The Information Content of Trading Activity and Quote Changes: Evidence from VIX Options

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ABSTRACT

We investigate the informational role of trading volume and quote changes in VIX options, along with their predictability on future movements in the index, based upon a high-frequency framework. Our results reveal that whilst volume imbalances convey no significant predictive information, quote changes in VIX options, particularly call options, can significantly predict changes in the index, with this predictive power being more pronounced for VIX calls around monetary policy announcement periods. Our findings imply that when acting on market-wide information, traders in VIX options may prefer to submit limit orders, as opposed to market orders, leading to such information being contained in the quote changes in VIX options. We also observe the existence of inventory control effects in the VIX options market. The information effects of quote revisions in the VIX options market are found to be robust to both intraday patterns in trading activity and alternative measures of trading volume.

Keywords: VIX index; VIX options; Trading activity; Quote changes.

JEL Classification: G12, G14.

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We investigate the informational role of trading volume and quote changes in VIX options, along with their predictability on future movements in the index, based upon a high-frequency framework. Our results reveal that whilst volume imbalances convey no significant predictive information, quote changes in VIX options, particularly call options, can significantly predict changes in the index, with this predictive power being more pronounced for VIX calls around monetary policy announcement periods. Our findings imply that when acting on market-wide information, traders in VIX options may prefer to submit limit orders, as opposed to market orders, leading to such information being contained in the quote changes in VIX options. We also observe the existence of inventory control effects in the VIX options market. The information effects of quote revisions in the VIX options market are found to be robust to both intraday patterns in trading activity and alternative measures of trading volume.

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1. INTRODUCTION

In a complete market economy featuring both primitive assets and options on those primitive assets, options trading should convey no information whatsoever on future movements in the price of the underlying asset; however, with the existence of trading friction within the financial market, investors may choose to initiate trades in the derivatives market, from which we can infer that the derivatives market may be capable of processing new information more rapidly than the spot market.

In the sequential trading model of Easley, O'Hara and Srinivas (1998),[1] it is argued that the depth or liquidity of both the options market and the underlying stock will affect the extent of informed trading within the options market.[2] In a more recent study involving the use of a multi-market asymmetric information model, Johnson and So (2012) found that the presence of short-sales costs in the underlying asset market tended to induce a negative relationship between relative trading activity and future price movements in the underlying asset.[3]

Based upon the notion of informed trading in the options markets,[4] there are at least two approaches that are commonly used in the options literature for measuring

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[1] Traders can choose to act on their information in either the options market or the underlying asset.

[2] Chakravarty, Gulen and Mayhew (2004) provided empirical evidence to show that stock option trading contributes to price discovery of the underlying asset depending on the relative bid-ask spread.

[3] Specifically, 'relative trading activity' is the trading volume in a derivative relative to the trading volume in the underlying asset.

[4] The notion can be traced back to Black (1975), who argued that informed traders choose to realize their profits in the options markets, as opposed to the underlying asset markets, essentially because of the higher leverage and lower transaction costs.

information content. Firstly, trading volume in the options market has been found to be a useful variable for extracting information on future price movements in the underlying asset, such as volume ratio,[5] and directional volume.[6] Secondly, option prices are widely regarded within the extant literature as an alternative outcome of information-based trading; indeed, a number of studies have used option prices as the means of examining the information contained in the options market,[7,8] whilst an alternative approach, one which adopted in the seminal works of Cremers and Weinbaum (2010) and Xing, Zhang and Zhao (2010), is to use implied volatility, which has a one-to-one correlation with option prices.

The leading informational role of both option trades and quote changes may be related to the order submission behavior of investors, since several studies within the market microstructure literature have provided theoretical models to reflect the essential tradeoff between market orders (which demand immediacy at the best available price) and limit orders (which are executed only when a counterparty meets

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[5] Pan and Poteshman (2006) constructed put-call volume ratios using new buyer-initiated volume, whilst the volume ratio of Roll, Schwartz and Subrahmanyam (2010) measured the ratio of the daily option volume to the corresponding stock volume.

[6] Easley et al. (1998) and Cao, Chen and Griffin (2005) used trade classification algorithms to classify the motivation behind a trade, essentially because signed volume is found to be more informative than raw trading volume.

[7] Examples include Manaster and Rendleman (1982), Chan, Chung and Fong (2002) and Muravyev, Pearson and Broussard (2013). The empirical results of Muravyev et al. (2013) revealed that option quotes contained no information on future stock prices that was not already publicly available.

[8] Chung, Tsai, Wang, and Weng (2011) utilized market prices of VIX call and put options to obtain implied VIX index, and then concluded that the information recovered from VIX options improves the prediction of returns, volatility, and density in the S&P 500 index.

the limit price), or indeed, between execution uncertainty and transaction costs.[9]

If informed traders have a preference for submitting aggressive market orders, such that their trades are initiated in the options market, then options trading would provide better predictive ability on the future returns of the underlying asset than that provided by changes in option quotes. However, if such investors find that the value of their private information is less than the cost of market orders, they may choose to submit limit orders, or indeed, elect not to trade at all, which thereby provides support for the informational role of option quote changes. Thus, a comparison between the costs of market orders and the value of the private information possessed by informed traders, which is the tradeoff that they are faced with, will determine whether option trades or quote changes have an informational advantage.

Our primary aim in the present study is to extend this line of research by analyzing the informational role of volume imbalances and quote changes in the Chicago Board Options Exchange (CBOE) VIX options market; we examine the predictive ability of these measures on future changes in the VIX index based upon an intraday framework.[10] In addition to our comparison of the information content, we

[9] Please refer to Cohen, Maier, Schwartz and Whitcomb (1981), Kumar and Seppi (1992), Holden and Chakravarty (1995) and Harris (1997).

[10] The CBOE is a floor-based hybrid market in which a significant proportion of trades are executed electronically without intervention by exchange floor members although the majority of the volume is executed manually. The launch of VIX options took place within the CBOE on 24 February 2006; as a result of the increasing demand for practical market risk management, these options have since become the most successful new product launch in the history of the CBOE. The VIX index, which is also referred to as the CBOE volatility index, is compiled using the market prices of S&P 500 index options,

also aim to provide a better understanding of the fundamental economic questions relating to: (i) whether information is embedded in an index options market (such as the VIX options market); and (ii) if such information does exist, how it becomes incorporated into the underlying asset price (such as the VIX index).

The empirical evidence in one particular strand of the extant literature on the existence of information effects in the index options markets is found to be rather contradictory and inconclusive; whilst numerous studies provide support for the notion of embedded information within the index options markets,[11] several other studies have found no confirmatory evidence.[12]

A semi-strong form of market efficiency, as proposed by Fama (1970), suggests that investors will be unable to accrue extraordinary profits based purely upon publicly-available information; however, it is possible for traders to extract profits as a result of trading on this type of market-wide information if they are able to act promptly on the information that is available to them or if they possess superior trading skills, such as that of high-frequency trading firms which are constantly watching for footprints of algorithmically-executed orders.[13]

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with the primary purpose being to provide the market with a measure of expected volatility in the S&P 500 index over the subsequent 30-day period.

[11] Examples include Cho and Engle (1999), Ahn, Kang and Ryu (2008), Kang and Park (2008), Chang, Hsieh and Lai (2009) and Chang, Hsieh and Wang (2010).

[12] See Schlag and Stoll (2005), Pan and Poteshman (2006) and Ryu (2013).

[13] Numerous studies have shown that, unlike most asset returns, which are generally proven to be a random walk, volatility is highly predictable, particularly when using option implied information. See, for example, Christensen and Prabhala (1998), Fleming (1998), Andersen, Bollerslev, Diebold and Ebens

Our distinct contributions in the present study include not only the provision of evidence on the information content of trades and quote changes in VIX options, an issue which has yet to be studied in depth within the related literature, but also an attempt to provide a better understanding of the information linkage between options and their underlying asset markets. Based upon the adoption of the Lee and Ready (1991) algorithm for VIX options, we hypothesize that information effects will be discernible in the VIX options market.[14]

We empirically examine and quantify quote changes and volume imbalances in the VIX index, along with their relevance to changes in the index, based upon a bivariate VAR structure, an approach involving modification of the econometric models of Hasbrouck (1991) and Chan et al. (2002). Our empirical results reveal that lagged quote changes in VIX options have significant predictive ability on changes in the VIX index, whilst volume imbalances in VIX options are found to convey no information on future movements in the index. Furthermore, the informational effect of quote changes in VIX calls is found to be more pronounced around monetary policy announcement days.

The evidence presented in this study on the informational role of quote changes in

(2001), Blair, Poon and Taylor (2001), Ederington and Guan (2002), Andersen, Bollerslev, Diebold and Labys (2003), Jiang and Tian (2005), Giot and Laurent (2007) and Taylor, Yadav and Zhang (2010). Since the focus in the present study is on one of the most important market volatility indices, the VIX index, certain traders may have superior skills which enable them to act swiftly on market-wide information.

[14] Note that, as shown in the study of Wang (2013), daily trading activity in VIX call options contained useful information regarding to future realized volatility of the S&P 500 index.

VIX options implies that when deciding to act on their volatility information, informed traders in the VIX options market may prefer to submit limit orders, as opposed to market orders. Furthermore, the absence of any predictive ability in options trading is consistent with several prior seminal works.[15] We also find significant inventory control effects in the VIX options market; for example, volume imbalances in VIX call and put options are found to be negatively correlated with their own subsequent quote changes, whilst quote changes are similarly found to exhibit a negative correlation with subsequent volume imbalances.

In addition to inventory control effects, we also observe order-splitting behavior in the VIX options market essentially as a result of our finding of a positive serial correlation with net trading volume for both VIX call and put options. Our empirical results remain unchanged when the periodical patterns of the intraday time series and alternative measures of option trades are taken into consideration.

The remainder of this paper is organized as follows. The hypotheses developed for our empirical analysis in this study are presented in Section 2, followed in Section 3 by a description of the empirical specifications. A discussion of the dataset used for our empirical analysis is provided in Section 4, with the main findings and empirical results subsequently being presented in Section 5. Section 6 presents the findings of

[15] See Stephen and Whaley (1990), Vijh (1990), Chan et al. (2002) and Choy and Wei (2012).

the robustness analyses carried out on our empirical results. Finally, the conclusions drawn from this study are presented in Section 7.

2. HYPOTHESIS DEVELOPMENT

2.1 Information Effects in the VIX Options Market

Given that market orders are executed immediately at the best price available, whilst limit orders are only executed at a specified or better price (the limit), when investors wish to trade in the VIX options market, they will invariably find that they are faced with a choice between order submission strategies; specifically, if investors wish to promptly act on any information that becomes available to them, they can choose to submit a market order before the information is exploited by other investors.[16]

Within this overall decision-making process, investors would need to determine whether the value of the information that they possessed exceeded the additional costs that they would be required to pay if they chose to submit market orders;[17] thus, if the value of the information was found to be less than the additional costs involved in market orders, as compared to limit orders, then it is highly likely that they would

[16] If investors wish to act quickly on public information relating to future volatility, or if certain investors possess private information, they may choose to trade in the VIX options market. As such, VIX option order flows convey information that should have predictive capability with regard to changes in the CBOE volatility index (VIX), thereby implying the existence of an information effect. However, as compared to information they may possess with regard to individual stocks, it is less likely for traders to have the advantage of private information in the VIX index; thus, in this particular market, there is a greater likelihood of investors being quicker to act on public information.

[17] Given that the trading costs vary with time, this will undoubtedly have an effect on the use of market orders amongst investors.

either use limit orders or choose not to trade at all.

Valuable information is, therefore, clearly revealed in VIX options trades if informed investors choose to initiate their trades through the use of market orders. Conversely, if investors choose to submit limit orders in the VIX options market, the information will be reflected in the limit order book and subsequently revealed in the quote changes in VIX options.

Numerous studies have provided support for the valuable role of trading volume in options with regard to the price discovery of the underlying asset. For example, it was demonstrated by Easley et al. (1998) that signed option volume was capable of predicting future stock prices, which is consistent with trading by informed investors in the individual stock options markets. Pan and Poteshman (2006) also identified informed trading in the equity options market based upon option trades initiated by buyers to open up new positions.

Roll, Schwartz and Subrahmanyam (2010) and Johnson and So (2012) used the relative trading volume of options and their underlying assets to detect informed trading in the equity options market,[18] whilst in a more recent study (Roll et al., 2014), they found that option volume in the S&P 500 index predicted absolute changes in those variables that effectively capture macroeconomic conditions, such as the short

[18] Extending the options/stock relative trading volume of Roll et al. (2010), Johnson and So (2012) found that informed traders would prefer to trade in the options market essentially as a result of the presence of high short sales costs in the equity market.

interest rate and the term spread. Roll et al., (2014) further demonstrated that the innovations to signed option volume had the strongest forecasting ability for signed shifts in the macroeconomic variables, thereby providing support for the notion that the index options market stimulates the most speculative activity relative to other contingent claims (the index futures and the S&P 500 ETF).

This therefore leads to the derivation of our first hypothesis, which aims to provide a better understanding of the informational role of trading activity in the VIX options market, an issue yet to be documented within the related literature:

Hypothesis 1: *Trading activity in VIX options contains information on subsequent movements in the VIX index.*

According to the CBOE rules, the best quotes in the market can be obtained from the public limit order book, so the information possessed by investors will be reflected in the public limit order book when such informed investors choose to submit limit orders in the options market.[19] Hence, it is likely that quote changes in VIX options will contain more information than order flows, essentially because, in an index such as the VIX, traders are less likely to be able to consistently obtain information of a higher value than the additional execution costs involved in market orders.

[19] The 'order book official' is responsible for maintaining the public limit order book, which involves entering all eligible orders into the limit order book from which the best bid and ask quotes are published. In addition to the limit order book, the best quotes in the market may also be updated from designated market makers (see Berkman, 1996; Chan et al. 2002).

Some studies within the finance literature (see Chan, Chung and Johnson, 1993; Chan et al., 2002) claim that option prices tend to lead price movements in the underlying stock. Chan et al. (2002) provided empirical evidence of the predictive ability of option quote changes based upon their analysis of the interdependence between net trading volume and quote changes in options for actively traded NYSE stocks and their CBOE- traded options. We therefore go on to propose our second hypothesis, contributing to the literature by providing supportive evidence on quote changes, as follows:

Hypothesis 2: *VIX option quote revisions contain more information than option trades on subsequent movements in the VIX index.*

2.2 Inventory Control Effects in the VIX Options Market

As documented by Ho and Stoll (1983) and Stoll (1989), market makers tend to revise quotes depending on their inventory concerns; thus, quote changes may be attributable to temporary liquidity insufficiency. If the trading amount of sell orders is greater than that of buy orders, this will lead to excess inventory for market makers, which will force them to respond by lowering the quoted prices; conversely, if the trading amount of buy orders is greater than that of sell orders, then the insufficient inventory will lead to market makers raising quotes in order to induce public sales.

Huang and Stoll (1994, 1997) provided empirical evidence on the presence of an inventory control effect in NYSE stocks; however, since there is a distinct lack of evidence in the VIX options market, our third hypothesis tests whether quote revisions in VIX options are the result of temporary liquidity insufficiency:

Hypothesis 3: *An inventory control effect exists in the VIX options market.*

3. EMPIRICAL METHODOLOGY AND PREDICTIONS

3.1 The VAR Model for VIX Option Trades and Quote Changes

We refer to the seminal works of Hasbrouck (1991) and Chan et al. (2002) specifying the following bivariate VAR structure for our analysis of the interrelationship between order flows and quote changes in the VIX options market:

$$r_t = a_1 r_{t-1} + \cdots + a_p r_{t-p} + b_0 v_t + b_1 v_{t-1} + \cdots + b_p v_{t-p} + e_{1,t}, \tag{1}$$

$$v_t = c_1 r_{t-1} + \cdots + c_p r_{t-p} + d_1 v_{t-1} + \cdots + b_p v_{t-p} + e_{2,t}, \tag{2}$$

where $r_t = [r_t^{VIX}, r_t^C, r_t^P]'$, $v_t = [v_t^C, v_t^P]'$, r_t^{VIX} are the changes in the VIX index during a five-minute interval, t;[20] r_t^C (r_t^P) refers to the quote returns in the VIX call (put) market;[21] and v_t^C (v_t^P) refers to the net trading volume in VIX calls (puts), which is defined as the difference between buyer- and seller-initiated volume in a five-minute interval, t; $a_1,\ldots, a_p$, $b_0,\ldots, b_p$, $c_1,\ldots, c_p$, $d_1,\ldots, d_p$, $f_1,\ldots, f_p$, $g_1,\ldots, g_p$ are coefficient matrixes; and $e_{1,t}$, $e_{2,t}$ are disturbance terms. Based upon the principle of parsimony, six lags (p) are selected for each explanatory variable, since we find that the results are

[20] The calendar clock (actual time) is divided into intervals of the same length of time, with the endpoint of each interval being labeled sequentially as t = 1, t = 2, and so on.

[21] The quote returns are calculated as the log of the ratio of the last quote during interval [t-1, t) to the last quote during interval [t-2, t-1).

unaffected when using more than six lag periods.

For each business day, the trading hours (8:30 a.m. to 3:15 p.m., Chicago time) are divided into 81 successive five-minute intervals, with the most actively traded call and put contracts (based on daily trading volume) being selected for our empirical analysis. We can generate five-minute return series for the VIX index and the most actively traded call and put options by extracting the last bid and ask quotes during each interval, with the return series being calculated as the logarithmic value of the ratio of two successive mid-quotes. We also compute buyer- and seller-initiated trading volume for each five-minute interval from the most actively traded contracts, and then define the net trading volume, or volume imbalance, as the difference between buyer- (seller-) initiated volume in the call (put) options market.[22]

In order to control for the cross-sectional variations across different options, we follow Easley et al. (1998) and Chan et al. (2002) to standardize the return and trading volume series; that is, we calculate the mean and standard deviation for each individual variable for each day, and then standardize the variable by subtracting the mean and then dividing the product by the standard deviation.

It should be noted that in the VAR model used here, the contemporaneous net trading volumes, v_t^C and v_t^P, are included as independent variables in Equations (1) and

[22] The classification of buyer- and seller-initiated trading volume is explained in the next sub-section.

(2) essentially because they are measured by summing up all of the option trades occurring during time interval [*t*-1, *t*), whilst the quote changes r_t^C and r_t^P are calculated using the last quote closest to time *t*. Therefore, the quote change at time *t* is assumed to be influenced by the net trading volume in the interval [*t*-1, *t*), but not vice versa, due to the timeline consideration.

3.2 Trade Classification of Buyer- and Seller-initiated Volume

For our measure of the net trading volume in VIX options, we categorize each VIX option trade as a buyer- or seller-initiated trade by adopting the Lee and Ready algorithm (1991), with the direction of the trades being identified by two separate steps.[23] In the first step, we compare the trade price with the prevailing bid/ask price; if the trade price occurs above (below) the bid-ask midpoint, then the trade is identified as a buy (sell) trade. For those trades executed at the bid-ask midpoint, which cannot be determined in the first step, we employ a tick test in the second step to compare each of the trade prices of the VIX options with their previous trade price(s).

In specific terms, if the current trade price occurs at a higher price than its previous trade price (an uptick), it is classified as a buyer-initiated trade; conversely, if the current trade is a downtick, it is classified as a seller-initiated trade. When a trade occurs on consecutive zero ticks, we identify the last trade price change and then apply

[23] The details also can be found in Easley et al. (1998) and Chan et al. (2002).

the tick test. All transactions can be categorized based upon this approach, with the exception of any occurrence of a first trade executed at the midpoint; such exceptions are defined as non-classified transactions.

3.3 Empirical Predictions

3.3.1 Impacts on changes in the VIX from net trading volume in VIX options

Since Easley et al. (1998) suggested that directional volume is more informative than raw volume, we use net trading volume in VIX options as the proxy for order flows to test the informational role of VIX option trades.

Positive (negative) call net trading volume represents a signal of favorable (unfavorable) news, which will invariably be followed by an upward (downward) change in VIX quotes and call quotes and a downward (upward) change in put quotes. Similarly, since positive (negative) put net trading volume signals unfavorable (favorable) news, this will invariably be followed by the opposite situation to that described above.

Consequently, according to the information hypothesis of volume imbalances in the VIX options market, we expect to find that call (put) net trading volume will have a positive (negative) correlation with the contemporaneous and subsequent VIX and call returns, and a corresponding negative (positive) correlation with the contemporaneous and subsequent put returns.

In addition to the predictions arising from the informational role of volume imbalances, the inventory control effect may also be found to play an important role in the impact on returns arising from net trading volume. As discussed in the previous section, market makers will provide upward revisions of the quotes following an increase in net trading volume in an attempt to induce sufficient orders to even out their inventory; as a result, the inventory control effect implies that VIX option net trading volume may affect the contemporaneous and subsequent returns in its own market, but not in the other markets.

3.3.2 Impacts of quote revisions

The lead-lag relationship between VIX option returns and changes in the VIX index may be attributable to the informational role of quote changes in VIX options. According to this hypothesis, if investors act on volatility information by submitting limit orders in the VIX options market, the lagged quote changes will establish a strong relationship with future changes in the VIX index, with the expectation of a positive (negative) sign on the coefficient relating to lagged VIX call (put) quote changes to changes in the VIX index.

Furthermore, the inventory control effects predict that investors will react to the quote revisions, causing a change in net trading volume, which will have a direct impact on the inventory available to market makers, thereby forcing them to make further revisions of the quote prices. Hence, we expect to find that the quote returns in the VIX option markets will individually display negative serial correlations as a result of the inventory control effect.

3.3.3 Impacts of quote changes on net trading volume in VIX options

The inventory control effect implies that market makers will revise their quote prices according to net trading volume in order to encourage the offsetting of existing orders. Following such revisions in quote prices, the reaction amongst investors to these changes will subsequently influence net trading volume; therefore, the inventory control effect implies that net trading volume will have a negative correlation with lagged quote changes in its own market.

3.3.4 Impacts of net trading volume in VIX options

As implied by the inventory control effect, market makers will quickly react to net trading volume by making appropriate adjustments to the quote prices, which will consequently induce offsetting orders and cause net trading volume to return to equilibrium; thus, the inventory control effect predicts that the net trading volume series will exhibit negative autocorrelation.

However, as recognized by Hasbrouck and Ho (1987) and Admati and Pfleiderer (1988), certain types of informed traders will often spread their trades over time by engaging in order-splitting behavior, which will also have the potential effect of minimize their trading costs. Since such informed traders do not wish to reveal their private information in a single large order, this expected behavior predicts that net trading volume will exhibit positive serial correlation in the VIX options market.

4. DATA

The dataset used in this study comprises of high-frequency intraday prices in the VIX index and VIX options market covering the period from January 2008 to March 2010, thereby providing a total of 566 trading days.[24] Following our scrutiny of the dataset, the data on six trading days with incomplete trading records were excluded from our sample, thereby providing complete trading records for a total of 560 days.

The VIX options dataset contains complete information on each transaction and quote, including the transaction or quote time (in seconds), expiration date, exercise price, bid and ask prices for a quote record, trade price and size for a trade record, and the value of the underlying VIX index closest to the option trade or quote.[25] A total of 827,796 transactions were executed in our 560-day trading sample period, with VIX call accounting for 558,757 of these transactions (67.50 per cent of the total), representing more than twice the amount of VIX put transactions.

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[24] The VIX index is calculated from the first and second nearby S&P 500 index options which have at least eight days left to expiration, with these options being weighted to produce a 30-day estimate of the expected volatility of the S&P 500 Index. Since its introduction in 1993, the VIX has become widely regarded as the leading indicator of the level of investor fear and market volatility.

[25] VIX options, in contrast to the VIX, which cannot directly trade in the exchanges, are European style options traded on the CBOE. As a result of the rapidly growing demand for volatility products, just five years after the launch date of 24 February 2006, the average daily trading volume in VIX options had grown exponentially, to 248,811 contracts, which was more than ten times the volume in the first year.

Our examination of the impact of option quote revisions follows the approach of Chan et al. (2002), with the most actively traded call and put contracts on each trading day being selected for our empirical analyses. In order to eliminate any option expiration effects, if the most active contract has ≤7 days to maturity, then the next most active contract is selected. We also consider the dates of the Federal Open Market Committee (FOMC) meetings held during our sample period (January 2008 to March 2010) in an attempt to gain a better understanding of the informational role of quote changes in VIX options around monetary policy announcements, since both Chen and Clements (2007) and Pástor and Veronesi (2013) found significant changes in the CBOE VIX index around such government policy announcement periods.

The summary statistics of the VIX options for various categories of moneyness and time-to-maturity are presented in Table 1; in addition to prices and trading volume, we also report the average buyer- and seller-initiated volume across trades using the Lee and Ready (1991) trade classification algorithm. As the table shows, the total trading volume in VIX options during our sample period was 73,644,822 contracts, 66.98 per cent (33.02 per cent) of which was accounted for by call (put) options, with the highest trading volume for both calls and puts being found in the groups of deep out-of-the-money options.

<Table 1 is inserted about here>

Of the five categories of moneyness, the highest average trading volume for VIX call options is found amongst trades in deep out-of-the-money call options, regardless of whether we consider buyer- or seller-initiated trades. As regards option prices, it is not at all surprising to find the average price monotonically increasing with respect to moneyness categories (from deep out-of-the-money to deep in-the-money).

We scrutinize the trading volume of VIX options for all options contracts on each trading day, and then select the largest trading volume as the most actively traded VIX option. If the most actively traded contract is found to have ≤7 days to maturity, then the most actively traded contract is replaced by the next most actively traded contract in order to minimize the liquidity effects of option expiration. The summary statistics on the most actively traded VIX options are presented in Table 2.

<Table 2 is inserted about here>

Panel A of Table 2 clearly shows that during our sample period, the most actively traded VIX call (put) options accounted for 22.81 per cent (30.97 per cent) of the total trading volume of all VIX call (put) options, thereby revealing that when the most active options trades are excluded, the remaining option contracts within the exchange are often thinly traded. Thus, trading activity in the most active contracts appropriately represents general trading conditions in the VIX options markets.

The 560 most actively traded VIX options contracts occurring during our sample period are categorized into five groups of moneyness in Panel B of Table 2, where moneyness is calculated as the ratio of the strike price to the average VIX index on the day, with the average VIX being calculated as the sum of the open and close levels divided by 2. As shown in Panel B, up to 75.71 per cent of the most actively traded contracts in VIX call options are in the deep out-of-the-money category, which is clearly larger than the 40.89 per cent for VIX put options in the same category.

The observation in this study that much more active trading is found in deep out-of-the-money options clearly suggests that investors in the VIX options market are much more likely to trade aggressively, and thus, they will tend to make use of the higher leverage characteristic of deep out-of-the-money VIX options.

5. EMPIRICAL RESULTS

5.1 Main Results

The vector autoregression (VAR) results presented in Table 3 summarize our empirical findings on the informational role of order flows and quote changes in the VIX options market. Firstly, our examination of the interrelationship between the three returns (call, put and VIX) reveals that the both the VIX call and put market lagged quote returns are capable of predicting VIX returns; indeed, VIX returns are found to be positively (negatively) correlated with lagged call (put) returns. In specific terms, the lagged one-period coefficient on the quote changes in VIX call options (0.0321) is found to be significant at the 1 per cent level. Our evidence provides not only statistical significance but also coefficient signs in support of the leading informational role of quote changes in the VIX options market.

Secondly, the empirical results on directional option volume demonstrate that the contemporaneous call and put net trading volume appears to have only a marginal effect on VIX returns, with the *t*-statistics being significant at the 10 per cent level, whereas the coefficients on the lagged net trading volume are found to have no statistical significance. Our results imply a weak relationship between VIX returns and option volume imbalance, thereby clearly suggesting the absence of any discernible informational effect in the VIX options market arising from trading volume. In other words, rather than VIX option volume imbalances, we find that it is quote changes in VIX options that convey more information on future changes in the VIX index.

<Table 3 is inserted about here>

In addition to providing support for the informational role of changes in quotes, three factors relating to inventory control effects in the VIX options market are also observed from Table 3. Firstly, the coefficients between option quote returns and lagged quote returns are found to be significantly negative; for example, the coefficients on the lag period 1 for VIX call and put quote changes are both found to be negative, with significance at the 1 per cent level.

Secondly, our observations on the coefficients on the impact of option net trading volume on option quote changes reveal that option quote changes are only affected by their own net trading volume, in both contemporaneous and lagged terms; that is, consistent with the expectations of the inventory control hypothesis, although contemporaneous and lagged net trading volume in the VIX call options market are found to have positive effects on VIX call quote changes, no significant effects are discernible on VIX and VIX put quote changes. Similarly, the contemporaneous and lagged net trading volume of VIX put options affects only VIX put quote changes.

Thirdly, from our examination of the coefficients on the impacts of lagged option quote changes on their own net trading volume, we find that the lag 1 coefficients are both negative and significant, at –0.0218 (–0.0340) for lag 1 call (put) returns, which also provides support for the existence of the inventory control effect.

The effects of order splitting in the VIX options market – where traders with large orders tend to divide their orders into several smaller trades and submit them over an extended period of time – is also discernible from Table 3. Such actions cause positive serial correlation, essentially because the VIX call and put net trading volume are both positively correlated at the 1 per cent level of significance.

5.2 Results around Monetary Policy Announcements

As noted in Table 3 of Pástor and Veronesi (2013), with an increase in the level of uncertainty regarding government policy, a corresponding significant increase is discernible in the CBOE VIX index. We therefore go on to examine the interdependence between net trading volume and quote revisions in the VIX option markets around monetary policy announcement periods arising from the meetings held by the Federal Open Market Committee (FOMC).[26]

We modify the bivariate VAR model shown in Equations (1) and (2) by including a monetary announcement dummy variable in order to assess the effects of monetary policy announcement days. As shown in Table 4, the dummy variable is multiplied by the quote changes in VIX calls and puts in order to determine whether the impact of quote changes are more pronounced on these announcement days.

<Table 4 is inserted about here>

We modify the original bivariate VAR structure as follows:

$$r_t = a_1 r_{t-1} + \cdots + a_p r_{t-p} + b_0 v_t + b_1 v_{t-1} + \cdots + b_p v_{t-p} + f_1 D\tilde{r}_{t-1} + \cdots + f_p D\tilde{r}_{t-p} + e_{1,t}, \tag{3}$$

$$v_t = c_1 r_{t-1} + \cdots + c_p r_{t-p} + d_1 v_{t-1} + \cdots + d_p v_{t-p} + g_1 D\tilde{r}_{t-1} + \cdots + g_p D\tilde{r}_{t-p} + e_{2,t}, \tag{4}$$

where the dummy variable, *D*, takes the value of 1 on a monetary policy announcement day; otherwise 0.

The empirical results, with the inclusion of the monetary policy announcement factor, are presented in Table 4, from which we can see that the coefficient on lagged

[26] Based upon their investigation of the behavior of the VIX spot index returns around monetary policy announcement periods, Chen and Clements (2007) showed that the VIX index was slightly affected by the dates of the FOMC meetings.

VIX call quote changes multiplied by the dummy variable is statistically significant at the 1 per cent level; thus, quote changes in VIX call options are more likely to incorporate future changes in the VIX index following FOMC meetings.

The dummy variable for monetary announcement days multiplied by net trading volume in VIX options is similarly included into the original VAR model in order to facilitate an investigation of the information effect of net trading volume around macroeconomic event days, with the results being reported in Table 5. The modified VAR model is rewritten as follows:

$$r_t = a_1 r_{t-1} + \cdots + a_p r_{t-p} + (b_0 + f_0 D) v_t + \cdots + (b_p + f_p D) v_{t-p} + e_{1,t}, \tag{5}$$

$$v_t = c_1 r_{t-1} + \cdots + c_p r_{t-p} + + (d_1 + g_1 D) v_{t-1} + \cdots + (d_p + g_p D) v_{t-p} + e_{2,t}, \tag{6}$$

where the dummy variable, D, takes the value of 1 on a monetary policy announcement day; otherwise 0.

The empirical results presented in Table 5 help to provide a better understanding of the informational role of volume imbalances with regard to future changes in the VIX index around monetary policy announcement days, since several studies within the related literature have documented that trading volume in the options markets can be used to take advantage of information in ways that are not readily available to investors trading in the underlying asset market alone.[27]

<Table 5 is inserted about here>

As shown in Table 5, the coefficients between lagged VIX call/put volume imbalances multiplied by the dummy variable for monetary policy announcement days and VIX returns are found to be statistically insignificant. Furthermore, the signs on the contemporaneous coefficients for the interaction term are not consistent with the prediction of the information effect in trading volume, although they are found to have significance at the 1 per cent level.

In other words, we find that volume imbalances in VIX options offer no significant predictive ability with regard to potential changes in the VIX index. One possible reason for this may be that in contrast to the possibility of accruing valuable information on individual stocks, it is much more difficult for traders to accrue superior information in an index market such as the VIX; thus, trading volume in the VIX options market cannot satisfactorily predict movements in the underlying asset.

6. ROBUSTNESS TESTS

[27] For example, Easley et al. (1998) clearly demonstrated that signed option volume predicted future stock prices in a way which was consistent with informed investors trading in the individual stock options markets. From their analysis of the informational role of stock options prior to takeovers, Cao et al. (2005) provided evidence to show that lagged call volume imbalances possessed significant ability to predict next-day stock returns. Pan and Poteshman (2006) went on to identify informed trading in the options market based upon the analysis of option trades that were initiated by buyers to open up new positions. From an examination of option market liquidity, Cao and Wei (2010) further demonstrated that information asymmetry played an important role in the individual stock options markets.

6.1 Intraday Pattern in Trading Volume

The average trading volume in VIX options for each fifteen-minute interval is illustrate in Figures 1, from which a U-shaped intraday pattern is clearly discernible in the VIX options markets; that is, trading volume is relatively higher during both the opening and closing periods. Motivated by this intraday pattern, we examine whether it may have some impact on the empirical results reported earlier; this is carried out by excluding VIX options data before 10:00 a.m. and after 2:45 p.m., thereby excluding a total of 19 five-minute intervals for each trading day.

<Figures 1 is inserted about here>

As shown in Table 6, the lagged one-period coefficients of quote changes in VIX calls (puts) are still found to be positive (negative) at the 1 per cent significance level. Hence, the empirical results continue to confirm that the informational linkages between VIX returns and quote changes in VIX options are not affected by the trading pattern in intraday trading volume.

<Table 6 is inserted about here>

6.2 Positive and Negative Option Volume

We follow Easley et al. (1998) to consider the positive (negative) volume measure, which comprises of the sum of buying calls and selling puts (buying puts and selling calls); the results are reported in Table 7. When comparing these results with those reported earlier in Table 3, the coefficients on quote changes for both VIX call and put options on VIX returns are still found to be significant at the 1 per cent level, although the coefficients on positive options volume (0.0129, with a *t*-statistic of 3.87) and negative options volume (–0.0163 with a *t*-statistic of –4.86) become significant during the contemporaneous period.

<Table 7 is inserted about here>

Overall, the information embedded in the VIX options market is not only found to continue to hold, but it is also found to be more pronounced, since both the positive and negative options volume exhibit stronger relationships with the changes in the VIX index than that of net trading volume measured as the difference between buyer- and seller-initiated trades.

6.3 Information from Number of Transactions and Dollar Volume

We go on to re-run the VAR model using the number of trades, as opposed to net trading volume, with the results being reported in Table 8. Our adoption of the number of trades essentially follows the approach of Jones, Kaul and Lipson (1994) who noted that as compared to trading volume, the number of transactions provides a better source of information on stock volatility. In specific terms, to accumulate the total number of transactions, we count each buyer-initiated trade as +1 and each seller-initiated trade as –1.

<Table 8 is inserted about here>

In addition to considering the number of trades, we also replace net trading volume by dollar option volume, which is calculated as the trading volume multiplied by the traded price for each VIX option contract. The results, which are reported in Table 9, are generally found to be consistent with the outcomes of our prior analyses, regardless of whether we examine the number of trades or dollar option volume. For example, similar to the results reported in Table 3, we find a significant correlation between the number of option trades and their own quote changes in the contemporaneous period. Furthermore, similar to the results on positive option volume reported in Table 7, the contemporaneous coefficient on the number of call transactions in Table 9 is found to be positively significant, with a *t*-statistic of 9.95.

<Table 9 is inserted about here>

7. CONCLUSIONS

We set out in this study to provide a comprehensive analysis under a high-frequency framework in order to explore whether order flows and quote changes in VIX options contain information on future changes in the VIX index. To the best of our knowledge, our study is the first of its kind to document the informational role of quote changes in the VIX options market.

One of the most important empirical outcomes of our study is the finding that lagged quote changes in VIX options have significant predictive ability with regard to future movements in the VIX index, whereas lagged volume imbalances in VIX options are found to have no predictive power with regard to VIX returns. Our results clearly indicate that when traders wish to act on the volatility information that they possess in the VIX options market, they are likely to choose to initiate their trades by submitting limit orders, as opposed to marketable orders.

Our empirical results also provide support for the inventory control effects in the VIX options market. In particular, we find that quote changes in VIX options not only generate negative serial correlation, but also have direct effects on subsequent option volume imbalances. We further observe direct impacts stemming from the directional volume of VIX options on their own quote changes in the bivariate VAR model, which thereby suggests that market makers will aggressively respond to the imbalances in inventory positions by revising the price quotes.

In order to fully examine and verify the scope of our conclusions, we collect details on the monetary policy announcement days arising from the meetings of the FOMC in order to analyze the information content of the quote changes in VIX options on future changes in the VIX around these macroeconomic events; and indeed, it is clear from this analysis that there are more pronounced quote changes in VIX call options around these monetary policy announcement periods.

Our results on the informational role of quote changes in the VIX options market are found to be robust to both intraday patterns in trading activity and alternative measures of trading volume; thus, overall, the results confirm the VIX price discovery capability of changes in VIX option quotes in the VIX options market, although no such predictive capability if discernible for trading volume.

REFERENCES

Admati, A. and P. Pfleiderer (1988), ‘A Theory of Intraday Patterns: Volume and Price Variability’, *Review of Financial Studies*, **1**: 3-40.

Ahn, H.-J., J. Kang and D. Ryu (2008), ‘Informed Trading in the Index Option Market: The Case of KOSPI200 Options’, *Journal of Futures Markets*, **28**: 1118-1146.

Andersen, T.G., T. Bollerslev, F.X. Diebold and H. Ebens (2001), ‘The Distribution of Realized Stock Volatility’, *Journal of Financial Economics*, **61**: 43-76.

Andersen, T.G., T. Bollerslev, F.X. Diebold and P. Labys (2003), ‘Modeling and Forecasting Realized Volatility’, *Econometrica*, **71**: 579-625.

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

Black, F. (1975), ‘Fact and Fantasy in the Use of Options’, *Financial Analysts Journal*, **31**: 36-72.

Blair, B.J., S.-H. Poon and S.J. Taylor (2001), ‘Forecasting S&P 100 Volatility: The Incremental Information Content of Implied Volatilities and High-frequency Index Returns’, *Journal of Econometrics*, **105**: 5-26.

Cao, C., Z. Chen and J.M. Griffin (2005), ‘Informational Content of Option Volume Prior to Takeovers’, *Journal of Business*, **78**: 1073-1109.

Cao, M., and J. Wei, (2010). Option market liquidity: Commonality and other characteristics. *Journal of Financial Markets*, **13**: 20-48.

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

Chan, K., Y.P. Chung and W.M. Fong (2002), 'The Informational Role of Stock and Option Volume', *Review of Financial Studies*, **15**: 1049-1075.

Chan, K., P. Chung and H. Johnson (1993), 'Why Option Prices Lag Stock Prices: A Trading-based Explanation', *Journal of Finance*, **48**: 1957-1967.

Chang, C.C., P.F. Hsieh and H.N. Lai (2009), 'Do Informed Investors Predict Stock Returns? Evidence from the Taiwan Stock Exchange', *Journal of Banking and Finance*, **33**: 757-764.

Chang, C.C., P.F. Hsieh and Y.H. Wang (2010), 'Information Content of Options Trading Volume for Future Volatility: Evidence from the Taiwan Options Market', *Journal of Banking and Finance*, **34**: 174-183.

Chen, E.T. and A. Clements (2007), 'S&P 500 Implied Volatility and Monetary Policy Announcements', *Finance Research Letters*, **4**: 227-232.

Cho, Y. and R.F. Engle (1999), 'Modeling the Impacts of Market Activity on Bid-Ask Spreads in the Option Market', *NBER working paper*.

Choy, S. and J. Wei (2012), 'Option Trading: Information or Differences of Opinion? *Journal of Banking and Finance*, **36**: 2299-2322.

Christensen, B.J. and N.R. Prabhala (1998), 'The Relation between Implied and Realized Volatility', *Journal of Financial Economics*, **50**: 125-150.

Chung, S.L., W.C. Tsai, Y.H. Wang and P.S. Weng (2011), 'The Information Content of the S&P500 Index and VIX Options on the Dynamics of the S&P500 Index', *Journal of Futures Markets*, **31**: 1170-1201.

Cohen, K., S. Maier, R. Schwartz and D. Whitcomb (1981), 'Transaction Costs, Order Placement Strategy and the Existence of the Bid-Ask Spread', *Journal of*

Political Economy, **89**: 287-305.

Cremers, M. and D. Weinbaum (2010), 'Deviations from Put-call Parity and Stock Return Predictability', *Journal of Financial and Quantitative Analysis*, **45**: 335-367.

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

Ederington, L.H. and W. Guan (2005), 'Forecasting Volatility', *Journal of Futures Markets*, **25**: 465-490.

Fama, E. (1970), 'Efficient Capital Markets: A Review of Theory and Empirical Work', *Journal of Finance*, **25**: 383-417.

Fleming, J. (1998), 'The Quality of Market Volatility Forecasts Implied by S&P 100 Index Option Prices', *Journal of Empirical Finance*, **5**: 317-345.

Giot, P. and S. Laurent (2007), 'The Information Content of Implied Volatility in Light of the Jump/Continuous Decomposition of Realized Volatility', *Journal of Futures Markets*, **27**: 337-359.

Harris, L. (1997), 'Optimal Dynamic Order Submission Strategies in Some Stylized Trading Problems', *Working Paper, University of Southern California.*

Hasbrouck, J. (1991), 'Measuring the Information Content of Stock Trades', *Journal of Finance*, **46**: 179-207.

Hasbrouck, J. and T. Ho (1987), 'Order Arrival, Quote Behavior and the Return-generating Process', *Journal of Finance*, **42**: 1035-1048.

Ho, T. and H. Stoll (1983), 'The Dynamics of Dealer Markets under Competition', *Journal of Finance*, **38**: 1053-1074.

Holden, C.W. and S. Chakravarty (1995), ‘An Integrated Model of Market and Limit Orders’, *Journal of Financial Intermediation*, **4**: 213-241.

Huang, R. and H. Stoll (1994), ‘Market Microstructure and Stock Return Predictions’, *Review of Financial Studies*, **7**: 179-213.

Huang, R. and H. Stoll (1997), ‘The Components of the Bid-Ask Spread: A General Approach’, *Review of Financial Studies*, **10**: 995-1034.

Jiang, G.J., and Y.S. Tian (2005), ‘Model-free Implied Volatility and its Information Content’, *Review of Financial Studies*, **18**: 1305-1342.

Johnson, T.L. and E.C. So (2012), ‘The Option to Stock Volume Ratio and Future Returns’, *Journal of Financial Economics*, **106**: 262-286.

Jones, C., G. Kaul and M. Lipson (1994), ‘Transactions, Volume and Volatility’, *Review of Financial Studies*, **7**: 631-651.

Kang, J. and H. Park (2008), ‘The Information Content of Net Buying Pressure: Evidence from the KOSPI 200 Index Option Market’, *Journal of Financial Markets*, **11**: 36-56.

Kumar, P. and D.J. Seppi (1992), ‘Limit and Market Orders with Optimizing Traders’, *Working Paper, Carnegie Mellon*.

Lee, C.M.C. and M.J. Ready (1991), ‘Inferring Trade Direction from Intraday Data’, *Journal of Finance*, **46**: 733-746.

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

Muravyev, D., N.D. Pearson and J.P. Broussard (2013), 'Is There Price Discovery in Equity Options?', *Journal of Financial Economics*, **107**: 259-283.

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

Pástor, Ľ. and P. Veronesi (2013), 'Political Uncertainty and Risk Premia', *Journal of Financial Economics*, **110**: 520-545.

Roll, R., E. Schwartz and A. Subrahmanyam (2010), 'O/S: The Relative Trading Activity in Options and Stocks', *Journal of Financial Economics*, **96**: 1-17.

Roll, R., E. Schwartz and A. Subrahmanyam (2014), 'Trading Activity in the Equity Market and its Contingent Claims: An Empirical Investigation', *Journal of Empirical Finance*, forthcoming.

Ryu, D. (2013), 'The Information Content of Trades: An Analysis of KOSPI 200 Index Derivatives', *Journal of Futures Markets*, forthcoming.

Stephan, J.A. and R.E. Whaley (1990), 'Intraday Price Change and Trading Volume Relationships in the Stock and Stock Options Markets', *Journal of Finance*, **45**: 191-220.

Schlag, C. and H. Stoll (2005), 'Price Impacts of Options Volume', *Journal of Financial Markets*, **8**: 69-87.

Stoll, H. (1989), 'Inferring the Components of the Bid-Ask Spread: Theory and Empirical Tests', *Journal of Finance*, **44**: 115-134.

Taylor, S.J., P.K. Yadav and Y. Zhang (2010), 'The Information Content of Implied Volatilities and Model-free Volatility Expectations: Evidence from Options Written on Individual Stocks', *Journal of Banking and Finance*, **34**: 871-881.

Vijh, A. (1990), 'Liquidity of the CBOE Equity Options', *Journal of Finance*, **45**: 1157-1179.

Wang, Y.H. (2013), 'Volatility Information in the Trading Activity of Stocks, Options, and Volatility Options', *Journal of Futures Markets*, **33**: 752-773.

Xing, Y., X. Zhang and R. Zhao (2010), 'What Does the Individual Option Volatility Smirk Tell Us about Future Equity Returns?', *Journal of Financial and Quantitative Analysis*, **45**: 641-662.

Table 1 Summary statistics of the VIX options dataset

This table presents the summary statistics of the VIX calls and puts based upon the Lee and Ready algorithm, with the sample period running from January 2008 to March 2010. We report the average trading volume of buyer- (seller-) initiated trades and the average price per trade across various categories of moneyness for call (Panel A) and put (Panel B) options, where moneyness is defined as the ratio of the strike price to the current VIX level.

Maturity	Moneyness					
	Deep ITM $m \leq 0.9$	ITM $0.9 < m \leq 0.97$	ATM $0.97 < m \leq 1.03$	OTM $1.03 < m \leq 1.1$	Deep OTM $m > 1.1$	Subtotals
Panel A: VIX Call Options						
<30 Days						
Trading Volume	2,185,696	1,436,488	2,120,465	3,338,486	15,300,130	24,381,265
$Avg\ VOL^{Buyer}$	49.23	46.18	52.49	69.17	111.01	80.97
$Avg\ VOL^{Seller}$	51.03	53.71	51.16	65.75	102.71	78.01
Average Price (US$)	8.14	2.99	1.93	1.29	0.65	2.22
30-180 Days						
Trading Volume	2,090,885	858,752	1,404,465	2,277,650	18,141,762	24,773,514
$Avg\ VOL^{Buyer}$	52.60	55.32	63.19	76.22	136.06	104.31
$Avg\ VOL^{Seller}$	48.17	49.92	69.26	84.51	102.17	85.85
Average Price (US$)	6.46	3.67	3.31	2.75	1.40	2.67
>180 Days						
Trading Volume	21,756	4,178	4,271	19,047	121,733	170,985
$Avg\ VOL^{Buyer}$	24.34	17.98	12.50	31.36	92.18	56.10
$Avg\ VOL^{Seller}$	28.07	18.75	20.79	70.41	126.84	66.41
Average Price (US$)	7.06	4.02	3.79	3.71	1.89	4.01
Subtotals						
Trading Volume	4,298,337	2,299,418	3,529,201	5,635,183	33,563,625	49,325,764
$Avg\ VOL^{Buyer}$	50.65	49.13	55.79	71.63	123.54	91.24
$Avg\ VOL^{Seller}$	49.48	52.14	57.41	72.55	102.52	81.54
Average Price (US$)	7.32	3.24	2.40	1.83	1.04	2.43

Table 1 (*Contd.*)

Maturity	Moneyness					
	Deep ITM $m \le 0.9$	ITM $0.9 < m \le 0.97$	ATM $0.97 < m \le 1.03$	OTM $1.03 < m \le 1.1$	Deep OTM $m > 1.1$	Subtotals
Panel B: VIX Put Options						
<30 Days						
Trading Volume	3,877,213	2,361,549	2,173,885	1,612,433	1,939,737	11,964,817
Avg VOL^{Buyer}	74.82	72.50	71.30	67.00	74.22	72.46
Avg VOL^{Seller}	76.80	82.35	78.86	81.46	79.30	79.26
Average Price (US$)	0.96	1.30	1.71	2.33	5.47	2.08
30-180 Days						
Trading Volume	4,531,651	1,983,002	1,705,776	1,728,862	2,327,668	12,276,959
Avg VOL^{Buyer}	112.64	120.03	120.37	123.57	119.79	117.47
Avg VOL^{Seller}	78.08	128.25	119.09	147.32	91.53	100.24
Average Price (US$)	1.76	2.17	2.51	2.74	5.73	2.81
>180 Days						
Trading Volume	22,895	14,636	16,793	10,057	12,901	77,282
Avg VOL^{Buyer}	47.86	398.28	312.49	159.62	86.04	107.29
Avg VOL^{Seller}	78.97	55.69	122.84	88.89	62.33	98.27
Average Price (US$)	1.06	2.50	2.57	3.73	10.93	3.92
Subtotals						
Trading Volume	8,431,759	4,359,187	3,896,454	3,351,352	4,280,306	24,319,058
Avg VOL^{Buyer}	92.04	88.52	85.88	86.84	94.11	90.06
Avg VOL^{Seller}	77.44	98.42	93.42	106.81	85.12	88.38
Average Price (US$)	1.34	1.60	1.97	2.48	5.61	2.39

Table 2 Summary statistics of the most actively-traded VIX options contracts

This table presents the summary statistics on the most actively-traded VIX call and put options, with the highest trading volume of call and put contracts on each trading day being taken as the most actively traded. The share of daily volume is calculated as the trading volume of the most active calls (puts) divided by the total trading volume for all calls (puts). Average Trade Size is calculated as the average daily volume divided by average daily number of trades. The moneyness (*m*) is calculated as the ratio of the strike price to the VIX index average, where the VIX index average is the sum of the open and close prices divided by 2.

Variables	VIX Call Options		VIX Put Options	
	No.	%	No.	%
Panel A: Most active VIX call and put options contracts				
Average Volume [1]	20,092.99	–	13,450.22	–
Average Volume (% of total volume)	–	22.81	–	30.97
Average No. of Trades [2]	85.53	–	63.73	–
Average Trade Size ([1]/[2])	234.93	–	211.04	–
Average Time to Expiration (Days)	36.80	–	39.47	–
Panel B: Most active contracts across five moneyness categories				
Deep ITM ($m \leq 0.9$)	35	6.25	60	10.71
ITM ($0.9 < m \leq 0.97$)	19	3.39	65	11.61
ATM ($0.97 < m \leq 1.03$)	28	5.00	92	16.43
OTM ($1.03 < m \leq 1.1$)	54	9.64	114	20.36
Deep OTM ($m > 1.1$)	424	75.71	229	40.89
Totals	560	100.00	560	100.00

Table 3 Regression analysis of the relationship between standardized five-minute VIX returns and the net trading volume of VIX call and put options

For each trading day, the trading hours (8:30 a.m. to 3:15 p.m., Chicago time) are divided into 81 successive five-minute intervals, with the most actively traded call and put contracts being selected based upon daily trading volume. We generate five-minute return series for the VIX index and the most actively traded calls and puts by extracting the last bid and ask quotes during each five-minute interval; we then compute the log of the ratio of the quote midpoints. In addition to quote revisions, we also compute the buyer- and seller-initiated trading volume of the most actively traded calls and puts for each five-minute interval and then measure the 'net trading volume' (NTV) as the difference between buyer- and seller-initiated volume or VIX call and put options. Finally, we standardize the return and trading volume series to control for any cross-sectional variations across different options. The VAR model is expressed as follows:

$$r_t = a_1 r_{t-1} + \cdots + a_p r_{t-p} + b_0 v_t + b_1 v_{t-1} + \cdots + b_p v_{t-p} + e_{1,t}, \qquad v_t = c_1 r_{t-1} + \cdots + c_p r_{t-p} + d_1 v_{t-1} + \cdots + b_p v_{t-p} + e_{2,t},$$

where $r_t = [r_t^{VIX}, r_t^C, r_t^P]'$, $v_t = [v_t^C, v_t^P]'$, r_t^{VIX} are the changes in the VIX index during a five-minute interval, t; r_t^C (r_t^P) refers to the quote returns in the VIX call (put) market; and v_t^C (v_t^P) refers to the net trading volume in VIX calls (puts), which is defined as the difference between buyer- and seller-initiated volume in a five-minute interval, t. We use the contemporaneous period (if applicable) and six lag periods as the explanatory variables, although only the contemporaneous and first two lag periods are reported. * indicates significance at the 1% level.

Explanatory Variables	Dependent Variables									
	VIX Returns		Call Returns		Put Returns		Call NTV		Put NTV	
	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.
Lagged VIX Returns										
Lag 1	0.0403	8.07*	0.1352	27.46*	–0.1266	–25.71*	–0.0117	–2.34	–0.0005	–0.09
Lag 2	0.0299	5.91*	0.0435	8.72*	–0.0599	–12.01*	–0.0007	–0.14	0.0008	0.16
Lagged Call Returns										
Lag 1	0.0321	6.37*	–0.1159	–23.36*	–0.0414	–8.33*	–0.0218	–4.32*	–0.0146	–2.89*
Lag 2	0.0176	3.46*	–0.0520	–10.38*	–0.0158	–3.15*	–0.0044	–0.86	–0.0035	–0.70
Lagged Put Returns										
Lag 1	–0.0176	–3.52*	–0.0453	–9.21*	–0.1197	–24.30*	–0.0033	–0.66	–0.0340	–6.80*
Lag 2	0.0052	1.02	–0.0173	–3.49*	–0.0654	–13.16*	–0.0116	–2.31	–0.0078	–1.54

Table 3 (*Contd.*)

Explanatory Variables	Dependent Variables									
	VIX Returns		Call Returns		Put Returns		Call NTV		Put NTV	
	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.
Lagged Call NTV										
Lag 0	0.0086	1.84	0.0312	6.75*	–0.0032	–0.68	–	–	–	–
Lag 1	–0.0038	–0.80	0.0171	3.69*	–0.0006	–0.14	0.0729	15.52*	–0.0115	–2.44
Lag 2	–0.0096	–2.03	0.0074	1.60	0.0085	1.82	0.0117	2.48	0.0027	0.57
Lagged Put NTV										
Lag 0	–0.0082	–1.75	–0.0036	–0.77	0.0374	8.09*	–	–	–	–
Lag 1	0.0062	1.31	–0.0028	–0.60	0.0178	3.84*	–0.0004	–0.08	0.0582	12.38*
Lag 2	–0.0016	–0.34	–0.0035	–0.76	0.0105	2.26	0.0023	0.50	0.0069	1.46

Table 4 Regression analysis of the relationship between standardized five-minute returns and the net trading volume of calls and puts with the inclusion of a dummy multiplied by option quote returns

A dummy variable is included in this regression analysis to test whether the impact of quote revisions is more pronounced on monetary policy announcement days. The VAR model is rewritten as follows:

$$r_t = a_1 r_{t-1} + \cdots + a_p r_{t-p} + b_0 v_t + b_1 v_{t-1} + \cdots + b_p v_{t-p} + f_1 D\tilde{r}_{t-1} + \cdots + f_p D\tilde{r}_{t-p} + e_{1,t}, \qquad v_t = c_1 r_{t-1} + \cdots + c_p r_{t-p} + d_1 v_{t-1} + \cdots + d_p v_{t-p} + g_1 D\tilde{r}_{t-1} + \cdots + g_p D\tilde{r}_{t-p} + e_{2,t},$$

where the dummy variable, D, takes the value of 1 on a monetary policy announcement day; otherwise 0; $r_t = [r_t^{VIX}, r_t^C, r_t^P]'$, $\tilde{r}_t = [r_t^C, r_t^P]'$, $v_t = [v_t^C, v_t^P]'$, r_t^{VIX} are the changes in the VIX index during a five-minute interval, t; r_t^C (r_t^P) refers to the quote returns in the VIX call (put) market; and v_t^C (v_t^P) refers to the 'net trading volume' (NTV) in VIX calls (puts), which is defined as the difference between buyer- and seller-initiated volume in the five-minute interval, t; $a_1,\ldots, a_p$, $b_0,\ldots, b_p$, $c_1,\ldots, c_p$, $d_1,\ldots, d_p$, $f_1,\ldots, f_p$, $g_1,\ldots, g_p$ are coefficient matrixes; and $e_{1,t}$, $e_{2,t}$ are disturbance terms. We use the contemporaneous period (if applicable) and six lag periods as the explanatory variables, although only the contemporaneous and first two lag periods are reported. * indicates significance at the 1% level.

Explanatory Variables	Dependent Variables									
	VIX Returns		Call Returns		Put Returns		Call NTV		Put NTV	
	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.
Lagged VIX Returns										
Lag 1	0.0400	8.02*	0.1353	27.47*	–0.1263	–25.63*	–0.0117	–2.34	–0.0005	–0.10
Lag 2	0.0298	5.90*	0.0434	8.71*	–0.0598	–11.98*	–0.0007	–0.14	0.0009	0.17
Lagged Call Returns										
Lag 1	0.0295	5.75*	–0.1162	–22.94*	–0.0396	–7.81*	–0.0232	–4.51*	–0.0157	–3.05*
Lag 2	0.0180	3.47*	–0.0516	–10.10*	–0.0130	–2.54	–0.0057	–1.09	–0.0035	–0.67
Lagged Put Returns										
Lag 1	–0.0197	–3.86*	–0.0457	–9.11*	–0.1191	–23.69*	–0.0016	–0.32	–0.0331	–6.50*
Lag 2	0.0032	0.61	–0.0165	–3.25*	–0.0651	–12.83*	–0.0127	–2.47	–0.0079	–1.53

Table 4 (*Contd.*)

Explanatory Variables	Dependent Variables									
	VIX Returns		Call Returns		Put Returns		Call NTV		Put NTV	
	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.
Lagged Call NTV										
Lag 0	0.0088	1.86	0.0313	6.76*	–0.0031	–0.68	–	–	–	–
Lag 1	–0.0038	–0.80	0.0171	3.67*	–0.0005	–0.11	0.0730	15.53*	–0.0116	–2.46
Lag 2	–0.0098	–2.07	0.0075	1.61	0.0084	1.81	0.0118	2.50	0.0027	0.57
Lagged Put NTV										
Lag 0	–0.0083	–1.78	–0.0037	–0.79	0.0376	8.12*	–	–	–	–
Lag 1	0.0063	1.34	–0.0028	–0.60	0.0179	3.86*	–0.0004	–0.07	0.0582	12.38*
Lag 2	–0.0016	–0.34	–0.0035	–0.76	0.0103	2.23	0.0024	0.51	0.0070	1.48
D x Lagged Call Returns										
Lag 1	0.0686	2.84*	0.0073	0.31	–0.0457	–1.92	0.0257	1.07	0.0225	0.93
Lag 2	0.0058	0.24	0.0100	–0.42	–0.0689	–2.86*	0.0286	1.17	–0.0013	–0.05
D x Lagged Put Returns										
Lag 1	0.0588	2.41	0.0111	0.46	–0.0216	–0.90	–0.0326	–1.34	–0.0163	–0.67
Lag 2	0.0510	2.07	–0.0207	–0.85	–0.0173	–0.71	0.0260	1.06	0.0029	0.12

Table 5 Regression analysis of the relationship between standardized five-minute returns and the net trading volume of calls and puts with the inclusion of a dummy multiplied by option net trading volume

A dummy variable is included in this regression analysis to test whether the impact of net trading volume (NTV) is more pronounced on monetary policy announcement days. The VAR model is rewritten as follows:

$$r_t = a_1 r_{t-1} + \cdots + a_p r_{t-p} + (b_0 + f_0 D)v_t + \cdots + (b_p + f_p D)v_{t-p} + e_{1,t}, \qquad v_t = c_1 r_{t-1} + \cdots + c_p r_{t-p} + +(d_1 + g_1 D)v_{t-1} + \cdots + (d_p + g_p D)v_{t-p} + e_{2,t},$$

where the dummy variable, D, takes the value of 1 on a monetary policy announcement day; otherwise 0; $r_t = [r_t^{VIX}, r_t^C, r_t^P]'$, $v_t = [v_t^C, v_t^P]'$, r_t^{VIX} are the changes in the VIX index during a five-minute interval, t; r_t^C (r_t^P) refers to the quote returns in the VIX call (put) market; and v_t^C (v_t^P) refers to the 'net trading volume' (NTV) in VIX calls (puts), which is defined as the difference between buyer- and seller-initiated volume in the five-minute interval, t; $a_1,\ldots, a_p$, $b_0,\ldots, b_p$, $c_1,\ldots, c_p$, $d_1,\ldots, d_p$, $f_1,\ldots, f_p$, $g_1,\ldots, g_p$ are coefficient matrixes; and $e_{1,t}$, $e_{2,t}$ are disturbance terms. We use the contemporaneous period (if applicable) and six lag periods as the explanatory variables, although only the contemporaneous and first two lag periods are reported. * indicates significance at the 1% level.

Explanatory Variables	Dependent Variables									
	VIX Returns		Call Returns		Put Returns		Call NTV		Put NTV	
	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.
Lagged VIX Returns										
Lag 1	0.0401	8.02*	0.1351	27.44*	–0.1265	–25.68*	–0.0119	–2.38	–0.0003	–0.07
Lag 2	0.0300	5.93*	0.0436	8.76*	–0.0599	–12.01*	–0.0006	–0.12	0.0009	0.18
Lagged Call Returns										
Lag 1	0.0321	3.37*	–0.1160	–22.36*	–0.0413	–8.32*	–0.0218	–4.33*	–0.0147	–2.92*
Lag 2	0.0176	3.47*	–0.0519	–10.36*	–0.0158	–3.15*	–0.0044	–0.86	–0.0037	–0.72
Lagged Put Returns										
Lag 1	–0.0177	–3.55*	–0.0454	–9.22*	–0.1197	–24.29*	–0.0034	–0.67	–0.0340	–6.81*
Lag 2	0.0051	1.01	–0.0173	–3.49*	–0.0655	–13.18*	–0.0117	–2.33	–0.0077	–1.52

Table 5 (*Contd.*)

Explanatory Variables	VIX Returns		Call Returns		Put Returns		Call NTV		Put NTV	
	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.
Lagged Call NTV										
Lag 0	0.0113	2.34	0.0330	6.97*	–0.0043	–0.91	–	–	–	–
Lag 1	–0.0030	–0.63	0.0185	3.89*	–0.0018	–0.37	0.0741	15.40*	–0.0123	–2.56
Lag 2	–0.0101	–2.09	0.0073	1.53	0.0085	1.79	0.0101	2.09	0.0031	0.65
Lagged Put NTV										
Lag 0	–0.0068	–1.41	–0.0030	–0.64	0.0377	7.96*	–	–	–	–
Lag 1	0.0086	1.78	–0.0021	–0.44	0.0179	3.76*	0.0009	0.18	0.0559	11.62*
Lag 2	–0.0009	–0.19	–0.0054	–1.13	0.0102	2.15	0.0032	0.66	0.0080	1.65
D x Lagged Call NTV										
Lag 0	–0.0598	–2.68*	–0.0411	–1.87	0.0276	1.25	–	–	–	–
Lag 1	–0.0170	–0.76	–0.0282	–1.28	0.0238	1.08	–0.0250	–1.11	0.0179	0.02
Lag 2	0.0140	0.63	0.0054	0.25	0.0010	0.05	0.0346	1.55	–0.0082	–0.37
D x Lagged Put NTV										
Lag 0	–0.0301	–1.35	–0.0099	–0.45	–0.0058	–0.26	–	–	–	–
Lag 1	–0.0516	–2.29	–0.0187	–0.84	–0.0010	–0.05	–0.0290	–1.29	0.0511	2.28
Lag 2	–0.0172	–0.76	0.0383	1.73	0.0073	0.33	–0.0170	–0.76	–0.0283	–1.25

Dependent Variables: VIX Returns, Call Returns, Put Returns, Call NTV, Put NTV.

Table 6 Regression analysis of the relationship between standardized five-minute returns and the net trading volume of calls and puts using 10:00a.m. to 2:45 p.m. observations

For each trading day, the trading hours (10:00 a.m. to 2:45 p.m., Chicago time) are divided into 57 successive five-minute intervals, with the most actively-traded call and put contracts being selected based upon daily trading volume. We generate five-minute return series for the VIX index and the most actively-traded calls and puts by extracting the last bid and ask quotes during each five-minute interval; we then compute the log of the ratio of the quote midpoints. In addition to quote revisions, we also compute the buyer- and seller-initiated trading volume of the most actively-traded calls and puts for each five-minute interval and then measure the 'net trading volume' (NTV) as the difference between buyer- and seller-initiated volume. Finally, we standardize the return and trading volume series to control for any cross-sectional variations across different options. The VAR model is expressed as follows:

$$r_t = a_1 r_{t-1} + \cdots + a_p r_{t-p} + b_0 v_t + b_1 v_{t-1} + \cdots + b_p v_{t-p} + e_{1,t}, \qquad v_t = c_1 r_{t-1} + \cdots + c_p r_{t-p} + d_1 v_{t-1} + \cdots + b_p v_{t-p} + e_{2,t},$$

where $r_t = [r_t^{VIX}, r_t^C, r_t^P]'$, $v_t = [v_t^C, v_t^P]'$, r_t^{VIX} are the changes in the VIX index during a five-minute interval, t; r_t^C (r_t^P) refers to the quote returns in the VIX call (put) market; and v_t^C (v_t^P) refers to the net trading volume in VIX calls (puts), which is defined as the difference between buyer- and seller-initiated volume in the five-minute interval, t; We use the contemporaneous period (if applicable) and six lag periods as the explanatory variables, although only the contemporaneous and first two lag periods are reported. * indicates significance at the 1% level.

Explanatory Variables	Dependent Variables									
	VIX Returns		Call Returns		Put Returns		Call NTV		Put NTV	
	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.
Lagged VIX Returns										
Lag 1	0.0419	7.03*	0.1455	25.48*	–0.1371	–23.83*	–0.0141	–2.08	0.0085	1.26
Lag 2	0.0233	3.85*	0.0400	6.89*	–0.0676	–11.58*	–0.0015	–0.21	0.0013	0.18
Lagged Call Returns										
Lag 1	0.0320	5.17*	–0.1376	–23.22*	–0.0590	–9.88*	–0.0296	–4.24*	–0.0237	–3.36*
Lag 2	0.0189	3.02*	–0.0635	–10.58*	–0.0303	–5.02*	–0.0151	–2.13	–0.0150	–2.09
Lagged Put Returns										
Lag 1	–0.0198	–3.26*	–0.0452	–7.74*	–0.1568	–26.69*	–0.0052	–0.76	–0.0490	–7.07*
Lag 2	–0.0060	–0.97	–0.0274	–4.63*	–0.0929	–15.59*	–0.0080	–1.14	–0.0155	–2.20

Table 6 (*Contd.*)

Explanatory Variables	Dependent Variables									
	VIX Returns		Call Returns		Put Returns		Call NTV		Put NTV	
	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.
Lagged Call NTV										
Lag 0	0.0126	2.54	0.0400	8.42*	–0.0034	–0.71	–	–	–	–
Lag 1	–0.0068	–1.38	0.0139	2.92*	0.0073	1.53	0.0681	12.15*	–0.0125	–2.21
Lag 2	–0.0077	–1.56	0.0134	2.81*	0.0140	2.93*	0.0155	2.75*	0.0069	1.21
Lagged Put NTV										
Lag 0	–0.0096	–1.95	–0.0064	–1.37	0.0389	8.20*	–	–	–	–
Lag 1	0.0050	1.02	–0.0017	–0.35	0.0215	4.53*	–0.0025	–0.45	0.0665	11.85*
Lag 2	0.0015	0.31	0.0013	0.27	0.0069	1.45	–0.0005	–0.09	0.0121	2.16

Table 7 Regression analysis of the relationship between standardized five-minute returns and the volume of calls and puts based upon positive or negative news

A further regression analysis is carried out in this table in which net trading volume is replaced by option volume based upon positive and negative news; these are referred to in the table as 'positive option volume' (POV) and 'negative option volume' (NOV). The VAR model is expressed as follows:

$$r_t = a_1 r_{t-1} + \cdots + a_p r_{t-p} + b_0 v_t + b_1 v_{t-1} + \cdots + b_p v_{t-p} + e_{1,t}, \qquad v_t = c_1 r_{t-1} + \cdots + c_p r_{t-p} + d_1 v_{t-1} + \cdots + b_p v_{t-p} + e_{2,t},$$

where, $r_t = [r_t^{VIX}, r_t^C, r_t^P]'$, $v_t = [v_t^{POS}, v_t^{NEG}]'$, r_t^{VIX} are the changes in the VIX index during a five-minute interval, t; r_t^C (r_t^P) refers to the quote returns in the VIX call (put) market; and v_t^{POS} (v_t^{NEG}) refers to the sum of buying calls and selling puts (buying puts and selling calls) in a five-minute interval, t; We use the contemporaneous period (if applicable) and six lag periods as the explanatory variables, although only the contemporaneous and first two lag periods are reported. * indicates significance at the 1% level.

Explanatory Variables	Dependent Variables									
	VIX Returns		Call Returns		Put Returns		POV		NOV	
	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.
Lagged VIX Returns										
Lag 1	0.0386	7.75*	0.1323	26.91*	–0.1222	–24.82*	0.0012	0.18	–0.0057	–0.81
Lag 2	0.0331	6.55*	0.0407	8.18*	–0.0580	–11.65*	0.0043	0.60	–0.0102	–1.42
Lagged Call Returns										
Lag 1	0.0360	6.48*	–0.1103	–22.25*	–0.0414	–8.34*	0.0188	2.62*	0.0391	5.49*
Lag 2	0.0186	3.66*	–0.0454	–9.09*	–0.0155	–3.10*	0.0087	1.20	0.0271	3.77*
Lagged Put Returns										
Lag 1	–0.0141	–2.84*	–0.0492	–10.01*	–0.1156	–23.51*	0.0288	4.06*	–0.0175	–2.48
Lag 2	0.0046	0.91	–0.0178	–3.59*	–0.0628	–12.66*	0.0225	3.14*	0.0108	1.51

Table 7 (*Contd.*)

Explanatory Variables	Dependent Variables									
	VIX Returns		Call Returns		Put Returns		POV		NOV	
	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.
Lagged POV										
Lag 0	0.0129	3.87*	0.0308	9.39*	–0.0226	–6.89*	–	–	–	–
Lag 1	0.0045	1.35	0.0094	2.84*	–0.0107	–3.22*	0.0930	19.59*	0.0440	9.32*
Lag 2	–0.0014	–0.42	0.0044	1.33	–0.0066	–1.99	0.0252	5.29*	0.0262	5.53*
Lagged NOV										
Lag 0	–0.0163	–4.86*	–0.0227	–6.90*	0.0321	9.72*	–	–	–	–
Lag 1	0.0005	0.15	–0.0072	–2.17	0.0050	1.49	0.0428	8.97*	0.0818	17.23*
Lag 2	–0.0011	–0.32	–0.0081	–2.43	0.0044	1.33	0.0222	4.65*	0.0193	4.05*

Table 8 Regression analysis of the relationship between standardized five-minute returns and the number of VIX option transactions

For each trading day, the trading hours (8:30 a.m. to 3:15 p.m., Chicago time) are divided into 81 successive five-minute intervals, with the most actively-traded call and put contracts being selected based upon the daily number of transactions. We generate five-minute return series for the VIX index and the most actively-traded calls and puts by extracting the last bid and ask quotes during each five-minute interval and then compute the log of the ratio of the quote midpoints. We then go on to calculate the number of buyer- and seller-initiated trades in the most actively-traded calls and puts for each five-minute interval. Finally, we standardize the return and trading volume series to control for any cross-sectional variations across different options. The VAR model is expressed as follows:

$$r_t = a_1 r_{t-1} + \cdots + a_p r_{t-p} + b_0 v_t + b_1 v_{t-1} + \cdots + b_p v_{t-p} + e_{1,t}, \qquad v_t = c_1 r_{t-1} + \cdots + c_p r_{t-p} + d_1 v_{t-1} + \cdots + b_p v_{t-p} + e_{2,t},$$

where $r_t = [r_t^{VIX}, r_t^C, r_t^P]'$, $v_t = [v_t^C, v_t^P]'$, r_t^{VIX} are the changes in the VIX index during a five-minute interval, t; r_t^C (r_t^P) refers to the quote returns in the VIX call (put) market; and v_t^C (v_t^P) refers to the net trading volume in VIX calls (puts), which is defined as the difference between buyer- and seller-initiated volume in the five-minute interval, t; We use the contemporaneous period (if applicable) and six lag periods as the explanatory variables, although only the contemporaneous and first two lag periods are reported. * indicates significance at the 1% level.

Explanatory Variables	Dependent Variables									
	VIX Returns		Call Returns		Put Returns		No. of Call Trades		No. of Put Trades	
	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.
Lagged VIX Returns										
Lag 1	0.0389	7.80*	0.1324	27.05*	–0.1238	–25.25*	0.0130	2.60*	–0.0199	–3.99*
Lag 2	0.0288	5.70*	0.0407	8.22*	–0.0579	–11.67*	0.0186	3.68*	–0.0106	–2.09
Lagged Call Returns										
Lag 1	0.0344	6.80*	–0.1136	–22.89*	–0.0420	–8.45*	–0.0671	–13.32*	–0.0222	–4.39*
Lag 2	0.0189	3.70*	–0.0495	–9.89*	–0.0167	–3.33*	–0.0260	–5.10*	–0.0044	–0.85
Lagged Put Returns										
Lag 1	–0.0195	–3.89*	–0.0460	–9.35*	–0.1176	–23.89*	–0.0130	–2.60*	–0.0607	–12.13*
Lag 2	0.0051	1.01	–0.0161	–3.24*	–0.0650	–13.08*	–0.0072	–1.42	–0.0149	–2.95*

Table 8 (*Contd.*)

Explanatory Variables	Dependent Variables									
	VIX Returns		Call Returns		Put Returns		No. of Call Trades		No. of Put Trades	
	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.
Lagged No. of Call Trades										
Lag 0	0.0468	9.95*	0.0993	21.50*	–0.0385	–8.32*	–	–	–	–
Lag 1	–0.0053	–1.12	0.0243	5.21*	0.0032	0.68	0.0898	19.01*	–0.0044	–0.93
Lag 2	–0.0078	–1.65	0.0076	1.64	0.0113	2.41	0.0265	5.59*	–0.0023	–0.49
Lagged No. of Put Trades										
Lag 0	–0.0429	–9.14*	–0.0384	–8.33*	0.1043	22.63*	–	–	–	–
Lag 1	0.0086	1.81	0.0061	1.32	0.0193	4.14*	–0.0101	–2.15	0.0746	15.79*
Lag 2	–0.0020	–0.42	–0.0076	–1.63	0.0126	2.72*	–0.0014	–0.29	0.0215	4.53*

Table 9 Regression analysis of the relationship between standardized five-minute returns and the dollar volume of VIX option transactions

For each trading day, the trading hours (8:30 a.m. to 3:15 p.m., Chicago time) are divided into 81 successive five-minute intervals, with the most actively-traded call and put contracts being selected based upon the daily dollar volume, which is calculated as the trade volume multiplied by the options price. We generate five-minute return series for the VIX index and the most actively-traded calls and puts by extracting the last bid and ask quotes during each five-minute interval and then compute the log of the ratio of the quote midpoints. We then go on to calculate the net trading volume as the difference between buyer- and seller-initiated dollar volume for VIX call and put options. Finally, we standardize the return and dollar volume series to control for any cross-sectional variations across different options. The VAR model is expressed as follows:

$$r_t = a_1 r_{t-1} + \cdots + a_p r_{t-p} + b_0 v_t + b_1 v_{t-1} + \cdots + b_p v_{t-p} + e_{1,t}, \qquad v_t = c_1 r_{t-1} + \cdots + c_p r_{t-p} + d_1 v_{t-1} + \cdots + b_p v_{t-p} + e_{2,t},$$

where $r_t = [r_t^{VIX}, r_t^C, r_t^P]'$, $v_t = [v_t^C, v_t^P]'$, r_t^{VIX} are the changes in the VIX index during a five-minute interval, t; r_t^C (r_t^P) refers to the quote returns in the VIX call (put) market; and v_t^C (v_t^P) refers to the net trading volume in VIX calls (puts), which is defined as the difference between buyer- and seller-initiated dollar volume in the five-minute interval, t; We use the contemporaneous period (if applicable) and six lag periods as the explanatory variables, although only the contemporaneous and first two lag periods are reported. * indicates significance at the 1% level.

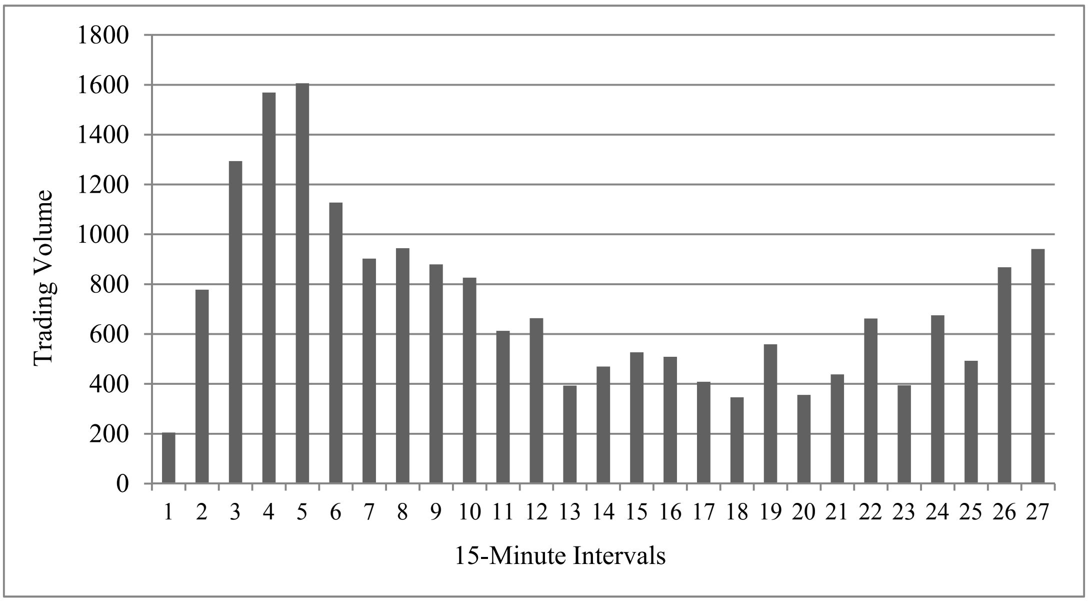
Explanatory Variables	Dependent Variables									
	VIX Returns		Call Returns		Put Returns		Call Dollar Volume		Put Dollar Volume	
	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.
Lagged VIX Returns										
Lag 1	0.0403	8.07*	0.1352	27.47*	–0.1266	–25.70*	–0.0129	–2.58*	−7.03E-06	–0.00
Lag 2	0.0299	5.92*	0.0435	8.73*	–0.0600	–12.03*	–0.0012	–0.23	0.0023	0.45
Lagged Call Returns										
Lag 1	0.0321	6.37*	–0.1160	–23.38*	–0.0414	–8.36*	–0.0189	–3.75*	–0.0147	–2.92*
Lag 2	0.0175	3.45*	–0.0520	–10.39*	–0.0159	–3.18*	–0.0020	–0.39	–0.0030	–0.59
Lagged Put Returns										
Lag 1	–0.0175	–3.51*	–0.0453	–9.21*	–0.1196	–24.29*	–0.0034	–0.68	–0.0338	–6.76*
Lag 2	0.0052	1.02	–0.0173	–3.49*	–0.0654	–13.17*	–0.0101	–2.00	–0.0068	–1.35

Table 9 (*Contd.*)

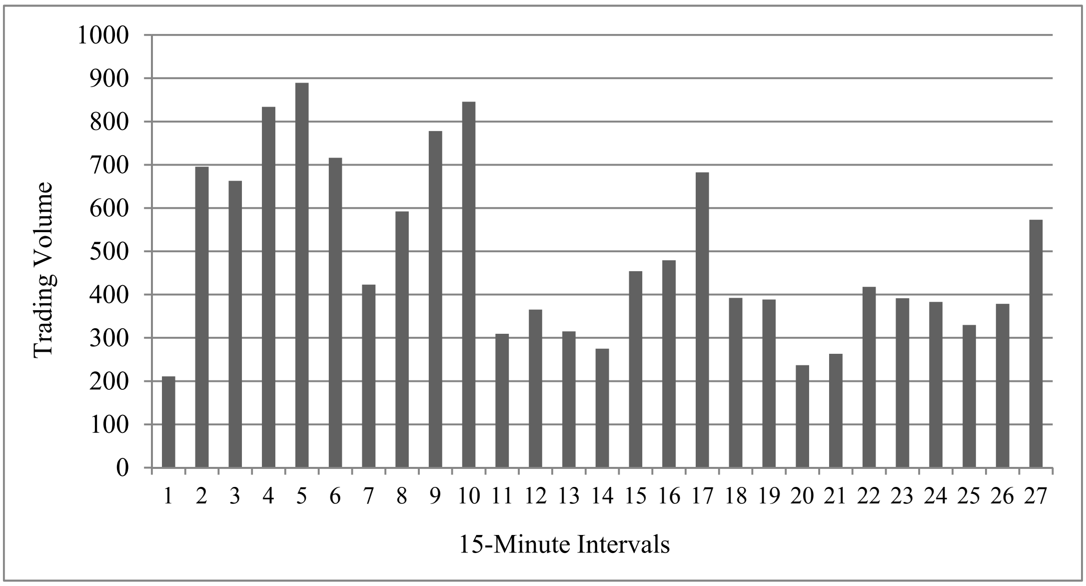
Explanatory Variables	Dependent Variables									
	VIX Returns		Call Returns		Put Returns		Call Dollar Volume		Put Dollar Volume	
	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.	Coeff.	*t*-stat.
Lagged Call Dollar Volume										
Lag 0	0.0086	1.84	0.0301	6.51*	–0.0031	–0.67	–	–	–	–
Lag 1	–0.0036	–0.77	0.0178	3.83*	–0.0023	–0.50	0.0744	15.82*	–0.0100	–2.13
Lag 2	–0.0075	–1.61	0.0069	1.49	0.0103	2.22	0.0115	2.45	0.0026	0.55
Lagged Put Dollar Volume										
Lag 0	–0.0069	–1.46	–0.0032	–0.68	0.0365	7.88*	–	–	–	–
Lag 1	0.0058	1.23	–0.0016	–0.34	0.0167	3.59*	–0.0003	–0.07	0.0619	13.17*
Lag 2	–0.0012	–0.26	–0.0042	–0.90	0.0092	1.97	0.0025	0.54	0.0052	1.10

Figure 1 Average trading volume of the most actively-traded VIX options in each 15-minute interval

For each trading day, the trading hours (8:30 a.m. to 3:15 p.m., Chicago time) are divided into 27 successive fifteen-minute intervals from which we identify the average trading volume of the most actively traded call and put contracts and then plot the average for each interval.



a. VIX Call Options



b. VIX Put Options