Order Cancellations, Fees, and Execution Quality in U.S. Equity Options

Todd Griffith

University of Mississippi

Dissertation: Essay 1

Abstract

Excessive limit order cancellation activity in equity options markets has forced exchange officials to proactively seek potential deterrents. We conduct difference in difference analysis to examine the execution quality implications of the enforcement of an order cancellation fee on the PHLX. We find that the cancellation fee is effective in reducing the rate at which limit orders are submitted and subsequently deleted. The reduction in order cancellation activity is associated with a significant increase in the probability of order execution. Also, we do not find significant evidence that the cancellation fee is accompanied with slower execution speeds nor less order flow. We do provide important insights into the behavior of limit order traders in equity options markets, in terms of differences in cancellation activity between trading venues, option types, moneyness, and time-to-expiration. Overall, our results suggest that reducing excessive order cancellation activity decreases the non-execution risk faced by limit order traders on the PHLX.

Keywords: Limit Orders, Cancellation Rates, Execution Quality

1. Introduction

Limit orders play a pivotal role in both equities and options markets (Berkman, 1996 and Chung, Van Ness, and Van Ness, 1999). The traditional view is that limit order traders patiently supply liquidity (Seppi, 1997 and Foucault, Kadan, and Kandel, 2005). This perspective often characterizes limit order traders as functional equivalents to dealers, who are generally modeled as risk-neutral liquidity providers, and are indifferent as to whether their orders execute.[1] Hasbrouck and Saar (2009), however, call into question the view of limit orders as patient providers of liquidity, as they find that nearly one-third of all non-marketable limit orders are canceled within two seconds of submission, in a sample of NASDAQ equity securities. The U.S. Securities and Exchange Commission (SEC) also documents that over 96 percent of orders placed in the equities market in the second quarter of 2013 are cancelled.[2]

Technology has changed financial markets, altering the trading behavior of limit order traders.[3] High-speed computerized trading strategies, and electronic order-driven trading platforms, enable limit order traders to better monitor their orders and make faster, more accurate decisions.[4] Trading in financial markets has entered the nanosecond age, where liquidity is added and subtracted in billionths of a second. The increase in trading speed coincides with an explosion in order cancellation activity (Hasbrouck and Saar, 2009, 2013).[5] Therefore, technology and computerized trading has ultimately changed the way liquidity is supplied and demanded, raising concerns about the effect of order cancellation activity on the trading welfare of market participants. For example, on June 5, 2013

---

[1] See Copeland and Galai (1983), Glosten and Milgrom (1985), and Easley and O'Hara (1987) for the modeling of dealers as risk-neutral traders subject to adverse selection. Glosten (1994) and Sandas (2001) model limit order books in a similar fashion.
[2] See "Trade to Order Volume Ratios" market structure research from the U.S. SEC released on October 9, 2013.
[3] See O'Hara (2015) for a discussion on how technology has changed financial markets and Boehmer, Saar, and Yu (2005) for a review of the literature on the evolution of limit order trading strategies.
[4] See Goldstein, Kumar, and Graves (2014) for a brief overview of the evolution of computerized trading.
[5] Wall Street's Need for Trading Speed: The Nanosecond Age. *The Wall Street Journal*, June 14, 2011.

the quotes for SPY options exceeded one billion, nearly 15 times greater than on the day of the flash crash, and the quote-to-trade ratio expanded to 11,254.[6]

The issue of traders who cancel a lot of their orders has drawn significant attention from the popular press, regulators, and exchange officials, each of whom proposes potential solutions. For instance, U.S. Democratic presidential candidate Hillary Clinton proposes a tax on high-frequency trading (HFT), targeting securities transactions with excessive levels of order cancellations, under the presumption that such trading strategies are abusive and detrimental to financial markets.[7] In response to the flash crash on May 6, 2010, the Commodity Futures Trading Commission (CFTC) and the U.S. SEC recommend a uniform fee across all exchanges to fairly allocate the costs imposed by high levels of order cancellations.[8] Exchange officials also believe that curbing excessive order cancellations will improve trading for their market participants. For example, The NASDAQ proposed a "minimum life" order type on its PSX equities exchange, with the intent on encouraging longer-lived limit orders (Jones, 2013). In the purpose section of the proposed rule change (see SEC Release No. 34-65610), the exchange states:

> *"Today's cash equities markets are characterized by high levels of automation and speed… In such an environment, the degree to which displayed orders reflect committed trading sentiment has become less predictable, because many entered orders are rapidly canceled. Market participants that seek to interact with orders that are canceled before they can execute may ultimately achieve less favorable executions than would have been the case if the order had not canceled."*

The NASDAQ OMX PHLX is also the only options exchange to enforce a fee on excessive order cancellation activity. On August 18, 2010, the PHLX filed with the U.S. SEC a proposal to

[6] See the research analysis posted by Nanex, LLC at http://www.nanex.net/aqck2/4308.html
[7] The HFT-specific aspects of the broad proposals for the financial system provided by Hillary Clinton in an op-ed piece in The New York Times on December 7, 2015 entitled, "How I'd Rein in Wall Street."
[8] Recommendations Regarding Regulatory Responses to the Market Events of May 6, 2010: Summary Report of the Joint CFTC-SEC Advisory Committee on Emerging Regulatory Issues, page 11.

assess a cancellation fee on electronically delivered all-or-none (AON) orders submitted by professional traders. In the purpose and statutory sections of the rule filing (see SEC Release No. 34-62744, page 2), it states:

> *"The Exchange has observed that the number of cancelled professional AON orders greatly exceeds the normal order cancellation activity on the Exchange for all other order types, and thus affects the automated order handling capacity of the Exchange's systems… The Exchange believes that the proposed amendments are reasonable because they will ease system congestion and allow the Exchange to recover costs associated with excessive order cancellation activity."*

The primary purpose of this study is to examine the relation between order cancellation activity and execution quality (i.e. order volume, fill rates, cancellation rates, and fill speeds). We utilize the change in cancellation fee policy on the PHLX as a natural setting to test whether order cancellation activity negatively impacts execution quality. If the rule change is effective in improving order execution quality, then competing U.S. options exchanges may consider adopting similar fee policies. In contrast, if the rule change is ineffective, then our results might discourage the use of similar fee schedules. Since the trading in options is shown to contribute to price discovery in the underlying equities markets, the results of this paper may also apply to equities.[9]

Since the PHLX is the only options exchange to enforce an order cancellation fee, the Exchange serves as a natural environment to test our research questions. First, we examine the overall effectiveness of an order cancellation fee in reducing the level of excessive cancellation activity on the PHLX. In our difference-in-difference regressions, we find that that the average order cancellation rate for options on the PHLX declines by 12.8 percentage points more than on the NOM, from the

[9] See Manaster and Rendleman (1982), Easley, O'Hara, and Srinivas (1998), and Chakravarty, Gulen, and Mayhew (2004) for a review of the finance literature on informed trading in stock and option markets.

17 days prior to the fee change to the 40 days following the change. Thus, the cancellation fee appears to be extremely successful in discouraging excessive order cancellation activity.

Next, we analyze the relation between order cancellations and the probability of order execution. The decline in order cancellation rates on the PHLX is associated with a significant marginal increase in the probability of an order filling. For instance, we find that the average limit order on the PHLX is over 7.3 percentage points more likely to fill in the post-fee trading environment, relative to the pre-fee period. We also examine the relations between cancellation activity and both order fill speeds and order volume. In our difference in difference analysis, we do not find consistent evidence that the change in cancellation fee significantly impacts order execution speeds nor order volume.

We take advantage of the unique features of the options market and study how cancellation activity varies by option type (call or put), option moneyness, and time-to-expiration. We find that order cancellation rates are 5.98 percentage points higher for put options, relative to call options, other factors held constant. We also show that order cancellation rates increase as an option becomes more in-the-money. In addition, option orders submitted on expiration days are at least 2.73 percentage points more likely to cancel than those submitted on non-expiration days, other things held constant. Interestingly, the probability of an order cancellation is roughly 20 percentage points higher on the PHLX than the NOM. This differential in order cancellations can be partially explained by the difference in order volume, the difference in order size, and the difference in cancellation speeds.

Since exchange officials on both options and equities markets are seeking to address the problems associated with excessive limit order cancellations, this study is of particular interest. We provide evidence that certain aspects of order execution quality are inversely correlated with cancellation activity. For instance, the introduction of the cancellation fee on the PHLX causes a significant increase in the probability of a limit order being filled. Since limit order traders face significant non-execution risk, increasing fill rates certainly improves their overall welfare. Thus, the benefits of reducing excessive order cancellation activity seems to outweigh the costs, in terms of limit order execution quality.

2. The PHLX Cancellation Fee Policy

Effective August 18, 2010, the PHLX updated its cancellation fee policy to include a $1.10 per order charge on each canceled electronically delivered AON order submitted by a professional, in excess of the total number of orders submitted and executed by the "professional" in a given month.[10] The order cancellation fee is only assessed in a month in which more than 500 electronically delivered orders are submitted and canceled by the same professional. The term professional refers to any person or entity that (1) is not a broker or dealer, and (2) submits more than 390 orders in listed options per day on average during a calendar month. An AON order is a limit order which executes in entirety or not at all. Electronic orders are delivered through the Exchange's options trading platform. The rule change applies to professional order flow only, however, the implications of such a fee change can affect all market participants on the exchange, as professionals both supply and demand liquidity in significant volume.

Since the majority of price changes on an exchange are made on monthly intervals, it is a rare occurrence for a fee change to publish and become effective mid-month. The data seems to suggest that the "true" effective date was closer to September 1, 2010, or around the turn-of-the-month (see Figure 1). It could be that firms simply assumed that the change would go into effect the following month, similar to other price changes. Alternatively, the exchange calculates the 500 order threshold in a particular calendar month and then assesses the per order fee. Therefore, the fees for August

[10] See the NASDAQ Options Trader Alert #2010 – 53 for a more detailed description of the updates to the cancellation fee assessment criteria effective August 18, 2010. See also the SEC Release No. 34-62744 for the notice of filing and immediate effectiveness of the proposed rule change relating to the cancellation fee.

would not be calculated until the end of the month, which could have possibly delayed the reaction of traders to the new pricing policy.

3. Hypothesis Development

3.1. Order Cancellations

Limit orders play an important role in establishing the national best bid and offer in financial markets. Chung, Van Ness, and Van Ness (1999) examine the role of limit orders of equities on the NYSE in the 1990's when the market had both specialists and limit-order traders establishing prices, and find that a majority of the quotes that make up the NBBO originate from the limit order book. The conventional view of limit order traders, is that they patiently supply liquidity (see Seppi, 1997 and Foucault, Kadan, and Kandel, 2005). Foucault, Kadan, and Kandel (2005) develop a dynamic model of a limit order market, and show that in equilibrium, patient traders submit limit orders while impatient traders submit marketable orders.

However, a feature of modern equity markets is that submitting orders and quickly canceling those orders is common and frequent. For instance, Hasbrouck and Saar (2009) investigate trading of 100 NASDAQ-listed equity securities on INET, an electronic limit order book, and find that over 35% of limit orders are canceled within two seconds of submission. Hasbrouck and Saar find that traders implement "fleeting order" strategies to chase market prices or search for latent liquidity.[11] Ellul, Holden, Jain, and Jennings (2007) analyze a sample of NYSE securities during January of 2001, and document that over one-third of all order submission are eventually canceled prior to execution. Van Ness, Van Ness, and Watson (2015) provide the first time trend analysis of cancellation activity in the equity market. They find that order cancellation rates are increasing over time, starting at 35% in 2001, and reaching around 90% in 2010.

[11] Baruch and Glosten (2013) also examine fleeting orders, orders that are submitted and canceled within two seconds, and find that traders manage the risk of getting undercut while sitting on the limit order book by quickly canceling their limit orders.

Liu (2009) argues that advancements in technology, and the transition of exchanges to electronic trading venues are convenient explanations for the high level of cancellation rates in the current marketplace (see also Goldstein, Kumar, and Graves, 2014). In fact, Boehmer, Saar and Yu (2005) show that cancellation activity increases following the introduction of NYSE OpenBook, which lowered trading latency. There are also more nefarious explanations for the excessive order cancellation rates observed in financial markets. For example, there is evidence of order spoofing, in which large limit orders are entered far away from the bid-ask to create an illusion of demand, and are subsequently canceled.[12] Lee, Eom, and Park (2013) show that traders in the Korea Exchange (KRX) strategically place orders with little chance of execution with the intent on misleading other market participants into thinking an order book imbalance exists, and capitalizing on subsequent price movements.

3.2. Order Cancellations and Execution Quality

Order execution quality is important for all market participants. Since limit orders impact both the supply of and demand for liquidity (see Chung, Van Ness, and Van Ness, 1999), it is important to understand the effect of order cancellation activity on execution quality. The canceling of limit orders in it of itself does not necessarily affect order execution quality. Hasbrouck and Saar (2009) find evidence that fleeting orders, limit orders canceled within two seconds of submission, are consistent with a strategy whereby traders chase market prices. Therefore, traders may position limit orders by canceling and resubmitting orders around prevailing market prices, in an attempt to earn market-making profits.

---

[12] Navinder Singh Sarao was imprisoned in 2010 for creating a spoofing algorithm trading E-mini S&P 500 future contracts, suspiciously close to the May 6, 2010 flash crash. The day-trader allegedly canceled more than 99 percent of orders being submitted. In addition, on October 8, 2015 the Securities Exchange Commission (Sec) settled spoofing charges with Briargate Trading for over $1 million.

Consider a simple example of a market maker attempting to balance supply and demand by constantly offering to buy or sell stock. Suppose the market maker places an order to buy 100 shares for a particular stock at $49.99, and contemporaneously places a sell order for 100 shares for the same stock at $50.01. If someone decides to buy 100 shares at $50.01, then the market maker can cancel the sell order at $49.99 and enter a new buy order at $50.00 and a new sell order at $50.02. Again, if someone decides to buy 100 shares at $50.02, then the market maker can cancel the sell order at $50.00 and adjust the orders upward. This simple example generates an order strategy whereby 50% of the orders are canceled without ever executing. Since the limit orders are being canceled and resubmitted in response to shifts in supply and demand, there is no reason to believe that trader execution quality be adversely affected.

If, however, order cancellations reduce the supply of liquidity, as is the case when orders are canceled and not resubmitted, then cancellation activity may have a negative impact on execution quality, such as fill rates and fill speeds. Yeo (2005) examines the set of actions available to limit order traders following an order cancellation: complete withdrawal, resubmission of a marketable order, or resubmission of a more aggressive limit order. Yeo (2005) finds that in most cases, limit order traders completely withdraw from trading after canceling a limit order, thereby reducing liquidity provisions. Thus, it is not surprising that the issue of traders who cancel a lot of their orders has received significant attention and debate. Regulatory agencies, such as the U.S. SEC, recommend a minimum duration on limit orders and/or fees on order cancellations.[13] For example, former U.S. SEC Chairwoman Mary Schapiro in an address given on September 7, 2010, states:

> *"A type of trading practice that has received recent attention involves submitting large volumes of orders into the markets, most of which are cancelled… There may, of course, be justifiable explanations for many cancelled*

[13] See page 47 of the January 14, 2010 SEC CFTC Concept Release on Equity Market Structure. SEC and CFTC report on February 18, 2011, a discussion about a uniform cancellation fee across all exchange markets. See also SEC May Ticket Speeding Traders: High-Frequency Firms Face Fees on Canceled Transactions. *The Wall Street Journal*, February 23, 2012.

orders to reflect changing market conditions… But we also must understand the impact this activity has on price discovery, capital formation and the capital markets more generally, and consider whether additional steps such as registration and trading requirements are needed to foster – not undermine – fair and orderly markets." [14]

Exchange officials on the PHLX acknowledge the costs associated with excessive order cancellations. Consequently, the exchange has established an order cancellation fee policy to help monitor trading practices with high levels of order submissions and cancellations.[15] The primary purpose of the fee policy is to reduce the number of canceled orders and improve the trading environment for all market participants. Traders can be made better off ex ante if the order cancellation fee policy increases the probability of completing a trade, as the welfare of traders depends on the non-execution risk faced by liquidity suppliers (Colliard and Foucault, 2012). Since limit orders are stored in the order book and do not demand immediacy, the execution of a limit order is not guaranteed (Hollifield, Miller, and Sandas, 1996; Foucault, 1999; Peterson and Sirri, 2002).

The probability that an order is filled may depend on a number of factors including prevailing market conditions, stock characteristics, and exchange fee structures (see Colliard and Foucault, 2012 and Brolley and Malinova, 2013). The fee structure on the PHLX includes a per order charge on excessive order cancellations. This type of fee policy might discourage traders from implementing certain limit order trading strategies that are shown to result in high levels of order cancellations. For instance, Hasbrouck and Saar (2009) show that fleeting orders arise when traders cancel and resubmit limit orders as the market moves away from their initial limit order prices. Market participants that seek to interact with orders that are canceled before they can execute, may ultimately never fill.

---

[14] Speech by SEC Chairman: "Strengthening Our Equity Market Structure" by Mary L. Schapiro on September 7, 2010.
[15] On the CHX, a $0.01 per order cancellation fee is assessed if a trader surpasses set criteria laid out in the fee schedule.

Therefore, reducing the number of canceled orders should improve the probability of an order achieving execution. Thus, we expect the following hypothesis to hold.

Hypothesis 1: The probability of order cancellation (execution) is lower (higher) following the enforcement of the cancellation fee policy.

Limit orders are not only exposed to the risk of non-execution, but also to the uncertainty in the time-to-execution. Speed of order execution has grown in importance since the proliferation of automated and computerized trading (Blume, 2001 and Boehmer, 2005). In fact, Boehmer, Jennings, and Wei (2007) show that exchanges receive more order flow when execution speeds increase. Time-to-execution is a random function of several variables including order price, order size, and market conditions (Lo, MacKinlay, and Zhang, 2002). Whereas a marketable order demands immediate execution, at least as soon as practicable (Peterson and Sirri, 2002), a limit order must await the arrival of a countervailing marketable order.

The altering of a fee structure undoubtedly impacts the trading dynamics on an exchange. Professional traders account for over 90% of order volume on the PHLX during our sample period. Prior to the fee change, professional traders could cancel numerous orders without penalty. Therefore, many of the orders submitted by traders may have lacked true trading sentiment. In some instances, traders intentionally flood the market with order submissions and cancellations in an attempt to create arbitrage opportunities (Brogaard, 2010 and Biais and Woolley, 2011). For example, the NASDAQ disciplined Citadel Securities LLC on June 16, 2014 for sending millions of orders to the exchange with few or no executions.[16] The cancellation fee policy may encourage traders to display orders that reflect committed trading sentiment, because there is a potential cost associated with submitting frivolous orders. Consequently, traders may be more willing to submit marketable orders,

[16] See the letter of acceptance, waiver and consent no. 20100223345-02 posted on June 16, 2014, page 6. On February 13, 2014 between 13:32:53:029 and 13:33:00:998 Citadel transmitted over 65,000 orders for 100 shares per order to buy Penn National Gaming, Inc. with zero executions.

quickening the speed with which an actual liquidity-supplying trader finds a counterparty. Thus, we expect the following hypothesis to hold.

Hypothesis 2: Order fill speeds are more rapid following the enforcement of the cancellation fee policy.

3.3. Order Cancellations – Option Features

Unique features of the options market give rise to several interesting questions with regards to order cancellations. First, options are negotiable contracts in which investors have the right, but not the obligation, to trade securities at predetermined prices, within a certain period of time. A call option gives the buyer the option to buy, while a put option gives the buyer the option to sell. In this study, we examine whether cancellation activity differs between puts and calls.

Trading volume for equity options is generally higher for calls, relative to puts (see Pan and Poteshman, 2006). In fact, the average put/call ratio for equity options volume on the PHLX has historically remained below one.[17] Biais and Weill (2009) develop a model showing that as the market approaches continuous trading, order cancellations increase monotonically. Therefore, as trading volume increases, as does order cancellation activity. Since the trading volume for calls is generally higher than that for puts, we might expect cancellation rates to be higher for calls compared to puts.

However, research also shows that trading costs, approximated by bid-ask spreads, are higher for calls than for puts. For instance, Battalio, Shkilko, and Van Ness (2016) find that effective spreads are higher for call options than for put options, in an analysis of eight option exchanges. Liu (2009) develops a model that predicts a negative relation between cancellation activity and spreads. Liu argues that as spreads widen, the marginal benefit of monitoring limit orders declines, thereby decreasing cancellation activity. To the extent that spreads are higher for calls than for puts, and spreads are inversely related with cancellation activity, we expect the following hypothesis to hold.

---

[17] Historical options data, including put-call ratios, for each option exchange are available at the following website: http://www.optionsclearing.com/webapps/put-call-ratio

Hypothesis 3: Cancellation rates are higher for put options, relative to call options.

Second, the value of an option contract if it were exercised immediately (i.e. intrinsic value) is often determined by the difference between the underlying stock price and the option strike price. Option contracts are often separated into moneyness categories: at-the-money, in-the-money, and out-of-the-money. If the strike price for a call option is less (greater) than the underlying stock price, then the option is in-the-money (out-of-the-money). The opposite is true for put options. If the strike price is equal to the underlying stock price, then the option is at-the-money. In this study, we examine how cancellation activity differs by option moneyness.

Lakonishok, Lee, Pearson, and Poteshman (2007) show that open volume in equity options, for both puts and calls, is concentrated in near-the-money options. In addition, volatility is shown to increase as options becomes more in-the-money (Rubinstein, 1994 and Jackwerth and Rubinstein, 1996). Since both trading volume and volatility are shown to have positive relations with order cancellation activity (see Biais and Weill, 2009 and Van Ness, Van Ness, and Watson, 2015), and option volume and volatility are greater for in-the-money options, we expect the following hypothesis to hold.

Hypothesis 4: Order cancellation rates are higher for options in-the-money, relative to options out-of-the-money.

Third, equity option contracts expire on the third Friday of every month. Research shows that both trading volume and volatility increase on and around option expiration days (see Stoll and Whaley, 1987 and Stephan and Whaley, 1990). For example, Day and Lewis (1988) provide evidence that market volatility is increasing around expiration days in index futures contracts. Large (2004) predicts a positive relation between order cancellation activity and market uncertainty. Since market volatility is increasing, it seems reasonable to assume that market uncertainty is also increasing. Therefore, we might expect to find an influx of canceled orders on option expiration days, as traders are less certain about the committed trading sentiment of displayed orders.

In addition, arbitrageurs and market makers often unwind positions around expiration days, forcing them to submit and cancel a large amount of orders as they move in and out of positions (see Ni, Pearson, and Poteshman, 2005). As option traders attempt to rebalance, a natural consequence might be an increase in both limit order submissions and cancellations. Therefore, we expect the following hypothesis to hold.

Hypothesis 5: Order cancellation rates are higher on expiration days, relative to non-expiration days.

4. Data Description

We obtain limit order data for two equity options exchanges, the Philadelphia Exchange (PHLX) and the NASDAQ Options Market (NOM). These data include orders added and removed from the limit order books. For each option series, we aggregate to the daily level the total number of orders and cancellations, order size, average limit order price, and the number of filled orders. An option series is defined as a particular underlying stock, call or put, strike price, and expiration date. The sample period ranges from July 26, 2010 to October 15, 2010. We elect to focus on this time period as to examine market quality around the introduction of the PHLX order cancellation fee, which commenced on August 18, 2010. To conduct unbiased comparisons in order cancellation rates between options with different features, we focus on a time period following the immediate shock of the structural change on the PHLX, September 15, 2010 to October 15, 2010. We include order data from the NOM to control for any macroeconomic trends and to assess whether order flow moved between exchanges. To ensure accurate comparisons among exchanges, we conduct a daily match between options series originating on the PHLX with those originating on the NOM by underlying stock, option type (put or call), strike price, and expiration date.

In an attempt to focus on the most actively traded options, we retain only underlying securities that trade every day of the sample period. In addition, we eliminate series that have fewer than 10 orders per day (see Battalio, Shkilko, and Van Ness, 2016). Also, we remove orders reported before

9:45 a.m. and after 3:50 pm to avoid trading during the opening and closing rotations. Complex orders, such as spreads and straddles, are priced as a package, so we remove them from the sample. We merge these data with closing prices and shares outstanding from the Center for Research in Security Prices (CRSP), and retain only common stocks.

Table 1 provides order statistics for options on both the PHLX and the NOM. In Panel A, we report order descriptive statistics for PHLX options in the pre-fee period, October 26, 2010 to August 17, 2010, while in Panel B we report order statistics for NOM options during the same time period. In Panel C, we display differences in means between the PHLX and the NOM. In Panels D through F, we report summary statistics for order submitted in the post-fee period, September 15, 2010 to October 15, 2010.

The mean (median) order size for an option on the PHLX in the pre-fee period is roughly 23 (15) contracts, or 2,300 (1,500) shares of underlying stock. In comparison, the mean (median) order size for an option on the NOM in the pre-fee period is 19.30 (9.09) contracts. Therefore, the average order size on the PHLX is 3.394 contracts, 339.4 shares of underlying stock, greater than the mean order size on the NOM, which is significant at the 0.01 level. Similarly, in the post-fee period (Panels D and E), the average order size on the PHLX is 25.213 contracts, relative to 22.354 contracts on the NOM. The difference in order size between PHLX and NOM options in the post-fee period is 2.859 contracts, which is significant at the 0.01 level.

[Insert Table 1 Here]

The value (moneyness) of an option contract is determined by the difference between the market price and the strike price. To capture the moneyness component of each option series, we estimate the ratio of the underlying stock price to the strike price (S/X). Since option volume is concentrated in in-the-money options (Lakonishok, Lee, Pearson, and Poteshman, 2007), it is not unexpected to find the median option series in our sample has an S/X ratio close to one. In the pre-fee period (Panels A and B of Table 1), the average option series has an S/X ratio of 1.098. In the post-fee period (Panels D and E), the median S/X ratio for both exchanges is 1.008. By construction, through our matching procedure, the difference in S/X ratios between the two trading venues is equal to zero. Option contracts also expire after a specified time period, generally the third Friday in the month. In the pre-fee period (Panels A and B), we find that the number of days until expiration for the average option series is 37.583. Similar to option moneyness, the difference in time-to-expiration between exchanges is zero. In the post-fee period (Panels D and E), the average option has 48.4 days until expiration.

Since the primary goal of this paper is to examine how order cancellation activity affects execution quality, we focus most of our discussion on four measures of limit order execution quality (similar to Battalio, Corwin and Jennings, 2015): the probability of a cancellation, the likelihood of a fill, the speed of fills, and order volume (# of orders). To estimate the probability of a cancellation we calculate daily order cancellation rates, or the ratio of the total number of orders canceled divided by the total number of orders submitted for an option series. Prior to the fee-change, the average cancellation rate is 9.07 percentage points higher on the NOM (99.89%), in comparison to the PHLX (90.82%). This difference is statistically significant at the 0.01 level (see Panel C). In the post-fee change period, the mean cancellation rate for orders submitted to the PHLX is 74.38%, relative to 99.78% on the NOM. This difference is both statistically significant at the 0.01 level (see Panel F) and economically meaningful, as the probability of order cancellation on the PHLX is 25.4 percentage points lower than on the NOM.

Similar to Foucault (1999), we estimate the likelihood of complete execution using daily fill rates, or the ratio of the number of orders filled divided by the total number of orders submitted for an option series. In the pre-fee change period (Panels A and B), we find that the mean fill rate for orders on the PHLX is 5.03%, compared to 0.11% on the NOM. In the post-fee change period

(Panels D and E), the average fill rate for orders on the PHLX is 17.20%, relative to 0.19% for orders on the NOM. Panels C and F show that these differences are statistically significant at the 0.01 level. Our results suggest that the probability of execution appears to be significantly higher on the PHLX, relative to the NOM.

We also analyze order fill speeds, which we calculate as the passage of time between order submission and complete execution. In the pre-fee change period (Panels A and B), the mean fill speed for orders executed on the PHLX is roughly 1,041 seconds, compared to 786 seconds on the NOM. The difference in average fill speeds between the PHLX and NOM equates to approximately four and one-half minutes, which is both statistically and economically significant. Similarly, the average fill speed for orders executed on the PHLX in the post-fee change period is 187 seconds slower than the orders executed on the NOM. Thus, limit orders submitted to the NOM appear to execute faster than those submitted to the PHLX.

Another important aspect of limit order execution quality, is the number of orders submitted to a particular venue. In the pre-fee change period, the daily average number of orders submitted for an option series on the NOM is 16,387, which is markedly higher than the daily average number of orders submitted for an option series on the PHLX, 493. We note that during the sample period, the NOM is a pure order-driven market, where all participants trade in limit orders. This includes quotations entered by market makers. In comparison, the PHLX is both quote driven and order driven. Therefore, it is not surprising that we find such a large difference in order volume, in terms of number of orders, between the two exchanges. Of course, we must control for order volume in a multivariate setting when examining the effects of order cancellation activity on execution quality.

5. Results – Order Cancellation Activity and Execution Quality

5.2. Univariate Analysis

The costs associated with excessive order cancellations has forced exchange officials to take corrective action. Hence, the primary purpose of the cancellation fee policy on the PHLX is to discourage traders from submitting frivolous orders that are immediately canceled. The exchange anticipates that the removal of excessive order cancellations will improve the trading process for all market participants (see SEC Release No. 34-62744). In this section, we examine the effectiveness of the cancellation fee policy in both deterring excessive order cancellations and improving execution quality for market participants. We test our first and second hypotheses by analyzing whether order execution quality changes for options around the August 18, 2010 cancellation fee policy on the PHLX.

Table 2 reports average execution metrics in a 31-day event window around the PHLX's fee change, which includes the event date and the 15 days before and the 15 days after. First, we examine how order cancellation activity is affected by the change in fee policy. As expected, we show that average cancellation rates for orders on the PHLX decline substantially from the pre-fee period to the post-fee period, although the largest decline occurs around the turn-of-the-month. For instance, the mean cancellation rate for orders on the PHLX drops from a high of 93.38% in the third day prior to the fee change, to a low of 64.45% in the eleventh day following the fee change. The delayed market reaction is perhaps explained by the timing of the fee change (i.e. middle of the month) and when the fee is assessed (i.e. end of the month). In contrast to the sharp decline in the probability of cancellation on the PHLX, the average cancellation rates for orders on the NOM fluctuate very little across the event window.

[Insert Table 2 Here]

Next, we analyze how the likelihood of complete execution is affected by the change in order cancellation fee policy. Since cancellation rates decline exogenously on the PHLX, it provides us with a natural setting to assess the market quality implications of a reduction in order cancellation activity.

In Table 2, we show that daily average fill rates for orders on the PHLX increase from a minimum of 3.03% in the third day prior to the change in fee policy to a maximum of 21.29% in the eleventh day after the fee change.

We also examine how limit order fill speeds change around PHLX's cancellation fee change. Although order fill rates improve following the effective date of PHLX's cancellation fee policy, average fill times appear to lengthen. It is difficult to see a distinct pattern from the averages reported in Table 2 around the event date, however, unlike order cancellation rates and fill rates, there appears to be no clear jump in execution speeds around the event date.

Last, we examine order volume, in terms of the number of orders, on both the PHLX and NOM around the event date. The results in Table 2 show that the number of limit orders submitted declines on both exchanges over the event window. Order volume does not appear to move from the PHLX to the NOM following the cancellation fee change. In fact, there appears to be more of a contagion effect, likely due to the fact the two venues are under the same group umbrella. The change in cancellation fee might cause some market participants to route their order flow to exchanges outside of the NASDAQ family.

Figure 1 provides a visual representation of how PHLX's cancellation fee change impacts limit order execution quality for options on the PHLX (solid dark line) and on the NOM (dotted light line). Panel A plots mean order cancellation rates over the event window. We show that average order cancellation rates for options on the PHLX decline dramatically around the fee change, and remain at a lower rate in the 25 days following the effective date.[18] In contrast, the probability of order cancellations on the NOM has no distinct pattern over the sample time period, with no large ebbs nor flows.

[18] In unreported results, we find that average cancellation rates for options on the PHLX remain at the lower rate for at least 60 days following the change in fee policy.

[Insert Figure 1 Here]

Panel B plots mean order fill rates for both options trading on the PHLX and NOM around the change in cancellation fee on the PHLX. We show a distinct increase in order fill rates for option on the PHLX around the change in cancellation fee policy. However, we find no distinct change in order fill rates for options on the NOM during the event window. Panel C plots average fill speeds, in seconds, for orders executed on the PHLX and NOM around the fee change. We find slight increases in order fill speeds for options on both the PHLX and NOM. Panel D of plots the average number of orders submitted for a particular option on the PHLX and NOM over the event window. The figure illustrates a striking decline in order flow for options on the PHLX around the event date, but a more gradual decline in order flow for options on the NOM over the event window.

Table 3 formally tests how limit order execution quality changes on the PHLX and NOM following the fee change. In Panel A, we use a 42-day event window, July 26, 2010 to September 23, 2010, or the 17 days prior to the event date and the 25 days after. July 26, 2010 is the first day for which we have order-level data on the PHLX. In Panel B, we expand the event window to 57 days, or the 17 days prior to the fee change to the 40 days after the change. Using a 42-day event window, we find that the average cancellation rate for orders on the PHLX declines from 90.74% in the pre-fee period to 80.13% in the post-fee period. This represents a 9.15 percentage point decline pre- to post-fee change, which is statistically significant.

[Insert Table 3 Here]

When we expand the event window to 57 days (Panel B), we find that mean cancellation rate on the PHLX decline from 90.74% in the pre-fee period to 77.93% in the post-fee period. Hence, the decline in the probability of order cancellation on the PHLX, following the fee change, is even more pronounced for the longer event window. In comparison, the difference in average cancellation rates between the pre- and post-fee change periods for orders on the NOM is only -0.07 percentage points, which is not economically meaningful. Thus, we are confident that the enforcement of the fee was effective in reducing excessive order cancellation activity on the PHLX, which provides support for our first hypothesis.

We also find a positive and significant increase in order fill rates for options on the PHLX from the pre-event period, 5.09%, to the post-event period, 12.36%. This represents a 7.27 percentage point increase following the enforcement of the cancellation fee, which is significant at the 0.01 level. If we expand the event window to 57 days, as in Panel B, we find the average fill rate for orders executed on the PHLX increases by 9.07 percentage points from the pre- to post-fee period. In comparison, average fill rates for orders executed on the NOM only increase from 0.11% in the pre-fee period to 0.15% in the post-fee period. Since the difference in order fill rates between the PHLX and NOM in the post-event period is 12.21 percentage points, which is higher than the 4.98 percentage point difference in the pre-event period, it is not the case that order fill rates are simply increasing across all options market during the sample period. Thus, the reduction in order cancellation activity leads to an improvement in at least one area of execution quality, the probability of an order achieving a complete fill, which supports our first hypothesis.

We do find that the average fill speed for option orders on the PHLX increases by roughly 77 seconds from the pre-fee period to the post-fee period. However, we also show that the average fill speed for option orders on the NOM increases by a similar margin, 77.5 seconds in the post-fee period, relative to the pre-fee period. Even though we find significant increases in order fill speeds around the change in fee policy, we cannot rule out the possibility that overall fill speeds are simply lengthening in equity options during the sample period. If we lengthen the event window, as in Panel B of Table 3, we find no significant difference in fill speeds for PHLX orders between the pre- and post-event periods. Therefore, the results from these univariate tests provide evidence against our second hypothesis, although we cannot completely reject hypothesis 2.

Our last set of tests in this section examine the changes in order flow for options on the PHLX and the NOM around the event date. The results in Panel A of Table 3 show that the average number of orders submitted per day for options on the PHLX declines by approximately 216 from the pre-event window to the post-event window. Similarly, we find a significant decline in the average number of orders submitted to the NOM from the pre-fee period to the post-fee period. However, as we note in Panel D of Figure 1, the decline in average order volume appears more abrupt on the PHLX, and more gradual on the NOM.

Overall, the results from these univariate tests suggest that the enforcement of a cancellation fee is effective in reducing cancellation rates. In addition, the fee policy change appears to improve the probability of an order achieving complete execution, as order fill rates increase. We do, however, note that order volume is lower and fill speeds are longer in the post-event period than the pre-event period. Although it is unclear at this point whether that is a result of macroeconomic conditions or the change in fee policy. We explore these relations further in the next section and control for such factors.

6.2. Multivariate Analysis

Providing univariate evidence that order execution quality changes for options around the change in fee structure is not tantamount to establishing a causal link. Therefore, we also perform a series of regression analyses in this section to control for other macroeconomic and firm-specific factors that could affect order execution quality. We estimate variations of the following equation for options on the PHLX.

$$
\begin{aligned}
&Order\ Execution\ Quality^{j}_{i,t} \qquad (1)\\
&\quad = \alpha + \beta_1 Post_t + \beta_2 \#\ Orders_{i,t} + \beta_3 Limit\ Price_{i,t} + \beta_4 Order\ Size_{i,t}\\
&\quad + \beta_5 Underlying\ Size_{i,t} + \beta_6 Call_{i,t} + \beta_7 Money1_{i,t} + \beta_8 Money2_{i,t}\\
&\quad + \beta_9 Expiry + \beta_{10} Days\ Expire_{i,t} + \varepsilon_{i,t},\\
&\quad j \in \{order\ volume, fill\ rate, cancel\ rate, fill\ speed\}
\end{aligned}
$$

The dependent variable is set to one of four order execution quality metrics: order cancellation rates, order fill rates, order fill speeds, or order volume. The variable of interest is *Post*, which is a categorical variable set equal to one if an observation is in the 25-day (40-day) post-event window, and zero otherwise. We exclude the event date in our regression analyses and, therefore, we do not include a pre-event categorical variable as to avoid violating the full column rank assumption for consistent estimation.

Since Battalio, Corwin, and Jennings (2016) show that limit order execution quality is a function of order volume, average price, and order size, we include the following as control variables. *Total Orders* is the average number of orders submitted for each option series on a particular day. *Limit Price* is the average limit order price on all orders submitted for a particular options series by day. *Order Size* is the average number of contracts attached to a limit order for each option series by day. Each contract is worth 100 shares of underlying stock. We also include the market capitalization on the underlying stock, since larger stocks may attract more option order volume.

Battalio, Shkilko, and Van Ness (2016) show that execution quality is related to option moneyness, option expiration, and option type (call or put). Therefore, we include an indicator variable *Money1,* which is set equal to one if the option has a ratio of underlying stock price to strike price (S/X) that is less than 0.9, and zero otherwise. *Money2* is an indicator variable set equal to one if the option has an S/X ratio of greater than 1.1, and zero otherwise. We exclude an indicator variable for options near-the-money (i.e. 0.9 <= S/X <= 1.1) and, therefore the coefficients on *Money1* and

Money2 are interpreted in comparison to options near-the-money. These cutoffs for option moneyness are consistent with those used by Lakonishok, Lee, Pearson, and Poteshman (2007). *Call* is an indicator variable set equal to one if the option is a call, and zero for a put. *Expiry* is a dummy variable set equal to one if the order is placed on an expiration date, and zero otherwise. *Days Expire* is a continuous measure that captures the number of days until option expiration. We include these latter variables not only to control for option features, but also to test our final three hypotheses. Hence, a more detailed discussion of the inclusion of these variables is found in section 3.3.

Since both order cancellation rates and fill rates cluster near one and zero, we estimate Equation (1) using both OLS and censored Tobit regressions for these dependent variables. Fill speeds and order volume are both highly positively skewed and, therefore, we estimate Equation (1) using both least squares and quantile (median) regressions for these dependent variables. We cluster our standard errors on the underlying stock.

[Insert Table 4 Here]

Table 4 reports the results of this analysis. As we expect, order cancellation rates are increasing in order volume and limit order price, and decreasing in order size. In Column [1] of Panel A, we find that the average order cancellation rate for options on the PHLX is 6.8 percentage points (t-value = -2.512) lower following the change in fee policy, other factors held constant. After censoring on zero and one, we find that the decline in cancellation rates from the pre-event period to the post-event period for PHLX options is 6.4 percentage points, which is significant at the 0.05 level. If we expand the post-fee period window to 40 days, we find even stronger results. For instance, Column [1] of Panel B shows that PHLX order cancellation rates decline between 8.1 and 8.3 percentage points from the pre-fee period to the post-fee period. These results are consistent with our univariate tests and support our first hypothesis in that the fee policy is effective in reducing order cancellations.

The reduction in order cancellation activity is likely to impact other aspects of execution quality, such as the probability of a fill, and this is exactly what we find. For instance, Column [2] of Panel A shows that the average order on the PHLX has a 4.7 percentage point greater probability of achieving a complete fill in the post-fee trading environment, relative to the pre-fee period. However, we believe these results to be understated, as fill rates are heavily biased toward zero. We correct for the potential bias in order fill rates using a Tobit regression model and find that the average order on the PHLX actually has a 7.5 percentage point greater probability of executing in the post-fee period, compared to the pre-fee period (see Column [4] of Panel A). Again, we find that the results are strengthened when we expand the event window to include the 40 days after the fee change. Specifically, Column [4] of Panel B shows that order fill rates on the PHLX increase by an average of 10.0 percentage points from the pre- to post-fee period. Thus, reducing order cancellations coincides with an improvement in execution probability. To the extent that trader welfare depends on the non-execution risk faced by liquidity suppliers (Colliard and Foucault, 2012), our results suggest that reducing order cancellations makes limit order traders on the PHLX better off ex ante. These results provide support for our first hypothesis, which states that order fill rates increase following the change in cancellation fee policy.

Next, we examine the impact of the cancellation fee policy on both order fill speeds and order volume. In Column [5] of Table 4, we find that the average order fill speed does not significantly change from the pre- to post-event period. Since fill speeds are highly skewed, we also report the results of estimating a median regression model, which are found in Column [6]. There we show that the median order fill speed is 68.93 seconds higher in the post-fee period than the pre-fee period. Our results suggest that it might take longer for limit order traders on the PHLX to find counterparties after the change in cancellation fee policy. However, when we lengthen the event window (see Panel B), we find that the difference in fill speeds pre to post disappears. Therefore, we do not find evidence in support of our second hypothesis, which is that order fill speeds are shorter following the change in cancellation fee policy.

One possible explanation for the lengthening in order fill speeds, is that less order volume is flowing to the exchange. Columns [7] and [8] of Table 4 show that the average daily number of orders declines for options in the PHLX in the post-fee change period, relative to the pre-fee change period. However, the median order volume on the PHLX remains constant across the event window. This result holds for both the 42-day event window (Panel A) and the 57-day event window (Panel B). Thus, we cannot confidently conclude that enforcing a cancellation fee reduces order flow.

Controlling for firm-specific factors and order characteristics is still not enough to establish a causal link between order cancellation activity and execution quality. Therefore, we perform difference-in-difference regression analysis to control for other macroeconomic factors affecting order execution quality. We estimate the following regression equation using our sample of options on orders from both the PHLX and the NOM.

$$\begin{aligned} &Order\ Execution\ Quality_{i,t}^{j} \qquad (2)\\ &= \alpha + \beta_1 Phlx \times Post_{i,t} + \beta_2 Phlx_i + \beta_3 Post_t + \beta_4 \#\ Orders_{i,t} \\ &+ \beta_5 Limit\ Price_{i,t} + \beta_6 Order\ Size_{i,t} + \beta_7 Underlying\ Size_{i,t} + \beta_8 Call_{i,t} \\ &+ \beta_9 Money1_{i,t} + \beta_{10} Money2_{i,t} + \beta_{11} Expiry + \beta_{12} Days\ Expire_{i,t} + \varepsilon_{i,t}, \\ &j \in \{order\ volume, fill\ rate, cancel\ rate, fill\ speed\} \end{aligned}$$

The dependent variable is again set to one of four limit order execution quality measures: cancellation rates, fill rates, fill speeds, or order volume. *Phlx* is an indicator variable set equal to one if the order originated on the PHLX, and zero for an order on the NOM. *Post* is a categorical variable set equal to unity if the order is submitted in the post-fee change period, and zero otherwise. We exclude the event date, August 18, 2010 in the analysis and, therefore, we do not include a pre-event dummy variable as to avoid violating the full column rank assumption for consistent estimation. The interaction term between *Phlx* and *Post* is the independent variable of interest, which captures the marginal impact of the cancellation fee change on execution quality, or the difference in difference test. We cluster our standard errors by the underlying stock.

We report the results of this analysis in Table 5. In Panel A, depending upon the regression analysis, we find that the average cancellation rate for orders submitted on the PHLX declines between 6.8 and 10.7 percentage points more than orders submitted on the NOM in the post-fee change period, relative to the pre-fee change period. These results are strengthened when we lengthen the event window to include the 40 days following the change in cancellation fee. Specifically, Columns [1] and [2] of Panel B show that order cancellation rates on the PHLX decline between 8.4 and 12.8 percentage points more than those on the NOM in the post-event period, relative to the pre-event period. Therefore, even after controlling for firm-specific factors and other macroeconomic trends, we fail to reject our first hypothesis that the probability of order cancellation declines following the fee change. In other words, the cancellation fee appears to be extremely effective in reducing order cancellation activity.

[Insert Table 5 Here]

The decline in cancellation activity seems to cause a significant increase in the likelihood of a fill. For instance, Column [4] of Panel A shows that the average fill rate for an option executing on the PHLX is 7.9 percentage point higher in the post-fee change period than the pre-fee change period, other factors held constant. If we lengthen the event window to 57 days (Panel B), then the average fill rate for orders executing on the PHLX increases by 10.1 percentage points more than on the NOM in the post-fee period, relative to the pre-fee period. The results from these difference-in-difference tests lend support for our first hypothesis that execution probability improves following the change fee policy. The implications of our results are broad, as they suggest that the PHLX improves a very important aspect of execution quality for its market participants by introducing a cancellation fee, at least on customers that engage in excessive cancellation activity.

In Columns [5] and [6] of Table 5, we find that the coefficients on the interaction term are insignificant, indicating that the cancellation fee has no marginal impact on order fill speeds. The same can be said for order volume, in terms of the average number of orders submitted to the venue. Therefore, we fail to find significant evidence in support of hypothesis 2, which is that order fill speeds shorten following the cancellation fee change. However, the results do suggest that the change in cancellation fee did not have a negative impact on either order flow nor fill speeds.

Overall, the results from this section suggest that order cancellation activity directly impacts execution quality. Specifically, a decline in order cancellation rates is associated with an increase in order fill rates, indicating an improvement in execution quality for limit-order traders. In addition, enforcing a cancellation fee does not seem to significantly alter average order fill times, nor does it seem to reduce order flow. Thus, exchanges with similar market structures to that of the PHLX, might consider an order cancellation fee policy.

6. Results – Order Cancellation Activity and Option Features

A noted feature of today's equity markets, is that orders are submitted and then quickly canceled (see Hasbrouck and Saar, 2009 and Baruch and Glosten, 2013). However, much less is known about order behavior in options markets, particularly order cancellation activity. Therefore, in the following section we provide a more in-depth analysis of limit order cancellation activity in two equity options markets, the PHLX and the NOM. To ensure that the following results are not biased due the structural change on the PHLX discussed above, we perform our tests using the time period after the PHLX fee change, from September 15, 2010 to October 15, 2010. We can see from Figure 1 that the effects of the cancellation fee change seem to stabilize by mid-September.

6.1. Univariate Analysis

A) Time to Order Cancellation

An important decision traders make each time they submit a limit order, is how long they allow that order to remain on the book. Hasbrouck and Saar (2009) show that nearly one third of limit orders on INET are canceled within two seconds of submission. We examine the pattern of cancellation rates by the time elapsed between order submission and deletion. Figure 2 plots order cancellation rates on both the PHLX and the NOM against the time from order submission to cancellation. For options on both exchanges, as more time passes following the submission of a limit order, the probability of cancellation declines. We find a near monotonic decrease in cancellation rates as the time between order submission and cancellation lengthens. For instance, the probability of an order being canceled is highest, 95.03% (99.9%), when an order is sitting on the PHLX (NOM) order book for less than ten seconds. The average cancellation rate for an option on the PHLX (NOM) reaches a minimum of 46.85% (98.21%) when the order sits on the book for more than 1,000 seconds, or 16½ minutes.

[Insert Figure 2 Here]

Table 6 reports mean limit order cancellation rates for options submitted to both the PHLX and the NOM disaggregated by time to cancellation. In unreported results, we find similar patterns in the standard deviations of cancellation rates between the two exchanges. There appears to be more dispersion in cancellation rates for options that sit on the book longer. We find that as the time-to-cancellation lengthens, the difference between order cancellation rates between the PHLX and the NOM increases. Specifically, for orders that sit on the book for more than 1,000 seconds, we find that that the average cancellation rate for orders on the PHLX is 51.36 percentage points lower than that on the NOM. This difference is significant at the 0.01 level. In contrast, when an order is on the book for less than a second, the difference in cancellation rates between the two exchanges in only 6.16 percentage points.

[Insert Table 6 Here]

B) Call Options vs. Put Options

Prior research highlights important differences between call options and put options, such as trading costs (Battalio, Shkilko, and Van Ness, 2016), open interest (Lakonishok et al. 2007), and trading volume (Roll, Schwartz, and Subrahmanyam, 2010). In this section, we examine how order cancellation activity differs between calls and puts. Table 7 reports the results of our univariate tests on order cancellation rates between call options and put options. In Panel A, we find that the average order cancellation rate for call options on the PHLX is 70.75%, which is 9.12 percentage points less than for put options. Similarly on the NOM, average order cancellation rates are higher for put options (99.84%), relative to call options (99.75%). We find that the average cancellation rate for PHLX call options is significantly less than that for NOM call options (difference = 28.99%, t-stat = 90.94). We also report that the average cancellation rate for PHLX put options is 19.97 percentage points less than that for NOM put options.

[Insert Table 7 Here]

In Panel B, we find that the put-to-call ratio on the PHLX exchange is 0.79, suggesting that order volume is slightly greater for call options, relative to put options. Similarly, the put/call ratio on the NOM is 0.62. This is consistent with the average sentiment in the market being more bullish than bearish. To the extent that order volume is a key driver behind order cancellation activity, our results suggest that the difference in cancellation rates between puts and calls is at least partially attributable to order flow. Overall, the results from these simple univariate tests support our third hypothesis, in which cancellation rates appear higher for put options, relative to call options.

C) Option Moneyness

Option contracts are often sorted into moneyness categories, based on the difference between the underlying stock price and option strike price. This value represents the profit that the option holder would receive if he or she exercised the option immediately. Lakonishok et al. (2007) show that open volume is concentrated in options that are near-the-money. Since order volume and cancellation rates are positively related, we expect cancellations to be increasing with option moneyness.

We separate observations by option type (put or call) and option moneyness. Similar to Lakonishok et al. (2007), we focus on three different ranges of option moneyness S/X. For call (put) options, an S/X ratio of less than 0.9 represents options out-of-the-money (in-the-money). An S/X range between 0.9 and 1.1 represents options near-the-money for both puts and calls. For call (put) options, an S/X ratio of greater than 1.1 identifies options in-the-money (out-of-the-money). We report the results of this analysis in Table 8.

[Insert Table 8 Here]

For both exchanges, we find that orders for options in-the-money are cancelled more frequently than any other option series. Specifically, the average order cancellation rate for in-the-money call (put) options on the PHLX is 10.41 (14.34) percentage points higher than the average cancellation rate for out-of-the-money call (put) options. Although smaller in magnitude, we find similar results for option orders submitted to the NOM. Our results suggest that the probability of order cancellation is highest for options in-the-money. Therefore, market participants are more likely to observe flickering orders in the more valuable options.

In Panel B of Table 8, we find that mean cancellation rates for call options on both exchanges increase gradually as the option becomes more in-the-money. Also, we find a non-monotonic decline in order cancellation rates for put options on the NOM as the option becomes more in-the-money. For put options on the PHLX, however, order cancellation rates are highest when the option is either in-the-money or deep out-of-the-money. In Figure 3, we plot order cancellation rates on both exchanges by option moneyness categories. Cancellation rates are on the primary and secondary vertical axes, while S/X ranges for moneyness are on the horizontal axis. We find that the plots are consistent with the findings in Panel B of Table 8. The results from this analysis provide support for our fourth hypotheses, at least for call options, that order cancellation activity is highest for options in-the-money. Thus, limit order traders are less likely to remain at a position on the order book when the option is increasing in value.

[Insert Figure 3 Here]

D) Time to Expiration

Prior research shows differences in trading behavior on, and around expiration days, relative to non-expiration days (see Stoll and Whaley, 1987 and Stephan and Whaley, 1990). In this section, we test our fifth hypothesis that order cancellation rates are higher on option expiration days than non-expiration days. Table 9 reports the results of our univariate analysis on mean cancellation rates between the two samples. We find that mean order cancellation rates for options on the PHLX are significantly higher on expiration days, relative to non-expiration days (difference = 4.11%, t-value = 3.34). In contrast, however, we find that order cancellation rates for options on the NOM are slightly lower on expiration days than on non-expiration days (difference = -0.07%, t-value = 2.85), although the difference is not economically significant. Therefore, our results provide some support for our fifth hypothesis that the probability of order cancellation is higher on expiration days, relative to non-expiration days.

[Insert Table 9 Here]

Figure 4 plots mean cancellation rates on the vertical axes and days-to-expiration on the horizontal axis. The dark solid line illustrates average order cancellation rates for options on the PHLX, whereas the light dotted line represents cancellation rates for options on the NOM. We find very different patterns in order cancellation rates disaggregated by time to expiration for options on the PHLX and NOM. For instance, we find that the relation between cancellation rates and the time to expiration on the PHLX is w-shaped, whereas it is more reversed u-shaped on the NOM. In Panel B of Table 9 we find that cancellation rates are higher on the NOM, relative to the PHLX across all expiration buckets. We might have expected order cancellation rates to continue to decline as the days-to-expiration increase, however, this is not what we find. We do note that order cancellation rates are relatively high for options on both exchanges that have between 25 and 50 days remaining until expiration.

[Insert Figure 4 Here]

6.2. Multivariate Analysis

We test the relation between order cancellation rates and option characteristics further in a multivariate setting, where we control for other factors that may affect the probability of cancellation. We estimate the following regression equation using both OLS and Tobit analysis.

$$\begin{aligned} Order\ Cancellation\ Rate_{i.t} \\ &= \alpha + \delta_t + \beta_1 Phlx_i + \beta_2 Cancel\ Speed_{i,t} + \beta_3 Call_{i,t} \\ &+ \beta_4 In - the - Money_{i,t} + \beta_5 Expiry\ Date + \beta_6 Days\ Expire_{i,t} \\ &+ \beta_7 \#Orders_{i,t} + \beta_8 Limit\ Price_{i,t} + \beta_9 Order\ Size_{i,t} + \varepsilon_{i,t} \end{aligned} \tag{3}$$

The dependent variable is daily cancellation rates, measured as the number of orders cancelled divided by the total number of orders submitted. The independent variables have all been defined previously, with the exception of the dummy variable *In-the-Money*, which is set equal to one if the option is in-the-money, and zero if the option is out-of-the-money. Since we are no longer performing an event study, it is important to control for time fixed effects, δ_t. We cluster the standard errors by underlying stock. The results of estimating Equation (3) are found in Table 10.

[Insert Table 10 Here]

Consistent with our univariate tests, we find that order cancellation rates are inversely related with the speed of cancellation. Consistent with our univariate tests, Columns [2] and [4] of Table 10 show that the average order cancellation rate on the PHLX is between 19.04 and 22.12 percentage points higher than on the NOM. Consistent with Figure 2, we find a negative and significant relation between the probability of order cancellation and the time-to-cancellation (cancel speed). Specifically, the coefficient on *Cancel Speed* is equal to a negative 0.0001 in each of the regression specifications. Since order cancellation speeds are measured in seconds, a one-minute increase in the speed of cancellation decreases the probability of order cancellation by 0.6 percentage points, other factors held constant.

In support of our third hypothesis, we find that order cancellation rates are significantly higher for put options relative to call options. For instance, Columns [4] of Table 10 shows that the average order on a call option has a cancellation rate that is about 5.98 percentage points lower than the average order on a put option. Therefore, traders ought to be aware of the difference in the probabilities of order cancellation between call options and put options. This is particularly important for traders submitting marketable orders, because the orders with which they seek to interact may be canceled before they can execute and, ultimately they may achieve less favorable executions.

In addition, we find support for our fourth and fifth hypotheses that order cancellation rates are significantly higher for in-the-money options and on option expiration days. In the full model, which includes day-fixed effects (Column [4]), we show that order cancellation rates are 4.29 percentage points higher on expiration days, relative to non-expiration days. The results also show that order cancellation rates are 5.45 percentage points higher for in-the-money options than out-of-the-money options. This is after controlling for other order and stock characteristics and exchange differences. Since option market makers often unwind, or move in and out of position, on expiration days (see Ni. Pearson, and Poteshman, 2005), this might help explain the higher probability of order cancellation observed on option expiration days.

In an attempt to explain the difference in orders cancellations between the PHLX and the NOM observed in the analysis above, we run the following regression model using data for our paired sample.

$$Order\ Cancellation\ Rate^{PHLX} - Order\ Cancellation\ Rate^{NOM} \tag{4}$$
$$= \alpha_0 + \sum \alpha_i (Y_i^{PHLX} - Y_i^{NOM}) + \sum \beta_j X_j + \varepsilon$$

The dependent variable is the difference in daily order cancellation rates between the PHLX and the NOM. Y_i (i = 1 to 4) represents one of four limit order characteristics: number of orders submitted, limit price, order size, and cancellation speed. X_j (j = 1 to 5) represents one of five option characteristics: option type (call or put), in-the-money options (money 1), out-of-the-money options (money 2), option expiration, and days to expiration. *Cancel Speed* is the number of seconds between order submission and cancellation. We include day fixed effects to control for time-series variation. All remaining control variables have previously been defined. Test-statistics are reported in parentheses and are obtained from standard errors clustered by underlying stock.

[Insert Table 11 Here]

The results of estimating Equation (4) are reported in Table 11. We find that the differential in order cancellation rates is significantly and positively related to the difference in order volume, in terms of the number of orders. This result suggests that the lower order volume on the PHLX at least partially explains the difference in order cancellation rates between the two exchanges. Since the NOM is an all-electronic options market, it might attract more algorithmic-type traders that are shown to cancel a substantial amount of their orders (see Hasbrouck and Saar, 2009).

We also find that the differential in order cancellation rates is significantly and negatively related to the difference in order size and cancellation speeds. Table 1 shows that orders submitted to the NOM are canceled, on average, 304 seconds faster than those submitted to the PHLX.

Therefore, the results from Table 11 suggest that the speed with which limit order traders cancel their orders on the NOM helps explain the higher probability of order cancellation.

7. Robustness

In this section we report the results of a series of robustness tests that help validate our findings. Since order cancellation rates, fill rates, and execution speeds remain constant for the sample of NOM orders, we are less concerned that our event study is biased due to the sample time period. However, it is still possible that order execution quality changed significantly during our particular sample period. Therefore, we perform a pseudo-event study, where we examine order execution quality for option on the PHLX around an alternative event date. We select the calendar year immediately following the event date, i.e. August 18, 2011.

We estimate Equation (1) for each order execution quality measure for orders submitted to the PHLX. Similar to our event study, we use a 50-day event window, the 25 days before the pseudo-event date and the 25 days after. The results of this analysis are found in the Appendix. We find that the coefficient on the categorical variable *Post*, is insignificant in each of the regressions, providing support for our main analysis. Since we do not observe any significant change around the pseudo-event date, we are confident that the fee change had a causal impact on order execution quality.

8. Concluding Remarks

Limit orders play a pivotal role in both equities and options markets (Berkman, 1996 and Chung, Van Ness, and Van Ness, 1999). The cancelling of those limit orders has captured significant attention from exchange officials, the popular press, and regulators. For instance, exchange officials believe that curbing excessive order cancellations through per order fees might improve the overall trading environment for all market participants (see SEC Release No. 34-62744, page 2). In this study, we examine the relation between order cancellation activities and limit order execution quality. We use the August 18, 2010 change in cancellation fee policy on the PHLX as a natural experiment.

We find that the commencement of the cancellation fee causes a significant drop in average order cancellation rates. For instance, in our difference-in-difference regression analysis, we find that the probability of cancellation for orders submitted to the PHLX declines by 10.7 percentage points more than on the NOM in the post-fee change period, relative to the pre-fee change period. Since order cancellation rates decline exogenously, it allows us to test the relation between cancellation activity and other aspects of execution quality.

We find that the probability of an order fill on the PHLX is at least 7.3 percentage points higher than on the NOM in the post-fee period, relative to the pre-fee period. Therefore, lower cancellation activity seems to have a positive impact on trader welfare, to the extent that limit order traders are better off when facing less non-execution risk (Colliard and Foucault, 2012). We fail to find significant evidence of a marginal impact of order cancellation activity on fill speeds or order flow. Therefore, assessing an order cancellation fee appears to improve the probability of a fill, without significantly affecting other aspects of limit order execution quality.

Our analysis also contributes to our understanding of limit order trading behavior in equity options markets. We find that the probability of order cancellation is approximately 5.98 percentage points higher for put options, relative to call options. In addition, orders submitted on option expiration days are 4.29 percentage points more likely to cancel than those submitted on non-expiration days. We also note that the probability of an order cancellation is roughly 20 percentage points higher on the PHLX, relative to the NOM. This differential in order cancellations is partially explained by the difference in order volume, order size, and cancellation speed.

Overall, the change in fee structure on the PHLX seems to significantly impact limit order execution quality, which is important for all market participants. Our result suggest that the benefits of reducing order cancellation rates seem to outweigh any perceived costs. Specifically, our results show that limit order traders submitted to the PHLX face significantly less execution risk in the post-fee change trading environment, relative to the pre-fee change period. The implications of our analysis are broad, as exchange officials in the equity options market might be encouraged to consider a similar type fee policy.

References

Baruch, S. and L. Glosten, 2013, "Fleeting Orders," Working Paper, Columbia Business School.

Battalio, R, A. Shkilko, and R. Van Ness, 2016, "To Pay or Be Paid? The Impact of Taker Fees and Order Flow Inducements on Trading Costs in US Options Markets," forthcoming in *The Journal of Financial and Quantitative Analysis*.

Berkman, H., 1996, "Large Option Trades, Market Makers, and Limit Orders. *Review of Financial Studies*, 9(3), 977-1002.

Biais, B. and P. Weill, 2009, "Liquidity Shocks and Order Book Dynamics (No. w15009). *National Bureau of Economic Research*.

Biais, B. and P. Woolley, 2011, "High Frequency Trading," Working Paper, Toulouse University.

Bloomfield, R., M. O'Hara, and G. Saar, 2005, "The "make or take" Decision in an Electronic Market: Evidence on the Evolution of Liquidity," *The Journal of Financial Economics*, 75(1), 165-199.

Boehmer, E., 2005, "Dimensions of Execution Quality: Recent Evidence for US Equity Markets," *The Journal of Financial Economics*, 78(3), 553-582.

Boehmer, E., R. Jennings, and L. Wei, 2007, "Public Disclosure and Private Decisions: the Case of Equity Market Execution Quality. Working Paper, Texas A&M University.

Boehmer, E., G. Saar, and L. Yu, 2005, "Lifting the Veil: An Analysis of Pre-Trade Transparency at the NYSE," *The Journal of Finance*, 60(2), 783-815.

Brogaard, J., 2010, "High Frequency Trading and its Impact on Market Quality," Working Paper, Northwestern University Kellogg School of Management.

Brolley, M. and K. Malinova, 2013, "Informed Trading and Maker-Taker Fees in a Low-Latency Limit Order Market," Working Paper, Wilfrid Laurier University.

Chakravarty, S., H. Gulen, and S. Mayhew, 2004, "Informed Trading in Stock and Option Markets," *The Journal of Finance*, 59(3), 1235-1258.

Chan, K., W. Christie, and P. Schultz, 1995, "Market Structure and the Intraday Pattern of Bid-Ask Spreads for NASDAQ Securities," *Journal of Business*, 35-60.

Chan, K., Y. Chung, and H. Johnson, 1995, "The Intraday Behavior of Bid-Ask Spreads for NYSE Stocks and CBOE Options," *The Journal of Financial and Quantitative Analysis*, 30(03), 329-346.

Chung, K., B. Van Ness, and R. Van Ness, 1999, "Limit Orders and the Bid–Ask Spread," *The Journal of Financial Economics*, 53(2), 255-287.

Colliard, J. and T. Foucault, 2012, "Trading Fees and Efficiency in Limit Order Markets," *The Review of Financial Studies*, 25(11), 3389-3421.

Copeland, T. and D. Galai, 1983, "Information Effects on the Bid-Ask Spread," *The Journal of Finance*, 38(5), 1457-1469.

Day, T. and C. Lewis, 1988, "The Behavior of the Volatility Implicit in the Prices of Stock Index Options," *The Journal of Financial Economics*, 22(1), 103-122.

Easley, D. and M. O'Hara, 1987, "Price, Trade Size, and Information in Securities Markets. *The Journal of Financial Economics*, 19(1), 69-90.

Easley, D., M. O'Hara, and P. Srinivas, 1998, "Option Volume and Stock Prices: Evidence on Where Informed Traders Trade," *The Journal of Finance*, 53(2), 431-465.

Ellul, A., C. Holden, P. Jain, and R. Jennings, 2007, "Order Dynamics: Recent Evidence from the NYSE," *The Journal of Empirical Finance*, 14(5), 636-661.

Foster, F. and S. Viswanathan, 1993, "Variations in Trading Volume, Return Volatility, and Trading Costs; Evidence on Recent Price Formation Models," *The Journal of Finance*, 48(1), 187-211.

Foucault, T., 1999, "Order Flow Composition and Trading Costs in a Dynamic Limit Order Market. *The Journal of Financial Markets*, 2(2), 99-134.

Foucault, T., O. Kadan, and E. Kandel, 2005, "Limit Order Book as a Market for Liquidity," *Review of Financial Studies*, 18(4), 1171-1217.

Foucault, T., O. Kadan, and E. Kandel, 2013, "Liquidity Cycles and Make/Take Fees in Electronic Markets," *The Journal of Finance*, 68(1), 299-341.

Glosten, L., 1994, "Is the Electronic Open Limit Order Book Inevitable?" *The Journal of Finance*, 49(4), 1127-1161.

Glosten, L. and P. Milgrom, 1985, "Bid, Ask and Transaction Prices in a Specialist Market with Heterogeneously Informed Traders," *The Journal of Financial Economics*, 14(1), 71-100.

Goldstein, M., P. Kumar, and F. Graves, 2014, "Computerized and High-Frequency Trading," *The Financial Review*, 49(2), 177-202.

Hasbrouck, J. and G. Saar, 2009, "Technology and Liquidity Provision: The Blurring of Traditional Definitions," *The Journal of Financial Markets*, 12(2), 143-172.

Hasbrouck, J. and G. Saar, 2013, "Low-Latency Trading," *The Journal of Financial Markets*, 16(4), 646-679.

Hollifield, B., R. Miller, P. Sandas, 1996, "An Empirical Analysis of a Pure Limit Order Market," Working Paper, Carnegie Mellon University.

Huck, P. and R. McDonald, 2010, "The Economics of Option Trading," Working Paper, Oklahoma State University.

Jackwerth, J. and M. Rubinstein, 1996, "Recovering Probability Distributions from Option Prices," *The Journal of Finance*, 1611-1631.

Large, J., 2004, "Cancellation and Uncertainty Aversion on Limit Order Books," Working Paper, Nuffield College, Oxford University.

Lee, C, B. Mucklow, and M. Ready, 1993, "Spreads, Depths, and the Impact of Earnings Information: An Intraday Analysis," *The Review of Financial Studies*, 6(2), 345-374.

Lee, E., J. Eom, and K. Park, 2013, "Microstructure-Based Manipulation: Strategic Behavior and Performance of Spoofing Traders," *The Journal of Financial Markets*, 16(2), 227-252.

Liu, W., 2009, "Monitoring and Limit Order Submission Risks," *The Journal of Financial Markets*, 12(1), 107-141.

Lo, A., A. MacKinlay, and J. Zhang, 2002, "Econometric Models of Limit-Order Executions," *The Journal of Financial Economics*, 65(1), 31-71.

Manaster, S. and R. Rendleman, 1982, "Option Prices as Predictors of Equilibrium Stock Prices," *The Journal of Finance*, 37(4), 1043-1057.

McInish, T. and R. Wood, 1992, "An Analysis of Intraday Patterns in Bid/Ask Spreads for NYSE Stocks," *The Journal of Finance*, 753-764.

Ni, S., N. Pearson, and A. Poteshman, 2005, "Stock Price Clustering on Option Expiration Dates," *The Journal of Financial Economics*, 78(1), 49-87.

O'Hara, M., 2015, "High Frequency Market Microstructure," *The Journal of Financial Economics*, 116(2), 257-270.

Pan, J. and A. Poteshman, 2006, "The Information in Option Volume for Future Stock Prices," *The Review of Financial Studies*, 19(3), 871-908.

Peterson, M. and E. Sirri, 2002, "Order Submission Strategy and the Curious Case of Marketable Limit Orders," *The Journal of Financial and Quantitative Analysis*, 37(2), 221-242.

Rubinstein, M., 1994, "Implied Binomial Trees," *The Journal of Finance*, 49(3), 771-818.

Sandås, P., 2001, "Adverse Selection and Competitive Market Making: Empirical Evidence from a Limit Order Market," *The Review of Financial Studies*, 14(3), 705-734.

Seppi, D., 1997, "Liquidity Provision with Limit Orders and a Strategic Specialist," *The Review of Financial Studies*, 10(1), 103-150.

Stephan, J. and R. Whaley, 1990, "Intraday Price Change and Trading Volume Relations in the Stock and Stock Option Markets," *The Journal of Finance*, 191-220.

Stoll, H. and R. Whaley, 1987, "Program Trading and Expiration-Day Effects," *The Financial Analysts Journal*, 43(2), 16-28.

Van Ness, B., R. Van Ness, and E. Watson, 2015, "Canceling Liquidity," *The Journal of Financial Research*, 38(1), 3-33.

Yeo, W., 2005, "Cancellations of Limit Orders. Working Paper, National University of Singapore.

Table 1
Descriptive Statistics

This table provides order statistics for the options series included in the analysis. Since the change in order cancellation fee policy on the PHLX occurs on August 18, 2010, we report two separate time periods, pre-event period that ranges from July 26, 2010 to August 17, 2010 and post-event period ranging from September 15, 2010 to October 15, 2010. We match PHLX option series (underlying symbol, option type (put or call), strike, and expiration date) by day with the same option series on the NOM. We are left with 105 unique option classes (underlying stocks) after matching series between the PHLX and NOM. The definitions of the variables are found in the text. We test for differences in means between the PHLX and the NOM using simple t-tests, which are reported in parenthesis. ***, **, and * represent statistical significance at the 0.01, 0.05, and 0.10 levels, respectively.

Pre Fee Change (07/26/2010 - 08/17/2010)									
	# Orders (100s)	Order Size (# contracts)	Limit Price	Fill Rate	Fill Speed (seconds)	S/X	Days-to-Expiration	Cancel Rate	Cancel Speed (seconds)
*Panel A. PHLX Orders **Pre** Fee Change*									
Mean	4.930	22.691	18.129	0.0503	1041.330	1.098	37.583	0.9082	373.464
Median	1.520	14.817	3.255	0.0000	343.218	1.025	26.000	0.9939	58.914
Std. Dev.	11.535	66.408	30.180	0.1279	1884.280	0.275	56.502	0.1980	860.831
Min	0.100	1.000	0.010	0.0000	0.000	0.385	0.000	0.0000	0.087
Max	306.810	2416.090	292.715	1.0000	21548.430	4.140	389.000	1.0000	19302.520
*Panel B. NOM Orders **Pre** Fee Change*									
Mean	163.865	19.296	18.175	0.0011	785.662	1.098	37.583	0.9989	89.367
Median	57.290	9.092	3.342	0.0000	240.820	1.025	26.000	1.0000	27.046
Std. Dev.	274.078	52.793	30.164	0.0100	1624.870	0.275	56.502	0.0100	230.169
Min	0.110	1.293	0.013	0.0000	0.000	0.385	0.000	0.3333	0.103
Max	3033.220	1559.290	292.125	0.6667	21575.040	4.140	389.000	1.0000	8848.190
Panel C. Difference in Means (PHLX - NOM)									
Difference	-158.935***	3.394***	-0.045	0.0492***	255.668***	0.000	0.000	-0.0907***	284.097***
t-stat	(79.02)	(5.46)	(0.15)	(52.27)	(9.65)	(0.00)	(0.00)	(62.43)	(43.48)

Table 1 - *Continued*

Post Fee Change (09/15/2010 - 10/15/2010)									
	# Orders (100s)	Order Size (# contracts)	Limit Price	Fill Rate	Fill Speed (seconds)	S/X	Days-to-Expiration	Cancel Rate	Cancel Speed (seconds)
Panel D. PHLX Orders									
Mean	1.693	25.213	8.825	0.1720	1001.550	1.040	48.400	0.7438	661.629
Median	0.320	8.357	2.025	0.0606	434.134	1.008	27.000	0.8889	105.031
Std. Dev.	4.332	73.310	25.699	0.2069	1651.350	0.211	83.430	0.2789	1219.040
Min	0.100	1.000	0.010	0.0000	0.000	0.397	0.000	0.0000	0.000
Max	99.340	2450.070	369.269	1.0000	20076.950	5.424	611.000	1.0000	20449.620
Panel E. NOM Orders									
Mean	155.879	22.354	8.788	0.0019	814.138	1.040	48.400	0.9978	89.583
Median	58.190	9.869	2.016	0.0005	329.358	1.008	27.000	0.9994	35.704
Std. Dev.	280.139	50.449	25.599	0.0052	1489.630	0.211	83.430	0.0057	227.753
Min	0.110	1.000	0.016	0.0000	0.000	0.397	0.000	0.8511	0.781
Max	3527.620	617.065	368.892	0.1489	19814.620	5.424	611.000	1.0000	7531.720
Panel F. Difference in Means (PHLX - NOM)									
Difference	-154.186***	2.859***	0.036	0.1701***	187.412***	0.000	0.000	-0.2541***	572.046***
t-stat	(60.89)	(3.56)	(0.11)	(90.95)	(7.81)	(0.00)	(0.00)	(100.76)	(51.04)

Table 2

Event Statistics – Order Cancellation Fee on PHLX

This table provides order statistics for matched options series on the PHLX and the NOM around the August 18, 2010 order cancellation fee policy change on the PHLX. We match option series (underlying symbol, option type, strike, expiration date) on the PHLX by day with the same option series on the NOM. We examine the 15 days prior to the fee change and the 15 days following the rule change. The delayed reaction by the market to the rule change is likely due to the rarity with which pricing changes take place during the middle of the month. Also, the minimum threshold to be charged a fee on order cancellations is not calculated until the end of the month, therefore, market participants might have been more prepared to change their trading strategies in the subsequent month.

Date	Day	Cancel Rate		Fill Rate		Fill Speed (seconds)		# Orders (100s)		Order Volume (100s)	
		PHLX	*NOM*	*PHLX*	*NOM*	*PHLX*	*NOM*	*PHLX*	*NOM*	*PHLX*	*NOM*
7/28/2010	-15	0.9194	0.9994	0.0452	0.0006	316	220	5.4500	179.4720	5961	195445
	-14	0.9064	0.9983	0.0550	0.0018	375	199	6.4440	201.2380	7041	219350
	-13	0.9200	0.9990	0.0427	0.0010	378	220	6.5670	192.8610	6635	193633
	-12	0.8639	0.9991	0.0783	0.0009	520	253	4.1360	148.1710	4318	153801
	-11	0.8993	0.9993	0.0538	0.0008	295	214	4.9920	170.7420	4936	168010
	-10	0.9019	0.9979	0.0513	0.0021	259	190	5.5130	192.6560	5932	206334
	-9	0.9139	0.9989	0.0448	0.0012	270	165	3.5160	145.0430	3659	149539
	-8	0.9110	0.9989	0.0522	0.0011	311	206	6.2290	206.5320	6596	217065
	-7	0.9203	0.9992	0.0358	0.0008	410	281	3.5570	143.1230	3412	135967
	-6	0.9181	0.9993	0.0458	0.0007	344	278	4.4300	165.1100	5215	192683
	-5	0.8987	0.9978	0.0626	0.0022	374	308	5.4920	167.1640	6597	198926
	-4	0.9129	0.9989	0.0497	0.0011	293	282	6.1040	164.0370	6916	183557
	-3	0.9338	0.9994	0.0303	0.0007	265	213	4.7700	134.3370	4888	136621
	-2	0.9271	0.9991	0.0371	0.0009	429	340	4.8710	139.8590	4223	120558
	-1	0.9021	0.9989	0.0554	0.0011	430	313	3.6480	115.9840	3404	106821
8/18/2010	0	0.9240	0.9993	0.0378	0.0007	287	283	4.5580	151.3710	3975	130634
	1	0.8944	0.9983	0.0636	0.0017	299	244	6.3960	177.4780	5943	163990
	2	0.8942	0.9989	0.0648	0.0011	332	237	4.9250	157.4420	4382	139021
	3	0.8572	0.9988	0.0722	0.0012	547	278	4.0460	136.6010	3507	117613
	4	0.9054	0.9991	0.0523	0.0009	315	159	4.7510	179.9000	3960	148777
	5	0.9135	0.9990	0.0474	0.0010	282	180	5.1360	169.9730	4227	138188
	6	0.9264	0.9991	0.0380	0.0009	293	194	4.8980	157.9110	3934	126487
	7	0.9108	0.9991	0.0466	0.0009	277	197	5.8000	191.4260	5004	164626
	8	0.7091	0.9984	0.1653	0.0016	614	336	1.0100	123.7930	275	32681
	9	0.7357	0.9988	0.1611	0.0012	413	273	2.4130	199.7020	827	67899
9/1/2010	10	0.6770	0.9979	0.2067	0.0021	491	391	1.3360	161.6630	606	71132
	11	0.6445	0.9969	0.2129	0.0031	721	406	1.1250	145.4690	320	39422
	12	0.7167	0.9978	0.1784	0.0023	592	378	0.6270	135.3400	378	77279
	13	0.7764	0.9988	0.1406	0.0012	287	314	1.2950	134.4090	501	51075
	14	0.6816	0.9977	0.2102	0.0023	573	298	0.8780	171.7320	391	74532
9/9/2010	15	0.7792	0.9987	0.1293	0.0013	489	259	0.9800	123.8390	516	63653

Table 3

Univariate Event Study – PHLX Order Cancellation Fee Change

This table provides univariate tests around the August 18, 2010 order cancellation fee policy change on the PHLX. We observe two event windows to test both the short-run and long-run effects of the fee change on order execution quality. Panel A reports the results from using a 42-day event window, the 17 days prior to August 18, 2010 and the 25 days after. July, 26, 2010 (day -17) is the first day for which we have order-level data on the PHLX. Panel B reports the results from using a 57-day event window, the 17 days prior to August 18, 2010 and the 40 days after. We exclude the event date in both analyses. Simple t-tests are used to calculate the difference in means. ***, **, and * denote statistical significance at the 0.01, 0.05, and 0.10 levels, respectively.

Panel A. Event Period [-17, 25] 07/26/2010 - 09/23/2010

	Pre		Post		Pre Difference	Post Difference	Difference PHLX	Difference NOM
	PHLX	NOM	PHLX	NOM	(PHLX - NOM)	(PHLX - NOM)	(Post - Pre)	(Post - Pre)
Cancel Rate	0.9074	0.9989	0.8013	0.9985	-0.0915***	-0.1972***	-0.1061***	-0.0004***
					(61.20)	(87.11)	(40.47)	(4.39)
Fill Rate	0.0509	0.0011	0.1236	0.0015	0.0498***	0.1221***	0.0727***	0.0004***
					(51.30)	(77.43)	(41.00)	(4.38)
Fill Speed (seconds)	1040.303	785.051	1117.084	862.599	255.252***	254.484***	76.780**	77.548***
					(9.42)	(9.40)	(2.55)	(3.17)
# Orders (100s)	4.948	164.473	2.784	150.305	-159.525***	-147.521***	-2.164***	-14.168***
					(76.88)	(71.96)	(19.88)	(4.79)

Panel B. Event Period [-17, 40] 07/26/2010 - 10/14/2010

	Pre		Post		Post Difference	Difference PHLX	Difference NOM
	PHLX	NOM	PHLX	NOM	(PHLX - NOM)	(Post - Pre)	(Post - Pre)
Cancel Rate	0.9074	0.9989	0.7793	0.9982	-0.2189***	-0.1281***	-0.0007***
					(117.88)	(52.08)	(8.30)
Fill Rate	0.0509	0.0011	0.1416	0.0017	0.1400***	0.0907***	0.0006***
					(105.58)	(53.11)	(6.62)
Fill Speed (seconds)	1040.303	785.051	1046.001	836.003	209.997***	5.697	50.953**
					(10.53)	(0.22)	(2.39)
# Orders (100s)	4.948	164.473	2.403	154.089	-151.686***	-2.545***	-10.384***
					(85.14)	(28.42)	(3.82)

Table 4

Impact of Cancellation Fee Change on PHLX's Order Execution Quality

This table reports the results of estimating the following equation for PHLX orders around the August 18, 2010 order cancellation fee change on the PHLX.

$$Order\ Execution\ Quality^{j}_{i,t} = \alpha + \beta_1 Post_t + \beta_2 \#\ Orders_{i,t} + \beta_3 Limit\ Price_{i,t} + \beta_4 Order\ Size_{i,t} + \beta_5 Underlying\ Size_{i,t} + \beta_6 Call_{i,t} + \beta_7 Money1_{i,t} + \beta_8 Money2_{i,t} + \beta_9 Expiry + \beta_{10} Days\ Expire_{i,t} + \varepsilon_{i,t},\ j \in \{order\ volume, fill\ rate, cancel\ rate, fill\ speed\}.$$

Panel A reports the results from using a 42-day event window, the 17 days prior to August 18, 2010 and the 25 days after. July, 26, 2010 (day -17) is the first day for which we have order-level data on the PHLX. Panel B reports the results from using a 57-day event window, the 17 days prior to August 18, 2010 and the 40 days after. The variable of interest, *Post,* is a categorical variable set equal to one if the observation is in the post-event period, and zero for the pre-event period. We exclude orders on the event date. All remaining independent variables are defined in the text (see pg. 21). Test-statistics are reported in parentheses and are obtained from standard errors clustered by underlying stock. ***, **, and * denote statistical significance at the 0.01, 0.05, and 0.10 levels, respectively.

Panel A. Event Period [-17, 25] 07/26/2010 - 09/23/2010

	Cancel Rate		Fill Rate		Fill Speed (seconds)		# Orders (100s)	
	OLS	Tobit	OLS	Tobit	OLS	Median	OLS	Median
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
Post	-0.068**	-0.064**	0.047**	0.075**	42.347	68.931**	-2.136***	-0.691*
	(-2.512)	(-2.017)	(2.299)	(2.016)	(1.568)	(1.989)	(-3.324)	(-1.800)
# Orders (100s)	0.005**	0.005**	-0.003***	-0.003*	-8.515**	-1.678		
	(2.650)	(2.449)	(-2.898)	(-1.907)	(-2.163)	(-0.686)		
Limit Price	0.001***	0.002***	-0.001***	-0.005***	-24.607***	-8.959***	0.001	0.013
	(3.313)	(3.827)	(-3.478)	(-2.620)	(-3.607)	(-4.163)	(0.110)	(1.619)
Order Size (# contracts)	-0.001***	-0.001***	0.000	0.000	3.917***	4.941***	-0.004	-0.001
	(-2.877)	(-2.950)	(0.590)	(0.787)	(11.439)	(18.233)	(-1.200)	(-1.142)
Underlying Size	-0.022**	-0.034***	0.009	0.022	109.153*	62.875***	1.110**	0.145**
	(-2.114)	(-2.671)	(1.251)	(1.492)	(1.800)	(3.250)	(2.331)	(2.389)
Call	-0.081***	-0.103***	0.044***	0.093***	181.117***	179.277***	-0.652***	-0.248**
	(-4.994)	(-5.105)	(5.778)	(7.802)	(5.352)	(6.930)	(-3.369)	(-2.523)
Money 1	0.095***	0.126***	-0.084***	-0.206***	189.498	-7.715	-1.746	-0.043
	(4.586)	(4.857)	(-7.960)	(-8.497)	(1.257)	(-0.152)	(-1.636)	(-0.249)
Money 2	0.118***	0.139***	-0.086***	-0.179***	239.231***	-32.830	-2.270*	-0.227
	(7.008)	(7.107)	(-8.526)	(-11.383)	(3.885)	(-1.221)	(-1.932)	(-0.915)
Expiry Date	0.037***	0.074***	-0.009	-0.012	-197.337**	-116.908***	1.023***	0.272
	(2.767)	(3.410)	(-0.758)	(-0.532)	(-2.032)	(-3.691)	(4.633)	(0.986)
Days Expire	-0.000	0.000	-0.000	0.000	1.359**	0.499	-0.013***	-0.002**
	(-0.421)	(0.128)	(-0.032)	(0.329)	(2.261)	(1.225)	(-2.707)	(-2.243)
Constant	0.947***	1.021***	0.061	-0.067	451.995***	-28.475	2.373**	0.918*
	(20.050)	(17.819)	(1.609)	(-0.830)	(2.772)	(-0.581)	(2.491)	(1.672)
R^2	0.241	0.391	0.188	0.412	0.062	0.050	0.050	0.023
N	31796	31796	31796	31796	15490	15490	31796	31796

Table 4 – *Continued*

Panel B. Event Period [-17, 40] 07/26/2010 - 10/14/2010								
	Cancel Rate		Fill Rate		Fill Speed (seconds)		# Orders (100s)	
	OLS	Tobit	OLS	Tobit	OLS	Median	OLS	Median
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
Post	-0.083**	-0.081**	0.061**	0.100**	-30.716	51.425	-2.507***	-0.811*
	(-2.541)	(-1.997)	(2.548)	(2.352)	(-1.358)	(1.183)	(-3.518)	(-1.832)
# Orders (100s)	0.006***	0.006***	-0.004***	-0.003**	-8.974**	-2.617		
	(2.916)	(2.692)	(-3.140)	(-2.037)	(-2.322)	(-0.680)		
Limit Price	0.001***	0.002***	-0.001***	-0.004***	-20.408***	-7.538***	0.003	0.011*
	(3.795)	(4.467)	(-4.305)	(-2.936)	(-3.342)	(-5.076)	(0.251)	(1.817)
Order Size (# contracts)	-0.001***	-0.001***	0.000	0.000	4.026***	4.756***	-0.005	-0.001
	(-3.322)	(-3.339)	(0.450)	(0.762)	(11.391)	(4.534)	(-1.457)	(-1.059)
Underlying Size	-0.029**	-0.042***	0.014	0.029*	113.774**	74.226***	0.864**	0.076**
	(-2.513)	(-2.916)	(1.508)	(1.711)	(2.056)	(4.175)	(2.224)	(2.261)
Call	-0.083***	-0.107***	0.047***	0.095***	160.111***	168.154***	-0.671***	-0.170***
	(-5.612)	(-5.773)	(6.388)	(7.849)	(5.228)	(5.825)	(-4.097)	(-2.689)
Money 1	0.099***	0.134***	-0.090***	-0.208***	171.703	-30.693	-1.341	0.018
	(4.574)	(4.914)	(-8.892)	(-8.846)	(1.148)	(-0.567)	(-1.593)	(0.211)
Money 2	0.119***	0.142***	-0.088***	-0.176***	180.806***	-46.892**	-1.795*	-0.094
	(8.389)	(8.433)	(-10.358)	(-12.138)	(3.175)	(-2.081)	(-1.914)	(-0.655)
Expiry Date	0.050***	0.085***	-0.021	-0.034	-182.538**	-114.555***	1.337***	0.295
	(3.046)	(3.448)	(-1.515)	(-1.364)	(-2.223)	(-2.985)	(4.139)	(1.364)
Days Expire	0.000	0.000	-0.000	-0.000	1.124**	0.244	-0.010***	-0.001***
	(0.124)	(0.613)	(-0.672)	(-0.210)	(2.411)	(0.576)	(-2.991)	(-2.900)
Constant	0.968***	1.051***	0.049	-0.099	443.741***	-55.104	3.018***	1.086**
	(16.685)	(14.417)	(1.058)	(-1.089)	(3.214)	(-1.041)	(3.613)	(2.015)
R^2	0.247	0.354	0.196	0.378	0.063	0.052	0.050	0.027
N	39555	39555	39555	39555	20773	20773	39555	39555

Table 5

Marginal Impact of Order Cancellation Fee on Execution Quality – Difference in Difference

This table reports the results of estimating the following equation for PHLX orders around the August 18, 2010 order cancellation fee change on the PHLX.

$$Order\ Execution\ Quality_{i,t}^{j} = \alpha + \beta_1 Phlx \times Post_{i,t} + \beta_2 Phlx_i + \beta_3 Post_t + \beta_4 \#\ Orders_{i,t} + \beta_5 Limit\ Price_{i,t} + \beta_6 Order\ Size_{i,t} + \beta_7 Underlying\ Size_{i,t} + \beta_8 Call_{i,t} + \beta_9 Money1_{i,t} + \beta_{10} Money2_{i,t} + \beta_{11} Expiry + \beta_{12} Days\ Expire_{i,t} + \varepsilon_{i,t},\ \ j \in \{order\ volume, fill\ rate, cancel\ rate, fill\ speed.$$

Panel A reports the results from using a 42-day event window, the 17 days prior to August 18, 2010 and the 25 days after. July, 26, 2010 (day -17) is the first day for which we have order-level data on the PHLX. Panel B reports the results from using a 57-day event window, the 17 days prior to August 18, 2010 and the 40 days after. *Phlx* is an indicator variable set equal to one if the order originated on the PHLX, and zero for orders on the NOM. *Post* is a categorical variable set equal to one if the observation is in the post-event period, and zero for the pre-event period. We exclude orders on the event date. All remaining independent variables are defined in the text (see pg. 21). Test-statistics are reported in parentheses and are obtained from standard errors clustered by underlying stock. ***, **, and * denote statistical significance at the 0.01, 0.05, and 0.10 levels, respectively.

Panel A. Event Period [-17, 25] 07/26/2010 - 09/23/2010

	Cancel Rate		Fill Rate		Fill Speed (seconds)		# Orders (100s)	
	OLS	Tobit	OLS	Tobit	OLS	Median	OLS	Median
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
Phlx * Post	-0.107***	-0.067**	0.073***	0.079***	14.403	33.344	11.499	-4.845
	(-3.985)	(-2.232)	(3.689)	(2.796)	(0.330)	(1.011)	(0.701)	(-0.440)
Phlx	-0.087***	-0.182***	0.046***	0.060**	127.502***	48.202	-158.742***	-54.966***
	(-3.149)	(-5.850)	(2.950)	(2.550)	(3.008)	(1.097)	(-8.338)	(-5.124)
Post	0.014***	-0.013***	-0.009***	0.004	61.537	49.862***	-16.622	3.570
	(7.496)	(-2.576)	(-7.652)	(0.824)	(1.215)	(3.900)	(-1.054)	(0.331)
# Orders (100s)	0.000***	-0.000***	-0.000***	0.000***	-0.400**	-0.010		
	(3.055)	(-3.704)	(-6.626)	(3.012)	(-2.671)	(-0.241)		
Limit Price	0.001***	0.002***	-0.000***	-0.003***	-19.347***	-7.218***	-0.070	0.007
	(3.136)	(4.197)	(-3.220)	(-3.079)	(-3.497)	(-4.848)	(-0.533)	(0.931)
Order Size (# contracts)	-0.000***	-0.000***	0.000	0.000	5.739***	6.586***	-0.238**	-0.034**
	(-2.684)	(-2.663)	(0.555)	(0.655)	(11.194)	(8.711)	(-2.298)	(-2.509)
Underlying Size	-0.008	-0.017*	0.003	0.011	74.283	36.180**	19.357**	0.769**
	(-1.520)	(-1.953)	(0.854)	(1.259)	(1.522)	(2.019)	(2.350)	(2.487)
Call	-0.042***	-0.065***	0.023***	0.050***	200.908***	131.220***	7.258*	-0.228
	(-5.011)	(-5.382)	(5.897)	(7.262)	(4.503)	(5.474)	(1.893)	(-0.692)
Money 1	0.044***	0.095***	-0.040***	-0.110***	209.524**	5.494	-51.841***	-3.375**
	(4.302)	(6.463)	(-7.765)	(-8.930)	(2.299)	(0.188)	(-3.108)	(-2.389)
Money 2	0.054***	0.091***	-0.040***	-0.090***	246.580***	10.375	-53.028***	-3.844***
	(6.372)	(8.674)	(-8.015)	(-11.692)	(5.298)	(0.452)	(-3.080)	(-2.988)
Expiry Date	0.018***	0.041***	-0.005	-0.011	-143.144**	-38.399	38.160**	0.111
	(2.850)	(3.107)	(-0.779)	(-0.894)	(-2.202)	(-1.537)	(2.657)	(0.230)
Days Expire	-0.000	-0.000	0.000	0.000	1.348***	0.557*	-0.356***	-0.041***
	(-0.751)	(-0.259)	(0.318)	(0.477)	(3.140)	(1.831)	(-3.567)	(-3.351)
Constant	1.021***	1.149***	0.005	-0.082**	316.403**	-18.691	127.701***	58.445***
	(41.042)	(26.216)	(0.311)	(-1.990)	(2.331)	(-0.314)	(4.568)	(5.263)
R^2	0.253	0.875	0.205	1.107	0.089	0.075	0.196	0.165
N	63592	63592	63592	63592	34166	34166	63592	63592

Table 5 – *Continued*

Panel B. Event Period [-17, 40] 07/26/2010 - 10/14/2010	Cancel Rate		Fill Rate		Fill Speed (seconds)		# Orders (100s)	
	OLS	Tobit	OLS	Tobit	OLS	Median	OLS	Median
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
Phlx * Post	-0.128***	-0.083**	0.090***	0.101***	-36.285	16.230	7.502	-4.106
	(-3.956)	(-2.348)	(3.913)	(3.140)	(-0.809)	(0.425)	(0.342)	(-0.359)
Phlx	-0.087***	-0.182***	0.046***	0.058**	127.407***	47.436	-158.692***	-55.032***
	(-3.111)	(-6.067)	(2.907)	(2.397)	(2.980)	(1.012)	(-8.339)	(-5.193)
Post	0.015***	-0.018***	-0.010***	0.007	41.826	53.032***	-11.607	2.646
	(5.682)	(-2.882)	(-5.924)	(1.135)	(1.120)	(3.691)	(-0.541)	(0.238)
# Orders (100s)	0.000***	-0.000***	-0.000***	0.000**	-0.409***	-0.029		
	(3.103)	(-2.835)	(-7.104)	(2.456)	(-2.700)	(-0.759)		
Limit Price	0.001***	0.002***	-0.000***	-0.003***	-16.549***	-6.330***	-0.047	0.006
	(3.609)	(4.710)	(-3.978)	(-3.221)	(-3.182)	(-4.045)	(-0.301)	(0.743)
Order Size (# contracts)	-0.000***	-0.000***	0.000	0.000	5.722***	6.469***	-0.253**	-0.030**
	(-2.942)	(-2.876)	(0.437)	(0.617)	(13.329)	(11.725)	(-2.455)	(-2.562)
Underlying Size	-0.012*	-0.022**	0.006	0.015	86.255*	46.247***	21.964**	0.714**
	(-1.965)	(-2.218)	(1.216)	(1.540)	(1.862)	(2.662)	(2.280)	(2.462)
Call	-0.044***	-0.068***	0.025***	0.052***	178.210***	126.844***	7.006	-0.255
	(-5.770)	(-6.128)	(6.746)	(7.656)	(5.074)	(5.511)	(1.661)	(-0.927)
Money 1	0.047***	0.099***	-0.043***	-0.113***	189.968*	-7.352	-49.300***	-2.521**
	(4.355)	(6.382)	(-8.707)	(-9.288)	(1.989)	(-0.227)	(-3.164)	(-2.357)
Money 2	0.055***	0.091***	-0.042***	-0.090***	210.793***	5.019	-48.474***	-2.858***
	(7.550)	(9.458)	(-9.736)	(-11.962)	(5.055)	(0.220)	(-3.248)	(-2.794)
Expiry Date	0.026***	0.049***	-0.011	-0.022	-152.562**	-51.582**	41.682***	-0.096
	(3.219)	(3.239)	(-1.635)	(-1.610)	(-2.677)	(-2.350)	(2.833)	(-0.233)
Days Expire	-0.000	0.000	-0.000	-0.000	1.221***	0.422	-0.333***	-0.034***
	(-0.186)	(0.211)	(-0.322)	(-0.032)	(3.363)	(1.340)	(-3.449)	(-3.481)
Constant	1.034***	1.172***	-0.003	-0.103**	279.697**	-52.415	113.665***	57.754***
	(37.781)	(24.596)	(-0.169)	(-2.288)	(2.328)	(-0.862)	(3.660)	(5.310)
R^2	0.286	0.792	0.238	0.999	0.089	0.077	0.192	0.158
N	79110	79110	79110	79110	45119	45119	79110	79110

Table 6
Order Cancellation Rates – Time to Cancel

This table provides the distribution of order cancellation rates on both the PHLX and the NOM by the time of order submission to cancellation. The sample time period is taken after the structural change on the PHLX, i.e. September 15, 2010 to October 15, 2010. We mean cancellation rates for different cancel time buckets. We test for differences in means using simple t-tests. ***, **, and * denote statistical significance at the 0.01, 0.05, and 0.10 levels, respectively.

Time to Cancellation	*Panel A. PHLX*	*Panel B. NOM*	*Panel C. Difference*	
(seconds)	PHLX	NOM	(PHLX - NOM)	(t-stat)
0-1	0.9383	0.9998	-0.0616**	(2.46)
2-10	0.9503	0.9993	-0.0489***	(14.96)
11-40	0.9333	0.9988	-0.0656***	(29.30)
41-70	0.8854	0.9983	-0.1129***	(23.77)
71-100	0.8607	0.9975	-0.1368***	(17.74)
101-200	0.7699	0.9967	-0.2269***	(31.11)
201-300	0.6637	0.9951	-0.3314***	(28.53)
301-400	0.6094	0.9928	-0.3834***	(24.44)
401-500	0.5866	0.9909	-0.4043***	(18.97)
501-600	0.6033	0.9926	-0.3894***	(14.75)
601-700	0.5965	0.9924	-0.3959***	(13.71)
701-800	0.5647	0.9830	-0.4182***	(9.64)
801-900	0.5380	0.9933	-0.4552***	(10.00)
901-1000	0.5275	0.9867	-0.4592***	(9.22)
>1000	0.4685	0.9821	-0.5136***	(25.07)

Table 7
Order Cancellation Rates – Calls vs. Puts

This table provides mean and median order cancellation rates disaggregated by option type, calls versus puts. The sample time period is taken after the structural break on the PHLX, i.e. September 15, 2010 through October 15, 2010. Panel A shows average daily order cancellation rates for options on both the PHLX and NOM. Panel B reports the average number of orders submitted to a particular exchange during regular trading hours. Simple t-tests are used to calculate the difference in means. ***, **, and * denote statistical significance at the 0.01, 0.05, and 0.10 levels, respectively.

Panel A. Order Cancellation Rates

	Call	Put	Difference (Call - Put)
PHLX	0.7075	0.7987	-0.0912***
			(17.93)
NOM	0.9975	0.9984	-0.0010***
			(9.22)
Difference (PHLX - NOM)	-0.2899***	-0.1997***	
	(90.94)	(54.54)	

Panel B. Total Orders (100s)

	Call	Put	Put/Call Ratio
PHLX	11571	9155	0.791
NOM	1178873	729554	0.619

Table 8

Order Cancellation Rates – Option Moneyness

This table provides daily order cancellation rates disaggregated by options moneyness and option type (put or call). The sample time period is taken after the structural change on the PHLX, i.e. September 15, 2010 to October 15, 2010. Panel A shows order cancellation rates for three ranges of option moneyness, in-the-money, near-the-money, and out-of-the-money. We define moneyness using the S/X ratio, which is the underlying stock price divided by the option strike price. A call (put) option is said to be in-the-money (out-of-the-money) if the S/X ratio is greater (less) than one. An option is said to be near-the-money if the S/X ratio is between 0.9 and 1.1. Panel B reports average daily order cancellation rates for ten different ranges of option moneyness. We test for differences in means using simple t-tests. ***, **, and * denote statistical significance at the 0.01, 0.05, and 0.10 levels, respectively.

Panel A. Order Cancellations by Option Moneyness

	Call Options			Put Options		
	PHLX	NOM	Difference PHLX - NOM	PHLX	NOM	Difference PHLX - NOM
[1] S/X < 0.9	0.7304	0.9960	-0.2657***	0.9776	0.9994	-0.0217***
			(27.95)			(5.30)
[2] 0.9 <= S/X <= 1.1	0.6702	0.9974	-0.3273***	0.7612	0.9985	-0.2374***
			(84.22)			(51.05)
[3] S/X > 1.1	0.8345	0.9985	-0.1640***	0.8342	0.9977	-0.1635***
			(21.99)			(21.80)
Differences:						
[1] - [2]	0.0602***	-0.0014***		0.2165***	0.0008***	
	(6.10)	(6.35)		(17.50)	(5.43)	
[1] - [3]	-0.1041***	-0.0025***		0.1434***	0.0017***	
	(8.73)	(7.17)		(12.21)	(4.63)	
[2] - [3]	-0.1643***	-0.0011***		-0.0730***	0.0009***	
	(19.31)	(6.27)		(7.99)	(5.13)	

Panel B. Cancellation Rates - Option Moneyness cont.

	Call Options			Put Options		
Options Moneyness:	PHLX	NOM	Difference	PHLX	NOM	Difference
0.00 < S/X <= 0.85	0.7068	0.9950	-0.2882***	0.9776	0.9992	-0.0216***
0.85 < S/X <= 0.90	0.7584	0.9972	-0.2388***	0.9778	0.9995	-0.0218***
0.90 < S/X <= 0.95	0.6901	0.9972	-0.3071***	0.9547	0.9997	-0.0450***
0.95 < S/X <= 1.00	0.5949	0.9967	-0.4019***	0.7561	0.9990	-0.2428***
1.00 < S/X <= 1.05	0.6768	0.9978	-0.3211***	0.6889	0.9980	-0.3092***
1.05 < S/X <= 1.10	0.7948	0.9986	-0.2038***	0.7473	0.9981	-0.2507***
1.10 < S/X <= 1.15	0.8282	0.9991	-0.1709***	0.8103	0.9977	-0.1874***
1.15 < S/X <= 1.20	0.8092	0.9983	-0.1891***	0.8335	0.9979	-0.1644***
1.20 < S/X <= 1.30	0.7820	0.9984	-0.2165***	0.8256	0.9977	-0.1721***
S/X > 1.30	0.8851	0.9980	-0.1129***	0.8813	0.9974	-0.1161***

Table 9
Order Cancellation Rates – Time to Expiration

This table provides average daily order cancellation rates disaggregated by time to expiration and exchange. Panel A reports differences in means for order cancellation rates on option expiration days, relative to those on non-expiration days. Simple t-tests are used to calculate the difference in means. Panel B reports mean cancellations rates separated by exchange, for different ranges of time-to-expiration, in terms of number of days. ***, **, and * denote statistical significance at the 0.01, 0.05, and 0.10 levels, respectively

Panel A. Order Cancellations - Expiration Days vs. Non-Expiration Days

	PHLX	NOM	Difference (PHLX - NOM)
Expiration Days	0.7831	0.9972	-0.2141***
			(20.00)
Non-Expiration Days	0.7420	0.9979	-0.2559***
			(98.81)
Difference (Expiration - Non-Expiration)	0.0411***	-0.0007***	
	(3.34)	(2.85)	

Panel B. Cancellation Rates by Days-to-Expiration

Days-to-Expiration:	PHLX	NOM	Difference (PHLX - NOM)
[0-1)	0.7831	0.9972	-0.2141***
[1-2)	0.6991	0.9973	-0.2982***
[2-10)	0.6952	0.9973	-0.3021***
[10-25)	0.6624	0.9985	-0.3361***
[25-50)	0.8119	0.9988	-0.1869***
[50-75)	0.8056	0.9979	-0.1923***
[75-100)	0.7566	0.9971	-0.2405***
[100-125)	0.6496	0.9972	-0.3476***
>125	0.7220	0.9944	-0.2724***

Table 10

Order Cancellation Rates – Option Features

This table reports the results of estimating the following equation on a sample of limit orders submitted to the PHLX and the NOM. The sample time period ranges from September 15, 2010 to October 15, 2010.

$$Order\ Cancellation\ Rate_{i.t} = \alpha + \delta_t + \beta_1 Phlx_i + \beta_2 Cancel\ Speed_{i,t} + \beta_3 Call_{i,t} + \beta_4 In - the - Money_{i,t} + \beta_5 Expiry\ Date + \beta_6 Days\ Expire_{i,t} + \beta_7 \#Orders_{i,t} + \beta_8 Limit\ Price_{i,t} + \beta_9 Order\ Size_{i,t} + \varepsilon_{i,t}$$

The dependent variable is daily order cancellation rates, estimated as the number of limit orders canceled divided by the total of limit orders submitted. *Phlx* is an indicator variable set equal to one if an order is routed to the PHLX, and zero for the NOM. *Cancel Speed* is the number of seconds between order submission and cancellation. We include day fixed effects to control for time-series variation. All remaining independent variables are defined in the text (see pg. 21). Test-statistics are reported in parentheses and are obtained from standard errors clustered by underlying stock. ***, **, and * denote statistical significance at the 0.01, 0.05, and 0.10 levels, respectively.

	OLS		Tobit	
	[1]	[2]	[3]	[4]
Phlx	-0.1902***	-0.1904***	-0.2204***	-0.2212***
	(-8.09)	(-8.12)	(-9.90)	(-10.06)
Cancel Speed (seconds)	-0.0001***	-0.0001***	-0.0001***	-0.0001***
	(-12.53)	(-12.58)	(-11.70)	(-11.76)
Call	-0.0365***	-0.0358***	-0.0608***	-0.0598***
	(-8.92)	(-9.10)	(-10.60)	(-10.52)
In-the-Money	0.0299***	0.0304***	0.0537***	0.0545***
	(6.78)	(7.40)	(6.34)	(6.60)
Expiry Date	0.0273**	0.0316**	0.0266	0.0429***
	(2.18)	(2.44)	(1.22)	(2.60)
Days Expire	0.0001***	0.0001***	0.0003***	0.0003***
	(3.00)	(3.09)	(2.84)	(2.90)
# Orders (1000s)	-0.0002***	-0.0002***	-0.0009***	-0.0009***
	(-3.92)	(-3.10)	(-3.37)	(-3.17)
Limit Price	0.0002*	0.0002	0.0007***	0.0006**
	(1.73)	(1.04)	(2.82)	(2.48)
Order Size (# contracts)	-0.0001	-0.0001	-0.0001	-0.0001
	(-0.55)	(-0.57)	(-0.90)	(-0.93)
Constant	1.0105***	1.0182***	1.0672***	1.0839***
	(279.94)	(110.72)	(101.81)	(61.90)
Day FE	No	Yes	No	Yes
Adj. R^2	0.4977	0.5002	0.9437	0.9556
N (all specifications)		24,453		

Table 11

Differential Order Cancellation Rates – PHLX vs. NOM

This table reports the results of estimating the following equation on a sample of limit orders submitted to the PHLX and the NOM. The sample time period ranges from September 15, 2010 to October 15, 2010.

$$Order\ Cancellation\ Rate^{PHLX} - Order\ Cancellation\ Rate^{NOM} = \alpha_0 + \sum \alpha_i \left(Y_i^{PHLX} - Y_i^{NOM}\right) + \sum \beta_j X_j + \varepsilon$$

The dependent variable is the difference in daily order cancellation rates between the PHLX and the NOM for each option series. Y_i (i = 1 to 4) represents one of four limit order characteristics, number of orders submitted, limit price, order size, and cancellation speed. X_j (j = 1 to 5) represents one of five option characteristics: option type (call or put), in-the-money options, out-of-the-money options, option expiration, and days to expiration. *Cancel Speed* is the number of seconds between order submission and cancellation. We include day fixed effects to control for time-series variation. All remaining independent variables are defined in the text (see pg. 21). Test-statistics are reported in parentheses and are obtained from standard errors clustered by underlying stock. ***, **, and * denote statistical significance at the 0.01, 0.05, and 0.10 levels, respectively.

	Order Cancellation Rates	
	[1]	[2]
Constant	-0.1606***	-0.1511***
	(-6.00)	(-5.17)
# Orders (100s)	0.0001***	0.0001***
	(4.41)	(4.37)
Limit Price	-0.0007	-0.0007
	(-0.46)	(-0.60)
Order Size (# contracts)	-0.0003**	-0.0003**
	(-2.50)	(-2.37)
Cancel Speed	-0.0001***	-0.0001***
	(-16.27)	(-16.27)
Call	-0.0563***	-0.0556***
	(-6.82)	(-6.66)
Money 1	0.0933***	0.0905***
	(5.42)	(5.72)
Money 2	0.0850***	0.0821***
	(4.33)	(3.89)
Expiry Date	0.0729***	0.0776***
	(3.15)	(3.37)
Days Expire	-0.0000	-0.0000
	(-0.46)	(-0.56)
Day FE	No	Yes
Adj. R^2	0.3423	0.3490
N	12,210	12,210

Figure 1

Order Execution Quality and Cancellation Fees – Event Study

Figure 1 plots average execution quality (order cancellation rates, order fill rates, order fill speeds, and order volume) over a 41-day event window [-15, 25] around August 18, 2010 when the PHLX changed its cancellation fee policy. Panel A plots order cancellation rates, measured as the number of orders canceled divided by the total number of orders submitted for a particular options series. Panel B plots order fill rates, or the sum of orders filled divided by total orders submitted. Panel C plots order fill speeds, measured as the number of seconds between order submission and complete fill. Panel D plots the daily average number of orders submitted. The solid dark line represents execution quality for orders submitted to the PHLX, while the dotted lighter line represents execution quality for orders submitted to the NOM. We perform a daily match between options that trade on the PHLX and the NOM.

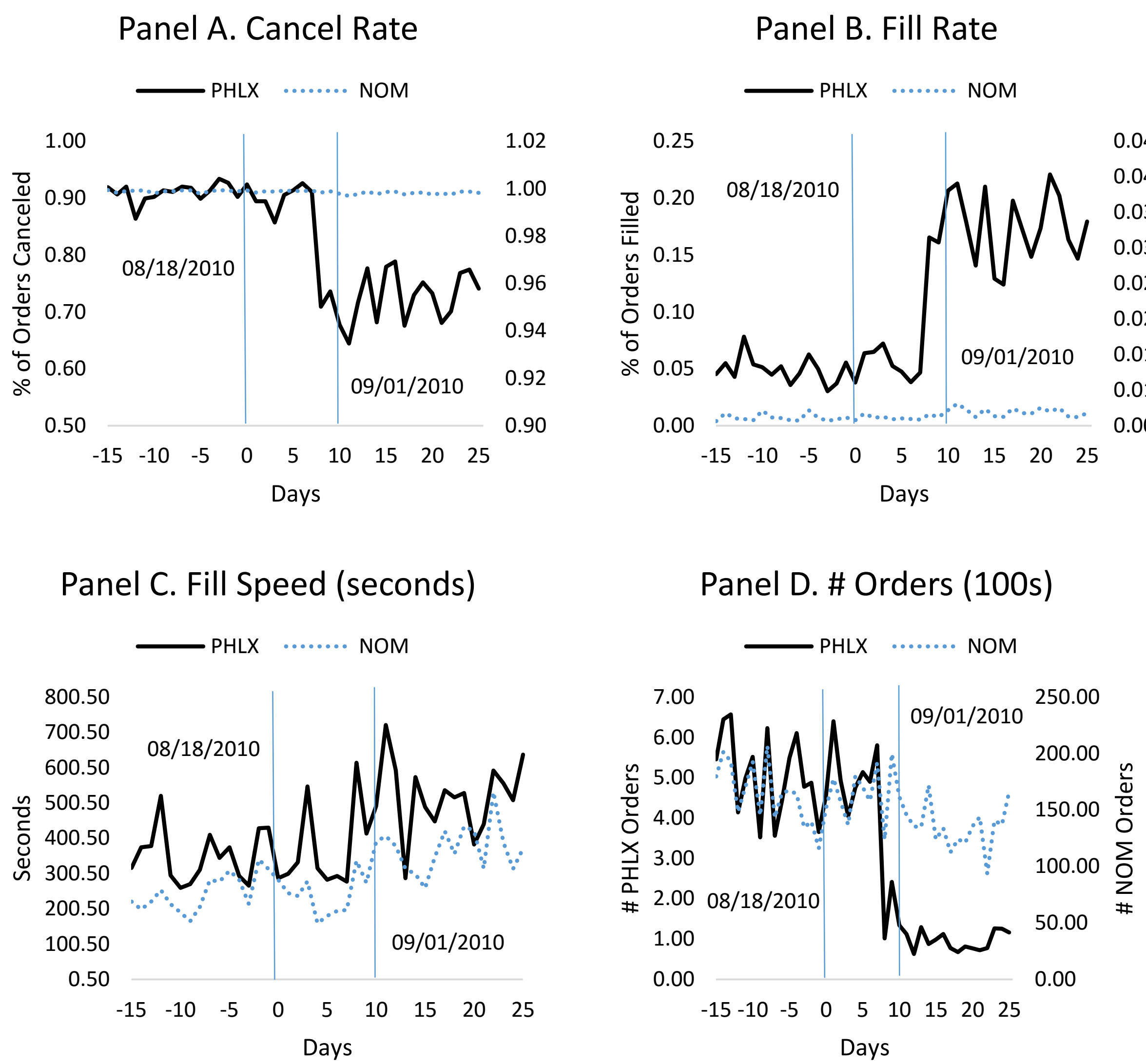


Figure 2
Order Cancellation Rates – Time-to-Cancellation

Figure 2 plots daily average order cancellation rates for options on both the PHLX and the NOM, disaggregated by the passage of clocktime from order submission to cancellation. The time-to-cancellation is measured in seconds. The sample time period ranges from September 15, 2010 to October 15, 2010, as to avoid biasing the results due to the cancellation fee policy on the PHLX. The solid dark line represents cancellation rates for orders submitted to the PHLX, while the dotted lighter line represents cancellation rates for orders submitted to the NOM. We perform a daily match between options that trade on the PHLX and the NOM.

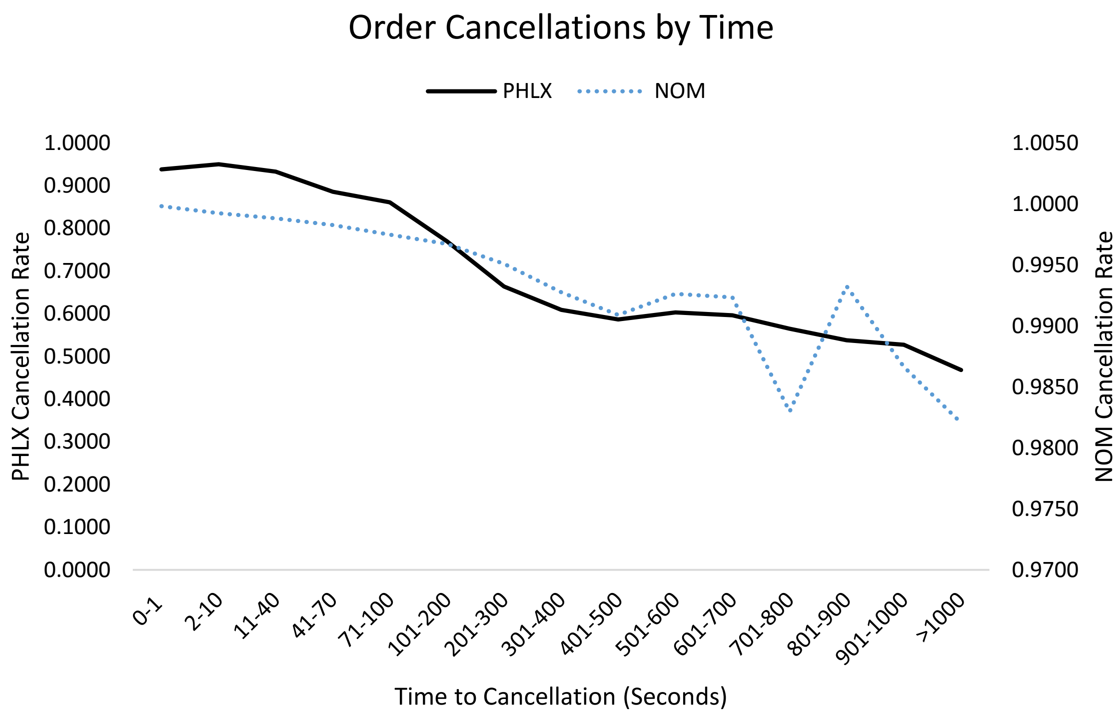
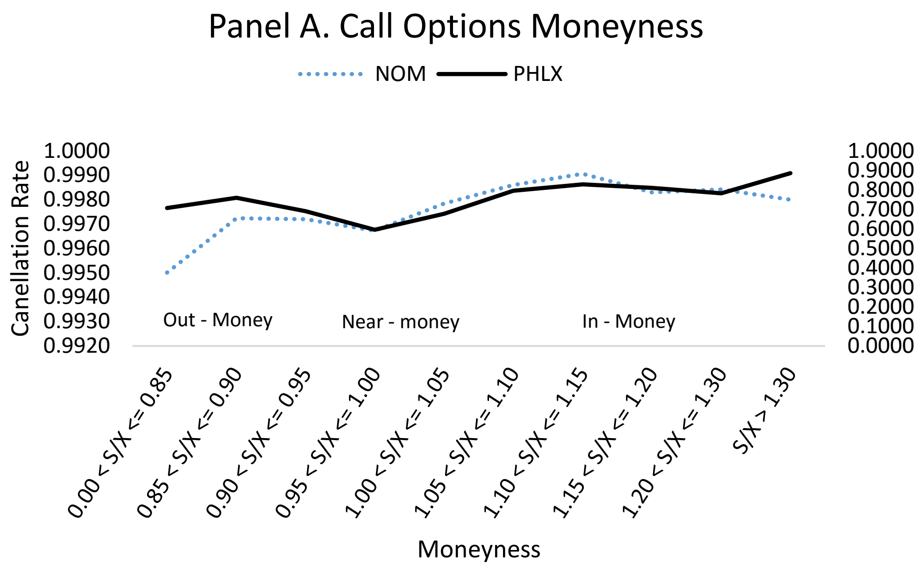


Figure 3
Order Cancellation Rates – Option Moneyness

Figure 3 plots daily average order cancellation rates for options on both the PHLX and the NOM, disaggregated by option type (call or put) and option moneyness. Option moneyness is valued as the ratio of the underlying stock price to the option strike price, S/X. A call (put) option is said to be in-the-money (out-of-the-money) if the S/X ratio is greater (less) than one. An option is said to be near-the-money if the S/X ratio is between 0.9 and 1.1. The sample time period ranges from September 15, 2010 to October 15, 2010. The solid dark line represents cancellation rates for orders submitted to the PHLX, while the dotted lighter line represents cancellation rates for orders submitted to the NOM. We perform a daily match between options that trade on the PHLX and the NOM.



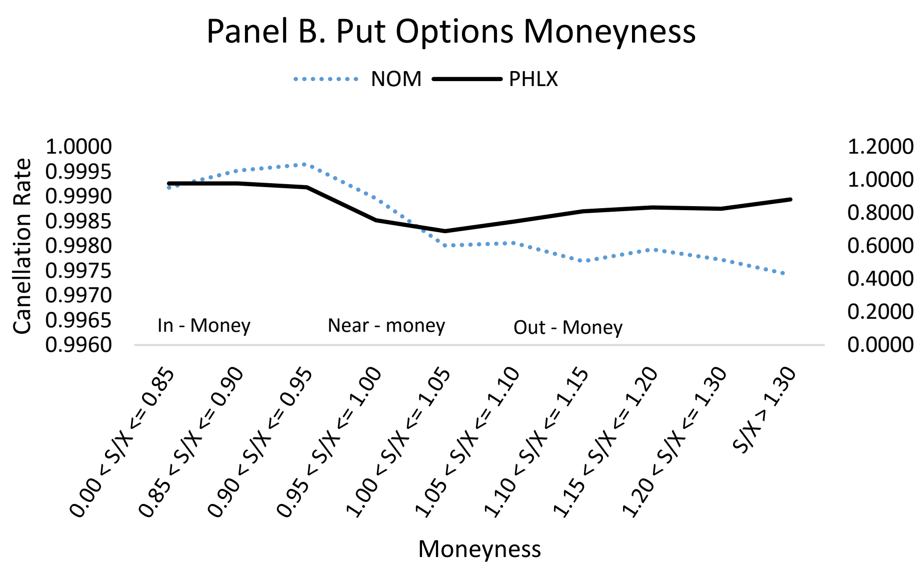


Figure 4
Order Cancellation Rates – Time to Expiration

Figure 4 plots daily average order cancellation rates on the vertical axes and the days to option expiration on the horizontal axis. Order cancellation rates are calculated as the total number of orders canceled divided by the number of orders submitted. The number of days until expiration are calculated as the total number of weekdays from the date of order submission to the expiration date. The sample time period ranges from September 15, 2010 to October 15, 2010. The solid dark line represents cancellation rates for orders submitted to the PHLX, while the dotted lighter line represents cancellation rates for orders submitted to the NOM. We perform a daily match between options that trade on the PHLX and the NOM.