ Market\ Cap_{i,t} + \beta_7 Call_{i,t} + \beta_8 Sell_{i,t} + \beta_9\ S/X_{i,t} \\ & + \beta_{10}(S/X)^2_{i,t} + \beta_{11} Days\ Expiration_{i,t} + \varepsilon_{i,t} \end{aligned} \tag{2}$$

The dependent variable, *PHLX Wins* equals one if the order resting on the PHLX executes before the order resting on the NOM. We include the following as independent variables. *Post Migration* is an indicator measure set equal to one if the i^{th} horserace occurs after the option class migrates to the PFOF model on the PHLX and zero otherwise.[46] *PHLX Receives Order First* equals one if the PHLX receives the first order in the i^{th} horserace and equals zero if the first order is received by the NOM. *PHLX Order Size* and *NOM Order Size* are the sizes of the two orders in the i^{th} horserace. *Limit Price* is the limit price of the two orders in the i^{th} horserace. *Underlying Market Cap* is the market capitalization of the underlying stock, *S/X* is the ratio of the underlying stock price to the strike price (which controls for the moneyness of the option) and S/X^2 is included to capture any non-linear relation between the moneyness of an option series and execution quality (see Battalio and Schultz, 2010). Lastly, we include the number of days until

[46] For horseraces conducted using limit orders seeking to trade control option classes, Post equals one if the matched sample option class has migrated to the PFOF model.

expiration for the option and an indicator variable that equals one if the option involved in the i^{th} horserace is a call. To calculate standard errors, we cluster on the underlying stock.

Table VII contains the results for orders involved in horseraces seeking to trade sample option classes. Consistent with the univariate results presented in Table V, the PHLX is significantly less likely to win a horserace when it is the first to receive an order involved in a horserace. While the PHLX is statistically more likely to win a horserace throughout the sample period, the coefficient on *Post Migration* is positive and statistically significant, indicating that the probability that the PHLX wins a given horserace is higher when sample option classes begin trading in the PFOF model on the PHLX. Thus, the results of our univariate horserace analysis survive in a multivariate setting.[47]

c. Market share when all are at the inside quote.

An implicit assumption made throughout this paper is that the improvement in limit order execution quality on the PHLX experienced after migration is attributable to the fact that the PHLX began utilizing the PFOF model. However, when making the change, PHLX also moved from being the exchange with the second lowest take fee for marketable customer orders (behind the ISE) to a venue that offered rebates for these orders. To understand whether the improvements in limit order execution quality identified thus far are attributable to the fact that the PHLX began utilizing the PFOF model or to the fact that the PHLX became a lower cost alternative to the ISE in terms of obtaining liquidity for customer orders, we next examine the relative market share in sample and control option classes before and after the PHLX migrations. A finding that the PHLX gains market share at the expense of the AMEX and/or the CBOE, the two venues utilizing the PFOF model to trade sample option classes, will suggest the results we document are attributable to the fact that customer limit orders are exposed to purchased order flow. A finding that the PHLX gains market share at the expense of the ISE will suggest that our results are attributable to the fact that the PHLX's take fee for customer orders was lower than the ISE's after the migration.

[47] The model is unable to estimate the logistic regression on the horseraces conducted using limit orders seeking to trade control option classes on a majority of days because of perfect prediction.

We present the across class average market share of trades in the 35 sample and the 35 control option classes respectively in Panels A and B of Table VIII. The median number of surviving trades executed in the thirty days before and the thirty days after migration are similar for both sample and control options.[48] Panel A reveals that two exchanges experience statistically significant changes in market share in sample option classes across the PHLX migration. The average market share executed by the CBOE, a PFOF venue, falls from 19.27% to 17.15% while the average market share on ARCA, which had a take fee of $0.45 per contract, increases from 14.74% to 15.59%. The CBOE's market share declines in 29 of the 35 sample option classes while ARCA's market share rises in 27 sample option classes. The results in Panel B show that the average market share of trades executed in control option classes is statistically higher on PHLX and NOM after the pseudo migration and is statistically lower on ARCA. The average market share of trades executed on the PHLX, which utilizes the PFOF model to trade control option classes, increases from 12.76% to 14.26% while the average market share of trades executed on NOM increases from 7.68% to 8.67%. Finally, the average market share of trades executed on ARCA declines from 14.56% to 12.97%.

Option market participants must comply with the trade through rule, which requires marketable orders to be executed at or within the NBBO. As a result, the set of venues on which marketable orders will execute upon arrival is restricted to those offering to sell (buy) option contracts at the NBO (NBB). As the results presented in Table VIII do not hold constant the set of venues offering to trade at the best quote, it is difficult to evaluate the impact that moving from the venue with the second lowest take fee for marketable customer orders to a venue that pays brokers for these orders has on order routing. For this reason, in Table IX we focus on trades executed at the NBB (NBO) when each of the seven options exchanges has a bid (offer) price that is equal to the NBB (NBO).

Panel A of Table IX contains each exchange's market share of trades executed when all relevant exchanges are at the best quote before and after PHLX migrates option classes to the PFOF model. Panel

[48] We present the median number of trades across option classes rather than the average because one of the migrating option classes, AAPL, had over 4.2 million trades before and after the move. The option class with the second highest number of trades, AMZN, had 324 thousand trades before migration and 405 thousand after migration.

B contains the same information for control options around their pseudo migration. Overall, 9.48% (10.16%) of the trades in sample (control) options occur when each of the seven exchanges listed in Table IX are at the best quote (results not reported). The first row of Panel A reveals that prior to the PHLX migration, the two venues utilizing the PFOF model have the largest market share of trades executed in migrating options when all venues are at the inside quote. Additionally, the market share of the exchanges utilizing the MT model is inversely related to the size of the venue's take fee for customer orders. The one exception is BATS, whose take fee is $0.01 per contract lower than the take fee charged by ARCA and NOM. As can be seen in the second row of Panel A, after the PHLX migration the CBOE's market share of trades executed when all are at the inside quote falls from 20.43% to 16.99% while the PHLX's market share rises from 5.58% to 10.49%. The PHLX realizes an increase in their market share of trades in 31 of the 35 migrating option classes while the CBOE loses market share in 28 of the migrating option classes. None of the other exchanges experiences a statistically significant change in market share. Finally, the total market share of the two pure PFOF venues prior to the migration, 76.15%, is close to the total market share of these venues plus the gain in market share realized by the PHLX after the migration, 75.00%. These results suggest that when given a choice, brokers routed their marketable customer orders to the CBOE and to the AMEX before the PHLX migration and to the CBOE, the AMEX and the PHLX after the PHLX migration. More importantly, the results suggest that the increase in customer orders routed to the PHLX came at the CBOE's expense, not the ISE's.[49]

Panel B of Table IX reveals each exchange's market share of trades in control options executed when all venues are at the inside quote around the pseudo migration date. Highlighting the fact that the control options are not as actively traded as the migrating options, only 22 of the 35 control option classes

[49] One possible reason that the AMEX did not lose market share across the PHLX migration is that on June 29, 2011, seven external investors purchased significant equity interest in the AMEX. These investors were Bank of America Merrill Lynch, Barclays Capital, Citadel Securities, Citi, Goldman Sachs, Ameritrade, and UBS. The 2012 NYSE Euronext 10k states that as part of the purchase agreement, the external investors "received an equity instrument tied to their individual contribution to the options exchange's success." According to a January 23, 2012 report on Dow Jones News, the AMEX's overall share of all U.S. options trading increased from 7% when the NYSE purchased the AMEX in 2008 to 13.3% in January 2012.

have trades in the pre and the post periods when all venues are at the inside quote. The three venues utilizing the PFOF model to arrange trades in control option classes execute 77.65% (78.17%) of trades that occur when all venues are at the inside quote prior to (after) the pseudo migration. As is the case with migrating option classes, the ISE has a greater market share of trades executed when all are at the inside quote than the three exchanges that assess a take fee of at least $0.44 per contract on marketable customer orders. Also consistent with the migrating option classes, the market share of BATS is lower than the market share of ARCA and NOM despite the fact that BATS has a take fee for customer orders that is $0.01 per contract lower. The only venue that realizes a statistically significant change in their market share of trades across the pseudo migration is the ISE, whose market share falls from 10.19% to 8.08%.

To summarize, we find a negative association between a venue's market share of trades executed when all are at the inside quote and that venue's relative take fee. The PHLX's market share of trades executed in these market conditions nearly doubles, rising from 5.58% to 10.49% when option classes migrate from the MT model to the PFOF model. We also find that the only venue that loses a statistically significant portion of their market share after the PHLX migration is the CBOE, which utilizes the PFOF model throughout our sample period. This evidence suggests that the improvement in limit order execution quality on the PHLX is attributable to the fact that after the migration, standing limit orders are exposed to marketable customer orders that are purchased from retail brokers.[50]

8. Conclusion

Using data from 4Q2012, we present evidence that the order flow routed by several retail brokers to options exchanges with high liquidity rebates contains a higher percentage of limit orders than the order flow these brokers route to options exchanges with wholesalers that pay for marketable orders. Other

[50] This finding is consistent with the following statement made by Thomas Peterffy, Chairman and CEO of Interactive Brokers, in a March 8, 2017 press release announcing Interactive Brokers' decision to cease option market making activities."Today retail order-flow is purchased by large order internalizers and joining them would represent a conflict we do not wish to have. On the other hand, providing liquidity to sophisticated, professional synthesizers of short-term fundamental, technical and big data is not a profitable activity." See "Interactive Brokers Group Announces Decision to Cease Options Market Making Activities," published by Business Wire on March 8, 2017. The article can be downloaded at:
http://finance.yahoo.com/news/interactive-brokers-group-announces-decision-215200044.html?soc_src=social-sh&soc_trk=ma.

brokers route all of their market and limit orders to wholesalers. While the former routing strategy generates higher order flow payments, the latter routing strategy allows customer limit orders to interact with marketable orders purchased by the wholesaler, which we empirically demonstrate enhances limit order execution quality.

Using PHLX order data, we find that the customer order flow routed to the PHLX contains more marketable orders and the limit order fill rate increases following migration to the PFOF model. We conduct horseraces between the PHLX and NOM and find the PHLX migration is associated with an improvement in PHLX limit order execution quality relative to the NOM, a venue charging the highest take fee throughout our sample period. To determine whether the improvement in limit order execution quality on the PHLX is attributable to the introduction of wholesalers to the PHLX, we use OPRA data to determine how the PHLX migration affected each of the significant options exchange’s market share of trades executed when all are offering to trade at the best posted price. We find that the PHLX gains market share at the expense of the CBOE, a venue that utilizes the PFOF model throughout our sample period. Together, our results suggest that brokers seeking to maximize limit order execution quality should route customer limit orders to options exchanges that actively purchase retail order flow.

More generally, our results suggest that brokers in equity markets could enhance limit order execution quality by routing all of their orders (both marketable and nonmarketable) to wholesalers. By increasing the likelihood of disintermediated trade, such a move would likely reduce the amount that wholesalers would pay for the marketable order flow. This type of routing also reduces (eliminates) the liquidity rebates generated by limit orders executing on venues utilizing the MT model to arrange trades. However, since wholesalers operating in U.S. equity markets do not generally execute orders on exchanges, they do not have to accept nonmarketable limit orders. Whether or not wholesalers operating in equity markets should be required to accept customer limit orders is a question we leave for future research.

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Table I. Make take fees for different options market participants in January 2012.

We present the make rebates and take fees generated by orders seeking to trade options in the Penny Pilot Program that are routed to exchanges by ITG in January 2012. Throughout 2012, the PHLX and the ISE use the PFOF model to arrange trades in certain option classes and the MT model to arrange trades in others. As noted by Lakonishok et al. (2006), Customer orders include those placed by customers of discount and full service brokers, BD orders are those placed by broker dealers, MM orders are those placed by market makers, Professional orders are those placed by professional traders, and proprietary orders include orders placed by employees of investment banks that are trading for the banks' own account. Fees and rebates are expressed in dollars per contract. PFOF (MT) indicates the fees and rebates apply to option classes trading under the PFOF (MT) model.

		Customer	BD	MM	Professional	Proprietary
PFOF						
AMEX	Make	0.00	0.20	0.00	0.20	0.20
	Take	0.00	0.20	0.00	0.20	0.20
CBOE	Make	0.00	0.45	0.20	0.20	0.20
	Take	0.00	**0.45**	0.20	0.20	0.20
ISE	Make	0.00	0.20	0.00	0.20	0.20
	Take	0.00	0.20	0.00	0.20	0.20
MIO	Make	0.00	0.45			
	Take	0.00	**0.45**			
PHLX	Make	0.00	0.45	0.00	0.20	0.25
	Take	0.00	**0.45**	0.00	0.20	0.25
MT						
BOX	Make	0.29	0.62	0.62	0.42	0.62
	Take	-0.15	0.18	0.18	-0.02	0.18
ISE Select	Make	0.00		0.10	0.10	0.10
	Take	0.15		0.28	0.29	0.29
PHLX Select	Make	-0.26	0.05	0.00	-0.23	0.05
	Take	0.31	**0.45**	0.00	**0.45**	**0.45**
C2OX	Make	-0.37	-0.35	-0.40	-0.35	-0.35
	Take	0.44	**0.45**	**0.45**	**0.45**	**0.45**
BATS	Make	-0.30	-0.22	-0.22	-0.22	-0.22
	Take	0.44	0.44	0.44	0.44	0.44
NOM	Make	-0.26	-0.10	-0.30	-0.29	-0.10
	Take	**0.45**	**0.45**	**0.45**	**0.45**	**0.45**
ARCA	Make	-0.25	-0.10	-0.32		-0.10
	Take	**0.45**	**0.45**	**0.45**		**0.45**

Table II. The order routing decisions of eight retail brokers in the 4th quarter of 2012

The table describes equity option order routing decisions for eight retail brokers. Panel A contains the percentage of nondirected orders routed to each venue and Panel B presents the ratio of market to market and limit orders routed to each venue. Data are from Rule 606 reports for the fourth quarter of 2012. Brokers are responsible for deciding where nondirected orders are routed. Brokers do not have to disclose destination venues that receive less than 5% of their orders. As a result, percentages may not sum to 100%. The ISE and the PHLX use the MT model to arrange trades in some option classes and the PFOF model to arrange trades in others. While the BOX appears to utilize an inverted MT model, as a result of quoting behavior on the BOX and the price improvement mechanism used to arrange trades on the BOX, liquidity demanders effectively pay liquidity fees and liquidity suppliers effectively earn liquidity rebates. The bolded venue in each panel is the venue receiving the largest percentage of the broker's orders. % market is the ratio of market orders to market and limit orders.

Panel A. Across venue market share.

	Ameritrade	E*Trade	Fidelity	IB	MB Trading	Schwab	Scottrade	Trade King
PFOF: Exchange								
AMEX	11.00%		11.83%	10.10%		29.10%		
CBOE	20.00%	14.45%	9.42%	22.00%		16.40%		
PFOF: Wholesaler								
Citadel							37.92%	24.74%
CITI					6.00%		22.64%	12.64%
NITE								25.73%
SIG					97.00%		20.08%	12.75%
UBS							12.52%	
Wolverine								22.20%
MT								
BATS	9.00%	14.18%	19.66%	7.60%		3.50%		
NOM	14.00%	34.27%	9.88%	23.10%		10.00%		
ARCA		6.65%	15.23%	16.40%		26.40%		
Hybrid								
ISE	9.00%	7.21%	10.89%	7.90%		2.90%		
PHLX	31.00%	13.51%	15.71%	6.00%		3.10%		
BOX			6.53%			7.70%		

Panel B. Percentage of market orders contained in the order flow routed to each venue.

Broker % market	Ameritrade 3.06%	E*Trade 13.91%	Fidelity 25.77%	IB 3.40%	MB Trading 7.14%	Schwab 13.81%	Scottrade 16.33%	Trade King 48.98%
PFOF: Exchange								
AMEX	5.68%		26.18%	5.68%		2.37%		
CBOE	5.09%	37.92%	31.98%	1.29%		10.74%		
PFOF: Wholesaler								
Citadel							16.26%	62.16%
CITI					3.19%		16.89%	68.56%
NITE								42.00%
SIG					7.28%		14.79%	61.50%
UBS							16.76%	
Wolverine								23.46%
MT								
BATS	1.26%	4.49%	3.55%	1.29%		15.02%		
NOM	0.42%	2.50%	2.50%	0.69%		13.40%		
ARCA		4.33%	2.98%	1.04%		1.91%		
Hybrid								
ISE	3.72%	15.34%	75.20%	3.74%		10.24%		
PHLX	2.09%	20.87%	20.87%	13.96%		10.32%		
BOX			65.39%			0.80%		

Table III

Sample selection and matching results

Panel A. Sample filters.

Initial sample of classes migrating from MT to PFOF on the PHLX:	92
Exclude option classes with fewer than one order execution per day:	27
Exclude option classes that are not on common stocks:	28
Final Sample:	37

Panel B. Dates and sample option classes migrating from MT to PFOF on the PHLX.

Date	Source: SEC Release No.	Classes migrating from MT to PFOF on PHLX
February 1, 2012	34-66252	AIG
March 1, 2012	34-66488	GS, LVS, MGM, MU, NVDA, QCOM, V, WYNN, and X
April 2, 2012	34-66756	AAPL, AMZN, C, CAT, IBM, JPM, T, and XOM
July 2, 2012	34-67439	EBAY, GLW, PG, SBUX, SNDK, and UAL
January 2, 2013	34-68674	AA, ARNA, CSCO, F, GE, INTC, ORCL, PFE, SIRI, VZ, and YHOO
July 1, 2013	34-69958	BAC and MSFT

Panel C. Characteristics of underlying stocks for migrating and control option classes.

	Underlying stock price		Market capitalization of equity	
	Migrate from MT	Remain PFOF	Migrate to MT	Remain PFOF
Average	$64.51	$79.72	$104.1 billion	$74.6 billion
Median	$34.01	$54.39	$61.4 billion	$61.0 billion

Table IV. Descriptive statistics for customer orders routed to the PHLX around the migration

This table provides descriptive statistics for option classes that migrate from the MT model to the PFOF model (Migrate) and for a matched sample of option classes that remain in the PFOF model over the entire sample period (Control). We report results for 4-month event windows centered on the date of migration. We average each measure by option class/day. We use t-tests to conduct difference in means tests and the Wilcoxon sign-ranked test to conduct difference in medians tests.

		2 months before		2 months after		Difference (Post - Pre)	
		Migrate	Control	Migrate	Control	Migrate	Control
Median # of orders	Marketable	2.0	1.0	3.0	1.0	1.0***	0.0***
	Nonmarketable	18.0	7.0	16.0	8.0	-2.0***	1.0***
Average # of orders	Marketable	10.4	3.8	10.1	5.1	-0.3	1.3***
	Nonmarketable	79.8	25.8	47.2	25.6	-32.6***	-0.2
Median order volume (# of contracts)	Marketable	24.0	8.0	50.0	14.0	26.0***	6.0***
	Nonmarketable	352.5	129.0	374.0	163.0	21.5	34.0***
Average order volume (# of contracts)	Marketable	156.6	57.1	205.8	89.7	49.2***	32.6***
	Nonmarketable	2,636.7	473.1	2,560.8	571.1	-75.9**	98.0**
Average order fill rate		35.51%	40.97%	38.08%	40.12%	2.57%***	-0.85%
Average order cancellation rate		48.89%	41.55%	49.35%	42.11%	0.46%	0.56%
Median fill speed (seconds)		648.6	829.3	596.4	778.2	-52.2	-51.1
% of marketable orders		12.51%	17.60%	20.03%	21.04%	7.52%***	3.44%***

Table V. Marginal impact of PHLX migration on customer order flow

We use quantile median regressions to estimate the following equation when the order flow variable is the median number of marketable orders (volume), the median number of nonmarketable orders (volume), or the median time execution speed, and we use OLS when the order flow variable is % of marketable orders.

$$\begin{aligned} Order\ Flow\ Variable_{i,t} &= \alpha + \beta_1 Post_t + \beta_2 Migrate_i + \beta_3 Post_t \times Migrate_i + \beta_4 Log(Underlying\ Trading\ Volume)_i + \beta_5 Underlying\ Pvolt_i \\ &+ \beta_6 Underlying\ Market\ Capitalization_i + \beta_7 S/X_{i,t} + \beta_8\ (S/X)^2{}_{i,t} + \beta_9 Days\ Expiration_{i,t} + \beta_{10} Call_{i,t} + \varepsilon_{i,t} \end{aligned}$$

We aggregate each order flow variable on a daily basis by option type (e.g., put or call) and option class. *Post* is an indicator measure set equal to one if the class/day occurs after the sample option class (or its matched sample option class) has migrated to the PFOF model on the PHLX and zero otherwise. *Migrate* is an indicator variable set equal to one for sample option classes and is set equal to zero for control option classes. *Log(Underlying Vol)* is the log of the CRSP daily share volume in the underlying stock. *Underlying Pvolt* is the difference between the CRSP daily high and daily low prices, scaled by the daily high price. *Underlying Mkt Cap* is the market capitalization of the underlying stock. *S/X* is the ratio of the underlying stock price to the strike price, *Days to Expiration* is the number of days until expiration for each option and *Call* is an indicator variable that equals one if the option is a call. To calculate standard errors, we cluster on the underlying stock.

	Median # of orders		Median order volume		Median fill speed (seconds)	% of marketable orders
	Marketable	Nonmarketable	Marketable	Nonmarketable		
Post	0.416***	1.348***	5.797***	48.604***	-41.3	0.021**
Migrate	0.435***	6.288***	5.576***	78.223***	-267.3***	-0.007
Post * Migrate	0.730***	-2.934***	16.035***	-42.355**	-17.1	0.040***
Log(Underlying Vol)	-0.106***	3.164***	2.912***	152.344***	128.4***	-0.056***
Underlying Pvolt	51.246***	280.503***	841.118***	6,203.315***	-1,621.2*	0.606***
Underlying mkt cap.	0.011***	0.040***	0.210***	0.839***	-0.6***	0.000***
S/X	0.576	8.338***	7.153	266.751***	766.1	-0.064
S/X^2	-0.105*	-1.804***	-0.370	-48.001***	-438.0	0.034***
Days to Expiration	-0.002***	-0.012***	-0.048***	-0.568***	0.9**	0.000
Call	0.805***	6.918***	10.695***	189.596***	116.9***	-0.022***
Constant	0.289	-59.013***	-71.524***	-2,659.760***	-1,544.1*	0.984***
R^2	0.205	0.125	0.204	0.123	0.015	0.143
N	9,827	9,827	9,827	9,827	8,360	9,827

Table VI. Horserace results

An Order Pair horserace involves a pair of displayed limit orders that have the same option series symbol, same order date, same order side (buy or sell), same limit price, but different destination venues. We require that the first order in the order-pair still be active when the second order in the order-pair is routed. We declare a horserace a tie if both orders execute within 500μs of one another. For limit sell (buy) orders, the Realized Spread is equal to two (negative two) times the difference between the trade price and the bid/ask midpoint five minutes after the order is executed.

Panel A. All horseraces.

	# of order pairs	Fill Rates			Mean Order Size		Median Fill Time (seconds)		Horseraces		
		PHLX	NOM	Both Fill	PHLX	NOM	PHLX	NOM	PHLX Fills 1st	NOM Fills 1st	Tie
Migrate (Fee = 0.26) vs. NOM (Fee = 0.45)	6,773	93.61%	36.42%	30.03%	13.32	8.08	182.51	250.98	84.57%	11.03%	4.40%
Migrate (Fee ≤ 0.00) vs. NOM (Fee = 0.45)	2,218	93.66%	35.28%	28.94%	15.33	8.24	142.65	421.04	86.95%	10.09%	2.96%
Control (Fee ≤ 0.00) vs. NOM (Fee = 0.45)	2,672	98.66%	14.02%	12.68%	6.93	3.09	145.16	57.49	93.84%	4.54%	1.62%

Panel B. PHLX migrating versus NOM summary for horseraces involving the most actively-traded option series.

	# of order pairs	Fill Rates			Mean Order Volume		Median Fill Time (seconds)		Horseraces		
		PHLX	NOM	Both Fill	PHLX	NOM	PHLX	NOM	PHLX Fills 1st	NOM Fills 1st	Tie
Migrate (Fee = 0.26) vs. NOM (Fee = 0.45)	1,133	89.84%	48.54%	38.38%	13.37	9.53	169.49	226.83	77.27%	16.52%	6.22%
Migrate (Fee $\leq$ 0.00) vs. NOM (Fee = 0.45)	319	91.87%	37.42%	29.29%	11.35	11.13	52.68	131.22	85.48%	11.80%	2.72%
Control (Fee $\leq$ 0.00) vs. NOM (Fee = 0.45)	620	93.56%	47.02%	40.59%	8.86	8.83	98.49	38.14	83.30%	13.25%	3.45%

Panel C. PHLX migrating versus NOM summary of horseraces in which PHLX order arrives first.

	# of order pairs	Fill Rates			Mean Order Volume		Median Fill Time (seconds)		Horseraces		
		PHLX	NOM	Both Fill	PHLX	NOM	PHLX	NOM	PHLX Fills 1st	NOM Fills 1st	Tie
Migrate (Fee = 0.26) vs. NOM (Fee = 0.45)	1,728	91.07%	52.71%	43.78%	13.19	10.32	340.68	173.48	79.08%	13.69%	7.24%
Migrate (Fee $\leq$ 0.00) vs. NOM (Fee = 0.45)	713	91.08%	52.58%	43.59%	14.69	9.54	344.44	361.49	81.24%	13.44%	5.31%

Panel D. PHLX migrating versus NOM summary of horseraces in which NOM order arrives first.

	# of order pairs	Fill Rates			Mean Order Volume		Median Fill Time (seconds)		Horseraces		
		PHLX	NOM	Both Fill	PHLX	NOM	PHLX	NOM	PHLX Fills 1st	NOM Fills 1st	Tie
Migrate (Fee = 0.26) vs. NOM (Fee = 0.45)	5,045	92.60%	29.32%	21.92%	12.98	7.27	124.18	610.15	85.84%	11.65%	2.50%
Migrate (Fee $\leq$ 0.00) vs. NOM (Fee = 0.45)	1,505	93.66%	26.94%	20.60%	16.42	8.58	77.99	614.94	88.26%	9.70%	2.04%

Table VII. Multivariate analysis of the probability that PHLX wins a horserace.

We use a Tobit censored regression to estimate the following model using the sample of orders involved in our horseraces:

$$
\begin{aligned}
PHLX\ Wins_{i,t} = {} & \alpha + \delta_t + \beta_1 Post\ Migration_t + \beta_2 PHLX\ Recieves\ Order\ First_{i,t} + \beta_3 PHLX\ Order\ Size_{i,t} \\
& + \beta_4 NOM\ Order\ Size_{i,t} + \beta_5 Limit\ Price_{i,t} + \beta_6 Underlying\ Market\ Cap_{i,t} + \beta_7 Call_{i,t} \\
& + \beta_8 Sell_{i,t} + \beta_9\ S/X_{i,t} + \beta_{10}(S/X)^2_{i,t} + \beta_{11} Days\ Expiration_{i,t} + \varepsilon_{i,t}
\end{aligned}
$$

PHLX Wins equals one if the order resting on the PHLX executes before the order resting on the NOM. *Post Migration* is an indicator measure set equal to one if the i^{th} horserace occurs after the option class migrates to the PFOF model and zero otherwise. *PHLX Receives Order First* equals one if the PHLX receives the first order in the i^{th} horserace and equals zero if the first order is received by the NOM. *PHLX Order Size* and *NOM Order Size* are the sizes of the two orders in the i^{th} horserace. *Limit Price* is the limit price of the two orders in the i^{th} horserace. *Underlying Market Cap* is the market capitalization of the underlying stock, *S/X* is the ratio of the underlying stock price to the strike price *Days to Expiration* is the number of days until expiration for each option, *Sell* is an indicator variable that equals one if the orders are sell orders and zero otherwise, and *Call* is an indicator variable that equals one if the orders seek to trade a call option and zero otherwise. To calculate standard errors, we cluster on the underlying stock.

Independent Variable	Coefficient	Standard Error	z-ratio	Probability	Odds Ratio
Post migration	3.3184	1.3180	2.52	0.012	27.6157
Order arrived on PHLX 1st	-0.9307	0.0659	-14.11	0.000	0.3943
PHLX order size	-0.0041	0.0010	-3.97	0.000	0.9959
NOM order size	-0.0085	0.0015	-5.47	0.000	0.9916
Limit price	0.0144	0.0032	4.58	0.000	1.0145
Underlying market cap.	-0.0013	0.0002	-5.50	0.000	0.9987
Call	-0.3558	0.0791	-4.50	0.000	0.7006
Sell	-0.2256	0.0643	-3.51	0.000	0.7980
S/X	0.2282	1.5166	0.15	0.880	1.2563
S/X^2	-0.1469	0.5811	-0.25	0.800	0.8634
Days to Expiration	-0.0029	0.0006	-4.65	0.000	0.9971
Constant	2.2041	1.0178	2.17	0.030	9.0618
Pseudo R^2	0.0729				
N	8,991				

Table VIII. Market share of regular, auto ex, spread and straddle trades executed at the NBB or NBO.

Panel A. Across-class average market share of trades in the 35 sample option classes that migrate from the maker-taker model to the PFOF model. The student's t-test is used to determine if the market share differ across migration. *** (*) indicates the venue's market share before and after migration is statistically different at the .01 (.05) level.

	N (median)	AMEX	CBOE	ISE	PHLX	BATS	ARCA	NOM
Pre	61,152	23.47%	19.27%	11.09%	9.11%	5.14%	14.74%	11.41%
Post	61,213	23.46%	17.15%	11.45%	9.37%	5.32%	15.59%	11.99%
Post-Pre		-0.01%	-2.12%***	0.36%	0.26%	0.18%	0.85%*	0.58%
% (Post – Pre) > 0		51.43%	17.14%	62.86%	57.14%	62.86%	77.14%	62.86%

Panel B. Across-class average market share of trades in the 35 control option classes before and after their matched option class migrates from the maker-taker model to the PFOF model. The student's t-test is used to determine if the market share differ across the pseudo-migration. *** (**) indicates the venue's market share before and after pseudo-migration is statistically different at the .01 (.025) level.

	N (median)	AMEX	CBOE	ISE	PHLX	BATS	ARCA	NOM
Pre	17,743	23.46%	18.86%	10.56%	12.76%	5.76%	14.56%	7.68%
Post	18,914	23.22%	18.00%	10.64%	14.26%	5.95%	12.97%	8.67%
Post-Pre		-0.24%	-0.86%	0.08%	1.50%***	0.19%	-1.59%**	0.98%***
% (Post – Pre) > 0		51.43%	34.27%	51.43%	68.57%	51.43%	40.00%	74.29%

Table IX. Market share of regular, auto ex, spread and straddle trades executed when each exchange is at the best quote.

Panel A. Across-class average market share of trades executed when each of the seven exchanges are at the best posted quote in the 35 sample option classes that migrate from the maker-taker model to the PFOF model. The student's t-test is used to determine if the market share differ across migration. *** indicates the venue's market share before and after migration is statistically different at the .01 level.

	N (median)	AMEX	CBOE	ISE	PHLX	BATS	ARCA	NOM
Pre	9,055	55.72%	20.43%	7.35%	5.58%	0.85%	2.82%	1.22%
Post	9,650	53.10%	16.99%	7.71%	10.49%	0.77%	3.38%	1.38%
Post - Pre		-2.62%	-3.44%***	0.36%	4.91%***	-0.08%	0.56%	0.16%
% Post – Pre > 0		42.86%	20.00%	42.86%	88.57%	48.57%	37.14%	54.29%

Panel B. Across-class average market share of trades in the control option classes before and after their matched option class migrates from the maker-taker model to the PFOF model. Only 22 of the 35 control option classes have trades that occur when each of the seven exchanges are at the best quote. The student's t-test is used to determine if the market share differ across migration. * indicates the venue's market share before and after migration is statistically different at the .05 level.

	N (median)	AMEX	CBOE	ISE	PHLX	BATS	ARCA	NOM
Pre	3,295	46.08%	19.20%	10.19%	12.37%	0.58%	2.94%	1.31%
Post	4,178	45.89%	18.33%	8.08%	13.95%	0.80%	2.59%	1.96%
Post - Pre		-0.20%	-0.88%	-2.10%*	1.58%	0.22%	-0.35%	0.65%
% Post - Pre > 0		45.45%	45.45%	31.82%	68.18%	68.18%	40.91%	63.64%

Appendix Table I. Make take fees for different options market participants in January 2012.

We present the make rebates and take fees generated by orders seeking to trade options in the Penny Pilot Program that are routed to exchanges by ITG in July 2012, December 2012, and January 2017. Throughout 2012, the PHLX and the ISE use the PFOF model to arrange trades in certain option classes and the MT model to arrange trades in others. As noted by Lakonishok et al. (2006), Customer orders include those placed by customers of discount and full service brokers, BD orders are those placed by broker dealers, MM orders are those placed by market makers, Professional orders are those placed by professional traders, and proprietary orders include orders placed by employees of investment banks that are trading for the banks' own account. Fees and rebates are expressed in dollars per contract. PFOF (MT) indicates the fees and rebates apply to option classes trading under the PFOF (MT) model.

Panel A. July 2012.

		Customer	BD	MM	Professional	Proprietary
PFOF						
AMEX	Make	0.00	0.28	0.20	0.28	0.20
	Take	0.00	0.28	0.20	0.28	0.20
CBOE	Make	0.00	0.45	0.20	0.30	0.20
	Take	0.00	**0.45**	0.20	0.30	0.20
ISE	Make	0.00	0.20	0.25	0.20	0.20
	Take	0.00	0.20	0.25	0.20	0.20
MIO	Make	0.00	0.45			
	Take	0.00	**0.45**			
PHLX	Make	0.00	0.45	0.00	0.25	0.40
	Take	0.00	**0.45**	0.00	0.25	0.40
MT						
BOX	Make	0.29	0.62	0.62	0.42	0.62
	Take	-0.15	0.18	0.18	-0.02	0.18
ISE Select	Make	0.00		0.10	0.10	0.10
	Take	0.15		0.28	0.29	0.29
PHLX Select	Make	-0.26	0.05	0.00	-0.23	0.05
	Take	0.39	**0.45**	0.00	**0.45**	**0.45**
C2OX	Make	-0.37	-0.35	-0.40	-0.35	-0.35
	Take	0.44	**0.45**	**0.45**	**0.45**	**0.45**
BATS	Make	-0.30	-0.22	-0.22	-0.22	-0.22
	Take	0.44	**0.45**	**0.45**	**0.45**	**0.45**
NOM	Make	-0.26	-0.10	-0.30	-0.29	-0.10
	Take	**0.45**	**0.45**	**0.45**	**0.45**	**0.45**
ARCA	Make	-0.25	-0.10	-0.32		-0.10
	Take	**0.45**	**0.45**	**0.45**		**0.45**

Panel B. December 1, 2012.

		Customer	BD	MM	Professional	Proprietary
PFOF						
AMEX	Make	0.00	0.28	0.20	0.28	0.20
	Take	0.00	0.28	0.20	0.32	0.20
CBOE	Make	0.00	0.45	0.20	0.30	0.20
	Take	0.00	**0.45**	0.20	0.30	0.20
ISE	Make	0.00	0.20	0.20	0.20	0.20
	Take	0.00	0.20	0.20	0.20	0.20
MIO	Make	0.00	0.45			
	Take	0.00	**0.45**			
PHLX	Make	0.00	0.45	0.00	0.25	0.40
	Take	0.00	**0.45**	0.00	0.25	0.40
MT						
BOX	Make	0.29	0.62	0.62	0.42	0.62
	Take	-0.15	0.18	0.18	-0.02	0.18
ISE Select	Make	0.00		0.10	0.10	0.10
	Take	0.15		0.32	0.33	0.33
PHLX Select	Make	-0.26	0.05	0.00	-0.23	0.05
	Take	0.43	**0.45**	0.00	0.45	0.45
C2OX	Make	-0.37	-0.35	-0.40	-0.35	-0.35
	Take	0.44	**0.45**	0.45	0.45	0.45
BATS	Make	-0.30	-0.22	-0.25	-0.25	-0.25
	Take	**0.45**	**0.45**	**0.47**	**0.47**	**0.47**
NOM	Make	-0.26	-0.10	-0.30	-0.29	-0.10
	Take	**0.45**	**0.45**	**0.47**	**0.47**	**0.47**
ARCA	Make	-0.25	-0.10	-0.32		-0.10
	Take	**0.45**	**0.45**	0.45		0.45

Panel C. January 1, 2017.

		Customer	BD	MM	Professional	Proprietary
PFOF						
AMEX	Make	0.00	0.50	0.25	0.50	0.42
	Take	0.00	**0.50**	0.25	**0.50**	0.42
CBOE[1]	Make	0.00	0.47	0.23	0.47	0.47
	Take	0.00	0.47	0.23	0.47	0.47
ISE[1]	Make	0.00		0.10	0.10	0.10
	Take	0.00		0.45	0.45	0.45
MIO	Make	0.00	0.47	0.23	0.47	
	Take	0.00	0.47	0.23	0.47	
PHLX[1]	Make	0.00	0.48	0.22	0.48	0.48
	Take	0.00	0.48	0.22	0.48	0.48
MT						
BOX	Make	0.05				
	Take	0.05				
BX	Make	0.39	0.46	0.39	0.46	0.46
	Take	0.00	0.46	0.46	0.46	0.46
EDGX	Make	-0.05	0.48	0.19	0.48	0.48
	Take	-0.05	0.48	0.19	0.48	0.48
GMNI	Make	-0.25		-0.30	-0.25	-0.25
	Take	0.45		0.49	0.49	0.49
MCRY	Make	-0.05		0.25	0.47	0.47
	Take	-0.05		0.20	0.47	0.47
C2OX	Make	-0.42	-0.40	-0.45	-0.40	-0.40
	Take	0.49	**0.50**	**0.50**	**0.50**	**0.50**
BATS	Make	-0.30	-0.22	-0.25	-0.25	-0.25
	Take	0.45	0.45	0.47	0.47	0.47
NOM	Make	-0.26	-0.10	-0.20	-0.20	-0.10
	Take	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**
ARCA	Make	-0.25	-0.10	-0.28	-0.25	-0.10
	Take	0.49	**0.50**	**0.50**	**0.50**	**0.50**

Notes: Data are obtained from ITG and reflect the fees they expected to incur when routing options orders. [1]SIG PFOF of $0.10/contract ($0.05/contract) on orders for 200 or fewer (more than 200) contracts in penny pilot options and $0.35/contract ($0.20/contract) on orders for 200 or fewer (more than 200) contracts in non-penny pilot options.

Appendix Table II. The order routing decisions of eight retail brokers in the 3rd quarter of 2016

The table describes equity option order routing decisions for eight retail brokers. Panel A contains the percentage of nondirected orders routed to each venue and Panel B presents the ratio of market to market and limit orders routed to each venue. Data are from Rule 606 reports for the third quarter of 2016. Brokers are responsible for deciding where nondirected orders are routed. Brokers do not have to disclose destination venues that receive less than 5% of their orders. As a result, percentages may not sum to 100%. The ISE and the PHLX use the MT model to arrange trades in some option classes and the PFOF model to arrange trades in others. While the BOX appears to utilize an inverted MT model, as a result of quoting behavior on the BOX and the price improvement mechanism used to arrange trades on the BOX, liquidity demanders effectively pay liquidity fees and liquidity suppliers effectively earn liquidity rebates. The bolded venue in each panel is the venue receiving the largest percentage of the broker's orders. % market is the ratio of market orders to market and limit orders.

Panel A. Market share of non-directed orders.

	Ameritrade	E*Trade	Fidelity	Interactive Brokers	MB Trading	Schwab	Scottrade	Trade King
PFOF								
AMEX				6.60%		1.20%		
CBOE	11.00%	16.69%	**35.40%**	7.20%		**21.30%**		
ISE	11.00%	4.81%				11.10%		
MIO		10.43%	12.00%			8.10%		
PHLX	**26.00%**	9.04%	12.36%			10.70%		
Am. Clearing	20.00%							
Citadel							**38.39%**	33.56%
CITI							9.77%	
Morg. Stan.							10.99%	
SIG							10.66%	4.52%
Wolverine							21.64%	**61.92%**
MT								
BOX			4.94%	12.50%		2.70%		
GMNI				12.20%				
BATS	7.00%	16.10%		5.60%		12.00%	8.56%	
NOM	13.00%	**24.90%**	10.72%	**27.00%**		16.00%		
ARCA	11.00%	12.40%	17.88%	19.20%		15.10%		

Panel B. Ratio of market orders to market and limit orders routed to trading venues in the third quarter of 2016.

	Ameritrade	E*Trade	Fidelity	Interactive Brokers	MB Trading	Schwab	Scottrade	Trade King
Broker's Mix	3.06%	13.52%	22.19%	2.65%		9.77%	12.35%	6.81%
PFOF								
AMEX				0.83%		19.74%		
CBOE	3.46%	29.58%	**20.93%**	4.95%		**15.71%**		
ISE	0.30%	3.64%				2.72%		
MIO	7.05%	35.15%	56.01%			27.87%		
PHLX	**3.06%**	27.28%	43.14%			15.15%		
Am. Clearing	5.09%							
Citadel							**13.92%**	5.40%
CITI							13.67%	
Morg. Stan.							17.47%	
SIG							13.46%	8.27%
Wolverine							10.79%	7.46%
MT								
BOX			27.39%	12.56%		48.46%		
GMNI				0.28%				
BATS	0.35%	1.03%		1.50%		1.29%		
NOM	0.39%	**0.45%**	1.45%	**0.13%**		0.48%		
ARCA		0.92%	0.97%	0.35%		0.76%		

Panel C. Market share of non-directed orders.

	Opt Xpress	Opt House	Capital One
PFOF			
AMEX			3.80%
CBOE	37.40%	**22.02%**	23.10%
ISE	17.10%	14.30%	
MIO	6.10%	11.30%	
PHLX	12.00%	8.58%	36.40%
MT			
BOX	2.30%	2.39%	19.20%
BX			
EDGX			
GMNI			
MCRY			
C2OX	1.50%		
BATS	6.40%	7.92%	3.80%
NOM	9.80%	18.20%	15.40%
ARCA	5.70%	12.03%	3.80%

Panel F. Ratio of market orders to market and limit orders routed to trading venues in the third quarter of 2016.

	Opt Xpress	Opt House	Capital One
Broker's Mix	9.01%	2.20%	42.30%
PFOF			
AMEX			100.00%
CBOE	**9.30%**	**2.94%**	33.32%
ISE	2.41%	0.51%	
MIO	29.81%	4.81%	
PHLX	12.73%	4.07%	**66.74%**
MT			
BOX	48.56%	12.14%	60.08%
BX			
EDGX			
GMNI			
MCRY			
C2OX	1.15%		
BATS	1.91%	0.48%	0.00%
NOM	0.72%	0.13%	0.00%
ARCA	2.00%	0.48%	0.00%