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Do (Should) Brokers Route Limit Orders to Options Exchanges That Purchase Order Flow?

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Abstract

We examine whether options exchanges' pricing schedules affect broker order routing behavior and limit order execution quality. We find that some brokers seemingly maximize the value of their order flow by selling marketable orders and sending nonmarketable orders to exchanges that offer large liquidity rebates. Other brokers appear to bypass liquidity rebates by routing both marketable and nonmarketable orders to exchanges that purchase order flow. Using a decision by the Philadelphia Stock Exchange (PHLX) to change its trading protocol, we provide empirical evidence that brokers can enhance limit order execution quality by routing nonmarketable limit orders to options exchanges that purchase order flow.

I. Introduction

In response to increased competition, U.S. equity options exchanges have introduced pricing schedules that offer cash payments for different types of orders. These pricing schedules generally take one of two forms: maker-taker (MT) pricing and payment for order flow (PFOF). The MT fee model is a pricing structure used by exchanges that pay their members a per share rebate to provide or make liquidity and charge them a fee to remove or take liquidity. The PFOF pricing model is used by exchanges, or market makers, that pay brokerage firms to route

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marketable retail orders to them. Nonmarketable customer limit orders are generally executed at no cost. The coexistence of the MT and PFOF fee models gives brokers the ability to make strategic, and potentially revenue-enhancing, order routing decisions (Angel, Harris, and Spatt (2011)).

Anand, Hua, and McCormick (2016) present evidence that cash incentive programs can affect options brokers' order routing behavior. As retail brokers do not generally pass the fees and rebates generated from customer order flow directly back to their customers (see Battalio, Corwin, and Jennings (2016)), the Securities and Exchange Commission (SEC) ((2015), p. 17) notes that brokers "may have an incentive to route to the venue with the highest rebate, rather than diligently search out the venue likely to deliver the best execution of its customer orders."[1] Furthermore, Credit Suisse ((2017), p. 24) explains that "if a broker is fully optimizing its order routing operation, we would expect most market orders to be sold to market-makers and limit orders to be sold to exchanges." Therefore, brokers that route both marketable and nonmarketable orders to options market makers, instead of to exchanges offering a high maker rebate, likely forgo lucrative liquidity incentives. In fact, Credit Suisse (2017) notes that Ameritrade, a broker that strategically routes marketable and nonmarketable orders to select venues based on order type, is paid 29% per contract more for its marketable options orders than Schwab, a broker that routes its options order flow mix similarly across all trading venues.

Assuming that Schwab is an economically rational agent, there must be a reason that it is willing to forego the enhanced rebate revenue associated with bifurcated order routing. One potential explanation is that by allowing its nonmarketable limit orders to interact with all of the market orders purchased by an options exchange, Schwab is able to increase the frequency that its limit orders execute. Therefore, equity options brokers may face a trade-off between fully monetizing their order routing and meeting best execution requirements. In other words, cash incentive programs, such as the MT and PFOF pricing models, might aggravate agency issues between brokers and their clients (Angel et al. (2011)).

In this paper, we empirically examine whether routing limit orders to options exchanges that purchase marketable retail orders, rather than to venues offering to pay high liquidity rebates, enhances execution quality. As our identification strategy, we use the 2012 decision by the Philadelphia Stock Exchange (PHLX) to migrate select option classes trading in the MT pricing model to the PFOF pricing model. In Table 1, we describe how the PHLX migration of option classes from the MT model to the PFOF model impacted the relative cost of liquidity in the equity options trading landscape.[2] Prior to the change, the PHLX was the second least costly MT venue on which to execute marketable customer orders. After the migration to PFOF, the PHLX joined the American Stock Exchange (AMEX) and the Chicago Board Options Exchange (CBOE) as preferred, or lowest-cost destinations for marketable order flow. To the extent that this lower liquidity cost

[1] See also the SEC's Feb. 9, 2004 report concerning the competitive developments in the options markets, which can be found here: https://www.sec.gov/rules/concept/34-49175.pdf.

[2] 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)).

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TABLE 1

Take Fees Before and After the PHLX Migration from the MT Model to the PFOF Model

Table 1 reports take fees for marketable orders in sample option classes before and after they migrate from the MT model to the PFOF model. Take fees on the MT exchanges are the fees encountered by the Investment Technologies Group (ITG) when routing marketable customer orders trading in the penny pilot program as of Jan. 2012. Take fees on the PFOF exchanges are derived from exchange filings and from Rule 606 filings made by retail brokers in 2012:Q4.

Relative Costs When PHLX Uses the MT Model			Relative Costs When PHLX Uses the PFOF Model	
Venue	Access Fee (Per Contract)		Venue	Access Fee (Per Contract)
AMEX: PFOF	$0 ≥ Fee ≥ −$0.40		AMEX: PFOF	$0 ≥ Fee ≥ −$0.40
CBOE: PFOF	$0 ≥ Fee ≥ −$0.40		CBOE: PFOF	$0 ≥ Fee ≥ −$0.40
			PHLX: PFOF	**$0 ≥ Fee ≥ −$0.40**
ISE: MT	Fee = +$0.15		ISE: MT	Fee = +$0.15
PHLX: MT	**Fee = +$0.31**			
BATS: MT	Fee = +$0.44		BATS: MT	Fee = +$0.44
ARCA: MT	Fee = +$0.45	HIGHEST LIQUIDITY COST	ARCA: MT	Fee = +$0.45
NOM: MT	Fee = +$0.45		NOM: MT	Fee = +$0.45

on the PHLX attracts additional marketable order flow, the move from the MT model to the PFOF model may affect both the speed and likelihood of limit order execution (Battalio et al. (2016)).

To show that cash incentive programs affect order routing behavior, we first document heterogeneity in order routing strategies across several large U.S. retail options brokers during our sample period. In the fourth quarter of 2012 (2012:Q4), 3 retail options brokers appear to route all of their market and limit orders to exchanges that purchase retail order flow. These brokers seem to be leaving rebate revenue on the table by not routing their nonmarketable orders to exchanges offering to pay high maker rebates. Five of the eight retail brokers we examine route orders to venues using 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 2012:Q4 are 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 ranges from 20.9% to 75.2%.[3] These results seem to suggest that some options brokers bifurcate their order flow to fully monetize cash incentives, while others do not.

We next examine whether execution quality can be enhanced by routing limit orders to exchanges that pay for marketable customer order flow rather than to exchanges offering high maker rebates. We begin by using order data to study how the PHLX's migration of select option classes from the MT model to the PFOF model impacts the arrival rate of marketable and nonmarketable customer orders. Relative to option classes trading on PHLX that continuously trade under the PFOF model, the median number of marketable (nonmarketable) customer

[3] 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.

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orders routed to the PHLX increases (decreases) after sample option classes migrate from the MT model to the PFOF model. Given these results, it is not surprising that relative to option classes that continuously trade under the PFOF model on the PHLX, 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 alter their order routing strategies in response to the change in fee structure on the PHLX. However, these results do not inform limit order routing decisions since they do not indicate how the migration to the PFOF model impacts limit order execution on the PHLX relative to limit order execution quality available on the MT exchanges.

As the take fee assessed by the Nasdaq Option Market (NOM) is the highest take fee across all options exchanges throughout our sample period for all market participants, 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.[4] For this reason, we conduct "horse races" 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 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 are lower on the PHLX than they are on the NOM before and after the migration. However, we find that the percentage of all horse races won by the PHLX increases from 84.57% to 86.95% after options migrate to the PFOF model on the PHLX. For more actively traded options, the percentage of horse races 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 market that purchases marketable order flow rather than to an exchange 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 International Securities Exchange (ISE) has a take fee that is lower than that charged by the PHLX before the migration and a take fee that is higher than the PHLX after migration. This means that the PHLX becomes a lower cost alternative to the ISE for customer marketable orders after the migration, which might explain why more marketable orders are routed to the PHLX after the move from the MT model to the PFOF model. To explore this possibility, we examine how the PHLX migration impacts each exchange's market share of trades when all venues are offering to provide liquidity at the National Best Bid or Offer (NBBO). We find that when option classes migrate from the MT model to the PFOF model, the PHLX gains market share at the expense of exchanges that use the PFOF model to arrange trades and not the ISE. This suggests that the improvements in relative limit order

[4] Conveniently, the NOM and PHLX are also both run by Nasdaq. As a result, the option exchanges share Nasdaq's INET technological architecture, have the same Financial Information Exchange interface, and share customer and trade support services. See https://www.nasdaqtrader.com/content/ProductsServices/Trading/OptionsMarket/options_market_faqs.pdf.

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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 execute on exchanges, our results suggest that retail brokers that do not pass fees and rebates directly through to their customers can improve limit order execution quality by routing limit orders to venues that purchase order flow. We find that in actively traded options for which the minimum tick size is binding, routing customer orders to exchanges that purchase order flow can increase the frequency with which standing limit orders execute. Since the SEC (2000) notes, "a broker-dealer must consider several factors affecting the quality of execution, including, for example, the opportunity for price improvement, the likelihood of execution (which is particularly important for customer limit orders), the speed of execution, and the trading characteristics of the security, together with other non-price factors such as reliability and service," our study may have important policy implications.

II. PHLX Trading Protocols

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 generally have priority over limit orders placed by other market participants at a price.[5] Limit orders placed by market makers, broker-dealers, 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 of limit order volume at a given price.

In an attempt to increase liquidity and attract order flow, the PHLX migrated select option classes from trading in the PFOF model to the MT model at the beginning of 2010.[6] Over the next several years, the exchange gradually removed these select option classes from trading in the MT model and placed them back into the PFOF model. 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.

III. Hypothesis Development

As there is a close association between an exchange's take fee and its make rebate, it is generally the case that the venue offering the most lucrative liquidity

[5]Orders seeking to trade 5 contracts or fewer that are eligible for automatic execution are first allocated to the specialist provided that these orders account for no more than 25% of automatically executed trades in the prior quarter. See www.nasdaqphlx.cchwallstreet.com.

[6]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.

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rebates also charges the largest take fee. Angel et al. (2011) suggest that for actively traded options, an exchange's relative fee structure can have an impact on limit order execution quality. When multiple markets are offering to buy (sell) at the National Best Bid (NBB) (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 for option series with thick order books, 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 venues. Battalio et al. (2016) present empirical evidence suggesting that for at-the-quote limit orders placed in U.S. equity markets, limit order execution quality decreases in an exchange's relative take fee.

Battalio et al. (2016) also present evidence from Rule 606 filings that suggests 4 retail brokers sold their marketable orders to market makers and routed their standing limit orders to the venue(s) offering the highest liquidity rebates in 2012:Q4. Each of these brokers charged a fixed commission and did not pass the fees and rebates generated by their orders directly through to their customers. 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. All else equal, one would expect fee-sensitive liquidity demanders to route their orders to the venue with the lowest take fee. Battalio et al. (2016), Sofianos and Yousefi (2010), and Pragma Trading (2013) present empirical results suggesting that in equity markets, 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.

How might a Smart Order Router route at-the-quote limit orders if its goal is to maximize execution quality? Assume, for the sake of illustration, that the current 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 she would like to maximize the probability that the order executes? Given that the order will establish a new NBB, the routing decision does not impact the probability of execution. In this instance, Broker A can route the order to a venue that charges the maximum 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 the 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 20 option contracts 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 that is lower than the venue on which Broker A's order rests. Although placing the

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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 Better Alternative Trading System (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 the NOM, an investor seeking immediacy would route her marketable sell order to BATS rather than the 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 take fees will execute before similarly priced limit orders displayed on venues with high take fees. This leads to our first hypothesis:

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

Prior to order flow migration, the PHLX had the second lowest take fee across exchanges using the MT model. Because options exchanges cannot refuse to accept customer orders, brokers can avoid paying a positive take fee by routing their marketable customer orders to one of the exchanges using the PFOF model. If the broker has (does not have) an arrangement with the exchange, the broker will receive a rebate (will pay nothing) for accessing liquidity on that exchange. This suggests that if an options exchange using the PFOF model is at the best bid or offer, that exchange is the preferred destination for marketable customer orders.

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

We expect brokers and self-directed customers to route their marketable orders to the market maker that is willing to pay the most for the order.[7] Indeed, the primary purpose of moving option classes from the MT model to the PFOF model is to attract marketable order flow to the PHLX exchange.[8] For some market participants, 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 MT 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 MT model incentivizes market participants to place passive orders through a subsidy provided by the takers of liquidity

[7] See the SEC's Mar. 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.

[8] See the purpose sections in SEC release No.'s 34-66252, 34-66488, 34-66756, and 34-67439.

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(Colliard and Foucault (2012), O'Donoghue (2015)).[9] Therefore, we might expect the MT model to be associated with an increase in nonmarketable limit order flow. Alternatively, depending upon the conditions in 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 retail order flow and execute more frequently in favorable market conditions. Whether 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 market conditions in which limit orders are placed.

Hypothesis 4. Customer nonmarketable limit order volume remains the same when the PHLX moves option classes from the MT 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 market makers to selectively pay market rates for options order flow. This suggests an increase in market share in migrated option classes realized by the PHLX will come primarily at the expense of the 2 other options exchanges using 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 MT model to the PFOF model will come primarily at the expense of the CBOE and/or the AMEX.

IV. Data Description and Sample Selection

A. Data Description

To test our hypotheses, we gather data from several sources. First, we obtain information regarding exchange fees and rebates as of the first of each month in 2012 and for Jan. 1, 2017 from the Investment Technologies Group (ITG). ITG is an independent broker that among other things, offers clients a smart router that allows them to access a variety of options exchanges. ITG also provides data as to when the fees and rebates in place as of Dec. 2012 were subsequently changed. From ITG's perspective, there were no substantive changes in relative fees across venues during our sample period. Furthermore, the more recent 2017 fee

[9]The retail broker Lightspeed, one of the few retail brokers that passes fees and rebates directly through to customers, 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/.

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environment in equity options is similar to the one under examination in this study (see Supplementary Material Table A).

Second, we obtain statistics characterizing the routing of nondirected options order flow by 8 national brokers during 2012:Q4. 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 use several of the routing reports used by Battalio et al. (2016) and a few that we obtain via web searches to evaluate broker routing in equity options markets during 2012:Q4.

Third, we obtain order-level data from the Nasdaq OMX PHLX Order data feed, which provides a real-time 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 canceled), limit price, and a market participant indicator (e.g., broker-dealer, customer, firm, market maker, or professional). 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.[10] We identify customer limit orders as marketable if the order executes within 500 milliseconds (or 0.5 seconds) of submission.[11] We eliminate orders received before 9:45 AM and after 3:50 PM 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 the underlying stock's closing prices and shares outstanding obtained from the Center for Research in Security Prices (CRSP).

Fourth, as some 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 the NOM, the venue charging the highest take fees (and offering aggressive liquidity rebates), we obtain order-level data on the NOM. The Nasdaq ITCH to Trade Options files 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 canceled. "Order delete" messages report when an order is deleted from the Nasdaq order book.

[10]The term "customer" applies to any transaction that is identified by a member or member organization in the Customer range at the Options Clearing Corporation, which is not for the account of a broker or dealer or for the account of a professional.

[11]The results are robust to various millisecond cutoff levels.

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 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 NBB 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 or auto ex and we restrict the sample to trades executed between 9:45 AM and 3:50 PM. We restrict our analysis to trades executed on the two exchanges that only use the PFOF model, the PHLX, the ISE, and the three MT venues with the largest market share of trading volume during our sample period.

B. Sample Selection

Panel A of Table 2 contains the filters used to arrive at our final sample of migrating option classes. Since the PHLX began offering order-level data on Sept. 1, 2010, our analysis is restricted to the migration of option classes from the MT model back to the PFOF model. We were able to identify, from SEC and PHLX rule filings, 100 option classes that were added to the MT program. The Standard & Poor's 500 exchange traded fund (SPY) was never removed from the MT program, so we exclude it from the sample. There were 4 other option classes that were removed from the program due to delisting or corporate action.[12] As the removals of these option classes were due to events that might bias the analysis, we exclude them from the final sample. We also exclude 4 additional option classes for which we were unable to verify migration dates. We remove 3 option classes that migrated before Sept. 1, 2010, which is the first day for which we have PHLX order data. Of the remaining 88 option classes that survive these first few screens, 40 symbols do not have CRSP common stock share codes of 10 or 11 and 11 symbols have fewer than one order fill per day during the sample period.[13] Excluding option classes on noncommon stocks, and infrequently traded option classes, gives us a final sample of 37 option classes that migrate from the MT model back to the PFOF model during our sample period.

Panel B of Table 2 contains the list of the 37 sample option classes that are analyzed in this study. We also report the migration dates and the respective SEC rule filings. For the event study analysis, we use a 4-month event window centered on each migration date. Since the first migration date in our sample is Feb. 1, 2012, our sample period ranges from Dec. 2011 to Sept. 2013. As only the most liquid

[12] The 3 option classes that were removed from the MT program due to delisting from the exchange were ABK (Nov. 9, 2010), AMR (Nov. 30, 2011), and EK (Jan. 19, 2012). The option class MOT was removed due to corporate action on Jan. 4, 2011.

[13] It is important to note that the results are robust to the sample of option classes on ETFs.

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TABLE 2
Sample Selection and Matching Results

Table 2 describes how the sample is selected and provides characteristics of the underlying stocks for sample and control option classes.

Panel A. Sample Filters

Initial sample of option classes included in the MT program	100
Exclude SPY as it was not removed from the MT program	1
Exclude option classes that were removed from the MT program due to delisting or corporate action	4
Exclude option classes with unverifiable migration dates from MT to PFOF	4
Exclude option classes that migrate from MT to PFOF before the sample period	3
Exclude option classes that are not CRSP common stocks	40
Exclude option classes with fewer than one order fill per day	11
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
Feb. 1, 2012	34-66252	AIG
Mar. 1, 2012	34-66488	GS, LVS, MGM, MU, NVDA, QCOM, V, WYNN, and X
Apr. 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
Jan. 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

options were transitioned to the MT model, our treatment sample consists only of option classes trading in the penny pilot program.

Part of our analysis uses 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 sample is selected by matching each migrating option class with a nonmigrating 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.[14] We report the distribution of the price and capitalization for both sample firms and their controls in Panel C of Table 2. 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 differences 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 stocks 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.

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

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V. Empirical Results

A. Cost of Executing Customer Orders

Table 1 contains details on the access fees encountered by ITG when routing customer orders in option classes trading in the penny pilot program as of Jan. 1, 2012.[15] Six exchanges use the MT model to arrange trades in some of their option classes and 5 use the PFOF model. The 4 exchanges using the MT model to arrange all trades account for 22% of trading volume in equity options in the first 8 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 2 exchanges that use both models to arrange trades, the ISE and the PHLX, respectively, account for 18% and 16% of trading volume.[16] The Boston Options Exchange (BOX), which uses a hybrid model to arrange trades, executes 5% of the trading volume in equity options through Aug. 2012.

Exchanges using the PFOF model charge nothing to arrange customer trades and they offer payment to retail brokers for their marketable orders. Payments made for orders seeking to buy or sell options that were (were not) trading in decimals are as high as \$0.10 (\$0.55) per contract during our sample period.[17] 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 the ARCA options exchange. 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.

Liquidity demanding (supplying) customer orders receive a rebate (pay a fee) when they trade in the BOX limit order book. Marketable customer orders are frequently internalized by broker-dealers in the BOX's price improvement auctions. The fee structure of these auctions combined with the high cost of posting liquidity on the BOX order book often make it possible for broker-dealers to internalize customer marketable orders at the NBBO. From the perspective of a market maker seeking to trade with customer order flow, the primary difference between the BOX and the venues using the PFOF model is that nonmarketable customer limit orders are not assessed a fee on the PFOF venues while they must pay \$0.29 per contract when they trade on the BOX.

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 Supplementary Material Table A 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 the ARCA, BATS, and NOM during 2012 reveals that the liquidity rebates listed in Supplementary Material Table A are the rebates associated with the lowest volume tier of liquidity providing orders. Liquidity providing customer orders that execute on BATS generate a rebate of at least \$0.30 per contract, while those executing on the NOM generate

[15] Supplementary Material Table A contains access fees and rebates for all market participants as of Jan. 1, 2012, July 1, 2012, Dec. 1, 2012, and Jan. 2017.

[16] See http://ir.cboe.com/~/media/Files/C/CBOE-IR-V2/presentations/barclays-slides-final.pdf.

[17] See Tradestation's 2012:Q4 Rule 606 filing.

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a rebate of at least $0.26 per contract. However, brokers that displayed sufficient liquidity in the NOM and ARCA order books (BATS order book) received a liquidity rebate of $0.43 ($0.47) per contract.[18] The C2 Options Exchange (C2OX) had no volume tiers; thus, the rebate paid to liquidity providing orders was independent of trading volume.[19] 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 options exchange offered the highest unconditional liquidity rebates for all types of market participants.

The evidence presented in this section suggests that retail brokers seeking to maximize the rebate revenue generated by executed customer orders in 2012 would have routed their nonmarketable limit orders to MT exchanges and sold their marketable orders to exchanges using the PFOF model to arrange trades. Assuming they were offering to provide liquidity at the national best price, the venues using the PFOF model were also the cost minimizing destinations for brokers possessing marketable customer orders that market makers would not purchase. If there were no PFOF venues offering to provide liquidity at the best quote, brokers in the lowest volume tiers seeking to minimize the cost of executing marketable customer orders would check the venues using the MT model in the following order: ISE, PHLX, C2OX or BATS, and then ARCA or NOM.

B. Broker Routing in 2012:Q4

Rule 606 requires brokers to report the percentage of nondirected market orders, limit orders, and other orders routed to different trading venues on a quarterly basis. Brokers are responsible for deciding where nondirected orders are routed and they do not have to disclose destination venues that receive less than 5% of their orders. As a result, percentages may not sum to 100%. Brokers are also required to provide details as to the nature of their relationships with each executing venue, including any PFOF or internalization arrangement that could represent a conflict of interest between brokers and their customers.[20] Only one of our sample brokers, Interactive Brokers (IB), passes on at least a portion of the fees and/or rebates generated by customer orders directly onto its customers.

Panel A of Table 3 contains the percentage of nondirected orders routed to three sets of trading venues: those using the PFOF model, those using the MT model, and those using multiple models to arrange trades. We refer to the last set of venues as "Hybrid." Examining the first row of Panel A, the first column reveals that MB Trading was responsible for routing 79% of its customer orders in a manner consistent with the pursuit of best execution (e.g., 79% of MB Trading's retail

[18] See SR-NASDAQ-2012-006 (https://www.sec.gov/rules/sro/nasdaq/2012/34-66158-ex5.pdf), NYSE Arca Options Fee Schedule, Effective Feb. 1, 2012 (https://www.sec.gov/rules/sro/nysearca/2012/34-66377-ex5.pdf), and BATS BZX Exchange Fee Schedule, Effective Nov. 1, 2012 (https://www.sec.gov/rules/sro/bats/2012/34-68204-ex5.pdf).

[19] On Jan. 24, 2014, the 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.

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

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TABLE 3
Order Routing Decisions of 8 Retail Brokers in 2012:Q4

Table 3 describes nondirected equity option order routing outcomes for 8 retail brokers. Panel A contains the percentage of nondirected orders routed to different executing venues. PFOF includes exchanges that use the PFOF model to arrange trades (AMEX and CBOE) and market makers (Citadel, Citigroup, Knight, Susquehanna, UBS, and Wolverine). MT includes exchanges that use the MT model to arrange trades (BATS, NOM, and ARCA). Hybrid includes exchanges that do not solely use the PFOF model or the MT model to arrange trades. Data are obtained from Rule 606 reports for 2012:Q4. 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. % Market is computed by dividing the number of market orders routed to a set of venues by the number of market and limit orders routed to those venues. The difference between the average HHI for the first 3 brokers and the average HHI for the last 5 brokers in Panel A is statistically significant at the 0.01 level. To evaluate whether routing outcomes are different across brokers, we assume the number of nondirected market and limit orders routed during the quarter is 1000. In Panel B, * and *** indicate that % of market orders routed to the PFOF (MT) venues is significantly higher (lower) than the overall percentage of market orders in the broker's order flow at the 0.10 and 0.01 levels, respectively. NA means not applicable.

Panel A. Across-Venue Market Share

Broker	% of Nondirected Orders	Market Share of Broker's Order Flow			HHI
		PFOF	Hybrid	MT	
MB Trading	79.0	103%	0%	0%	10,000
Trade King	100.0	98%	0%	0%	10,000
Scottrade	100.0	93%	0%	0%	10,000
Ameritrade	99.0	31%	40%	23%	3,090
Schwab	100.0	46%	14%	40%	3,912
Fidelity	98.6	21%	33%	45%	3,555
IB	99.1	32%	14%	47%	3,429
E*Trade	99.1	14%	21%	55%	3,662

Panel B. % of Market Orders Routed to Different Venues

Broker	Overall % Market	% Market Routed to PFOF	% Market Routed to Hybrid	% Market Routed to MT
MB Trading	7.14	7.14	NA	NA
Trade King	48.98	48.98	NA	NA
Scottrade	16.33	16.33	NA	NA
Ameritrade	3.06	5.19***	2.46	0.75***
Schwab	5.54	5.36	4.85	5.94
Fidelity	25.77	28.80*	53.34	3.55***
IB	3.70	3.41	8.05	0.91***
E*Trade	13.91	37.92***	18.96	3.23***

orders were nondirected).[21] Together, the second, third, and fourth columns reveal that MB Trading routes all of its nondirected orders to exchanges that purchase order flow.[22] In the fifth column, we compute the Herfindahl–Hirschman Index (HHI) to assess the concentration of each broker's order flow on each type of venue. As MB Trading routes all of its market and limit orders to PFOF venues, the HHI is equal to the maximum possible value of 10,000. Two other brokers, Trade King and Scottrade, also send all of their market and limit orders to exchanges that purchase order flow and have the maximum possible HHI of 10,000.

The data presented in Panel A suggest that brokers have different order routing strategies. Three brokers route all of their orders to venues that purchase order flow. While this type of order routing likely results in lower per contract payments for customer order flow, it may enhance relative limit order execution quality. The remaining 5 brokers that we examine route nondirected orders to each of the three

[21] A directed order is an order for which the customer has provided the broker with specific routing instructions.

[22] MB Trading's 2012:Q4 Rule 606 filing apparently has a typo as it states that the broker routes 97% of its non-directed order flow to Susquehanna and 6% of its non-directed order flow to Citigroup. Both firms are market makers that purchase options orders and execute them on an options exchange in 2012:Q4.

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types of venues and have HHI values ranging from 3,090 to 3,912. The difference between the average HHI for the 3 brokers that only route to PFOF venues and the average HHI for the 5 brokers that route to each type of venue is statistically significant at the 0.01 level, suggesting the 2 groups of brokers use different routing strategies.

Panel B of Table 3 describes the percentage of market orders in the order flow routed by each broker to the three types of options exchanges as well as the broker's overall average. The percentage of market orders is computed by taking the ratio of market orders to both market and limit orders for a given collection of orders. We expect that brokers seeking to maximize rebate revenue will route market orders to the PFOF venues and limit orders to the MT venues offering large liquidity rebates. This suggests the percentage of market orders in the order flow routed by a rebate maximizing broker to the PFOF (MT) venues will be higher (lower) than the average percentage of market orders in the broker's order flow.

To assess whether the percentage of market orders in the order flow routed by a broker to the three different sets of venues is statistically different from the broker's overall percentage, we must make an assumption regarding the number of nondirected orders routed by each broker in 2012:Q4. In Panel B, we make the conservative assumption that each broker routes a total of 1,000 nondirected market and limit orders in 2012:Q4 to statistically evaluate whether brokers increase (decrease) the percentage of market orders in the order flow they route to the PFOF (MT) venues.[23] Of the 5 brokers in our sample that route customer orders to both the PFOF and MT venues, 3 route a higher (lower) percentage of market orders to the PFOF (MT) venues: Ameritrade, Fidelity, and E*Trade. Of the sample brokers, E*Trade has the largest difference in the mix of market and limit orders sent to the PFOF and MT venues. While 13.91% of the retail orders E*Trade routes in 2012:Q4 are market orders, 37.92% (3.23%) of the orders sent to the PFOF (MT) venues are market orders. When we use 1,000 orders to evaluate whether brokers route a different mix of orders to the PFOF and MT venues, we find there is no difference in the percentage of market orders sent by Schwab to the three groups of options exchanges.[24]

Overall, the results presented in Panel B suggest MB Trading, Trade King, Scottrade, and Schwab do not route their customers' options orders in a manner consistent with maximizing liquidity rebates, as they appear to give their limit orders the possibility of trading with their market orders. The remaining 4 brokers, however, appear to route orders in a manner that increases the opportunity to earn liquidity rebates. The order flow routed by each of these brokers to the MT venues contains a higher percentage of limit orders than the brokers' overall average in 2012:Q4. We next examine how the PHLX migration of option classes from the MT model to the PFOF model impacts the level and composition of customer order flow routed to the PHLX. Later, we examine whether brokers that route both

[23] Interactive Brokers' 10K states that the total daily average revenue of trades was 413,000 in 2012. See https://www.sec.gov/Archives/edgar/data/1381197/000104746913002439/a2213156z10-k.htm.

[24] If we assume that Schwab routes 18,500 orders (87,000 orders) in 2012:Q4, the percentage of market orders routed to the MT venues (PFOF venues) is different from Schwab's overall percentage at the 0.10 level.

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marketable and nonmarketable options orders to venues that purchase order flow, presumably at the cost of receiving lower order flow payments, receive enhanced limit order execution quality relative to brokers that bifurcate their order flow.

C. Customer Order Arrival Rates

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 5 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 33% when option classes migrate to the MT model. Due to data limitations, the authors are unable to determine whether this decline is primarily attributable to a reduction in marketable or nonmarketable customer orders. We use 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.

Table 4 presents univariate statistics that describe how the flow and composition of customer orders routed to the PHLX changes in the sample (control) option classes after migration (pseudo-migration). We also present order fill rates and average time to execution for nonmarketable customer limit orders before and after the (pseudo) event date. Order fill rates are estimated as the number of complete fills to total orders submitted. The PHLX historical feed does not report individual execution messages, so we cannot estimate partial fill rates. The unit of observation is an option class-day.

The average (median) number of contracts demanded by customer marketable orders routed to the PHLX in migrating option classes increases by 26 contracts (49.2 contracts) per day after migration, while the average (median)

TABLE 4

Descriptive Statistics for Customer Orders Routed to the PHLX around the Migration

Table 4 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. *, **, and *** indicate significant changes from the pre-migration period to the post-migration period at the 0.10, 0.05, and, 0.01 levels, respectively.

		2 Months Before		2 Months After		Difference (Post – Pre)		Difference-in-Differences
		Migrate	Control	Migrate	Control	Migrate	Control	(Migrate – Control)
Average order fill rate (%)		35.5	41.0	38.2	40.1	2.6***	−0.9	3.4***
% of marketable orders		12.5	17.6	20.0	21.0	7.5***	3.4***	4.1***
Median fill speed (seconds)		648.6	829.3	596.4	779.6	−52.2*	−49.6	−2.6
Median no. of orders	Marketable	2.0	1.0	3.0	1.0	1.0***	0.0	1.0***
	Nonmarketable	18.0	7.0	16.0	8.0	−2.0***	1.0***	−3.0***
Average no. of orders	Marketable	10.4	3.8	10.1	5.1	−0.3	1.3***	−1.6
	Nonmarketable	79.8	25.8	47.2	25.6	−32.6***	−0.2	−32.4***
Median order volume (no. of contracts)	Marketable	24.0	8.0	50.0	14.0	26.0***	6.0***	20.0***
	Nonmarketable	353.0	129.0	374.0	163.0	21.0	34.0***	−13.0
Average order volume (no. of contracts)	Marketable	156.6	57.1	205.8	89.7	49.2***	32.6***	16.6
	Nonmarketable	2636.7	473.1	2560.8	571.1	−75.9**	98.0**	−173.9

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volume of marketable customer orders in control option classes increases by 6 contracts (32.6 contracts) across their pseudo-migration. The median number of marketable orders routed by customers to the PHLX in migrating options 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 median volume of nonmarketable customer limit orders routed to the PHLX in migrating (control) option classes decreases by 75.9 contracts (increases by 98 contracts) per class-day. The unconditional fill rate for customer limit orders placed in sample option classes increases by 2.6 percentage points after migration, while the fill rate for similar orders placed in control options is statistically unaffected by the pseudo-migration. The % of marketable orders routed by customers to the PHLX in the sample (control) option classes increases by 7.5 (3.4) 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 migrated from the MT model to the PFOF model. While our findings provide support for Hypothesis 3, we reject Hypothesis 4.

As many factors can influence order arrival rates, we next examine the impact of migrating sample option classes from the MT model to the PFOF model on order flow in a multivariate setting. More specifically, we estimate the following regression using our sample of migrating option classes and the matched, control option classes. The unit of measurement in the following regression equation is option class/option type (put or call)/day. We aggregate each order flow variable on a daily basis by option type and option class using simple averages across the option series.

$$
\begin{aligned}
(1)\quad \text{ORDER_FLOW_VARIABLE}_{i,j,t} \;=\; & \alpha + \beta_1 \text{POST}_t + \beta_2 \text{MIGRATE}_{i,j} \\
& + \beta_3 \text{POST}_t \times \text{MIGRATE}_{i,j} + \beta_4 \text{Log}\left(\text{UNDERLYING_TVOL}\right)_{i,t} \\
& + \beta_5 \text{UNDER_PVOLT}_{i,t} + \beta_6 \text{UNDER_MARKET_CAP}_{i,t} + \beta_7 \frac{S}{X}_{i,j,t} \\
& + \beta_8 \left(\frac{S}{X}\right)^2_{i,j,t} + \beta_9 \text{DAYS_TO_EXPIRATION}_{i,j,t} + \beta_{10} \text{CALL}_j + \varepsilon_{i,j,t}.
\end{aligned}
$$

One of the option classes in the migrating sample, Apple, has over 13 times the average daily trading volume of the next most actively traded migrating option class, Amazon. For this reason, we use quantile median regressions to estimate equation (1) when the order flow variable is the number of marketable orders, the number of nonmarketable orders, the marketable order volume, the nonmarketable order volume, or the time to complete execution.[25] We use ordinary least squares (OLS) to estimate equation (1) when the order flow variable is the % of marketable orders or the order fill rate. We include the following as independent variables: POST is an indicator measure set equal to 1 if the observation occurs after the sample option class (or its matched control option class) has migrated to the PFOF model on the PHLX, and 0 otherwise. MIGRATE is an indicator variable equal to 1 for sample option classes that migrate on the

[25] We obtain qualitatively similar results when estimating equation (1) using OLS.

PHLX from the MT to PFOF, and 0 for control option classes that remain in the PFOF. Log(UNDERLYING_TVOL) is the log of the CRSP daily share volume in the underlying stock. UNDER_PVOLT is the underlying stock's daily price volatility measured as the difference between the CRSP daily high and daily low prices, scaled by the daily high price (see Diether, Lee, and Werner (2009)). UNDER_MARKET_CAP is the market capitalization of the underlying stock measured daily as the share price times the number of shares outstanding. *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 nonlinear relation between the moneyness of an option series and execution quality (see Battalio and Schultz (2011)). The *S/X* ratio is measured at the option series level and then averaged to the daily level by option type and class. We also include the average number of days until option expiration and an indicator variable that equals 1 if the option is a call, and 0 for a put.[26]

Columns 1 and 2 of Table 5 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 that 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 that in control option classes. The results in columns 3 and 4 of Table 5 show that the median marketable (nonmarketable) customer order volume in sample option classes increases (decreases) by 16.035 (42.355) 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 the 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 potentially improved following migration to the PFOF model.

The results in column 5 of Table 5 show that 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. The results in column 6 of Table 5 indicate that after migration, the percentage of marketable orders in the order flow seeking to trade sample option classes on the PHLX increases significantly by 4 percentage points relative to the control options. Finally, column 7 presents the results that suggest that the increase in

[26] We estimate equation (1) with day fixed effects and the results are qualitatively the same.

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TABLE 5

Marginal Impact of PHLX Migration on Customer Order Flow

In Table 5, we use quantile median regressions to estimate the following equation when the order flow variable is the number of marketable orders (volume), the number of nonmarketable orders (volume), or the time execution speed, and we use OLS when the order flow variable is % of marketable orders or limit order fill rate.

$$\begin{aligned}\text{ORDER_FLOW_VARIABLE}_{i,j,t} &= \alpha + \beta_1 \text{POST}_t + \beta_2 \text{MIGRATE}_{i,j} + \beta_3 \text{POST}_t \times \text{MIGRATE}_{i,j} \\ &+ \beta_4 \text{Log}(\text{UNDERLYING_TVOL})_{i,t} + \beta_5 \text{UNDER_PVOLT}_{i,t} + \beta_6 \text{UNDER_MARKET_CAP}_{i,t} \\ &+ \beta_7 S/X_{i,j,t} + \beta_8 (S/X)^2_{i,j,t} + \beta_9 \text{DAYS_TO_EXPIRATION}_{i,j,t} + \beta_{10} \text{CALL}_j + \varepsilon_{i,j,t}.\end{aligned}$$

We take a simple average of each order flow variable across option series on a daily basis by option type (put or call) and option class. POST is an indicator measure equal to 1 if the observation occurs after the sample option class (or its matched control option class) migrates from MT to PFOF on the PHLX, and 0 otherwise. MIGRATE is an indicator variable equal to 1 for sample option classes that migrate from MT to PFOF on the PHLX, and 0 for control option classes that remain in PFOF. Log(UNDERLYING_TVOL) is the log of the CRSP daily share volume in the underlying stock. UNDER_PVOLT is the underlying stock's daily price volatility measured as the difference between the CRSP daily high and daily low prices, scaled by the daily high price. UNDER_MARKET_CAP is the market capitalization of the underlying stock, or price times shares outstanding. *S/X* is the ratio of the underlying stock price to the strike price. DAYS_TO_EXPIRATION is the average number of days until expiration for each option. CALL is an indicator variable that equals 1 if the option is a call, and 0 for a put. To calculate standard errors, we cluster on the underlying stock. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	Median No. of Orders		Median Order Volume		Median Fill Speed (Seconds)	% of Marketable Orders	Limit Order Fill Rate
	Marketable	Nonmarketable	Marketable	Nonmarketable			
POST	0.416***	1.348***	5.797***	48.604***	−41.3	0.021**	−0.007
MIGRATE	0.435***	6.288***	5.576***	78.223***	−267.3***	−0.007	−0.023***
POST × MIGRATE	0.730***	−2.934***	16.035***	−42.355**	−17.1	0.040***	0.034***
log(UNDER_TVOL)	−0.106***	3.164***	2.912***	152.344***	128.4***	−0.056***	−0.048***
UNDER_PVOLT	51.246***	280.503***	841.118***	6,203.315***	−1,621.2*	0.606***	0.594***
UNDER_MARKET_CAP	0.011***	0.040***	0.210***	0.839***	−0.6***	0.000***	0.000***
S/X	0.576	8.338***	7.153	266.751***	766.1	−0.064	−0.139***
S/X^2	−0.105*	−1.804***	−0.370	−48.001***	−438.0	0.034***	0.043***
DAYS_TO_EXPIRATION	−0.002***	−0.012***	−0.048***	−0.568***	0.9**	0.000	−0.000***
CALL	0.805***	6.918***	10.695***	189.596***	116.9***	−0.022***	−0.048***
Constant	0.289	−59.013***	−71.524***	−2,659.760***	−1,544.1*	0.984***	1.273***
R^2	0.205	0.125	0.204	0.123	0.015	0.143	0.065
N	9,827	9,827	9,827	9,827	8,360	9,827	9,827

customer market orders as a percentage of all customer orders in sample options after their migration leads to a 3.4% increase in the fill rate of customer limit orders on the PHLX.

Overall, the results presented in Table 5 suggest that the migration of sample option classes alters 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 changed their routing strategies in response to the PHLX migration. Furthermore, both the number and the percentage of marketable customer orders in sample option classes increases, while the number of nonmarketable customer orders falls after the 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.

Perhaps more importantly, even if the absolute fill rate for customer orders on the PHLX would have fallen following migration, limit order execution quality on the PHLX relative to that available on the MT exchanges could have improved. For example, in option series where the limit order routing decision is relevant (e.g., all displayed liquidity at a price is not exhausted), the movement of standing

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limit orders from an exchange with a high take fee (and rebate) to the PHLX could reduce the fill rate on the PHLX and reduce the volume of marketable orders that ultimately reach the high fee exchange. In the next section, we empirically examine how the migration of options from the MT model to the PFOF model impacts limit order execution quality on the PHLX relative to limit order execution quality on the NOM, an exchange charging the maximum take fee throughout our sample period.

D. Horse races

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 the destination of last resort for marketable orders. In other words, it is likely that the only instances in which the NOM receives marketable orders are when it is 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.[27]

Following Sofianos and Yousefi (2010) and Battalio et al. (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 the NOM limit orders. For each order pair, we begin a horse race when the orders are first concurrently displayed on both venues. We identify orders with the same order date, option 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 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 horse races.

To crown a winner of a horse race, we require that at least one of the two orders fills. In the case where both orders fill, the venue wins if it fills the order at least 500,000 nanoseconds (500 microseconds) before the paired counterparty order fills on the competing venue. If both orders in a pair fill within 500,000 nanoseconds of each other, then we classify the horse race 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 21-day window centered on the migration (pseudo-migration) date that are routed to the PHLX and NOM to construct horse races. Horse races

[27]The NOM matches limit orders based on price-time priority, meaning it will execute all trading interest at the best price level within the System before executing trading interest at the next best price. Within each price level, if there are 2 or more quotes or orders at the best price, trading interest will be executed in time priority. Customer orders do not receive priority on the NOM. In fact, the NOM provides equal access to all participants (i.e., customers, market makers, firms, and broker-dealers), regardless of whether the quotes are the result of orders or market maker quotations. See http://nasdaq.cchwallstreet.com/NASDAQTools/TOCChapter.asp?manual=/nasdaq/main/nasdaq-optionsrules/chp_1_1/default.asp&selectedNode=chp_1_1.

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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. Horse races 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 NOM before and after option classes migrated to the PFOF model provide an estimate as to the value of having limit orders displayed on an exchange that pays for order flow rather than on an exchange that charges liquidity demanders the second lowest take fee in the market.

The first row of Panel A in Table 6 presents results for the 6,773 horse races conducted using "identical" nonmarketable limit orders in sample option classes trading under the MT model on both the PHLX and NOM. The unconditional fill rates for orders involved in these horse races are 93.61% on the PHLX and 36.42% on the NOM. In 30% of the horse races, 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 horse races, the limit order that is routed to the PHLX executes while the limit order routed to the NOM does not. Consistent with Hypothesis 1, the median time to execution on the PHLX is 182.5 seconds versus a median time to execution of 251 seconds on the NOM. Overall, the limit order resting on the PHLX (NOM) order book executes first in 84.57% (11.03%) of the horse races, while 4.40% of the horse races result in ties.

The second row of Panel A presents results for the 2,218 horse races conducted using nonmarketable limit orders seeking to trade sample option classes trading under the PFOF model on the PHLX and the MT model on the NOM. The unconditional fill rates on the PHLX and NOM are 93.66% and 35.28%, respectively, and both orders in a horse race fill 28.94% of the time. These statistics are similar to those obtained for horse races conducted when the PHLX used the MT model to trade sample option classes. The fill rates for orders participating in horse races are much higher than the unconditional fill rates, suggesting these horse races occur in more actively traded option series. The median time to execution on the PHLX falls from 182.5 seconds to 142.7 seconds after migration, while the median time to execution on the NOM increases from 251 seconds to 421 seconds. The percentage of horse races won by the NOM falls from 11.03% to 10.09% after option classes migrate to the PFOF model and the percentage of horse races won by the PHLX increases from 84.57% to 86.95%. Overall, the results of the horse races 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, which is consistent with Hypothesis 2.

The third and fourth rows of Panel A present results for the 1,213 (1,459) horse races 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 before (after) the sample option classes' migration. The fill rates

TABLE 6
Horse race Results

An Order Pair horse race 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 horse race a tie if both orders execute within 500 μs of one another. The PHLX charges marketable customer orders a take fee of $0.26 per contract before and less than $0.00 per contract after the migration of Sample Classes from MT to PFOF. The NOM (PHLX) charges a take fee of $0.45 per contract (less than $0.00 per contract) throughout the sample period. ** and *** indicate significance at the 5% and 1% levels, respectively.

		Fill Rates (%)			Median Order Size		Median Fill Time (Seconds)		Horse races (%)		
PHLX vs. NOM	No. of Order Pairs	PHLX	NOM	Both Fill	PHLX	NOM	PHLX	NOM	PHLX Fills 1st	NOM Fills 1st	Tie
Panel A. All Horse races											
Sample classes before migration	6,773	93.61	36.42	30.03	6.3	3.5	182.5	251.0	84.57	11.03	4.40
Sample classes after migration	2,218	93.66	35.28	28.94	7.3	2.5	142.7	421.0	86.95	10.09	2.96
Control classes before pseudo-migration	1,213	98.62	14.46	13.08	2.0	1.0	157.4	48.0	93.97	4.31	1.72
Control classes after pseudo-migration	1,459	98.70	13.66	12.35	2.8	1.0	133.0	66.9	93.74	4.73	1.53
Diff-in-diff									2.61***	−1.36**	−1.25**
Panel B. PHLX Migrating vs. NOM Summary for Horse races Involving the Most Actively Traded Option Series											
Sample classes before migration	1,133	89.84	48.54	38.38	5.4	3.4	169.5	226.8	77.27	16.52	6.22
Sample classes after migration	319	91.87	37.42	29.29	2.6	3.6	52.7	131.2	85.48	11.80	2.72
Control classes before pseudo-migration	443	92.84	48.70	41.55	3.8	3.5	48.8	37.5	83.25	13.63	3.12
Control classes after pseudo-migration	177	95.37	42.81	38.18	5.8	4.9	148.2	38.7	83.44	12.30	4.26
Diff-in-diff.									8.02***	−3.39***	−4.64***
Panel C. PHLX Migrating vs. NOM Summary of Horse races in Which PHLX Order Arrives First											
Sample classes before migration	1,728	91.07	52.71	43.78	5.0	4.0	340.7	173.5	79.08	13.69	7.24
Sample classes after migration	713	92.57	52.58	43.59	4.3	3.4	344.4	361.5	81.24	13.44	5.31
Difference									2.16	−0.25	−1.93
Panel D. PHLX Migrating vs. NOM Summary of Horse races in Which NOM Order Arrives First											
Sample classes before migration	5,045	92.60	29.32	21.92	6.6	3.3	124.2	610.2	85.84	11.65	2.50
Sample classes after migration	1,505	93.66	26.94	20.60	5.0	2.8	78.00	614.9	88.26	9.70	2.04
Difference									2.42	−1.95	−0.46

for limit orders participating in horse races before (after) the pseudo-migration are 98.62% (98.70%) on the PHLX and 14.46% (13.66%) on the NOM. Across all horse races involving the control options, 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 horse races 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, before (after) the pseudo-migration, the PHLX wins 93.97% (93.74%) of the horse races versus 4.31% (4.73%) for the NOM, while 1.72% (1.53) of the horse races end in ties. The final row of Panel A shows that the difference-in-differences in horse race results are statistically significant.

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As noted by Battalio et al. (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 6, we present results for horse races 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 horse races conducted using orders in the control option classes and the horse races 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 horse races when it operates as an MT venue and 85.48% of the horse races when it moves to the PFOF model. The NOM wins 16.52% of the horse races before the PHLX migration and 11.80% after. For the control option classes, which trade in the PFOF model throughout the sample period, the PHLX (NOM) wins 83.25% (13.63%) before the pseudo-migration and 83.44% (12.30%) after the pseudo-migration. The difference-in-differences are all statistically significant. These results suggest that the benefit of routing nonmarketable limit orders to PFOF exchanges is greater when orders are exposed to a higher volume of purchased order flow.

In Panels C and D, we present results for horse races involving sample option classes conditional on the venue that receives the first order involved in a horse race. We present results for horse races 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 horse races that use orders in sample option classes. Across this set of horse races, the PHLX is victorious 79.08% of the time before migration and 81.24% after migration. In the set of horse races 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 horse races, 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 horse races are significantly higher than the unconditional fill rates for customer limit orders presented in Table 4. Moreover, the unconditional fill rates on the NOM for orders involved in horse races are nearly twice as high when the PHLX receives the first order involved in a horse race (see Panels C and D of Table 6). These results suggest that horse races are likely conducted in selective market conditions. For these reasons, we estimate the following logistic regression using the sample of orders involved in our horse races in select option classes that migrate from the MT model to PFOF model on the PHLX. The unit of observation in the following regression equation is horse race/day.

$$
\begin{aligned}
(2)\quad \text{PHLX_WINS}_{i,t} \;=\; & \alpha + \beta_1 \text{POST}_t + \beta_2 \text{PHLX_RECEIVES_ORDER_FIRST}_i \\
& + \beta_3 \text{PHLX_ORDER_SIZE}_i + \beta_4 \text{NOM_ORDER_SIZE}_i \\
& + \beta_5 \text{LIMIT_PRICE}_i + \beta_6 \text{UNDER_MARKET_CAP}_i + \beta_7 \text{CALL}_i \\
& + \beta_8 \text{SELL}_i + \beta_9 S/X_i + \beta_{10}(S/X)_i^2 + \beta_{11} \text{DAYS_TO_EXPIRATION}_i + \varepsilon_{i,t}.
\end{aligned}
$$

The dependent variable, PHLX_WINS, equals 1 if the order resting on the PHLX executes before the order resting on the NOM. We include the following as independent variables. POST is an indicator measure set equal to 1 if the

*i*th horse race occurs after the select option class migrates from MT to PFOF on the PHLX, and 0 otherwise.[28] PHLX_RECEIVES_ORDER_FIRST equals 1 if the PHLX receives the first order in the *i*th horse race, and 0 if the first order is received by the NOM. PHLX_ORDER_SIZE and NOM_ORDER_SIZE are the sizes of the 2 orders in the *i*th horse race. LIMIT_PRICE is the limit price of the 2 orders in the *i*th horse race. UNDER_MARKET_CAP is the market capitalization of the underlying stock. CALL is an indicator variable equal to 1 if the option type is call, and 0 for a put. SELL is a categorical variable equal to 1 if the *i*th horse race is for a sell order, and 0 for a buy order. *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 nonlinear relation between the moneyness of an option series and execution quality (see Battalio and Schultz (2011)). Last, we include the number of days until expiration for the option. To calculate standard errors, we cluster on the underlying stock.

Table 7 contains the results for orders involved in horse races seeking to trade sample option classes. Consistent with the results presented in Table 6, the PHLX is significantly less likely to win a horse race when it is the first to receive an order involved in a horse race. While the PHLX is statistically more likely to win a horse race throughout the sample period, the coefficient on POST is positive and statistically significant, indicating that the probability that the PHLX wins a given horse race is higher when sample option classes begin trading in the PFOF model on the PHLX. Thus, the results of our univariate horse race analysis survive in a multivariate setting.[29]

E. 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 using the PFOF model. However, when making the change, the 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 using 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 using 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.

[28] For horse races conducted using limit orders seeking to trade control option classes, POST equals 1 if the matched sample option class has migrated to the PFOF model.

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

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TABLE 7

Multivariate Analysis of the Probability that PHLX Wins a Horse race

We use a logistic regression in Table 7 to estimate the following model using the sample of orders involved in our horse races on select option classes that migrate from the MT model to the PFOF model on the PHLX:

$$\begin{aligned}\text{PHLX_WINS}_{i,j,s,t} = {} & \alpha + \beta_1 \text{POST}_t + \beta_2 \text{PHLX_RECEIVES_ORDER_FIRST}_{i,j,s,t} \\ & + \beta_3 \text{PHLX_ORDER_SIZE}_{i,j,s,t} + \beta_4 \text{NOM_ORDER_SIZE}_{i,j,s,t} + \beta_5 \text{LIMIT_PRICE}_{i,j,s,t} \\ & + \beta_6 \text{UNDER_MARKET_CAP}_{i,t} + \beta_7 \text{CALL}_j + \beta_8 \text{SELL}_s + \beta_9 S/X_{i,j,s,t} \\ & + \beta_{10} (S/X)^2_{i,j,s,t} + \beta_{11} \text{DAYS_TO_EXPIRATION}_{i,j,s,t} + \varepsilon_{i,j,t}\end{aligned}$$

PHLX_WINS equals 1 if the order resting on the PHLX executes before the order resting on the NOM. POST is an indicator measure set equal to 1 if the *i*th horse race occurs after the option class migrates from the MT model to the PFOF model on the PHLX, and 0 otherwise. PHLX_RECEIVES_ORDER_FIRST equals 1 if the PHLX receives the first order in the *i*th horse race, and 0 if the first order is received by the NOM. PHLX_ORDER_SIZE and NOM_ORDER_SIZE are the sizes of the 2 orders in the *i*th horse race. LIMIT_PRICE is the limit price of the 2 orders in the *i*th horse race. UNDER_MARKET_CAP is the market capitalization of the underlying stock. CALL is an indicator variable that equals 1 if the orders seek to trade a call option, and 0 for a put option. SELL is an indicator variable that equals 1 if the orders are sell orders, and 0 for buy orders. *S/X* is the ratio of the underlying stock price to the strike price during the *i*th horse race. DAYS_TO_EXPIRATION is the number of days until expiration for each option. To calculate standard errors, we cluster on the underlying stock.

Independent Variable	Coefficient	Standard Error	*z*-Ratio	Probability	Odds Ratio
POST	3.3184	1.3180	2.52	0.012	27.6157
PHLX_RECEIVES_ORDER_FIRST	−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
UNDER_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				

Option market participants must comply with the trade-through rule, which requires marketable orders to execute 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). For this reason, we follow Battalio et al. (2016) and 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 8 contains each exchange's market share of trades that execute when all relevant exchanges are at the best quote before and after the PHLX migrates option classes to the PFOF model. Panel B contains the same information for control options around their pseudo-migration. Overall, 10.69% (10.64%) of the trades in sample (control) options occur when each of the 7 exchanges listed in Table 8 is at the best quote (results not reported). The first row of Panel A reveals that prior to the PHLX migration, the two venues using 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 shares of the exchanges using the MT model is generally negatively 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 the 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 that execute when all are at the inside quote

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TABLE 8

Market Share of Regular and Automatically Executed Trades When All Exchanges are at the Best Quote

Table 8 reports the across-class average market share of (in Panel A) trades executed when each of the 7 exchanges are at the best posted quote in the 35 sample option classes that migrate from the MT model to the PFOF model and (in Panel B) trades in the control option classes before and after their matched option class migrates from the MT model to the PFOF model. Only 22 of the 35 control option classes have trades that occur when each of the 7 exchanges are at the best quote. We use the student's *t*-test to determine if the market share differs across migration. Panel C gives the *p*-value for difference in the average change in an exchange's market share of trades occurring at the NBB (NBO) when the relevant exchanges are each quoting at the NBB (NBO). We examine the 22 sample option classes whose controls have trades in both the pre and the post periods. We conduct a 2-tailed test of the hypothesis that the average change in market share of an exchange across the sample option class's migration is equal to the average change in market share of that exchange across the control option class's pseudo-migration. *, **, and *** indicate significance difference before and after migration at the 10%, 5%, and 1% levels, respectively.

	N (Median)	AMEX	CBOE	ISE	PHLX	BATS	ARCA	NOM
Panel A. Best-Posted Quotes								
Pre	8,773	59.22%	20.72%	5.40%	5.04%	0.78%	2.33%	1.40%
Post	8,120	58.37%	16.71%	5.17%	9.29%	0.58%	3.47%	1.51%
Post − Pre		−0.85%	−4.01%***	−0.23%	4.25%***	−0.20%	1.14%*	0.11%
% Post − Pre > 0		48.57%	22.86%	40.00%	88.57%	51.43%	57.14%	45.71%
Panel B. Before and After Migration to the PFOF Model								
Pre	1,888	51.58%	19.21%	7.92%	10.56%	0.52%	2.52%	1.50%
Post	3,358	51.12%	18.69%	5.92%	11.70%	0.69%	2.52%	2.23%
Post − Pre		−0.46%	−0.52%	−2.00%*	−1.14%	0.17%	−0.00%	0.73%
% Post − Pre > 0		45.45%	54.55%	22.73%	54.55%	54.55%	45.45%	59.09%
Panel C. Difference in Market Share Trade Averages								
z-stat.		−0.9779	−2.3648**	2.3454**	3.0118***	−1.67338*	1.4236	−1.1442

falls from 20.72% to 16.71%, while the PHLX's market share rises from 5.04% to 9.29%. The PHLX realizes an increase in its market share of trades in 31 of the 35 migrating option classes, while the CBOE loses market share in 27 of the migrating option classes. ARCA, whose market share increases from 2.33% to 3.47%, is the only other exchange with a statistically significant change (at the 0.10 level) in market share. Finally, the total market share of the two pure PFOF venues prior to the migration, 79.94%, is close to the total market share of these venues plus the gain in market share realized by the PHLX after the migration, 79.33%. 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, and consistent with Hypothesis 5, the results suggest that the increase in customer orders routed to the PHLX came at the expense of the CBOE, not the ISE.[30]

Panel B of Table 8 reveals each exchange's market share of trades in control options that execute when all venues are at the inside quote around the pseudo-migration date. Highlighting the fact that the control options are not as actively

[30]One possible reason that the AMEX did not lose market share across the PHLX migration is that on June 29, 2011, 7 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 Jan. 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 Jan. 2012.

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traded as the migrating options, only 22 of the 35 control option classes have trades in the pre and the post periods when all venues are at the inside quote. The three venues using the PFOF model to arrange trades in control option classes execute 81.35% (81.51%) 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 that execute when all are at the inside quote than the 3 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 shares of the 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 7.92% to 5.92%.

Panel C of Table 8 contains the results of 2-tailed tests of the hypothesis that the average changes in market share for an exchange in sample and control option classes are the same across the sample option classes' migration. This test involves the 44 option classes for which there are trades in both the pre and the post periods. We find that relative to the control options, the increase in market share on the PHLX is statistically significant at the 0.05 level, while the decrease in market share on the CBOE is statistically significant at the 0.08 level. These results are consistent with our fifth hypothesis that the PHLX gains market share in the migrating option class at the expense of the CBOE.

To summarize, we find a negative association between a venue's market share of trades, which execute when all markets are at the inside quote, and that venue's relative take fee. The PHLX's market share of trades, which execute 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 its market share after the PHLX migration is the CBOE, which uses the PFOF model throughout our sample period. This evidence suggests that the improvement in limit order execution quality on the PHLX seems to be attributable to the fact that after the migration, standing limit orders are exposed to marketable customer orders that are purchased from retail brokers.

VI. Conclusion

There are 2 pricing schedules that dominate the U.S. equity options trading landscape, namely, PFOF and MT pricing. The coexistence of these 2 fee models gives brokers the ability to make strategic order routing decisions (Angel et al. (2011)). We show that several retail brokers route their limit orders to options exchanges that offer high maker rebates and their market orders to exchanges that pay for marketable order flow. Other brokers route all of their market and limit orders to exchanges that pay for marketable order flow. 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 exchange, which according to Credit Suisse (2017), has the potential to improve order execution outcomes for customers.

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In this study, we empirically examine whether routing limit orders to options exchanges that purchase marketable retail order flow, rather than to venues offering high liquidity rebates, enhances limit order execution quality. To do so, we use the 2012 decision by the PHLX to migrate select option classes from trading in the MT pricing model to the PFOF pricing model. We find that more customer marketable orders, and less customer nonmarketable orders, are routed to the PHLX following the migration to the PFOF model in select option classes, relative to control option classes. We also find higher limit order fill rates on the PHLX after the migration to the PFOF model. To control for stock, option, and market conditions that may affect order execution quality, we conduct horse races between identically priced limit orders to buy (or sell) contracts of the same option class displayed concurrently on the PHLX and NOM. We use the NOM as a benchmark as it is the venue charging the highest take fee throughout our sample period and take fees have been shown to be inversely related with limit order execution quality (Battalio et al. (2016)). In these horse race tests, we find that the PHLX migration to the PFOF is associated with an improvement in relative limit order execution quality.

Since the PHLX moved from being the exchange charging the second lowest take fee for marketable customer orders (behind the ISE) to offering rebates, it might be that our results are driven by the PHLX becoming a lower cost alternative to the ISE, rather than being driven by the implementation of the PFOF model. Accordingly, we examine how the PHLX migration to the PFOF affected each of the significant options exchange's market share of trades executed when all venues 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 uses the PFOF model throughout our sample period, rather than the ISE. Therefore, it appears that the increase in limit order execution quality on the PHLX after the migration to the PFOF is attributable to the switch in pricing models from the MT to PFOF.

Together, our results suggest that brokers that do not pass fees and rebates directly back to their customers can enhance limit order execution quality by routing nonmarketable orders to exchanges that actively purchase order flow rather than to exchanges offering high liquidity rebates. In Oct. 2019, Charles Schwab, Ameritrade, and E*Trade cut online brokerage commissions to zero, reportedly wiping out a combined market value of $16.4 billion. Given the loss in commission revenue, retail brokers may be more inclined to route options orders in a manner that maximizes order flow payments rather than limit order execution quality. In this zero-commission environment, our results suggest that investors and regulators should monitor brokers to ensure that their nonmarketable limit orders are not always routed to options exchanges that offer the highest liquidity rebates.

Supplementary Material

Supplementary Material for this article is available at https://doi.org/10.1017/S0022109019001078.

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