ESSAYS ON THE EFFECTS OF FOMC ANNOUNCEMENT — PRE-ANNOUNCEMENT PREMIUM AND OPTION TRADING ACTIVITY

By

GUANZHONG PAN

A dissertation submitted in partial fulfillment of
the requirements for the degree of

DOCTOR OF PHILOSOPHY

WASHINGTON STATE UNIVERSITY
Carson College of Business

MAY 2019

To the Faculty of Washington State University:

The members of the Committee appointed to examine the dissertation of GUANZHONG PAN find it satisfactory and recommend that it be accepted.

George J. Jiang, Ph.D., Chair

David A. Whidbee, Ph.D.

Sheen Liu, Ph.D.

ACKNOWLEDGMENT

First, I'd like to thank my committee chair, Dr. George Jiang. This dissertation cannot be done without his efforts. I cannot remember how many times we have discussed in the process of writing this dissertation. I can always seek help from him when I get stuck and he always is willing to spend time for me.

I'd like to thank Dr. Sheen Liu and Dr. David Whidbee of my dissertation committee. I have learned a lot from them. They are always willing to help when I need.

I'd like to thank professors and my fellow Ph.D. students in this nice program. They teach me, we discuss, they give me a lot of good suggestions about not only this dissertation but also my life.

Especially, I'd like to thank my wife Xiaolan Ma. She gave me an adorable daughter during my Ph.D. student life and take care of the family. Without her, I can't persevere and finish this dissertation.

ESSAYS ON THE EFFECTS OF FOMC ANNOUNCEMENT — PRE-ANNOUNCEMENT PREMIUM AND OPTION TRADING ACTIVITY

Abstract

by Guanzhong Pan, Ph.D.
Washington State University
May 2019

Chair: George J. Jiang

This dissertation consists of two essays. Essay 1 proposes a rational expectations equilibrium model for pre-scheduled economic announcements to examine the effect of information uncertainty and liquidity trading on the pre-announcement premium. The model predicts that pre-announcement premium is positively related to information uncertainty of the upcoming announcements. Liquidity traders withdraw their trading when the information uncertainty is high, which leads informed investors to trade less aggressively. As a result, the price is less informative, which elevates pre-announcement premium. We use Volatility Index (VIX) as a proxy of information uncertainty and show that empirical results are mostly consistent with model predictions. Essay 2 investigates options trading activity prior to Federal Open Market Committee (FOMC) announcements. We find informed traders use option to speculate on their private information. Specifically, abnormal trading volume of call options on S&P500 index during the pre-announcement window positively predicts post-announcement index returns, and this predictability mainly comes from near-the-money call options. Moreover, buyer-initiated call option trading volume positively predicts post-announcement index returns. We find no evidence that investors use options to hedge post-announcement market uncertainty.

TABLE OF CONTENTS

Page

LIST OF TABLES

ESSAY 1

ESSAY 2

LIST OF FIGURES

ESSAY 1

ESSAY 2

ESSAY 1

PRE-ANNOUNCEMENT PREMIUM

I. INTRODUCTION

The literature documents large excess returns prior to pre-scheduled economic announcements, including FOMC announcements (Lucca and Moench, 2015), corporate earnings announcements (Frazzini and Lamont, 2007; Barber, George, Lehavy, and Trueman, 2013) and announcements of macroeconomic news. [1] Such an excess return is referred to as pre-announcement premium. What's more, the literature also documents that the large excess return is typically associated with low return volatility, posing challenges for conventional asset pricing theory.[2] A public annoucement is essentially the revelation of information, and hence information uncertainty should play an important role for pre-annoucement premium. However, this seemingly paulasible explanation is yet formally explored in the literature. [3]

In the paper, we propose a rational expectation equilibrium (REE) model for pre-scheduled economic news announcements to examine the determinants of pre-announcement premium. In particular, we focus on the role of information uncertainty because a public announcement essentially reveals information from private to public. We consider an REE model (e.g. Grossman and Stiglitz, 1980) with two additional dates in which a public announcement happens. In the market, there is one risky asset whose payoff has two random components, and the public

[1]Lucca and Moench (2015) show that the S&P500 index has an average of 0.49% excess return during the 24-hour window prior to the pre-scheduled release of FOMC statement; Frazzini and Lamont (2007) document 7% annualized earnings announcement premium; Using international data, Barber, George, Lehavy, and Trueman (2013) report 7.16% annualized earnings announcement premium, with 83% of the premium is realized 10-day period prior to the announcement; Savor and Wilson (2013) document excess returns during days with pre-scheduled announcements on the releases for inflation, unemployment and various interest rates.

[2]For instance, Lucca and Moench (2015) show that realized volatility calculated from intraday returns during the pre-announcement period is actually lower than that during non-FOMC announcement days.

[3]In a recent paper, Hu, Pan, Wang, and Zhou (2018) propose a hypothesis based on heightened uncertainty for the pre-FOMC premium as investors cautiously await the upcoming announcement.

announcement is modelled by revealing one random component before the final date. Informed traders can observe the noisy signal about the upcoming public announcement, but the uninformed traders can only observe the price. Thus, the trading equilibrium before the public announcement is a standard REE model. Consistent to the REE literature, we also introduce the liquidity trading in the model to prevent a fully revealed price.[4] Moreover, we assume a non-zero mean of liquidity trading to analyze the price implications when liquidity traders withdraw their demand due to high information uncertainty.[5]

The multi-period model is solved by backwards induction. Starting from the last period, we solve the equilibrium prices, we derive the expression of the pre-announcement premium based on the prices before and on the public announcement day. In addition, we also solve the abnormal trading volume during the per-announcement period. We show that per-announcement premium is positively related to information uncertainty of the upcoming announcement and is negatively related to the mean of liquidity trading. For the abnormal trading volume, it is negatively related to information uncertainty of the upcoming announcement. Thus, it seems that the information uncertainty is the key driver for both per-announcement premium and abnormal trading volume, which has the potential to explain the puzzling fact that the high excess return is associated with low realized volatility.

Using data on pre-scheduled macroeconomic news announcements during stock market trading hours, we perform empirical tests and show that the empirical results are mostly consistent with model predictions. Data used in our study includes macroeconomic news announcements and market survey from Bloomberg, intraday returns of S&P 500 index and the CBOE volatility index

[4] As shown in Grossman and Stiglitz (1980), if the price is fully revealed, then no one has any incentive to acquire information, which will lead to the Grossman and Stiglitz paradox.

[5] The analysis is conducted by doing comparative statics with respect to the mean of liquidity trading.

(VIX) from tickdata.com, trade and quote data on S&P500 tracking ETF (SPY) from TAQ database. In particular, we use VIX and dispersion of Bloomberg survey as proxies of information uncertainty of the upcoming announcements. So and Wang (2014) use implied volatility as a measure of information uncertainty for upcoming earnings announcements. Empirically, we show that changes of VIX during the pre-announcement period have a significant explanatory power of pre-announcement premium and Changes in VIX also have a significantly negative relation with abnormal trading volume which, in turn, has a significantly negative effect on the magnitude of pre-announcement premium. Moreover, uncertainty measures constructed from Bloomberg surveys on macroeconomic news announcements also have significant explanatory power of pre-announcement premium.

We perform further analysis by decomposing trading activities into informed trading and liquidity shocks and test how liquidity shocks affect pre-announcement premium. Specifically, we employ the Lee and Ready (1991) algorithm combined with the interpolated time technique proposed by Holden and Jacobsen (2014) to classify transactions as buyer-initiated or seller-initiated. The trades are then classified as either informed trading or liquidity trading based on the level of S&P 500 index following macroeconomic news announcements. The results show that large negative liquidity shocks during the pre-announcement period are also responsible for large excess returns prior to pre-scheduled FOMC announcements. The effect of informed trading on per-announcement premium is subject to the constraint of liquidity provision by uninformed traders and therefore is a function of liquidity shocks during the pre-announcement period. When information uncertainty is high, liquidity traders withdraw their trading, which leads informed investors to trade less aggressively and less information is incorporated into the price. As a result, the price is less informative, which elevates the pre-announcement premium.

Our paper focuses on the determinants of the pre-announcement premium, with asset pricing implications from public announcements. The literature has documented a significant pre-announcement premium for the public announcements about macroeconomic data such as inflation, unemployment and various interest rates, (e.g. Lucca and Moench, 2015; Savor and Wilson, 2013, Balduzzi and Moneta, 2017; Altavilla, Giannone, and Modugno, 2017), and the public announcements by firms, such as corporate earnings (Barber, George, Lehavy, and Trueman, 2013; Bernard and Thomas, 1989; Frazzini, 2006, Dellavigna and Pollet, 2009). Moreover, as shown by Lucca and Moench (2015), pre-announcement premium is normally accompanied by low realized volatility, which is inconsistent with standard asset pricing models. Theoretically, Ai and Bansal (2016) propose an explanation based on the modification of utility functions. They show that some utility functions in class of revealed preferences can deliver pre-announcement premium. Our paper investigates the determinants for pre-announcement premium from the perspective of information uncertainty.

Our analysis is based on a standard competitive rational expectations equiliriubm (REE) model (e.g. Grossman and Stiglitz, 1980; Grossman, 1976; Hellwig， 1980; Diamond and Verrecchia, 1981). To analyze the pre-announcement premium, we construct a multiple period model with a public announcement. The multiple period model is similar to Tetlock (2010) and Llorente et al. (2002). In particular, Tetlock (2010) models the revelation of the public information but does not focus on pre-announcement premium.

One important prediction of our theoretical model is that liquidity trading has an important effect on the magnitude of pre-announcement premium. We use a non-zero mean of liquidity trading to model the behavior of liquidity traders. Theoretically, we follow Admati and Pfleiderer

(1988) and do not make lquidity traders silient.[6] Emprically, we follow Lee and Ready (1991) algorithm and Holden and Jacobsen (2014) to identify the trades initiated by liquidity traders. The model prediction is supported by evidence from our empirical analysis.

The rest of the paper is structured as follows. Section II proposes a model of pre-scheduled announcement and delivers theoretical predictions on the determinants of trading volume and pre-announcement premium. Section III performs empirical tests of theoretical implications derived in the model, with further analysis in Section IV. Section V concludes.

II. THE MODEL OF PRE-SCHEDULED ANNOUNCEMENTS

In this section, we build a rational expectation equilibrium (REE) model with a pre-scheduled announcement. Our purpose is to analyze the role of information for the determinants of pre-announcement premium.

A. Basic Model Setup

We consider a discrete time model with four dates, *t=0, 1, 2, 3*. There are one risky asset and a risk-free asset in the market. For simplicity, the interest rate of the risk-free asset is normalized to be zero. The risky asset has a constant supply 1 and pays off a liquidity value *v* at t=3. The payoff of the risky asset *v* has two random dividends, *e* and *d*, which is

$$v = e + d .$$

where $e \text{ and } d$ are independently normally distributed with $e \sim N(0, V_e)$ and $d \sim N(0, V_d)$. In the model, *e* represents the public information about the risky asset payoff, which can be revealed before the final date. In particular, we assume that there is a public announcement at *t=2*, in which

[6]Admati and Pfleiderer (1988) introduces discretionary liquidity traders to explain the U-shaped pattern of daily volatility and trading volume observed in stock market.

the random component e is revealed. Thus, at *t=2*, only d is a random variable, which will be fully revealed at *t=3*.

There are measure one of investors in the market. Among all investors, m mess of investors are informed and $(1-m)$ are uninformed. Uninformed investors are composed of liquidity traders who assume a liquidity shock,

$$U = \mu + u \text{ with } u \sim \mathcal{N}(0, V_u),$$

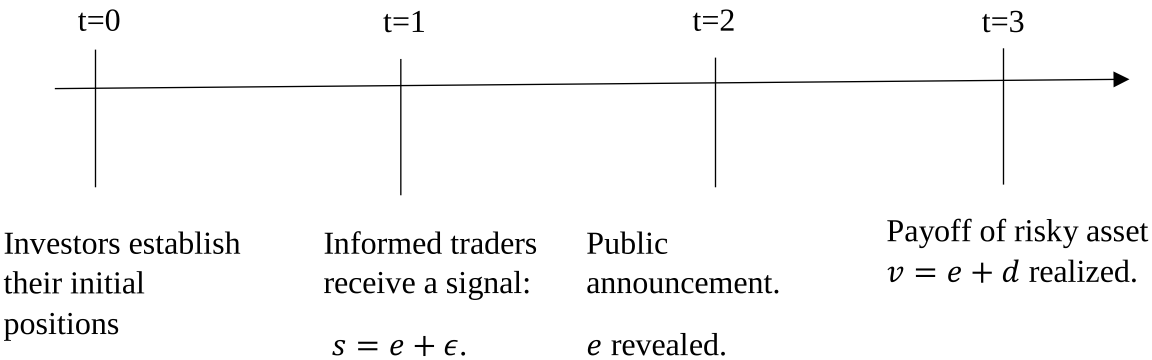
and competitive market makers. Note that the mean of noise trading is not zero, which differs from standard REE model, e.g. Grossman and Stiglitz (1980). By making this assumption, we try to model the behaviors of noise traders when they face a public announcement. We call those noise traders discretionary liquidity traders as in Admati and Pfleiderer (1988) because they can choose to withdraw from the market, i.e. μ decreases. In the model, it is equivalent to the change of market supply, that the market supply is not a constant 1 anymore but is effectively $c \equiv 1 - (1-m)\mu$.

At t=0, investors are identical, and all of them establish their initial positions. We introduce information heterogeneity among informed investor groups by having n informed groups who receive different but correlated private signals ($s_i, i = 1, \cdots, n$) at $t = 1$:

$$s_i = e + \epsilon_i, \quad i = 1, \cdots, n,$$

where $\epsilon \sim N(0, V_\epsilon)$, and is independent to *e.* Because e will be revealed by a pre-scheduled public announcement at *t=2*, informed investors effectively receive a signal about the public information of the risky asset. All investors have Constant Absolute Risk Aversion (CARA) utility functions with risk aversion equal to one. Both informed and uninformed investors adjust their portfolio holdings based on their information set. Below is the timeline of the model:

Exhibit 1: Timeline of public announcement



In the model, we have four random variables, e, d, ϵ and u, which are summarized by the following expression

$$\begin{pmatrix} e \\ d \\ \epsilon \\ u \end{pmatrix} \sim N \left\{ \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}, \begin{pmatrix} V_e & 0 & 0 & 0 \\ 0 & V_d & 0 & 0 \\ 0 & 0 & V_\epsilon & 0 \\ 0 & 0 & 0 & V_u \end{pmatrix} \right\}.$$

B. Solving the Model

We solve the model by backward induction. First, start from the ending period $t = 3$. In each period, we first guess a linear pricing function, then derive the demand functions for both informed and uninformed traders based on their information sets. Then by the market clearing condition, we can obtain the equilibrium price. Second, based on the price at *t=2*, we solve the equilibrium price and the optimal demand at *t=1*. Finally, we solve the similar equilibrium at *t=0*. In the end, based on equilibrium prices and traders' demands, we can derive closed form expected abnormal trading volume and pre-announcement premium and can investigate their properties with respect to the underlying parameters. We summarize our equilibrium price solutions of our model in the following proposition. [7]

Proposition 1: the equilibrium prices are:

At $t=3$: $p_3 = v = e + d$

At $t=2$: $p_2 = e - V_d$

At $t=1$: $p_1 = \alpha + \beta(s + \gamma u^*)$, where

$$\alpha = -\frac{cV_e V_\epsilon\left(1+V_{u*}V_\epsilon\right)}{V_e + V_\epsilon + mV_e V_{u*}V_\epsilon + V_{u*}V_\epsilon^2} - V_d$$
$$\beta = \frac{V_e\left(1+mV_{u*}V_\epsilon\right)}{V_e + V_\epsilon + mV_e V_{u*}V_\epsilon + V_{u*}V_\epsilon^2}$$
$$\gamma = V_\epsilon$$

At $t=0$: $p_0 = \alpha - \beta^2(V_e + V_\epsilon + \gamma^2 V_{u*})$

Note that the public announcement is at *t=2*. Hence, in the model, we get the pre-announcement stock price p_1 at *t=1*, which is the focus of our analysis.

C. Model Implications

In this sub section, we derive the pre-announcement abnormal trading volume ATV,

$$\mathrm{ATV} \equiv m^*\left|x_1^{\mathrm{I}} - x_0^{\mathrm{I}} - \mathrm{E}\left[x_1^{\mathrm{I}} - x_0^{\mathrm{I}}\right]\right| \equiv m^*\left|\xi s + \eta u^*\right|,$$

where

$$m^* = \frac{m}{c}, \quad \xi = \frac{1}{V_\epsilon} - \beta\frac{V_e + V_\epsilon}{V_e V_\epsilon}, \quad \eta = 1 - \beta\gamma\frac{V_e + V_\epsilon}{V_e V_\epsilon}.$$

[7] We only present the prices in the proposition and leave all the details in the Appendix.

ATV is the unexpected change in informed traders' demand multiplied by informed traders' fraction m. In ATV, absolute value is taken to make sure trading volume is positive. Because in our model trading takes place only between informed and uninformed traders, we can get the same solution of ATV from the uninformed traders' demand side. We then derive the pre-announcement expected abnormal trading volume $\overline{ATV}$,

$$\overline{\mathrm{ATV}} = \mathrm{E}[\mathrm{ATV}] = \sqrt{\frac{2}{\pi}} m * \sqrt{\xi^2 V_e + \xi^2 V_\epsilon + \eta^2 V_{u*}} = \frac{m*(1-m)\sqrt{\frac{2}{\pi}} V_u V_\epsilon \sqrt{V_e + V_\epsilon + V_{u*} V_\epsilon^2}}{V_e + V_\epsilon + m V_e V_{u*} V_\epsilon + V_{u*} V_\epsilon^2}$$

Based on the equilibrium stock price p_2 at the announcement and p_1 one-period preceding the announcement, we derive the pre-announcement risk premium PaP,

$$\mathrm{PaP} \equiv \mathrm{E}[p_2 - p_1] = -V_d - \alpha = \frac{c V_e V_\epsilon \left(1 + V_{u*} V_\epsilon\right)}{V_e + V_\epsilon + m V_e V_{u*} V_\epsilon + V_{u*} V_\epsilon^2} = \frac{\left(1-(1-m)\mu\right) V_e V_\epsilon \left(1 + V_{u*} V_\epsilon\right)}{V_e + V_\epsilon + m V_e V_{u*} V_\epsilon + V_{u*} V_\epsilon^2}.$$

Taking derivatives of $\overline{ATV}$ or PaP with respect to underlying parameters, we derive the model's predictions of interest about pre-announcement abnormal trading volume and premium. We summarize our model's predictions about abnormal trading volume and pre-announcement risk premium PaP in the following two propositions.

Proposition 2. The pre-announcement expected abnormal trading volume $\overline{ATV}$ is decreasing with n and V_e, increasing with V_ϵ, V_u and μ :

$$\frac{\partial \overline{\mathrm{ATV}}}{\partial n} < 0, \frac{\partial \overline{\mathrm{ATV}}}{\partial V_e} < 0, \frac{\partial \overline{\mathrm{ATV}}}{\partial V_\epsilon} > 0, \frac{\partial \overline{\mathrm{ATV}}}{\partial V_u} > 0, \frac{\partial \overline{\mathrm{ATV}}}{\partial \mu} > 0.$$

Proposition 3. The pre-announcement risk premium PaP is positive, decreasing with n and μ, increasing with V_e, V_ϵ and V_u:

$$\frac{\partial \text{PaP}}{\partial \mu} < 0, \frac{\partial \text{PaP}}{\partial n} < 0, \frac{\partial \text{PaP}}{\partial V_e} > 0, \frac{\partial \text{PaP}}{\partial V_\epsilon} > 0, \frac{\partial \text{PaP}}{\partial V_u} > 0.$$

There are three sources of uncertainty in our model, information uncertainty V_e, signal noise V_ϵ, and liquidity trading uncertainty V_u. Risk averse investors adjust their demands with these uncertainties. Specifically, informed investors are affected by V_e and V_ϵ, and uninformed investors are affected by V_e, V_ϵ and V_u. When one uncertainty increases, at least one group of investors' demand decreases, resulting in lower total demand and higher pre-announcement premium PaP. That's why PaP is positively related to V_e, V_ϵ and V_u.

We illustrate the effect of non-zero mean liquidity shock on PaP as follows. In anticipation of the upcoming public news announcement, some liquidity traders, so called discretionary liquidity traders, realize their information disadvantage relative to informed investors, and hence choose to withdraw from the market. When discretionary liquidity traders withdraw from the market,[8] the total market demand for the risky asset decreases. Because we have a constant market supply, the pre-announcement asset price has to decrease to restore the market equilibrium. Due to the lower price, other investors buy more stocks, resulting in high pre-announcement premium.

Our model can help us further illustrate the mechanism in the retreat of discretionary liquidity trading. The modeling choice of discretionary liquidity traders effectively changes the total shares that are available to other market participants. If they choose to withdraw their trading, the supply of the risky asset to investors existing in the market is increased. Therefore, for the market to restore equilibrium, the pre-announcement asset price decreases, resulting in high pre-announcement premium.

[8] In the model, it means the mean of noise trading, μ, decreases.

III. EMPIRICAL TESTS

A. Data

We use data from several sources in our empirical tests: Macro news announcements and Bloomberg survey from Bloomberg terminal; intraday S&P 500 Index (SPX) level and CBOE Volatility Index (VIX) from tickdata.com; S&P500 ETF (SPY) TAQ data from WRDS. Our sample period spans from July 2003 to December 2016. Table I reports the summary statistics of pre-scheduled macroeconomic news announcements and variables constructed from Bloomberg market participant survey.

[Insert Table I about here]

Panel A of Table I lists basic information about the five macroeconomic news announcements used in our empirical analysis, which take place during stock market regular trading hours. There are 8 pre-scheduled FOMC announcements per year and 108 announcements in total during our sample period, and among them 66 times take place at 14:15, 31 times at 14:00, 8 times at 12:30, and 3 times around 14:15. For other macroeconomic news announcements, University of Michigan Consumer Sentiment Index is scheduled twice a month, and all other three, Consumer Confidence Index, ISM Manufacturing Index and New Home Sales are scheduled once a month. And all other macroeconomic news announcements take place at 10:00. In Panel B, #SP is the number of market participants. SUR is the announcement surprise, which is defined as the standardized surprise associated with a macroeconomic news announcement,

$$SUR_t = \frac{A_t - \overline{F}_t}{\hat{\sigma}(A_t - \overline{F}_t)}, \qquad (2)$$

where A_t is the actual value and $\overline{F_t}$ is the median of market participants' forecasts. DIS is the dispersion of forecasts, which is defined by

$$\text{DIS}_t = \frac{\text{SD}_t}{\hat{\sigma}(\text{SD}_t)}, \quad \text{SD}_t = \sqrt{\frac{1}{N_t - 1}\sum_{i=1}^{N_t}\left(F_{it} - \frac{1}{N_t}\sum_{i=1}^{N_t} F_{it}\right)^2} \quad , \tag{3}$$

where N_t is the number of forecasts at time t, F_{it} is the forecast value from participant i at time t. We follow Pasquariello and Vega (2007) to calculate SUR and DIS. In Panel B of Table I, we see that the FOMC announcement has on average 86 survey participants, which is largest among all the five macroeconomic news announcements. The number of survey participants varies from 60 to 74 for other four macroeconomic news announcements. This reflects the importance of the FOMC announcement. Panel B also reports the number and the percentage of announcement surprises deviating away from 0 with one to three standard deviations. Moreover, the FOMC announcement has only 3 (2.78%) SURs deviating from 1 standard deviation, the least among all the macroeconomics news announcements.

[Insert Table II about here]

In Table II, we report both the one-day and the half-day returns of pre-announcement period, VIX level and its changes, excess realized volatility, and abnormal trading volume for the FOMC announcement and other macro news announcements during the pre-announcement period. The one-day pre-announcement return $\text{Ret}_{[t\text{-}d,t]}$ is computed as,

$$Ret_{[t-d,t]} = \ln P_t - \ln P_{t-d}, \tag{4}$$

where P_t is the SPX level on the announcement day 15 minutes before the announcement time, P_{t-d} is the SPX level 24 trading hours prior t. The one-day pre-announcement VIX level change $\Delta\text{VIX}_{[t\text{-}d,t]}$ is computed as,

$$\Delta VIX_{[t-d,t]} = VIX_t - VIX_{t-d}, \tag{5}$$

where VIX_t is the VIX level on the announcement day 15 minutes before the announcement time, VIX_{t-d} is the VIX level 24 trading hours before t.

For each announcement day *t*, we compute the excess realized volatility of one-day pre-announcement period as follows: First, we sum up the squared 1-minute log returns of SPX during the one-day pre-announcement period (with the 15-minute lag as above), to compute the one-day pre-announcement realized volatility RV_t; then we move back 1 trading day and similarly compute RV_{t-1}; the difference between these two RV quantities is our excess realized volatility,

$$ExRV_{[t-d,t]} = RV_t - RV_{t-1}. \quad (6)$$

We follow the similar procedures above to compute abnormal trading volume of one-day pre-announcement period. Specifically, for each announcement day t, we compute the abnormal trading volume as follows: First, we sum up the trading volume (size × transaction price) of each transaction during the one-day pre-announcement period (with the 15-minute lag as well), to compute the one-day pre-announcement trading volume TV_t; then we move back 1 trading day and similarly compute TV_{t-1}; the difference between these two TV quantities is our abnormal trading volume,

$$ATV_{[t-d,t]} = TV_t - TV_{t-1}. \quad (7)$$

When d is replaced with d/2 in these variables, we computed the half-day variables, using 12 trading hours SPX and VIX level prior to t.

In Table II, the FOMC announcement has high pre-announcement return, on average 33.6 basis points for the one-day pre-announcement period and 79% of it is realized in the first half-day. Corresponding to the increase of price, as a measure of information uncertainty, VIX level significantly drops on average 0.35 basis point during the one-day pre-announcement period, indicating significant uncertainty resolution. Moreover, the FOMC announcement has low realized volatility and trading volume during the pre-announcement period: one-day realized volatility drops 0.129 and trading volume drops 1.25 $billion on average relative to prior 24 trading hours. The high pre-announcement mean return, low realized volatility and low trading volume are consistent with the empirical facts in Lucca and Moench (2015). Other macroeconomic news announcements' pre-announcement mean returns, drops in VIX, realized volatility and trading volume are dwarfed by the FOMC announcement: The one-day pre-announcement mean return is only 2.5 basis points, the drops in VIX and realized volatility are insignificant, and the trading volume is even positive although insignificant. And the one-day and half-day numbers are similar. In Figures 1 to 3, we differentiate the FOMC announcement (Panel A) and other macroeconomic news announcements (Panel B) and compare the cumulative mean return, realized volatility, and VIX level changes during two consecutive trading days for announcement and non-announcement. The patterns in these figures about cumulative mean return, realized volatility, and VIX level change are consistent with the numbers presented in Table II.

[Insert Figures 1, 2 and 3 about here]

B. Determinants of Trading Volume and Pre-announcement Premium

We have a 12 (month) × 5 (news) panel dataset per year by the following procedure. There are 8 pre-scheduled FOMC announcements in a year. We use the average value in a year of all the variables in the regression as the value of the other 4 months with no announcements. For University of Michigan Consumer Sentiment Index (CSI), there are two announcements per month. We take the average value of these two announcements in a month, then let this average value to be the value in that month. For other 3 news, CSI, ISM, and New Home Sales, they are monthly announcements and so we just keep the original values.

[Insert Table III about here]

Table III reports the results of panel regression of abnormal trading volume (ATV) against potential determinant variables: $VIX_{t\text{-}d}$, $-\Delta VIX_{[t\text{-}d,t]}$, #SP, |SUR|, and DIS, where $VIX_{t\text{-}d}$ and $-\Delta VIX_{[t\text{-}d,t]}$ are proxies of information uncertainty V_e, #SP is the proxy for the number of informed traders groups n, |SUR| and DIS are proxies for forecast uncertainty V_ϵ. As we can see from the results in Table III, the only important determinant of ATV is information uncertainty, and the result is robust for different proxies (e.g.$VIX_{t\text{-}d}$ and $-\Delta VIX_{[t\text{-}d,t]}$). Column (5) shows that if the VIX level reduces one more point during the pre-announcement period, the pre-announcement trading volume on average reduces 0.715 $billion relative to non-announcement days. Forecast variables have no significance in explaining ATV.

[Insert Table IV about here]

Table IV reports the results of panel regression of pre-announcement premium ($Ret_{[t\text{-}d,t]}$) against potential determinant variables including $VIX_{t\text{-}d}$, $-\Delta VIX_{[t\text{-}d,t]}$, $ExRV_{[t\text{-}d,t]}$, #SP, |SUR|, DIS, and ATV. $VIX_{t\text{-}d}$, $-\Delta VIX_{[t\text{-}d,t]}$ and $ExRV_{[t\text{-}d,t]}$ are proxies of information uncertainty V_e, #SP is the proxy for the number of informed traders groups n, |SUR| and DIS are proxies for forecast uncertainty V_ϵ. As we can see from the results in Table IV, the most important determinant of pre-announcement premium is information uncertainty, and the result is robust for different proxies. Column (5) shows that if VIX level reduces one more point during the pre-announcement period, the pre-announcement return on average increases 0.547 basis points relative to non-announcement days. Moreover, the adjusted R^2 is 0.663, which is much larger than other explanatory variables. In column (9), consistent with existing empirical facts, excess realized volatility $ExRV_{[t\text{-}d,t]}$ is negatively associated with pre-announcement return, indicating the puzzling empirical fact that high pre-announcement return is accompanied by low realized volatility. Columns (4) and (5) provide an explanation for this puzzle if we use proper proxies from VIX, VIX_{t-d} or $-\Delta VIX_{[t-d,t]}$, for information uncertainty. Furthermore, column (10) shows if we throw both $-\Delta VIX_{[t-d,t]}$ and $ExRV_{[t-d,t]}$ into the regression, the effect $-\Delta VIX_{[t-d,t]}$ on pre-announcement return remains significant, but the effect of $ExRV_{[t-d,t]}$ is subsumed by $-\Delta VIX_{[t-d,t]}$.

Moreover, the results in Table IV show other factors matter in determining pre-announcement return even after we control information uncertainty. In columns (7) and (8), forecast variable DIS also has significance in explaining pre-announcement premium and is positively associated with it. However, other forecast variables have no explanatory power.

Given extant empirical evidence, there is no surprise that ATV is significantly negatively associated with pre-announcement return as shown in column (6). But columns (7) and (8) show that although the magnitude is not so large, after controlling information uncertainty and forecast variables, the effect of ATV on pre-announcement return is still significant, indicating ATV contains information that cannot be subsumed by information uncertainty and participants' forecast, potentially information about liquidity shocks, which we will test in the next subsection. The results with and without news type fixed effects are very similar, which indicates the regression coefficient is driven by variation over time within each news, not by variation across different news.

C. Informed Trading and Liquidity Trading

For each announcement day t, we compute uninformed abnormal trading volume and informed abnormal trading volume according to the following procedures:

1. We identify every trading activity during normal trading hours as buyer-initiated or seller-initiated by Lee and Ready (1991) algorithm. [9]

2. For one day prior to the announcement time, denote the transaction price of a pre-announcement trading as P_{t-}, the transaction price 15 minutes after the announcement time as P_{t+15}. A pre-announcement trading is identified as an informed trading if it is buyer-initiated and $P_{t-} < P_{t+15}$ or it is seller-initiated and $P_{t-} > P_{t+15}$. Transactions that are not informed trading is then identified as uninformed trading. Compute both total informed and uninformed trading during the one-day pre-announcement period, denoted as TVI_t and TVU_t.

3. Move backwards one day and do the same thing for the trading day before the announcement day, and get both total informed and uninformed, denoted as TVI_{t-1} and TVU_{t-1}.

4. The difference between (un)informed trading volume of t and t-1 is abnormal (un)informed trading volume:

$$ATVI_t = TVI_t - TVI_{t-1}, \quad (5)$$

$$ATVU_t = TVU_t - TVU_{t-1}, \quad (6)$$

[Insert Table V about here]

Table V reports summary statistics of ATVI and ATVU, proxies for informed and uninformed abnormal trading volume. Panel A shows that for the FOMC announcement, both abnormal informed and uninformed trading volume drop significantly during the one-day period of pre-announcement, but ATVI drops more. On average, ATVI drops 0.8 $billion per announcement and ATVU drops 0.45 $billion, so that ATVI drops 35 $million more than ATVU

[9] We use the SAS code provided by Holden and Jacobsen (2014) to process the SPY TAQ data.

during the one-day period of pre-announcement. For other macro news, there is no such significant drops about trading volume during the pre-announcement period.

[Insert Table VI about here]

Table VI reports the results of panel regression of liquidity shock ATVU against potential determinants. The results show that the forecast variables have no significant effect on liquidity shock. The only important determinant of liquidity shock is information uncertainty of the upcoming announcement. Moreover, liquidity shock is negatively related to information uncertainty. Column (5) shows that one point increase of the information uncertainty[10] results in 391 $million decrease in uninformed trading volume during the pre-announcement period.

Our explanation of this result is that the high uncertainty before the pre-scheduled announcement deters discretionary liquidity traders. Admati and Pfleiderer (1988) model discretionary liquidity traders' behavior and show that discretionary liquidity traders tend to concentrate their trading on equilibrium. Admati and Pfleiderer (1988) use their model to explain the U-shape of intraday trading volume and volatility: discretionary liquidity traders concentrate their trading at market open and close, resulting high trading volume and volatility at market open and close. Here we provide evidence that discretionary liquidity traders avoid to concentrate their trading in anticipation of important pre-scheduled announcement, resulting low trading volume and volatility during the pre-announcement period. Because all market participants are risk-neutral in Admati and Pfleiderer (1988) model, risk premium is not their objective to examine. We provide evidence that enriches the implications of discretionary liquidity traders' behavior.

[Insert Table VII about here]

[10] It is measured by VIX level change during the pre-announcement period.

Table VII reports the results of panel regression of informed trading ATVI against potential determinants. We add liquidity shock ATVU as an explanatory variable because its lubricant role in facilitating informed trading in our model. Columns (2) and (3) show that information uncertainty is negatively associated with informed trading, but after we add liquidity shock, the effects of information uncertainty on informed trading are either substantially reduced in column (7) or subsumed in column (8). Moreover, the adjust R^2 with liquidity shock as explanatory variable is as high as 0.79. Consistent with our model's prediction, results in Table VII show that liquidity shock is the most important factor that drives informed trading: one dollar uninformed liquidity trading is on average accompanied by about 80 cents informed trading. Based on this relation, we can predict that if liquidity provision is constrained by the retreatment of discretionary liquidity traders. Then informed traders will reduce their trading and there will be less information incorporated into prices, resulting in lower resolution of uncertainty and hence high pre-announcement premium.

[Insert Table VIII about here]

Table VIII reports the results of panel regression of pre-announcement premium ($Ret_{[t-d,t]}$) against proxies for informed trading and liquidity shock and other potential determinants. ATVI is informed abnormal trading volume, a proxy for informed trading. ATVU is uninformed abnormal trading volume, a proxy for liquidity shock. Columns (1) to (4) show both ATVU and ATVI are negatively associated with pre-announcement premium. Column (5) shows this result is robust even after we add information uncertainty and forecast variables into the regression. In addition to information uncertainty and forecast uncertainty, negative liquidity shock also plays an important role in generating high pre-announcement premium.

The results in Table VIII support our prediction that if liquidity provision is constrained by the retreatment of discretionary liquidity traders, the informed traders will reduce their trading and there will be less information incorporated into prices, resulting in lower resolution of uncertainty and high pre-announcement premium. In addition to the important role of discretionary liquidity traders in generating high trading volume and volatility as described in Admati and Pfleiderer (1988), we provide evidence that discretionary liquidity traders' behavior can also have effects on risk premium.

D. What Drives Lower Realized Volatility?

By definition, realized volatility is the sum of squared changes in log prices. Price changes either due to information flow or noise, such as bid-ask spread, price discreteness, market maker's inventory adjustment, etc. Therefore, realized volatility can be decomposed into two parts: realized volatility due to information flow and due to noise. In this subsection, we examine the driver of realized volatility

[Insert Table IX about here]

Table IX reports the results of panel regression of excess realized volatility ($ExRV_{[t-d,t]}$) against several potential determinants, ATV, ATVI, and ATVU. In column (2) of Table IX, |SUR| is significantly negatively associated with $ExRV_{[t-d,t]}$, which means that high forecast uncertainty results in less information generated realized volatility. Column (4) show that the trading volume is positively associated with pre-announcement excess realized volatility and the large portion comes from trading volume, with adj. R^2 about 16%. When we decompose trading activities into informed trading and liquidity shocks, columns (5) and (6) show that both of them have significantly explanatory power of the pre-announcement realized volatility. However, when we throw both informed trading and liquidity shocks into the regression, column (7) show that the effect of liquidity shocks on excess realized volatility is subsumed by informed trading. The results of column (7) indicate that both |SUR| and informed trading drive the pre-announcement realized volatility, and high |SUR| and low informed trading result in lower pre-announcement realized volatility.

IV. CONCLUSION

In this article, we propose a rational expectation equilibrium (REE) model with pre-scheduled announcement to examine the role of information for pre-announcement premium and trading volume. Our model predicts that pre-announcement premium is positively related to information uncertainty in the upcoming announcements. Informed trading attenuates pre-announcement premium as it helps incorporate information into asset prices. However, the effect of informed trading is subject to the constraint of liquidity provision by uninformed investors. Thus, if liquidity provision is constrained, informed traders reduce their trading, so less information is incorporated into prices, resulting in lower resolution of uncertainty and hence high pre-announcement premium.

The results of our empirical test are largely consistent with model predictions. Specifically, using VIX as a proxy of information uncertainty, we show that changes of VIX during the pre-announcement period have significant explanatory power of pre-announcement premium. Moreover, abnormal trading volume has a negative effect on the magnitude of pre-announcement premium. Further decomposing trading activities into informed trading and liquidity shocks, we show that large negative liquidity shocks during the pre-announcement period are also responsible for large excess returns prior to pre-scheduled FOMC announcements.

REFERENCES

Admati, Anat R, and Paul Pfleiderer, 1988, A Theory of Intraday Patterns: Volume and Price Variability, *Review of Financial Studies* 1, 3–40.

Ai, H. and R. Bansal, 2018, Risk Preferences and The Macro Announcement Premium, *Econometrica*, 86, 1383-1430.

Altavilla, C., D. Giannone, and M. Modugno, 2017, Low frequency effects of macroeconomic news on government bond yields," *Journal of Monetary Economics*, 92, 31-46.

Balduzzi, P. and F. Moneta, 2017, Economic Risk Premia in the Fixed-Income Markets: The Intraday Evidence, *Journal of Financial and Quantitative Analysis*, 52, 1927-1950.

Barber, B. M., E. T. D. George, R. Lehavy, and B. Trueman, 2013, The earnings announcement premium around the globe, *Journal of Financial Economics*, 108, 118 -138.

Bernard, V. L. and J. K. Thomas, 1989, Post-Earnings-Announcement Drift: Delayed Price Response or Risk Premium? *Journal of Accounting Research*, 27, 1-36.

Dellavigna, S. and J. M. Pollet, 2009, Investor Inattention and Friday Earnings Announcements, *Journal of Finance*, 64, 709-749.

Diamond, D. and Verrecchia, R., 1981, Information aggregation in a noisy rational expectations economy, *Journal of Financial Economics* 9, 221-235.

Foster, F Douglas, and S Viswanathan, 1996, Strategic Trading When Agents Forecast the Forecasts of Others, *The Journal of Finance* 51, 1437–1478.

Frazzini, A., 2006, The Disposition Effect and Underreaction to News, *Journal of Finance*, 61, 2017-2046.

Frazzini, A., and Lamont, O. A., 2007, The Earnings Announcement Premium and Trading Volume. *National Bureau of Economic Research*.

Grossman, Sanford, 1976, On the Efficiency of Competitive Stock Markets Where Trades Have Diverse Information, *The Journal of Finance* 31, 573–585.

Grossman, Sanford J, and Joseph E Stiglitz, 1980, On the Impossibility of Informationally Efficient Markets, *American Economic Review* 70, 393–408.

Hellwig, M., 1980, On the aggregation of information in competitive markets. *Journal of Economic Theory* 22(3), 477-498.

Holden, Craig W., and Stacey Jacobsen, 2014, Liquidity Measurement Problems in Fast, Competitive Markets: Expensive and Cheap Solutions, *The Journal of Finance* 69, 1747–1785.

Hu, Grace Xing and Pan, Jun and Wang, Jiang and Zhu, Haoxiang, Premium for Heightened Uncertainty: Solving the FOMC Puzzle (November 26, 2018). Available at SSRN: https://ssrn.com/abstract=3290649 or http://dx.doi.org/10.2139/ssrn.3290649

Kyle, Albert S, 1985, Continuous Auctions and Insider Trading, *Econometrica* 53, 1315–1335.

Lee, Charles M. C., and Mark J. Ready, 1991, Inferring Trade Direction from Intraday Data, *The Journal of Finance* 46, 733–746.

Llorente, Guillermo, Roni Michaely, Gideon Saar, and Jiang Wang, 2002, Dynamic Volume-Return Relation of Individual Stocks, *Review of Financial Studies* 15, 1005–1047.

Lucca, David O, and Emanuel Moench, 2015, The Pre-FOMC Announcement Drift, *The Journal of Finance* 70, 329–371.

Pasquariello, Paolo, and Clara Vega, 2007, Informed and Strategic Order Flow in the Bond Markets, *Review of Financial Studies* 20, 1975–2019.

Savor, P. and M. Wilson, 2013, How Much Do Investors Care About Macroeconomic Risk? Evidence from Scheduled Economic Announcements, *Journal of Financial and Quantitative Analysis*, 48, 343-375.

So, Eric C. and Wang, Sean, 2014, News-Driven Return Reversals: Liquidity Provision Ahead of Earnings Announcements, *Journal of Financial Economics* 114, 20-35.

Tetlock, Paul C, 2010, Does Public Financial News Resolve Asymmetric Information? *Review of Financial Studies* 23, 3520–3557.

APPENDIX A: MODEL SOLUTIONS

We solve the model backward, starting from the ending period $t = 3$, then stepping back one period at a time, all the way back to the initial period $t = 0$. Specifically, at each period t, we first identify the information sets $\mathcal{F}_t^I$ and $\mathcal{F}_t^U$ of informed and uninformed traders, then derive their demands x_t^I and x_t^U for the stock,

$$x_t^I \equiv \frac{\mathrm{E}[p_{t+1} \mid \mathcal{F}_t^{\mathrm{I}}] - p_t}{\mathrm{Var}[p_{t+1} \mid \mathcal{F}_t^{\mathrm{I}}]}, \quad x_t^U \equiv \frac{\mathrm{E}[p_{t+1} \mid \mathcal{F}_t^{\mathrm{U}}] - p_t}{\mathrm{Var}[p_{t+1} \mid \mathcal{F}_t^{\mathrm{U}}]} + U,$$

where $U = \mu + u$ with $u \sim \mathcal{N}(0, V_u)$ represents liquidity shock when there is a liquidity shock at t, otherwise u^* is zero. We finally solve the equilibrium price p_t of the stock by the market clearing condition:

$$m x_t^I + (1-m) x_t^U = 1.$$

Based on the stock demands at pre-announcement periods $t = 0$ and $t = 1$, we derive the pre-announcement abnormal trading volume ATV of the stock, which is defined by

$$\mathrm{ATV} \equiv m^* \left| x_1^{\mathrm{I}} - x_0^{\mathrm{I}} - \mathrm{E}\left[x_1^{\mathrm{I}} - x_0^{\mathrm{I}} \right] \right|,$$

where $m^* = m/(1-(1-m)\mu)$ with the fraction m of informed investors adjusted by $1 - (1-m)\mu$ due to non-zero mean liquidity shock.

We then derive its expectation, the pre-announcement expected abnormal trading volume $\overline{ATV}$.

We also derive how Pap and $\overline{ATV}$ change with respect to change in model's underlying parameters.

Based on the equilibrium prices before and at the public announcement period, $t = 1$ and $t = 2$, we derive the pre-announcement risk premium PaP of the stock, which is defined by

$$\mathrm{PaP} \equiv \mathrm{E}[p_2 - p_1].$$

At $t = 3$, all uncertainty is resolved and hence the stock price is equal to its liquidation value,

$$p_3 = v = e + d.$$

At $t = 2$, the information sets are

$$\mathcal{F}_2^{\mathrm{I}} = \mathcal{F}_2^{\mathrm{U}} = \{e, p_2\}$$

We derive the conditional expectation and conditional variance of p_3 for both informed and uninformed traders,

$$\mathrm{E}[p_3 \mid \mathcal{F}_2^I] = \mathrm{E}[p_3 \mid \mathcal{F}_2^U] = e, \quad \mathrm{Var}[p_3 \mid \mathcal{F}_2^I] = \mathrm{Var}[p_3 \mid \mathcal{F}_2^U] = V_d.$$

Substitute these conditional moments into the market clearing condition, we get

$$p_2 = e - V_d$$

At $t = 1$, we guess the equilibrium price p_1 has the following linear form,

$$p_1 = \alpha + \beta(s + \gamma u^*)$$

To solve the pre-announcement stock price, we use a little trick to make the form of our model's solution simpler and easier to derive implications. First we write down the market clearing condition at the pre-announcement time $t = 1$,

$$m \cdot \left[\frac{\mathrm{E}[p_{t+1} \mid \mathcal{F}_t^{\mathrm{I}}] - p_t}{\mathrm{Var}[p_{t+1} \mid \mathcal{F}_t^{\mathrm{I}}]} \right] + (1-m) \cdot \left[\frac{\mathrm{E}[p_{t+1} \mid \mathcal{F}_t^{\mathrm{U}}] - p_t}{\mathrm{Var}[p_{t+1} \mid \mathcal{F}_t^{\mathrm{U}}]} + \mu + u \right] = 1,$$

where the LHS is the total demand for the risky asset and the RHS is the supply, a constant 1. By introducing non-zero mean in liquidity shock, we depart from the models in Llorente et al. (2002) and Tetlock (2010). Then we transform it into

$$m \cdot \left[\frac{\mathrm{E}[p_{t+1} \mid \mathcal{F}_t^{\mathrm{I}}] - p_t}{\mathrm{Var}[p_{t+1} \mid \mathcal{F}_t^{\mathrm{I}}]} + u^* \right] + (1-m) \cdot \left[\frac{\mathrm{E}[p_{t+1} \mid \mathcal{F}_t^{\mathrm{U}}] - p_t}{\mathrm{Var}[p_{t+1} \mid \mathcal{F}_t^{\mathrm{U}}]} \right] = c.$$

where

$$u^* \equiv \frac{1-m}{m} u, \quad c \equiv 1 - (1-m)\mu \, .$$

And we have $u^* \sim \mathcal{N}(0, V_{u^*})$ with $V_{u^*} = V_u \left(1-m\right)^2 / m^2$. The above market clearing condition corresponds to a Tetlock type model. In this transformed model, liquidity shock has zero mean and is combined with informed demand, and the supply of the risky asset is not a fixed number 1 but a function of mean liquidity trading μ, varying μ is equivalent to varying asset supply. To make sure the transformed model has positive asset supply, we assume $c > 0$.

At $t=1$, both informed and uninformed traders observe the market price p_1, but only informed traders receive a private signal s. Hence, the information sets are

$$\mathcal{F}_t^{\mathrm{I}} = \{s, p_1\} = \{s, u*\}, \qquad \mathcal{F}_t^{\mathrm{U}} = \{p_1\} = \{s + \gamma u*\}$$

We derive the conditional expectation and conditional variance of p_2 for informed traders,

$$\mathrm{E}[p_2 \mid \mathcal{F}_1^I] = -V_d + \frac{sV_e}{V_e + V_\epsilon}, \quad \mathrm{Var}[p_2 \mid \mathcal{F}_1^I] = \frac{V_e V_\epsilon}{V_e + V_\epsilon},$$

and for uninformed traders,

$$\mathrm{E}[p_2 \mid \mathcal{F}_1^U] = -V_d + \frac{(s+\gamma u*)V_e}{V_e + \gamma^2 V_{u*} + V_\epsilon}, \quad \mathrm{Var}[p_2 \mid \mathcal{F}_1^U] = V_e - \frac{V_e^2}{V_e + \gamma^2 V_{u*} + V_\epsilon}.$$

Substitute these conditional moments into the market clearing condition, we get

$$p_1 = \alpha + \beta(s + \gamma u*),$$

where

$$\alpha = -\frac{cV_e V_\epsilon \left(1 + V_{u*} V_\epsilon\right)}{V_e + V_\epsilon + mV_e V_{u*} V_\epsilon + V_{u*} V_\epsilon^2} - V_d$$

$$\beta = \frac{V_e \left(1 + mV_{u*} V_\epsilon\right)}{V_e + V_\epsilon + mV_e V_{u*} V_\epsilon + V_{u*} V_\epsilon^2}$$

$$\gamma = V_\epsilon$$

At $t=0$, the information sets are

$$\mathcal{F}_0^I = \mathcal{F}_0^U = \emptyset.$$

We derive the conditional expectation and conditional variance of p_1 for both informed and uninformed traders,

$$\mathrm{E}[p_1 \mid \mathcal{F}_0^I] = \mathrm{E}[p_1 \mid \mathcal{F}_0^U] = \alpha, \quad \mathrm{Var}[p_1 \mid \mathcal{F}_0^I] = \mathrm{Var}[p_1 \mid \mathcal{F}_0^U] = \beta^2 (V_e + V_\epsilon + \gamma^2 V_{u*}).$$

Substitute these conditional moments into the market clearing condition, we get

$$p_0 = \alpha - \beta^2 (V_e + V_\epsilon + \gamma^2 V_{u*}).$$

We derive the pre-announcement abnormal trading volume ATV,

$$\mathrm{ATV} \equiv m * \left| x_1^{\mathrm{I}} - x_0^{\mathrm{I}} - \mathrm{E}\left[x_1^{\mathrm{I}} - x_0^{\mathrm{I}}\right] \right| \equiv m * \left| \xi s + \eta u * \right|,$$

where

$$m^* = \frac{m}{c}, \quad \xi = \frac{1}{V_\epsilon} - \beta \frac{V_e + V_\epsilon}{V_e V_\epsilon}, \quad \eta = 1 - \beta\gamma \frac{V_e + V_\epsilon}{V_e V_\epsilon}.$$

We then derive the pre-announcement expected abnormal trading volume EATV,

$$\overline{\text{ATV}} = \text{E}[\text{ATV}] = \sqrt{\frac{2}{\pi}} m^* \sqrt{\xi^2 V_e + \xi^2 V_\epsilon + \eta^2 V_{u*}} = \frac{m^*(1-m)\sqrt{\frac{2}{\pi}} V_u V_\epsilon \sqrt{V_e + V_\epsilon + V_{u*} V_\epsilon^2}}{V_e + V_\epsilon + m V_e V_{u*} V_\epsilon + V_{u*} V_\epsilon^2}$$

Then we get EATV's derivatives with respect to underling parameters. The pre-announcement expected abnormal trading volume $\overline{ATV}$ is non-determinant with m, decreasing with V_e, increasing with μ, V_ϵ and V_u:

$$\frac{\partial \overline{\text{ATV}}}{\partial m} = -\frac{\sqrt{\frac{2}{\pi}} V_{u^*} V_\epsilon \sqrt{V_e + V_{u^*} V_\epsilon^2 + V_\epsilon} \left(V_e \left(m^2 V_{u^*} V_\epsilon + 2m - 1 \right) + (2m-1) V_\epsilon \left(V_{u^*} V_\epsilon + 1 \right) \right)}{\left(m V_e V_{u^*} V_\epsilon + V_e + V_{u^*} V_\epsilon^2 + V_\epsilon \right)^2}$$

$$\frac{\partial \overline{\text{ATV}}}{\partial \mu} = \frac{(1-m)}{(1-(1-m)\mu)} \overline{\text{ATV}} > 0$$

$$\frac{\partial \overline{\text{ATV}}}{\partial V_e} = \frac{(-1+m) m V_{u^*} V_\epsilon \left(m V_e V_{u^*} V_\epsilon + V_e + V_\epsilon \left(V_{u^*} V_\epsilon + 1 \right) \left(2m V_{u^*} V_\epsilon + 1 \right) \right)}{\sqrt{2\pi} \sqrt{V_e + V_{u^*} V_\epsilon^2 + V_\epsilon} \left(m V_e V_{u^*} V_\epsilon + V_e + V_{u^*} V_\epsilon^2 + V_\epsilon \right)^2} < 0$$

$$\frac{\partial \overline{\text{ATV}}}{\partial V_\epsilon} = \frac{(1-m) m V_{u^*} \left(V_e V_\epsilon \left(2m V_{u^*}^2 V_\epsilon^2 + (m+2) V_{u^*} V_\epsilon + 3 \right) + 2 V_e^2 + V_\epsilon^2 \left(V_{u^*} V_\epsilon + 1 \right) \right)}{\sqrt{2\pi} \sqrt{V_e + V_{u^*} V_\epsilon^2 + V_\epsilon} \left(m V_e V_{u^*} V_\epsilon + V_e + V_{u^*} V_\epsilon^2 + V_\epsilon \right)^2} > 0$$

$$\frac{\partial \overline{\text{ATV}}}{\partial V_u} = \frac{m^3 V_\epsilon \left(V_e V_\epsilon \left(m V_{u^*}^2 V_\epsilon^2 + 3 V_{u^*} V_\epsilon + 4 \right) + 2 V_e^2 + V_\epsilon^2 \left(V_{u^*}^2 V_\epsilon^2 + 3 V_{u^*} V_\epsilon + 2 \right) \right)}{(1-m)\sqrt{2\pi} \sqrt{V_e + V_{u^*} V_\epsilon^2 + V_\epsilon} \left(m V_e V_{u^*} V_\epsilon + V_e + V_{u^*} V_\epsilon^2 + V_\epsilon \right)^2} > 0$$

We derive the pre-announcement risk premium PaP,

$$\text{PaP} \equiv \text{E}[p_2 - p_1] = -V_d - \alpha = \frac{c V_e V_\epsilon \left(1 + V_{u*} V_\epsilon \right)}{V_e + V_\epsilon + m V_e V_{u*} V_\epsilon + V_{u*} V_\epsilon^2} = \frac{\left(1 - (1-m)\mu \right) V_e V_\epsilon \left(1 + V_{u*} V_\epsilon \right)}{V_e + V_\epsilon + m V_e V_{u*} V_\epsilon + V_{u*} V_\epsilon^2} > 0.$$

The pre-announcement risk premium PaP is positive, decreasing with m, increasing with V_e, V_ϵ and V_u:

$$\frac{\partial \text{PaP}}{\partial \mu} = -\frac{(1-m)V_e V_\epsilon \left(1+V_{u*}V_\epsilon\right)}{V_e + V_\epsilon + mV_e V_{u*} V_\epsilon + V_{u*} V_\epsilon^2} < 0$$

$$\frac{\partial \text{PaP}}{\partial V_e} = \frac{cV_\epsilon^2 \left(1+V_{u*}V_\epsilon\right)^2}{\left(V_e + V_\epsilon + mV_e V_{u*} V_\epsilon + V_{u*} V_\epsilon^2\right)^2} > 0$$

$$\frac{\partial \text{PaP}}{\partial V_\epsilon} = \frac{cV_e^2 \left(1+2V_{u*}V_\epsilon + mV_{u*}^2 V_\epsilon^2\right)}{\left(V_e + V_\epsilon + mV_e V_{u*} V_\epsilon + V_{u*} V_\epsilon^2\right)^2} > 0$$

$$\frac{\partial \text{PaP}}{\partial V_u} = \frac{c(1-m)V_e^2 V_\epsilon^2}{\left(mV_e V_{u*} V_\epsilon + V_e + V_{u*} V_\epsilon^2 + V_\epsilon\right)^2} > 0$$

The model with information heterogeneity

When there are n informed groups, we denote the information set of informed group $i(i=1,\cdots,n)$ at t by

$$\mathcal{F}_t^{\text{I}}(i),$$

and the demands for the stock by

$$x_t^I(i) = \frac{1}{n}\frac{\text{E}[p_{t+1} \mid \mathcal{F}_t^{\text{I}}(i)] - p_t}{\text{Var}[p_{t+1} \mid \mathcal{F}_t^{\text{I}}(i)]},$$

where $u=0$ when there is no liquidity shock at t. The market clearing condition at t is

$$m\sum_{i=1}^{n} x_t^I(i) + (1-m)x_t^U = 1.$$

At $t=3$, all uncertainty is resolved and hence the stock price is its liquidation value,

$$p_3 = v = e + d$$

At $t=2$, the information sets are

$$\mathcal{F}_2^{\text{I}}(i) \equiv \mathcal{F}_2^{\text{I}} = \mathcal{F}_2^{\text{U}} = \{e, p_2\}, i = 1,\cdots,n.$$

We derive the conditional expectation and conditional variance of p_3 for both informed and uninformed traders,

$$\text{E}[p_3 \mid \mathcal{F}_2^I(i)] = \text{E}[p_3 \mid \mathcal{F}_2^U] = e, \quad \text{Var}[p_3 \mid \mathcal{F}_2^I(i)] = \text{Var}[p_3 \mid \mathcal{F}_2^U] = V_d, \quad i = 1,\cdots,n.$$

Substitute these conditional moments into the market clearing condition, we get

$$p_2 = e - V_d$$

At $t=1$, we guess the equilibrium price p_1 has the following linear form,

$$p_1 = \alpha + \beta(\overline{s} + \gamma u^*),$$

where

$$\overline{s} = \frac{1}{n}\sum_{i=1}^{n} s_i = \frac{1}{n}\sum_{i=1}^{n}(e+\epsilon_i) = e + \frac{1}{n}\sum_{i=1}^{n}\epsilon_i \equiv e + \overline{\epsilon}$$

We have

$$V_{\overline{\epsilon}} \equiv \mathrm{Var}[\overline{\epsilon}] = \frac{1}{n^2}\mathrm{Var}\left[\sum_{i=1}^{n}\epsilon_i\right] = \frac{1}{n^2} n \cdot V_{\epsilon} = \frac{V_{\epsilon}}{n},$$

and we see $V_{\overline{\epsilon}}$ is decreasing with n.

And the information sets are

$$\mathcal{F}_1^{\mathrm{I}}(i) = \{s_i, u^*, p_1\} = \{s_i, \overline{s}, u^*\} \quad i = 1, \cdots, n; \qquad \mathcal{F}_1^{\mathrm{U}} = \{p_1\} = \{\overline{s} + \gamma u^*\}.$$

Denote $\mathcal{F}_1^{\mathrm{I}} \equiv \{\overline{s}, u^*\}$. We have the aggregate informed investors demand:

$$\sum_{i=1}^{n}\left[\frac{1}{n}\frac{\mathrm{E}[p_2 \mid \mathcal{F}_1^{\mathrm{I}}(i)] - p_1}{\mathrm{Var}[p_2 \mid \mathcal{F}_1^{\mathrm{I}}(i)]}\right] = \frac{\mathrm{E}[p_2 \mid \mathcal{F}_1^{\mathrm{I}}] - p_1}{\mathrm{Var}[p_2 \mid \mathcal{F}_1^{\mathrm{I}}]}.$$

Comparing to the previous model without multiple informed groups, we see the only difference of this model is that s in information sets of informed investors is replaced by $\overline{s}$. And the difference of $\overline{s}$ from s is that ϵ is replaced by $\overline{\epsilon}$. We have $V_{\overline{\epsilon}}$ is decreasing with n. Intuitively, when there are more informed investor groups (n is greater), the informed investors as a whole group has more information and hence informed trading incorporate more information into the market price. Therefore, substitute $V_{\overline{\epsilon}} = V_{\epsilon}$ into the solution of p_1 in the previous model, we obtain the solutions of the prices at $t=1$ and $t=0$, the pre-announcement risk premium PaP, and the pre-announcement expected abnormal trading volume $\overline{ATV}$.

Based on the above argument and the relationship between $V_{\overline{\epsilon}}$ and V_{ϵ}, we can infer the properties of $\overline{ATV}$ and PaP:

The pre-announcement expected abnormal trading volume $\overline{ATV}$ is non-determinant with m, decreasing with n and V_e, increasing with V_{ϵ}, V_u and μ:

$$\frac{\partial \overline{\mathrm{ATV}}}{\partial n} < 0, \frac{\partial \overline{\mathrm{ATV}}}{\partial V_e} < 0, \frac{\partial \overline{\mathrm{ATV}}}{\partial V_{\epsilon}} > 0, \frac{\partial \overline{\mathrm{ATV}}}{\partial V_u} > 0, \frac{\partial \overline{\mathrm{ATV}}}{\partial \mu} > 0. \qquad \text{(A1)}$$

The pre-announcement risk premium PaP is positive, decreasing with n and μ, increasing with V_e, V_ϵ and V_u:

$$\frac{\partial \text{PaP}}{\partial \mu} < 0, \frac{\partial \text{PaP}}{\partial n} < 0, \frac{\partial \text{PaP}}{\partial V_e} > 0, \frac{\partial \text{PaP}}{\partial V_\epsilon} > 0, \frac{\partial \text{PaP}}{\partial V_u} > 0. \tag{A2}$$

Based on the results in (A1) and (A2), we get the model predictions of interest summarized in proposition 2 and 3.

Table I: Summary statistics of macroeconomic news announcements

Panel A lists the five pre-scheduled macro news announcements during trading hours of US stock markets: FOMC Announcement (FOMC), Consumer Confidence Index (CCI), University of Michigan Consumer Sentiment Index (CSI), ISM Manufacturing Index (ISM), and New Home Sales. Day and time denote the day of month and the time of the announcement. N denotes the number of announcements during our sample period from July 2003 to December 2016. Panel B reports summary statistics of Bloomberg survey. #SP is the number of survey participants, SUR is the standardized announcement surprise, DIS is the standardized dispersion of forecasts. We also report the number (percentage) of announcements with surprise greater than 2 and 3 standard deviations.

Panel A: List of pre-scheduled macroeconomic news announcements

Macro News	Day	Time	N
FOMC	Eight regularly scheduled meetings per year	14:15*	108
CCI	Around 25th of the month	10:00	162
CSI	Second and fourth Friday (revised) of the month	10:00	323
ISM	Around 16th of the month	10:00	162
New Home Sales	17th workday of the month (around 25th/26th)	10:00	161

*From July 2003 to Dec. 2016, FOMC pre-scheduled announcements took place 66 times at 14:15, 31 times at 14:00, 8 times at 12:30, and 1 time each at 14:14, 14:17 and 14:19. Data Source: www.bloomberg.com.

Panel B: Summary statistics of market surveys

Variable	Mean	Median	Std Dev	Min	Max	|SUR|>2	|SUR|>3
FOMC: N = 108							
#SP	85.519	93.000	24.602	33.000	143.000		
SUR	-0.098	0.000	1.000	-6.960	3.341	3 (2.78%)	3 (2.78%)
DIS	0.504	0.000	1.000	0.000	4.790		
CCI: N = 162							
#SP	68.049	68.000	6.516	48.000	81.000		
SUR	0.037	0.071	1.000	-2.825	2.492	4 (2.47%)	0 (0.00%)
DIS	3.492	3.311	1.000	1.742	7.411		
CSI: N = 323							
#SP	60.424	61.000	6.290	44.000	74.000		
SUR	-0.083	0.000	1.000	-3.442	3.198	25 (7.74%)	3 (0.93%)
DIS	2.518	2.410	1.000	0.983	7.551		
ISM: N = 162							
#SP	74.673	75.000	7.298	55.000	88.000		
SUR	0.118	0.080	1.000	-3.201	3.948	7 (4.32%)	2 (1.23%)
DIS	3.495	3.340	1.000	1.784	7.455		
New Homes Sales: N = 161							
#SP	69.174	72.000	7.131	50.000	82.000		
SUR	0.029	-0.051	1.000	-2.833	4.164	8 (4.97%)	3 (1.86%)
DIS	1.633	1.196	1.000	0.513	5.486		

Table II: Summary statistics of pre-announcement return on SPX and VIX variables

This table reports summary statistics of the return, VIX level and its change, excess realized volatility, and abnormal trading volume for FOMC announcement and other macro news announcement during one-day pre-announcement period in Panel A and those of the same variables during half-day pre-announcement period in Panel B. $Ret_{[t-d,t]}$ is the one-day pre-announcement return, $\Delta VIX_{[t-d,t]}$ is the one-day pre-announcement change of VIX level, VIX_{t-d} is the VIX level one day prior to the announcement, $ExRV_{[t-d,t]}$ is the one-day pre-announcement excess realized volatility and $ATV_{[t-d,t]}$ is the one-day pre-announcement abnormal trading volume. Both one-day and half-day pre-announcement return are expressed in percentage. (Sample period is from 2003/07 to 2016/12.)

Panel A: One-day pre-announcement period

Variable	Mean	Median	Std Dev	Min	Max
FOMC announcement (N = 108)					
$Ret_{[t-d,t]}$	0.336	0.142	1.229	-2.152	9.566
VIX_{t-d}	19.713	17.025	9.471	11.050	75.380
$\Delta VIX_{[t-d,t]}$	-0.349	-0.205	1.397	-7.230	3.220
$ExRV_{[t-d,t]}$	-0.129	-0.062	0.477	-2.695	1.654
$ATV_{[t-d,t]}$	-1.254	-1.044	4.137	-21.915	11.738
Other macro news announcement (N = 749)					
$Ret_{[t-d,t]}$	0.033	0.079	1.055	-4.638	5.882
VIX_{t-d}	19.243	16.490	9.171	9.980	85.460
$\Delta VIX_{[t-d,t]}$	-0.007	-0.010	1.598	-12.930	8.570
$ExRV_{[t-d,t]}$	-0.016	-0.004	1.274	-15.227	18.220
$ATV_{[t-d,t]}$	0.105	-0.060	5.948	-19.749	29.845

Panel B: Half-day pre-announcement period

Variable	Mean	Median	Std Dev	Min	Max
FOMC announcement (N = 108)					
$Ret_{[t-d/2,t]}$	0.072	0.000	0.389	-0.592	1.726
$VIX_{t-d/2}$	19.421	16.755	9.032	10.720	69.660
$\Delta VIX_{[t-d/2,t]}$	-0.057	0.005	0.617	-2.810	1.380
$ExRV_{[t-d/2,t]}$	-0.087	-0.029	0.294	-1.370	1.417
$ATV_{[t-d/2,t]}$	-1.248	-0.745	2.462	-9.345	3.718
Other macro news announcement (N = 749)					
$Ret_{[t-d/2,t]}$	0.024	0.090	0.962	-5.062	9.321
$VIX_{t-d/2}$	19.180	16.300	9.100	9.870	78.580
$\Delta VIX_{[t-d/2,t]}$	0.056	0.010	1.391	-10.410	8.170
$ExRV_{[t-d/2,t]}$	-0.038	-0.006	0.868	-10.473	9.797
$ATV_{[t-d/2,t]}$	0.129	-0.019	4.116	-16.801	23.136

Table III: Determinants of Trading Volume

This table reports the results of panel regression of abnormal trading volume (ATV) against several potential determinants, VIX_{t-d}, $-\Delta VIX_{[t-d,t]}$, #SP, |SUR|, and DIS. VIX_{t-d} is the VIX level one day prior to the announcement, $\Delta VIX_{[t-d,t]}$ is the one-day pre-announcement change of VIX level, #SP is the number of survey participants, |SUR| is the absolute value of forecast surprise, and DIS is the forecast dispersion. We model news type fixed effects and report within estimators for coefficients. Below each coefficient estimate is the corresponding standard error. *** denotes significant at 1% level; ** denotes significant at 5% level; * denotes significant at 10% level.

	Dependent variable: $ATV_{[t-d,t]}$						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
#SP	0.015					0.015	0.016
	(0.015)					(0.015)	(0.015)
|SUR|		-0.173				-0.105	-0.101
		(0.275)				(0.284)	(0.279)
DIS			-0.054			0.101	0.049
			(0.196)			(0.206)	(0.199)
VIXt-d				-0.053***		-0.054***	
				(0.020)		(0.021)	
$-\Delta VIX_{[t-d,t]}$					-0.715***		-0.716***
					(0.122)		(0.123)
News type FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	803	803	803	803	803	803	803
Adj. R^2	-0.005	-0.006	-0.006	0.003	0.035	0.0004	0.033

Table IV: Determinants of Pre-announcement Premium

This table reports the results of panel regression of pre-announcement premium ($Ret_{[t-d,t]}$) against several potential determinants, VIX_{t-d}, $-\Delta VIX_{[t-d,t]}$, $ExRV_{[t-d,t]}$, #SP, |SUR|, DIS, and ATV. VIX_{t-d} is the VIX level one day prior to the announcement, $\Delta VIX_{[t-d,t]}$ is the one-day pre-announcement change of VIX level, $ExRV_{[t-d,t]}$ is the one-day pre-announcement excess realized volatility, #SP is the number of market participants, |SUR| is the absolute value of forecast surprise, DIS is the forecast dispersion and ATV is the abnormal trading volume. We model news type fixed effects and report within estimators for coefficients. Below each coefficient estimate is the corresponding standard error. *** denotes significant at 1% level; ** denotes significant at 5% level; * denotes significant at 10% level.

	Dependent variable: $Ret_{[t-d,t]}$									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
#SP	-0.002						-0.001	-0.002		
	(0.003)						(0.003)	(0.002)		
|SUR|		0.086*					0.027	0.001		
		(0.052)					(0.053)	(0.031)		
DIS			0.116***				0.074*	0.064***		
			(0.037)				(0.038)	(0.022)		
VIXt-d				0.020***			0.016***			
				(0.004)			(0.004)			
$-\Delta VIX_{[t-d,t]}$					0.547***			0.545***		0.543***
					(0.014)			(0.014)		(0.015)
$ATV_{[t-d,t]}$						-0.031***	-0.028***	0.001		
						(0.007)	(0.007)	(0.004)		
ExRV									-0.285***	-0.016
									(0.034)	(0.022)
News type FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	803	803	803	803	803	803	803	803	803	803
Adj. R^2	-0.006	-0.003	0.006	0.027	0.663	0.020	0.050	0.666	0.077	0.663

Table V: Summary Statistics of Informed Trading and Liquidity Trading

This table reports summary statistics of informed trading and liquidity trading. ATVI is abnormal informed trading volume, a proxy for informed trading. ATVU is uninformed abnormal trading volume, a proxy for liquidity shock. The unit of ATVI and ATVU is in $billion. (Sample period is from 2003/07 to 2016/12.)

Panel A: One-day pre-announcement period

FOMC announcement (N = 108)					
Variable	Mean	Median	Std Dev	Min	Max
ATVI	-0.803	-0.687	2.267	-12.773	6.337
ATVU	-0.453	-0.341	2.171	-10.679	5.853
Other macro news announcement (N = 749)					
ATVI	0.091	0.060	2.903	-9.701	14.905
ATVU	0.007	-0.043	3.204	-12.424	14.940

Panel B: Half-day pre-announcement period

FOMC announcement (N = 108)					
ATVI	-0.612	-0.348	1.218	-4.318	2.767
ATVU	-0.620	-0.399	1.381	-5.654	2.168
Other macro news announcement (N = 749)					
ATVI	0.081	-0.055	2.037	-8.668	12.451
ATVU	0.043	-0.012	2.211	-9.595	10.685

Table VI: Determinants of Liquidity Trading

This table reports the results of panel regression of liquidity trading (ATVU) against several potential determinants, VIX_{t-d}, $-\Delta VIX_{[t-d,t]}$, #SP, |SUR|, and DIS. VIX_{t-d} is the VIX level 24 hours prior to the announcement, $\Delta VIX_{[t-d,t]}$ is the one-day pre-announcement change of VIX level, #SP is the number of market participants, |SUR| is the absolute value of forecast surprise, and DIS is the forecast dispersion. We model news type fixed effects and report within estimators for coefficients. Below each coefficient estimate is the corresponding standard error. *** denotes significant at 1% level; ** denotes significant at 5% level; * denotes significant at 10% level.

	Dependent variable: $ATVU_{[t-d,t]}$						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
#SP	0.003					0.003	0.003
	(0.008)					(0.008)	(0.008)
|SUR|		-0.039				-0.003	0.006
		(0.150)				(0.155)	(0.152)
DIS			-0.036			0.020	0.003
			(0.107)			(0.113)	(0.109)
VIXt-d				-0.023**		-0.024**	
				(0.011)		(0.011)	
$-\Delta VIX_{[t-d,t]}$					-0.391***		-0.391***
					(0.067)		(0.067)
News type FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	803	803	803	803	803	803	803
Adj. R^2	-0.006	-0.006	-0.006	-0.0005	0.035	-0.004	0.032

Table VII: Determinants of Informed Trading

This table reports the results of panel regression of informed trading (ATVI) against several potential determinants, $VIX_{t\text{-}d}$, $-\Delta VIX_{[t\text{-}d,t]}$, #SP, |SUR|, DIS and ATVU. $VIX_{t\text{-}d}$ is the VIX level 24 hours prior to the announcement, $\Delta VIX_{[t\text{-}d,t]}$ is the one-day pre-announcement change of VIX level, #SP is the number of market participants, |SUR| is the absolute value of forecast surprise, DIS is the forecast dispersion, and ATVU is liquidity shock. We model news type fixed effects and report within estimators for coefficients. Below each coefficient estimate is the corresponding standard error. *** denotes significant at 1% level; ** denotes significant at 5% level; * denotes significant at 10% level.

	Dependent variable: $ATVI_{[t\text{-}d,t]}$							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
#SP	0.013*						0.011***	0.011***
	(0.008)						(0.003)	(0.003)
|SUR|		-0.142					-0.107*	-0.117*
		(0.134)					(0.063)	(0.063)
DIS			-0.029				0.054	0.035
			(0.095)				(0.046)	(0.045)
$VIX_{t\text{-}d}$				-0.029***			-0.010**	
				(0.010)			(0.005)	
$-\Delta VIX_{[t\text{-}d,t]}$					-0.326***			-0.016
					(0.060)			(0.028)
ATVU						0.794***	0.791***	0.792***
						(0.015)	(0.014)	(0.015)
News type FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	803	803	803	803	803	803	803	803
Adj. R^2	-0.002	-0.005	-0.006	0.005	0.030	0.787	0.791	0.790

Table VIII: Determinants of Pre-announcement Premium – Effect of Informed Trading and Liquidity Trading

This table reports the results of panel regression of pre-announcement premium ($Ret_{[t-d,t]}$) against proxies for informed trading and liquidity trading and other potential determinants. ATVI is informed abnormal trading volume, a proxy for informed trading. ATVU is uninformed abnormal trading volume, a proxy for liquidity trading. VIX_{t-d} is the VIX level 24 hours prior to the announcement, $\Delta VIX_{[t-d,t]}$ is the one-day pre-announcement change of VIX level, #SP is the number of market participants, |SUR| is the absolute value of forecast surprise, DIS is the forecast dispersion and ATV is the abnormal trading volume. We model news type fixed effects and report within estimators for coefficients. Below each coefficient estimate is the corresponding standard error. *** denotes significant at 1% level; ** denotes significant at 5% level; * denotes significant at 10% level.

	Dependent variable: $Ret_{[t-d,t]}$					
	(1)	(2)	(3)	(4)	(5)	(6)
#SP			-0.0004	-0.001	-0.001	-0.002
			(0.003)	(0.003)	(0.003)	(0.002)
|SUR|			0.041	0.048	0.029	0.0003
			(0.053)	(0.053)	(0.053)	(0.031)
DIS			0.107***	0.105***	0.073*	0.064***
			(0.038)	(0.038)	(0.038)	(0.022)
VIXt-d					0.016***	
					(0.004)	
$-\Delta VIX_{[t-d,t]}$						0.545***
						(0.014)
ATVI	-0.060***		-0.060***		-0.006	-0.003
	(0.014)		(0.014)		(0.030)	(0.017)
ATVU		-0.057***		-0.056***	-0.048*	0.003
		(0.012)		(0.012)	(0.026)	(0.016)
News type FE	Yes	Yes	Yes	Yes	Yes	Yes
N	803	803	803	803	803	803
Adj. R^2	0.018	0.020	0.027	0.030	0.050	0.666

Table IX: Determinants of Excess Realized Volatility – Effect of Informed Trading and Liquidity Trading

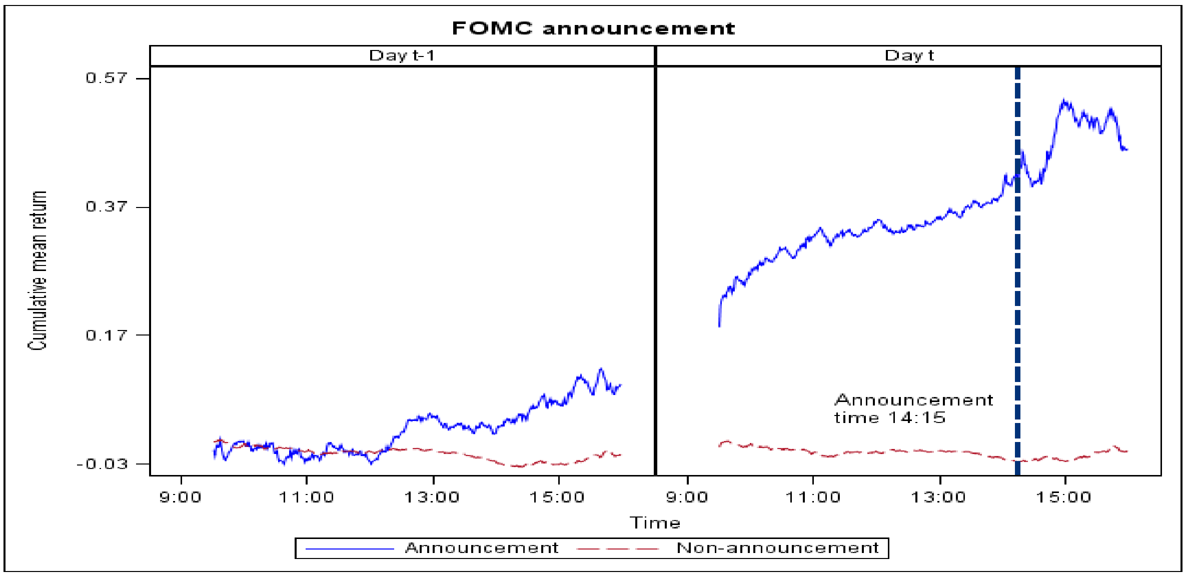
This table reports the results of panel regression of excess realized volatility ($ExRV_{[t-d,t]}$) against several potential determinants, #SP, |SUR|, DIS, ATV, ATVI, and ATVU. ATV is the abnormal trading volume, ATVI is informed abnormal trading volume, a proxy for informed trading, and ATVU is uninformed abnormal trading volume, a proxy for liquidity shock. We model news type fixed effects and report within estimators for coefficients. Below each coefficient estimate is the corresponding standard error. *** denotes significant at 1% level; ** denotes significant at 5% level; * denotes significant at 10% level.

	Dependent variable: $ExRV_{[t-d,t]}$						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
#SP	0.001						-0.001
	(0.003)						(0.003)
|SUR|		-0.201***					-0.196***
		(0.052)					(0.049)
DIS			0.012				0.050
			(0.038)				(0.035)
ATV				0.078***			
				(0.006)			
ATVI					0.164***		0.152***
					(0.013)		(0.028)
ATVU						0.132***	0.010
						(0.012)	(0.025)
News type FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	803	803	803	803	803	803	803
Adj. R^2	-0.006	0.012	-0.006	0.159	0.169	0.134	0.181

Figure 1: Cumulative returns of the S&P 500 index.

This figure reports the average cumulative returns on the S&P 500 index during two consecutive trading days, announcement vs non-announcement period. We report FOMC announcement in panel A and other macroeconomic news announcement in panel B. In each panel, the x-axis is calendar time, and the y-axis is cumulative mean return in percentage; the solid line is the cumulative mean return during announcement period, and the dashed line is the cumulative mean return during non-announcement period; for announcement period, day t is the announcement day, and day t-1 is the prior trading day; the vertical dash line indicates the announcement time, 14:15 for FOMC announcement and 10:00 for other macroeconomic news announcement.

Panel A FOMC announcement



Panel B Other macro news announcement

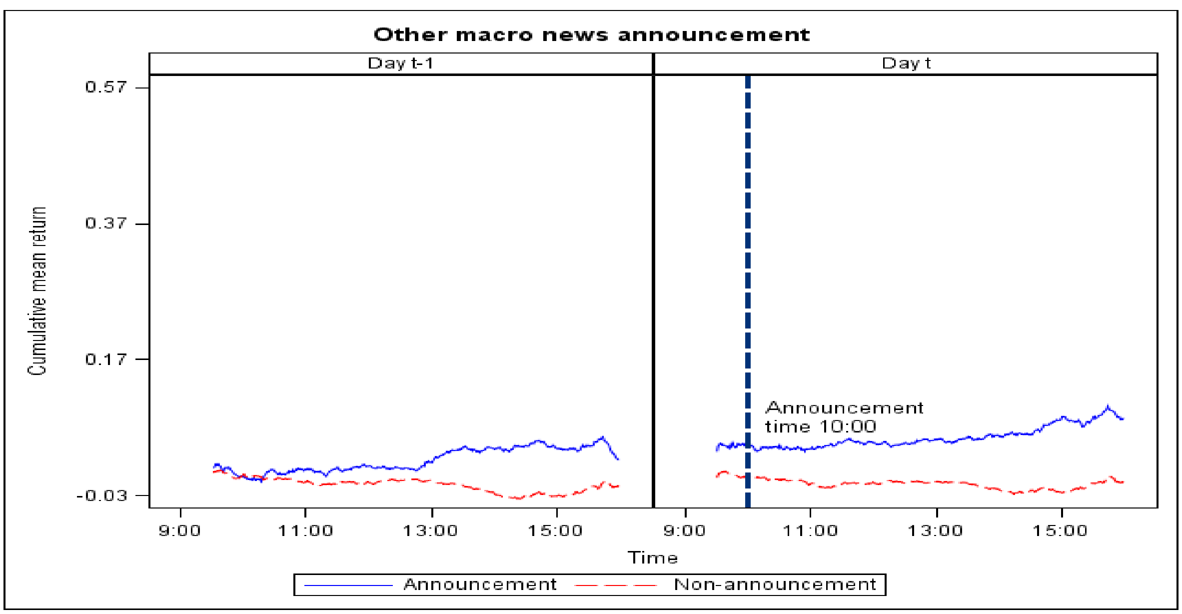
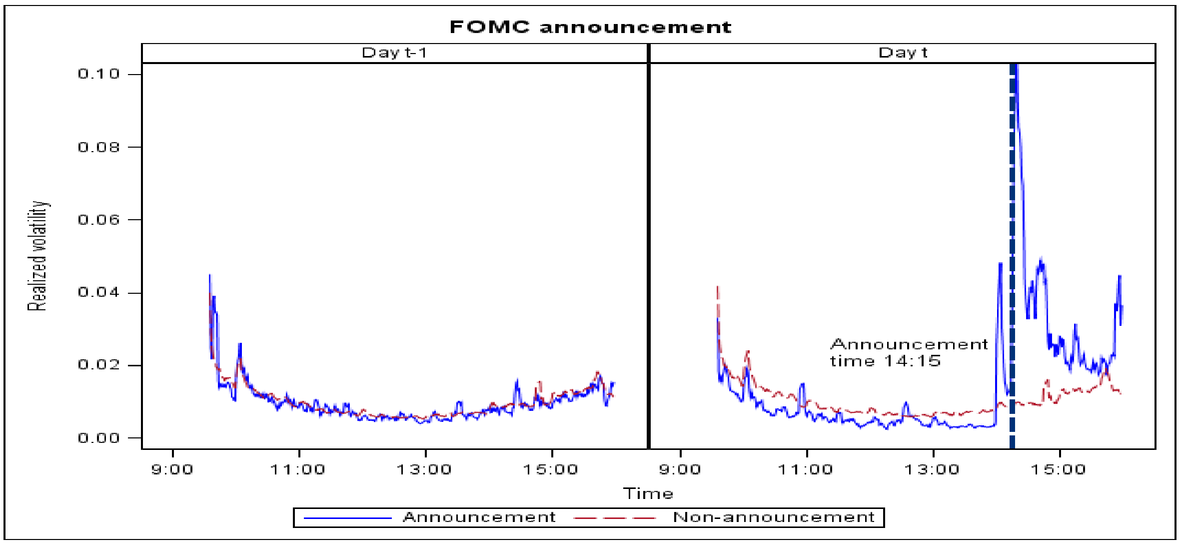


Figure 2: Intraday realized volatility of S&P 500 index returns.

This figure reports the average realized volatility on the S&P 500 index during two consecutive trading days, announcement vs non-announcement period. We report FOMC announcement in panel A and other macroeconomic news announcement in panel B. In each panel, the x-axis is calendar time, and the y-axis is average 5-minute realized volatility in squared percentage; the solid line is the realized volatility during announcement period, and the dashed line is the realized volatility during non-announcement period; for announcement period, day t is the announcement day, and day t-1 is the prior trading day; the vertical dash line indicates the announcement time, 14:15 for FOMC announcement and 10:00 for other macroeconomic news announcement.

Panel A FOMC announcement



Panel B Other macro news announcement

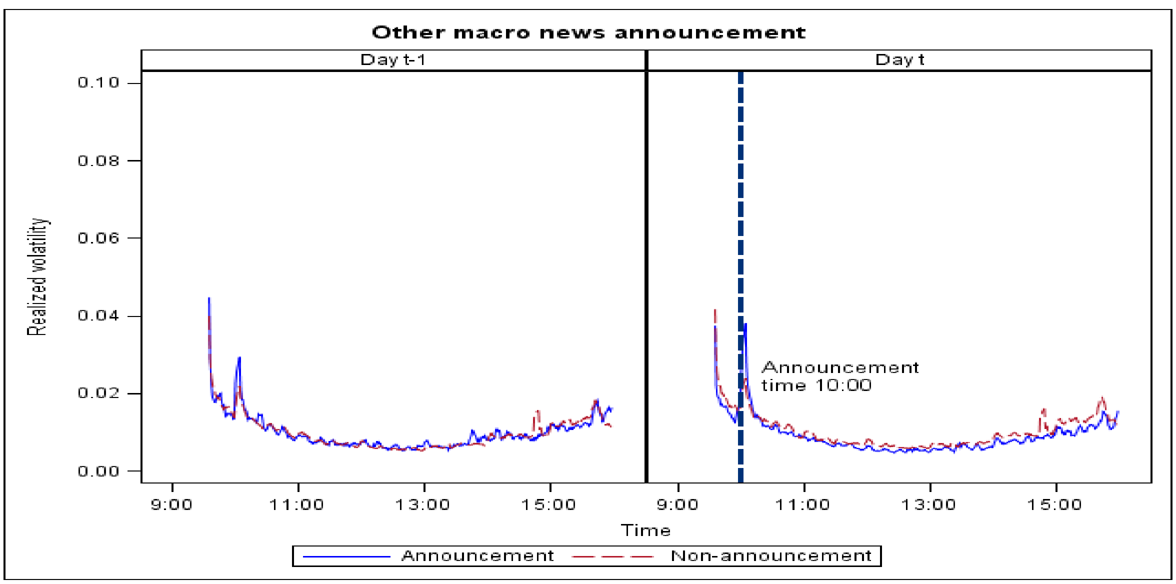
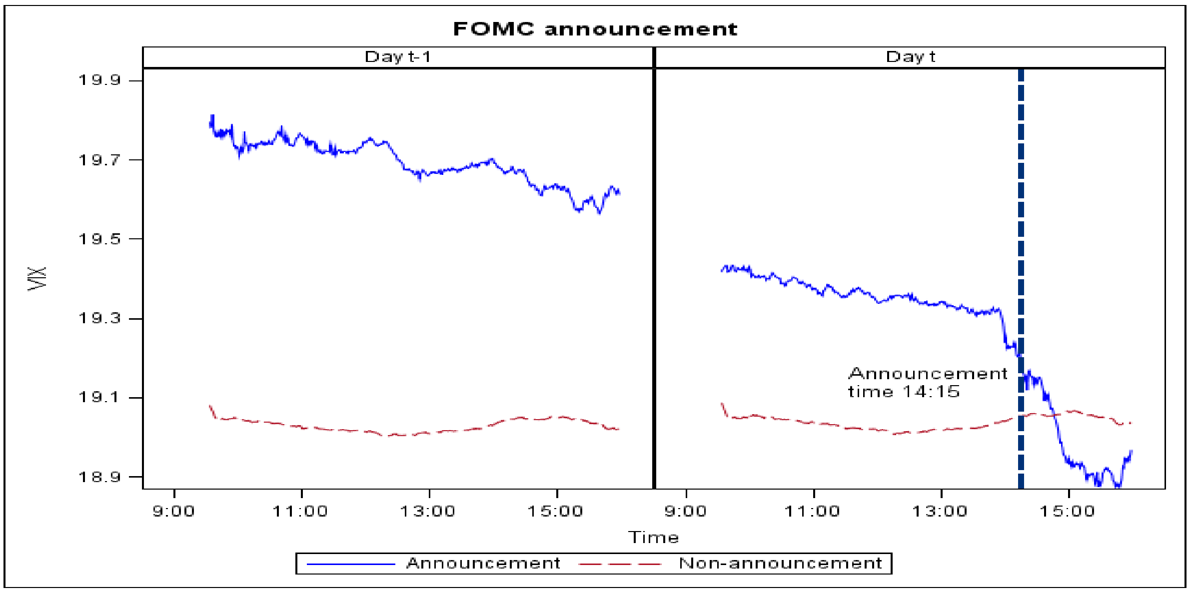


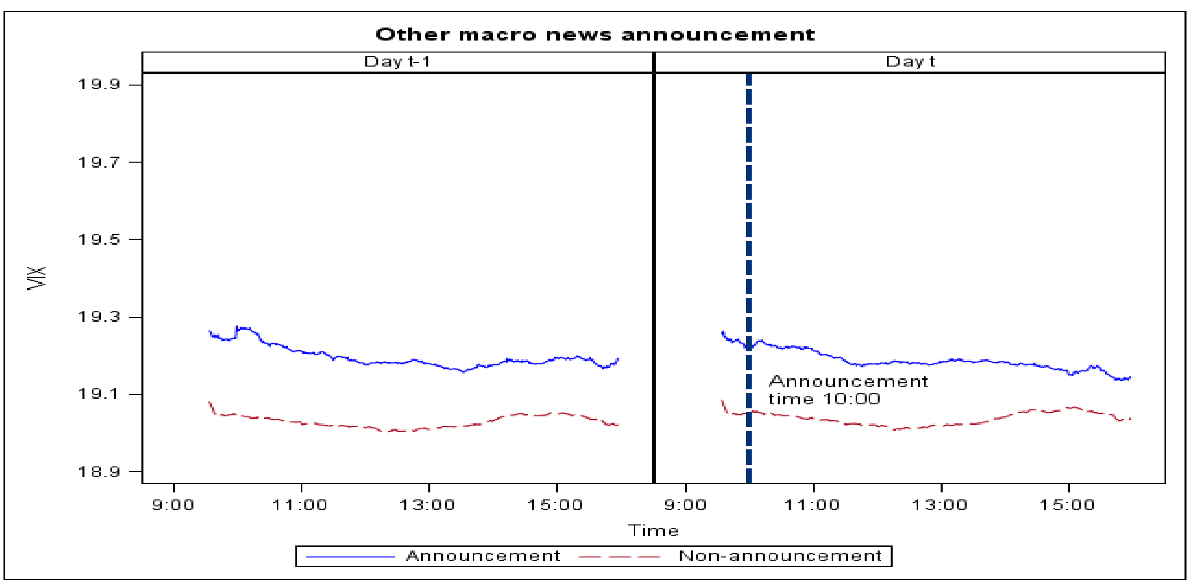
Figure 3: Intraday VIX level change around Macroeconomic News Announcements.

This figure reports the average VIX level during two consecutive trading days, announcement vs non-announcement period. We report FOMC announcement in panel A and other macroeconomic news announcement in panel B. In each panel, the x-axis is calendar time, and the y-axis is 1-minute mean VIX level; the solid line is the mean VIX level during announcement period, and the dashed line is the mean VIX level during non-announcement period; for announcement period, day t is the announcement day, and day t-1 is the prior trading day; the vertical dash line indicates the announcement time, 14:15 for FOMC announcement and 10:00 for other macroeconomic news announcement.

Panel A FOMC announcement



Panel B Other macro news announcement



ESSAY 2

SPECULATION OR HEDGING? — OPTIONS TRADING PRIOR TO FOMC ANNOUNCEMENTS

I. INTRODUCTION

The Federal Open Market Committee (FOMC) announcement is an important macro-economic event that not only attracts great attention of market participants and the media but also has significant effect on market returns. During the one-hour post-announcement window, the return on S&P500 index ranges from -2.28% to 2.50% over the period of 2004 to 2016.

Interestingly, we also observe substantial change in options premium prior to FOMC announcements. The average VIX level starts to increase three trading days before the FOMC announcement, up to the peak in two trading days. As VIX is basically the implied volatility of option price, and high VIX corresponds to high option price, the increase VIX level during the pre-FOMC announcement window is interesting and naturally arises two questions: Do investors trade options to speculate on the information of the upcoming FOMC announcement? Do investors trade options to hedge the uncertainty of the upcoming FOMC announcement?

Options are used to speculate, hedge, and arbitrage. There is a voluminous literature, both in theory and empirics, and textbook in finance about the role of options playing in price discovery and hedging, such as Easley, O’Hara, and Srinivas (1998), Hull (2006), Pan and Poteshman (2006), Roll, Schwartz, and Subrahmanyam (2010), Xing, Zhang, and Zhao (2010), Ge, Lin, and Pearson (2016).

Extant literature also documents abnormal trading activity in option market around information relevant economic events and option trading’s role in price discovery, such as earnings announcement (Amin and Lee, 1997), M&A (Cao, Chen, and Griffin, 2005; Augustin, Brenner, Grass, and Subrahmanyam, 2018; Cremers, Fodor, Muravyev, and Weinbaum, 2019), share repurchase announcement (Hao, 2016), dividend change announcement (Zhang, 2018).

The above economic events are interesting and important in themselves. However, they are all in firm level, and there is no literature so far examines the effects of option trading around macro level economic events. In this paper, we examine the effects of option trading on speculation and hedging when market is in anticipation of an important macroeconomic event, the FOMC announcement. We find informed traders use option to speculate on their private information. Specifically, abnormal trading volume of call options on S&P500 index during the pre-announcement window of the FOMC announcement positively predicts post-announcement index return, and this predictability mainly comes from near-the-money (NTM) call option. Moreover, we further breakdown trading volume based on the direction of trade and show buyer-initiated call option trading volume positively predicts post-announcement index return. However, we find no evidence of investors using options to hedge post-FOMC announcement market uncertainty.

The remainder of this paper is organized as follows. Section II is literature review and hypotheses development; section III describes data used in empirical analysis and summary statistics; section IV specifies our empirical tests and presents main results; section V concludes the paper.

II. LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

The literature presents that informed investors use option market to speculate, both theoretically and empirically. Easley, O'Hara, and Srinivas (1998) develop a sequential trade model with multiple trading venues in which investors can trade in both stock and option markets. Some traders are informed and other traders are uninformed, and risk-neutral competitive market makers coordinate the transactions. Easley, O'Hara, and Srinivas (1998) derive a “pooling equilibrium” in which informed traders trade in the option market when the liquidity in the stock market is low or the fraction of informed traders is high. Basically, their model predicts that when investors can trade both in stock and option markets, because of high leverage of options, informed investors with financial constraint prefer option to speculate.

Empirically, the literature documents that various option trading variables can predict future stock returns. Signed option trading volume (Amin and Lee, 1997; Easley, O'Hara, and Srinivas, 1998), put-call ratios from option volume initiated by buyers to open new positions (Pan and Poteshman, 2006), implied volatility spreads (Bali and Hovakimian, 2009, Cremers and Weinbaum, 2010), Bali and Murray (2013), Cremers and Weinbaum (2010), the ratio of option trading volume to stock trading volume (O/S) (Roll, Schwartz, Subrahmanyam, 2010).

Literature also documents intensified option trading activity before (or around) information relevant events. Amin and Lee (1997) find option trading volume increases four days before quarterly earnings announcement, the direction of this preannouncement trading predicts subsequent earnings news, and there are informed option traders whose trading help incorporated their private information into stock price. They also find informed traders not necessarily trade options with greatest leverage, because they trade off the benefit of greater leverage against the higher costs from bid-ask spreads and the risk of detection. Augustin, Brenner, Grass, and Subrahmanyam (2018) document the pervasiveness of informed trading activity in target companies’ equity options before the announcement of takeovers, such that 25% of all takeovers have positive abnormal volumes and which are greater for short-dated out-of-the-money calls. Zhang (2018) find a positive (negative) association between pre-announcement abnormal implied volatility spread and cumulative abnormal stock returns around dividend change announcement.

If informed traders use options to speculate, then their trading activities contain information and can predict future stock returns. When informed investors have positive private information about future stock prices, they can either buy call option or sell put option to speculate on their private information. One important character of options is that their payoff functions are asymmetric when the underlying stock price goes up or goes down. The payoff function of a call option has no upper bound, and the holder of a call option in theory potentially have infinite large payoff when the underlying stock price goes up. And the payoff function of a call option has a low bound, that is the call option premium. The greatest loss that a call option holder can generate is the call option premium. On the other hand, the payoff function of has an upper bound and the greatest payoff a seller of put option can get is the option premium. However, the potential loss of a put option can be very large, as large as the strike price when the underlying stock price goes down to zero. Therefore, informed investors prefer to buy call option to speculate when they have positive information about future stock returns. When speculators buy call option, ceteris paribus, call option trading volume will increase. So we expect abnormal trading volume of call option positively predicts post-FOMC announcement returns. As we have seen in Amin and Lee (1997), informed traders trade off the benefit of greater leverage against the higher costs from bid-ask spreads and the risk of detection. The market for out-of-money (OTM) options is less liquid, has wider bid-ask spread and high transaction costs. So when breakdown options based on moneyness, we expect speculators use near-the-money (NTM) option to trade, and hence abnormal trading volume of NTM call option positively predicts post-FOMC announcement returns. Further, as in classical sequential trading model such as Glosten and Milgrom (1985), Easley, O'Hara, and Srinivas (1998), informed investors actively trade based on their private information, that is, investors with positive information tend to buy at the ask price and investors with negative information tend to sell at the bid price. Hence the direction of a trade (buyer-initiated or buyer-initiated) contains information about future asset prices. Under our setting when informed investors have positive information about future stock price, we expect the abnormal trading volume of buyer-initiated call option positively, even stronger than non-differentiated call option trading volume, predicts post-FOMC announcement returns.

When informed investors have negative private information about future stock prices, they can either buy put option or sell call option to speculate on their private information. However, index put options are expensive, especially the out-of-the-money (OTM) index put options. As Bollen and Whaley (2004) point out, the index implied volatility function decreases monotonically across exercise prices since October 1987. Basically, it says since the market crash of 1987, market becomes more worrisome about future market crash and the demand for the market crash insurance, put options, especially OTM put options, dramatically increases. On the other hand, the supply of put options is limited because limits of arbitrage and hence market maker can only produce enough put option with high costs. Combining these two factors, the put option price since 1987 is much higher than before. Under our FOMC announcement setting, this event is short-term of only 2 to 3 days, the magnitude of index drop is unlikely very large, hence the price of index put option may be high enough to deter informed investors to use it to speculate. So we expect the abnormal trading volume of put option has no predictive power for post-FOMC announcement returns.

Below we summarize above analysis into our testable hypothesis 1:

H1: If informed traders use options to speculate, then abnormal trading volume of options predicts post-FOMC announcement returns.

- H1a: More conservative informed traders mainly use near-the-money options to speculate because of liquidity concerns.
- H1b: In particular, buyer-initiated options have stronger predictability.

Due to low transaction costs of options, portfolio managers often use option to hedge risk of portfolio. When investors expect future market uncertainty is high, they are going to buy option to hedge the risk of their portfolio. So we expect abnormal trading volume of options is positively associated with future market uncertainty after the announcement when investors use options to hedge.

Below we summarize above analysis into our testable hypothesis 2:

H2: If investors hedge uncertainty in the upcoming announcement, then abnormal trading volume of options predicts uncertainty of the announcement.

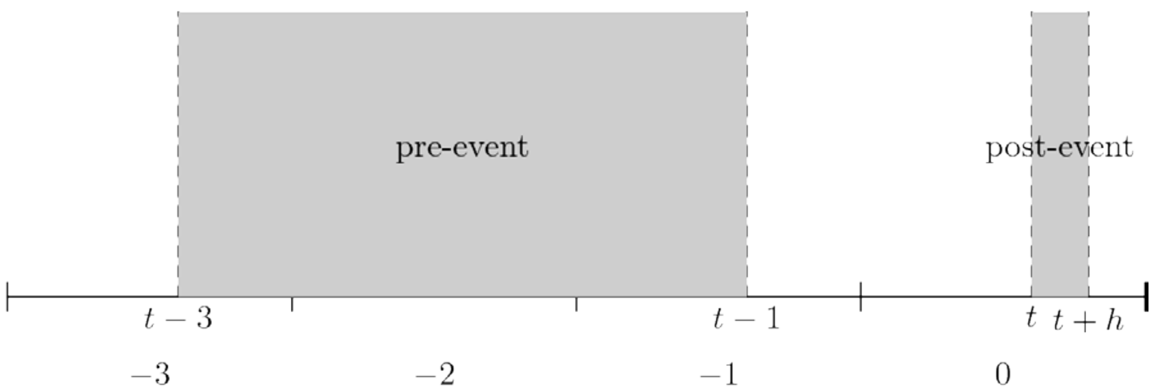
III. DATA AND METHODOLOGY

We use data from several sources in our empirical tests. We obtain options trade data from www.cboe.com. Included with each trade is the option type, expiration, and strike, the trade price and size, the exchange where the trade printed, the NBBO quote and depth, the underlying bid and ask, and each of the individual exchange markets. Other data used include: intraday returns of S&P 500 index and the CBOE volatility index (VIX) from www.tickdata.com, trade and quote data on S&P500 tracking ETF (SPY) from TAQ database. Our sample period spans from 2004 to December 2016.

We examine the effects of option trading around the FOMC announcement. Below in Exhibit 1, we illustrate the event window in our analysis: We examine four consecutive trading days around the FOMC announcement, the announcement day 0, and three trading days preceding it, -3, -2 and

-1; We examine intra-day market activities around FOMC announcement, the announcement time is *t*, 1 hour post-announcement time is *t+h*, 1 trading day prior to the announcement time *t* is *t*-1, and 3 trading days prior to the announcement time *t* is *t*-3. Our pre-announcement window is from *t*-3 to *t*-1, and post-announcement window is from *t* to *t+h*.

Exhibit 1: Event Window



We observe a distinguished pattern of VIX change around the FOMC announcement window. In Figure 1, we plot the average VIX level of four consecutive days before the FOMC announcement, three days before the announcement time, the VIX starts to increase from the level of 19.2, gradually goes up through the second trading day before the announcement, finally around the open of the first trading day before the announcement, arrives the highest point at 19.8, and then goes down gradually as the uncertainty resolved to the lowest point below 19.0 1-hour post the announcement.

Basically, our empirical tests run two types of regression, in one the dependent variable is 1-hour post-announcement return, in the other the dependent variable is 1-hour post-announcement VIX level change, and the dependent variables are various types of abnormal option trading volume. The dependent variable 1-hour post announcement log return on S&P 500 index, *Ret_1h*, is defined by $Ret\_1h = \ln P_{t+h} - \ln P_t$, where t is the FOMC announcement time, P_t is the S&P 500 index level at the FOMC announcement time, P_{t+h} is the S&P 500 index level one hour post the FOMC announcement time.

The dependent variable, 1-hour post announcement VIX level change, *dvix1h*, is defined by $dvix1h = VIX_{t+h} - VIX_t$, where VIX_t is the VIX level at the FOMC announcement time, VIX_{t+h} is the VIX level one hour post the FOMC announcement time.

Table I reports summary statistics of these two dependent variables used in our empirical analysis. We see from Table I that the mean return on S&P 500 index one hour post the FOMC announcement is 15 basis points, being 24.57% annualized return; the VIX level drops about 0.45 points on average one hour post the FOMC announcement.

We focus on short-term options of which time-to-maturity is less than 37 days, which is the largest maturity CBOE used to calculate VIX. We construct abnormal option trading volumes by the following procedure. First, we compute abnormal trading volumes (ATVs) of calls and puts (C&P) relative to previous five trading days.

To test informativeness of option trading based on moneyness, we break down trading volume into near-the-money (NTM) and out-of-the-money (OTM) trading volumes. For call options, we classify

- NTM option when $K/S < 1.10$ and OTM option when $K/S \geq 1.10$.

For put options, we classify

- OTM option when $K/S < 1.10$ and NTM option when $K/S \geq 1.10$.

Then, we use Lee and Ready (2001) algorithm to identify buyer-initiated and seller-initiated transactions for call and put option contracts. Specifically, we first use a quote test first, then a tick test. In the quote test, if the price of an option trade is higher than the midpoint of the NBBO bid and ask, then the trade is classified as buyer-initiated. If the price is lower than the midpoint, the trade is classified as seller-initiated. When they are equal, the tick test is utilized. In the tick test, if the price is higher than the previous price, it is classified as buyer-initiated and if it is lower, then the trade is classified as seller-initiated. Other cases are considered as non-determined.

Then we compute abnormal trading volumes for each type of trades. So in our finest breakdown of option trading volume, we have 2×2×2=8 categories of abnormal trading volume (call or put, NTM or OTM, and buyer or seller-initiated). For example, we have 2 types of Seller initiated Call abnormal trading volumes: SC(NTM) and SC(OTM).

Table II reports summary statistics of independent variables used in our empirical analysis, various breakdowns of abnormal trading volumes of S&P 500 index option, and a control variable, the VIX level one trading day before the FOMC announcement time, *VIX*. We see from Table II that on average, during the pre-announcement trading window, $[t-3, t-1)$, option's trading volume drops about 20.49 million dollars relative to previous five trading days. We have seen in Lucca and Moench (2015) that in stock market, trading volume actually drops one trading day immediately before the FOMC announcement, that is, during the pre-announcement trading window, $[t-1, t)$. So option market moves earlier than stock market in anticipation of the FOMC announcement. Call option's trading volume (C) and put option's trading volume (P) drop with similar magnitude, both are about 10 million dollars. When we break down option's trading volume based on moneyness, the big proportion of both call option and put option's trading volume drop come from near-the-money (NTM) option's trading: Near-the-money call option trading volume C(NTM) drops 9.89 million dollars, whereas out-of-the-money call option trading volume C(OTM) only drops 0.28 million dollars; put option's trading has similar pattern, near-the-money put option trading volume P(NTM) drops 8.97 million dollars, whereas out-of-the-money call option trading volume P(OTM) only drops 1.36 million dollars. We also break down option's trading volume based on buyer-initiated or seller-initiated trading classified by Lee and Ready (1991) algorithm. We see from Table II that for both call and put options, the buyer-initiated and seller-initiated abnormal trading volumes have similar pattern: Buyer-initiated call (BC) drops 4.72 million dollars, comparable to seller-initiated call (SC)'s 5.44 million dollars; buyer-initiated put (BP) drops 5.25 million dollars, comparable to seller-initiated put (SP)'s 5.08 million dollars. Our further breakdowns of option's trading volume based on moneyness and buyer (seller) initiated trading also show us the patterns of abnormal option trading volume: The trading volume drops of call option and put option are similar, of buyer (seller) initiated trading are similar, but of moneyness are quite different, most of the drop of trading volume comes from near-the-money option's trading.

IV. EMPIRICAL TESTS AND RESULTS

A. Tests based on abnormal trading volume

To test H1, if option trading is due to speculation, then ATVs correctly predict the announcement return, we run the following regressions:

$$Ret1h_{[t,t+h)} = \alpha + \beta ATVs_{[t-3,\, t-1)} + \epsilon_t, \tag{1}$$

$$Ret1h_{[t,t+h)} = \alpha + \beta ATVs_{[t-3,\, t-1)} + \gamma VIX_{t-1} + \epsilon_t, \tag{2}$$

We control for the market uncertainty at 1-day before the FOMC announcement time in the above regression, and we use VIX level as a measure of uncertainty.

Table III reports the regression results of testing H1 of speculation. The results in Table III Panel A suggest that two to three days in anticipation of FOMC announcement, there is informed trading in option market and informed traders use call options to speculate. In column (2), when we regress 1-hour post-announcement return on abnormal pre-announcement call option trading volume (denoted by C), controlling for risk measured by VIX level (denoted by *VIX*), the estimated coefficient is 0.02, significant at 5% level. Economically, this says if pre-announcement trading volume of call options increases 1 million dollars, then 1-hour post-announcement return will on average increase by 2 basis points, or 32.76% annualized return. The result in column (4) of put option is not significant, which provides no evidence that informed traders use put options to speculate.

To explore what types of call option are used by speculators, we further break down call options based on moneyness into two categories, near-the-money (NTM) call and out-of-the-money (OTM) call. In column (6), when we regress 1-hour post-announcement return on abnormal pre-announcement NTM call option trading volume (denoted by C(NTM)), controlling for risk measured by VIX level (denoted by VIX), the estimated coefficient is 0.021, significant at 5% level. The result is statistically and economically similar to the result of call option, which suggests that the informativeness of call option trading is mainly driven by near-the-money call option. In column (8), when we regress 1-hour post-announcement return on abnormal pre-announcement OTM call option trading volume (denoted by C(OTM)), controlling for risk measured by VIX level (denoted by VIX), the estimated coefficient is -0.693, significant at 1% level. This result is opposite to the prediction of speculation. Examining further into the results, the sign of *VIX* is changed to be negative and insignificant, which suggests C(OTM) is correlated with risk measure *VIX*. The result show decrease in C(OTM) predicts high 1-hour post-announcement return, possibly because high uncertainty deters traders in OTM call option. Figure 2 plots the time series of daily VIX level during our sample period from 2004 to 2016, with the shaded area covering the financial crisis period of 2008 to 2009. We see from Figure 2 that during financial crisis of 2008 to 2009, the VIX level is as high as 80, indicating market uncertainty is historically high. Because our sample covers this financial crisis period, we do the same analysis by excluding financial crisis period of 2008 to 2009 and the results are reported in Table III Panel B. The results of call option and NTM call remain: The coefficient estimate of C is 0.016 and significant at 10% level and the coefficient estimate of C(NTM) is also 0.016 and significant at 10% level. However, the effect of OTM call is gone: The coefficient estimate of C(OTM) is not significant any more. The results in Table III suggest that the informativeness of NTM call is robust, whether we exclude financial crisis period or not, but the negative association between OTM call option trading and 1-hour post-announcement return is mainly driven by the extreme high uncertainty during the financial crisis of 2008 to 2009.

To test H2, option traders' hedging demand is high when expected announcement uncertainty is high, we run the following regressions:

$$dvix1h_{[t,t+h)} = \alpha + \beta ATVs_{[t-3,\, t-1)} + \epsilon_t, \tag{3}$$

$$dvix1h_{[t,t+h)} = \alpha + \beta ATVs_{[t-3,\, t-1)} + \gamma VIX_{t-1} + \epsilon_t, \tag{4}$$

Similarly, we also control for the market uncertainty at 1-day before the FOMC announcement time in the above regression.

Table IV reports the regression results of testing H2 of hedging. Table IV Panel A reports the results of full sample from 2004 to 2016, and Panel B the results of excluding financial crisis period of 2008 to 2009. In column (2) of Panel A, when we regress 1-hour post-announcement VIX level change (denoted by *dvix1h*) on abnormal pre-announcement call option trading volume (denoted by C), controlling for risk measured by VIX level (denoted by *VIX*), the estimated coefficient is -0.02, significant at 10% level. The results in column (6) suggests this effect mainly comes from OTM call option. Although the coefficient estimate of C is significant, its sign is negative, contrary to the implication of hedging in H2. Therefore, the results of call option trading provide no evidence that traders use call option to hedge post-announcement risk. In table IV Panel A, the results of put option trading have no significance, so neither there is evidence that traders use put option to hedge post-announcement risk. In Table IV Panel B, the significance of call option is gone, and no significance for put option, which provide no evidence of trading using option to hedge post-announcement risk.

B. Tests based on directional trades

To explore whether active-side trades play a role in speculation or hedging, we further break down option's trading into buyer-initiated or seller-initiated trades according to Lee and Ready (1991) algorithm.

To test speculation base on directional trading, we run the following regression:

$$Ret_{[t,t+h)} = \alpha + \beta ATV\_B_{[t-3,\,t-1)} + \gamma VIX_{t-1} + \epsilon_t \tag{5}$$

$$Ret_{[t,t+h)} = \alpha + \beta ATV\_S_{[t-3,\,t-1)} + \gamma VIX_{t-1} + \epsilon_t \tag{6}$$

where $ATV\_B(S)_{[t-3,\,t-1)}$ denotes buyer (seller)-initiated abnormal trading volume.

Table V reports the regression results of testing H1 of speculation considering active-side trades. Table V Panel A reports the results of full sample from 2004 to 2016, and Panel B the results of excluding financial crisis period of 2008 to 2009. In column (1) of Panel A, when we regress 1-hour post-announcement return on abnormal pre-announcement buyer-initiated call option trading volume (denoted by BC), controlling for risk measured by VIX level (denoted by *VIX*), the estimated coefficient is 0.046, significant at 5% level. Economically, this says if pre-announcement buyer-initiated trading volume of call options increases 1 million dollars, then 1-hour post-announcement return will on average increase by 4.6 basis points. This result is consistent with the prediction in H1. And the result is stronger when we have a finer breakdown rather than only call option: The magnitude of coefficient estimate is more than doubled, from 0.02 in Table III Panel A column (2) to 0.046 in Table III Panel B column (1), and adjusted R^2 increases from 6.7% to 8.2%. The result in column (3) suggests this effect mainly comes from NTM call option, consistent with Table III Panel A column (6). The results in column (5) and column (11) are also significant, but their signs are contrary to predictions in H1. Specifically, in column (5), the coefficient estimate of buyer-initiated, OTM call (denoted by BC(OTM)) is -1.203 and significant at 1% level; in column (11), the coefficient estimate of buyer-initiated, OTM put (denoted by BP(OTM)) is 0.295 and significant at 5% level. In Panel B when financial crisis period is excluded, the positive significance of BC and BC(NTM) remains, but the significance of BC(OTM) and BP(OTM) disappear. These results suggest the contrary predictions of OTM options about informed trading are driven by the financial crisis.

To test hedging base on directional trading, we run the following regressions:

$$dvix_{[t,t+h)} = \alpha + \beta ATV\_B_{[t-3,\, t-1)} + \gamma VIX_{t-1} + \epsilon_t \tag{7}$$

$$dvix_{[t,t+h)} = \alpha + \beta ATV\_S_{[t-3,\, t-1)} + \gamma VIX_{t-1} + \epsilon_t \tag{8}$$

where $ATV\_B(S)_{[t-3,\, t-1)}$ denotes buyer (seller)-initiated abnormal trading volume.

Table VI reports the regression results of testing H2 of hedging considering active-side trades. Table VI Panel A reports the results of full sample from 2004 to 2016, and Panel B the results of excluding financial crisis period of 2008 to 2009. Column (1) and (3) show the negative association between pre-announcement abnormal trading volume on call option mainly comes from buyer-initiated and in particular NTM call option. These results remain even after we exclude the financial crisis period of 2008 to 2009. In Panel A column (5), the estimated coefficient of BC(OTM) is 0.981 and significant at 10% level. There is a weak evidence of traders buy out-of-the-money call options to hedge. However, when we exclude the financial crisis period of 2008 to 2009 in Panel B, this effect is gone.

C. Joint test: Reverse Regressions

As we see from previous sections, certain types of abnormal option trading volume can predict both post-FOMC announcement return and VIX level change. A question then arises: What information do informed traders use? Is it information about future return or volatility? To answer this question, we do a joint test, i.e., we run the following reverse regressions:

$$ATV_{[t-3,\, t-1)} = \alpha + \beta Ret_{[t,t+h)} + \epsilon_t \tag{9}$$

$$ATV_{[t-3,\, t-1)} = \alpha + \beta dvix_{[t,t+h)} + \epsilon_t \tag{10}$$

$$ATV_{[t-3,\, t-1)} = \alpha + \beta_1 Ret_{[t,t+h)} + \beta_2 dvix_{[t,t+h)} + \epsilon_t \tag{11}$$

where the dependent variable *ATV* is an abnormal option trading volume which significantly predicts post-announcement return or VIX level change in regressions (2) and (4). The use of reverse regression is introduced in econometrics textbooks, such as Maddala (1978) and Leamer (1978).

First, we identity the ATVs which significantly predict post-FOMC announcement return *Ret_1h* and/or VIX level change *dvix1h*, C, C(NTM), BC, BC(NTM), BC(OTM), BP(OTM). Then we run regression (11) for each of these ATVs. The results of regression in (11) are reported in Table VII.

We see in Panel A of whole sample when throw both post-FOMC announcement return *Ret_1h* and VIX level change *dvix1h* into the regression, only the association between *Ret_1h* and abnormal option trading volume is significant, but the association between *dvix1h* and abnormal option trading volume is not significant. These results provide further evidence of speculation but no of hedging. However, in Panel B of excluding financial crisis period of 2008 to 2009, all the significant results are gone. We provide further evidence by doing Vuong (1989)'s test. Vuong's test is a likelihood ratio test of distinguishable models, which can be applied to both nested and nonnested models. In our setting, model (11) nests both model (9) and model (10). The null hypothesis of Vuong's test is the large model fits as well as the small model, and the alternative hypothesis is the large model fits better than the small model. The p-value of the test measure the distance of the small model to the large model, high p-value means the small model is close to the large model. We report p-values of Vuong's test in Table VIII. We see in Panel A of whole sample most of p-values of model (9) with *Ret_1h* as explanatory variable are greater than model (10) with *dvix1h* as explanatory variable, which shows model (9) is closer to model (11) than model (10) for most of the ATV variables. We get similar results in Panel B of excluding financial crisis period of 2008 to 2009. Intuitively, these results indicate post-announcement return is better predicted by ATVs than volatility change, and informed traders are more inclined to use their private information to speculate than hedge.

V. CONCLUSION

This paper investigates options trading activity prior to FOMC announcements. We observe VIX start to increase three trading days prior to the FOMC announcement, which indicates option market moves before the stock market, because stock market index starts to drift upward and trading volume to decrease one trading day prior. We find informed traders use option to speculate on their private information. Specifically, abnormal trading volume of call option on S&P500 index three to two trading days prior to the FOMC announcement positively predicts post-announcement index return, and this predictability mainly comes from NTM call option and from buyer-initiated call option trading when we further breakdown trading volume based on the direction of trade. We find no evidence of investors using options to hedge post-FOMC announcement market risk.

REFERENCES

Amin, Kaushik I, and Charles M C Lee, 1997, Option Trading, Price Discovery, and Earnings News Dissemination, *Contemporary Accounting Research* 14, 153–192.

Augustin, Patrick and Brenner, Menachem and Grass, Gunnar and Subrahmanyam, Marti G., How Do Insiders Trade? (September 28, 2016). CFS Working Paper, No. 541. Available at SSRN: https://ssrn.com/abstract=2848989 or http://dx.doi.org/10.2139/ssrn.2848989

Bali, Turan G, and Scott Murray, 2013, Does Risk-Neutral Skewness Predict the Cross-Section of Equity Option Portfolio Returns?, *Journal of Financial and Quantitative Analysis* 48, 1145–1171.

Bollen, Nicolas P B, and Robert E Whaley, 2004, Does Net Buying Pressure Affect the Shape of Implied Volatility Functions?, *The Journal of Finance* 59, 711–753.

Cao, Charles, Zhiwu Chen, and John M Griffin, 2005, Informational Content of Option Volume Prior to Takeovers, *The Journal of Business* 78, 1073–1109.

Chan, Konan, Li Ge, and Tse-Chun Lin, 2015, Informational Content of Options Trading on Acquirer Announcement Return, *Journal of Financial and Quantitative Analysis* 50, 1057–1082.

Cremers, Martijn, and David Weinbaum, 2010, Deviations from Put-Call Parity and Stock Return Predictability, *Journal of Financial and Quantitative Analysis* 45, 335–367.

Cremers, K. J. Martijn and Fodor, Andy and Muravyev, Dmitriy and Weinbaum, David, How Do Informed Option Traders Trade? Option Trading Activity, News Releases, and Stock Return Predictability (February 6, 2019). Available at SSRN: https://ssrn.com/abstract=2544344 or http://dx.doi.org/10.2139/ssrn.2544344

Easley, David, Maureen O'Hara, and P S Srinivas, 1998, Option Volume and Stock Prices: Evidence on Where Informed Traders Trade, *The Journal of Finance* 53, 431–465.

Ge, Li, Tse-Chun Lin, and Neil D Pearson, 2016, Why does the option to stock volume ratio predict stock returns?, *Journal of Financial Economics* 120, 601–622.

Glosten, Lawrence R., and Paul R. Milgrom, 1985, Bid, ask and transaction prices in a specialist market with heterogeneously informed traders, *Journal of Financial Economics* 14, 71–100.

Hao, (Grace) Qing, 2016, Is there information leakage prior to share repurchase announcements? Evidence from daily options trading, *Journal of Financial Markets* 27, 79–101.

Hull, John C, 2006, *Options, Futures, and Other Derivatives*. 6th ed. (Prentice Hall).

Lee, Charles M. C., and Mark J. Ready, 1991, Inferring Trade Direction from Intraday Data, *The Journal of Finance* 46, 733–746.

Leamer, E., 1978, *Specification searches: Ad-hoc inference with non-experimental data* (Wiley, New York, NY).

Lucca, David O, and Emanuel Moench, 2015, The Pre-FOMC Announcement Drift, *Journal of Finance* 70, 329–371.

Maddala, G., 1977, *Econometrics* (McGraw-Hill, New York, NY).

Pan, Jun, and Allen M Poteshman, 2006, The Information in Option Volume for Future Stock Prices, *The Review of Financial Studies* 19, 871–908.

Roll, Richard, Eduardo Schwartz, and Avanidhar Subrahmanyam, 2010, O/S: The relative trading activity in options and stock, *Journal of Financial Economics* 96, 1–17.

Vuong, Quang H., 1989, Likelihood Ratio Tests for Model Selection and non-nested Hypotheses, *Econometrica* 57, 307–333.

Xing, Yuhang, Xiaoyan Zhang, and Rui Zhao, 2010, What Does the Individual Option Volatility Smirk Tell Us About Future Equity Returns?, *Journal of Financial and Quantitative Analysis* 45, 641–662.

Zhang, Jun, 2018, Informed Options Trading Prior to Dividend Change Announcements, *Financial Management* 47, 81–103.

Table I: Summary Statistics of Return and VIX Level Change

This table reports the summary statistics of our dependent variables. The dependent variable 1-hour post announcement log return on S&P 500 index, *Ret_1h*, is defined by $Ret\_1h = \ln P_{t+h} - \ln P_t$, where t is the FOMC announcement time, P_t is the S&P 500 index level at the FOMC announcement time, P_{t+h} is the S&P 500 index level one hour post the FOMC announcement time. The dependent variable, 1-hour post announcement VIX level change, *dvix1h*, is defined by $dvix1h = VIX_{t+h} - VIX_t$, where VIX_t is the VIX level at the FOMC announcement time, VIX_{t+h} is the VIX level one hour post the FOMC announcement time.

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Median	Pctl(75)	Max
Ret_1h	104	0.15	0.72	-2.28	-0.20	0.16	0.47	2.50
dvix1h	104	-0.45	1.02	-4.23	-0.69	-0.26	0.07	2.64

Table II: Summary Statistics of Pre-FOMC Announcement VIX and Option Abnormal Trading Volumes

This table reports the summary statistics of our independent variables, control variable VIX and various abnormal option trading volumes. VIX is the VIX level at 1-day before the FOMC announcement time, a measure of market uncertain. We compute abnormal trading volumes of calls and puts (C&P) relative to previous five trading days. For call options, we classify NTM option when $K/S < 1.10$ and OTM option when $K/S \geq 1.10$. For put options, we classify OTM option when $K/S < 1.10$ and NTM option when $K/S \geq 1.10$. We use Lee and Ready (2001) algorithm to identify buyer-initiated and seller-initiated transactions for call and put option contracts. Specifically, we first use a quote test first, then a tick test. In the quote test, if the price of an option trade is higher than the midpoint of the NBBO bid and ask, then the trade is classified as buyer-initiated. If the price is lower than the midpoint, the trade is classified as seller-initiated. When they are equal, the tick test is utilized. In the tick test, if the price is higher than the previous price, it is classified as buyer-initiated and if it is lower, then the trade is classified as seller-initiated. Other cases are considered as non-determined. Then we compute abnormal trading volumes for each type of trades. So in our finest breakdown of option trading volume, we have 2×2×2=8 categories of abnormal trading volume (call or put, NTM or OTM, and buyer or seller-initiated), denoted as BC(NTM), SC(NTM), BC(OTM), SC(OTM), BP(NTM), SP (NTM), BP (OTM), SP (OTM).

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Median	Pctl(75)	Max
VIX	104	19.69	9.61	11.02	13.66	16.69	21.71	74.39
C&P	104	-20.49	16.00	-95.41	-24.70	-17.61	-9.48	0.38
C	104	-10.16	7.60	-33.41	-13.14	-8.75	-4.49	3.76
P	104	-10.33	10.28	-63.55	-12.43	-8.29	-3.94	5.16
C(NTM)	104	-9.89	7.47	-32.62	-12.96	-8.23	-4.49	3.85
C(OTM)	104	-0.28	0.49	-3.00	-0.30	-0.10	-0.02	0.00
P(NTM)	104	-8.97	9.49	-56.52	-10.73	-7.09	-3.96	5.82
P(OTM)	104	-1.36	1.11	-7.03	-1.91	-1.18	-0.51	0.18
BC(NTM)	104	-4.57	3.84	-15.94	-6.11	-3.77	-2.22	8.14
SC(NTM)	104	-5.32	4.53	-23.40	-6.45	-4.22	-2.10	-0.43
BC(OTM)	104	-0.15	0.31	-2.00	-0.20	-0.10	-0.01	0.00
SC(OTM)	104	-0.12	0.20	-1.00	-0.20	-0.10	0.00	0.00
BP(NTM)	104	-4.55	4.73	-28.86	-5.24	-3.57	-1.97	1.56
SP(NTM)	104	-4.42	4.91	-27.66	-5.15	-3.47	-1.87	4.45
BP(OTM)	104	-0.70	0.60	-3.99	-0.99	-0.54	-0.25	0.17
SP(OTM)	104	-0.66	0.56	-3.05	-0.88	-0.54	-0.27	0.01

Table III: The Predictability of Option Trading Volumes for Post FOMC Announcement Returns

This table reports the results of testing whether informed investors speculate by trading options. The test is done by regressing 1-hour post-FOMC announcement return, Ret_1h, on various abnormal option trading volumes. Abnormal option trading volumes on pre-announcement window [t-3, t-1] are calculated by the specific type of option trading volume minus the preceding 5 trading days' average trading volume. The abnormal trading volume of call option is denoted by C, put option by P, near-the-money call by C(NTM), out-of-the-money call by C(OTM), near-the-money put by P(NTM), out-of-the-money put by P(OTM), and the control variable is the VIX level 1-day prior to the announcement time, denoted by VIX. The t-statistics are reported in the parentheses which are calculated by using Newey-West standard errors. Panel A reports the regression results of full sample period from 2004 to 2016, and Panel B reports the regression results of excluding financial crisis period of 2008 to 2009.

Panel A: The regression results of full sample period: 2004 to 2016

	Dependent variable: Ret_1h											
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
C	0.012*	0.020**										
	(0.007)	(0.009)										
P			-0.005	0.005								
			(0.008)	(0.011)								
C(NTM)					0.015**	0.021**						
					(0.007)	(0.009)						
C(OTM)							-0.434***	-0.693**				
							(0.094)	(0.283)				
P(NTM)									-0.005	0.005		
									(0.008)	(0.011)		
P(OTM)											-0.047	0.141
											(0.075)	(0.105)
VIX		0.020**		0.019		0.020**		-0.015		0.018		0.028*
		(0.009)		(0.012)		(0.009)		(0.015)		(0.012)		(0.015)
Constant	0.275**	-0.051	0.099	-0.170	0.294**	-0.034	0.030	0.259	0.104	-0.168	0.087	-0.216
	(0.118)	(0.168)	(0.096)	(0.173)	(0.125)	(0.167)	(0.064)	(0.224)	(0.094)	(0.171)	(0.109)	(0.197)
Observations	104	104	104	104	104	104	104	104	104	104	104	104
Adjusted R^2	0.007	0.067	-0.005	0.029	0.013	0.070	0.079	0.080	-0.005	0.028	-0.005	0.046
Note:										*p<0.1; **p<0.05; ***p<0.01		

Panel B: The regression results of excluding financial crisis period of 2008 to 2009

	Dependent variable: Ret_1h											
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
C	0.016*	0.016*										
	(0.009)	(0.009)										
P			0.006	0.005								
			(0.009)	(0.009)								
C(NTM)					0.017*	0.016*						
					(0.009)	(0.009)						
C(OTM)							0.147	-0.017				
							(0.382)	(0.332)				
P(NTM)									0.006	0.005		
									(0.009)	(0.009)		
P(OTM)											0.059	0.046
											(0.088)	(0.095)
VIX		-0.003		-0.006		-0.004		-0.008		-0.006		-0.004
		(0.012)		(0.012)		(0.012)		(0.011)		(0.012)		(0.012)
Constant	0.255**	0.307	0.149	0.233	0.255**	0.311	0.118	0.235	0.143	0.234	0.165	0.215
	(0.129)	(0.246)	(0.106)	(0.232)	(0.128)	(0.246)	(0.088)	(0.206)	(0.099)	(0.232)	(0.143)	(0.222)
Observations	88	88	88	88	88	88	88	88	88	88	88	88
Adjusted R^2	0.024	0.013	-0.006	-0.016	0.024	0.014	-0.010	-0.019	-0.006	-0.016	-0.005	-0.016
Note:												*p<0.1; **p<0.05; ***p<0.01

Table IV: The Predictability of Option Trading Volumes for Post FOMC Announcement VIX Level Change

This table reports the results of testing whether investors hedge post-FOMC announcement risk by trading options. The test is done by regressing 1-hour post-FOMC VIX level change, dvix1h, on various abnormal option trading volumes. Abnormal option trading volumes on pre-announcement window [t-3, t-1] are calculated by the specific type of option trading volume minus the preceding 5 trading days' average trading volume. The abnormal trading volume of call option is denoted by C, put option by P, near-the-money call by C(NTM), out-of-the-money call by C(OTM), near-the-money put by P(NTM), out-of-the-money put by P(OTM), and the control variable is the VIX level 1-day prior to the announcement time, denoted by vix_1. The t-statistics are reported in the parentheses which are calculated by using Newey-West standard errors. Panel A reports the regression results of full sample period from 2004 to 2016, and Panel B reports the regression results of excluding financial crisis period of 2008 to 2009.

Panel A: The regression results of full sample period: 2004 to 2016

	Dependent variable: dvix1h											
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
C	-0.003	-0.020*										
	(0.014)	(0.010)										
P			0.027*	0.008								
			(0.014)	(0.013)								
C(NTM)					-0.007	-0.020**						
					(0.013)	(0.010)						
C(OTM)							0.753***	0.331				
							(0.174)	(0.313)				
P(NTM)									0.028*	0.010		
									(0.015)	(0.013)		
P(OTM)											0.197	-0.157
											(0.145)	(0.124)
VIX		-0.044***		-0.035***		-0.043***		-0.025		-0.034***		-0.054***
		(0.013)		(0.011)		(0.013)		(0.021)		(0.011)		(0.017)
Constant	-0.480***	0.224	-0.171	0.321	-0.513***	0.209	-0.238***	0.134	-0.190	0.322	-0.178	0.395*
	(0.179)	(0.226)	(0.127)	(0.196)	(0.178)	(0.227)	(0.083)	(0.304)	(0.118)	(0.196)	(0.176)	(0.228)
Observations	104	104	104	104	104	104	104	104	104	104	104	104
Adjusted R^2	-0.009	0.143	0.063	0.127	-0.007	0.144	0.124	0.129	0.061	0.129	0.037	0.135

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Panel B: The regression results of excluding financial crisis period of 2008 to 2009

	Dependent variable: dvix1h											
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
C	-0.020	-0.024										
	(0.014)	(0.016)										
P			0.004	-0.001								
			(0.012)	(0.011)								
C(NTM)					-0.020	-0.024						
					(0.014)	(0.016)						
C(OTM)							0.372	-0.118				
							(0.522)	(0.556)				
P(NTM)									0.005	0.0002		
									(0.013)	(0.012)		
P(OTM)											-0.025	-0.145
											(0.131)	(0.148)
VIX		-0.029		-0.023		-0.028		-0.024		-0.022		-0.035
		(0.023)		(0.021)		(0.022)		(0.021)		(0.021)		(0.023)
Constant	-0.550***	-0.099	-0.328**	0.015	-0.552***	-0.105	-0.310***	0.039	-0.325***	0.015	-0.390**	0.069
	(0.211)	(0.326)	(0.130)	(0.327)	(0.211)	(0.324)	(0.101)	(0.318)	(0.121)	(0.325)	(0.190)	(0.342)
Observations	88	88	88	88	88	88	88	88	88	88	88	88
Adjusted R^2	0.013	0.030	-0.010	-0.006	0.014	0.030	-0.007	-0.006	-0.010	-0.006	-0.011	0.007
Note:												*p<0.1; **p<0.05; ***p<0.01

Table V: The Predictability of Directional Option Trading Volumes for Post FOMC Announcement Returns

This table reports the results of testing whether informed investors speculate by trading options based on directional trades. The test is done by regressing 1-hour post-FOMC announcement return, Ret_1h, on various abnormal option trading volumes classified as buyer-initiated or seller-initiated by Lee and Ready (1991) algorithm. Abnormal option trading volumes on pre-announcement window [t-3, t-1] are calculated by the specific type of option trading volume minus the preceding 5 trading days' average trading volume. The abnormal trading volume of buyer-initiated call option is denoted by BC, seller-initiated call option by SC, buyer-initiated put option by BP, seller-initiated put option by SP, near-the-money buyer-initiated call by BC(NTM), near-the-money seller-initiated call by SC(NTM), out-of-the-money buyer-initiated call by BC(OTM), out-of-the-money seller-initiated call by SC(OTM), near-the-money buyer-initiated put by BP(NTM), near-the-money seller-initiated put by SP(NTM), out-of-the-money buyer-initiated put by BP(OTM), out-of-the-money seller-initiated put by SP(OTM), and the control variable is the VIX level 1-day prior to the announcement time, denoted by VIX. The t-statistics are reported in the parentheses which are calculated by using Newey-West standard errors. Panel A reports the regression results of full sample period from 2004 to 2016, and Panel B reports the regression results of excluding financial crisis period of 2008 to 2009.

Panel A: The regression results of full sample period: 2004 to 2016

	Dependent variable: Ret_1h												
	Call volumes							Put volumes					
	(1)	(2)	(3)	(4)	(5)	(6)		(7)	(8)	(9)	(10)	(11)	(12)
BC	0.046**						BP	0.010					
	(0.019)							(0.019)					
SC		0.021					SP		0.010				
		(0.014)							(0.021)				
BC(NTM)			0.048**				BP(NTM)			0.008			
			(0.019)							(0.021)			
SC(NTM)				0.022			SP(NTM)				0.009		
				(0.014)							(0.022)		
BC(OTM)					-1.203***		BP(OTM)					0.295**	
					(0.417)							(0.144)	
SC(OTM)						(0.701)	SP(OTM)						0.157
						(0.551)							(0.207)
VIX	0.022**	0.018**	0.021**	0.018**	(0.016)	0.003		0.019	0.019	0.018	0.018	0.029**	0.023
	(0.010)	(0.009)	(0.009)	(0.009)	(0.014)	(0.012)		(0.012)	(0.012)	(0.011)	(0.012)	(0.013)	(0.015)
Constant	(0.058)	(0.092)	(0.035)	(0.086)	0.292	(0.001)		(0.172)	(0.168)	(0.168)	(0.166)	(0.220)	(0.191)
	(0.155)	(0.176)	(0.151)	(0.176)	(0.221)	(0.192)		(0.173)	(0.172)	(0.171)	(0.170)	(0.190)	(0.189)
Observations	104	104	104	104	104	104		104	104	104	104	104	104
Adjusted R2	0.082	0.043	0.088	0.044	0.102	0.036		0.029	0.03	0.028	0.029	0.054	0.033

Panel B: The regression results of excluding financial crisis period of 2008 to 2009

	Dependent variable: Ret_1h												
	Call volumes							Put volumes					
	(1)	(2)	(3)	(4)	(5)	(6)		(7)	(8)	(9)	(10)	(11)	(12)
BC	0.031**						BP	0.011					
	(0.014)							(0.017)					
SC		0.019					SP		0.008				
		(0.019)							(0.017)				
BC(NTM)			0.032**				BP(NTM)			0.010			
			(0.014)							(0.019)			
SC(NTM)				0.019			SP(NTM)				0.009		
				(0.019)							(0.017)		
BC(OTM)					(0.812)		BP(OTM)					0.198	
					(0.589)							(0.153)	
SC(OTM)						0.830	SP(OTM)						(0.053)
						(0.701)							(0.194)
VIX	(0.003)	(0.005)	(0.003)	(0.005)	(0.016)	0.001		(0.005)	(0.006)	(0.006)	(0.006)	0.002	(0.010)
	(0.012)	(0.012)	(0.012)	(0.012)	(0.011)	(0.012)		(0.012)	(0.012)	(0.012)	(0.012)	(0.013)	(0.012)
Constant	0.290	0.287	0.294	0.289	0.306	0.141		0.228	0.236	0.230	0.238	0.187	0.239
	(0.229)	(0.252)	(0.228)	(0.252)	(0.200)	(0.225		(0.230)	(0.234)	(0.229)	(0.235)	(0.233)	(0.208)
Observations	88	88	88	88	88	88		88	88	88	88	88	88
Adjusted R2	0.015	-0.0003	0.016	-0.001	-0.009	-0.01		-0.015	-0.016	-0.016	-0.016	-0.003	-0.018

Table VI: The Predictability of Directional Option Trading Volumes for Post FOMC Announcement VIX Level Change

This table reports the results of testing investors hedge post-FOMC announcement risk by trading options. The test is done by regressing 1-hour post-FOMC VIX level change, dvix1h, on various abnormal option trading volumes classified as buyer-initiated or seller-initiated by Lee and Ready (1991) algorithm. Abnormal option trading volumes on pre-announcement window [t-3, t-1] are calculated by the specific type of option trading volume minus the preceding 5 trading days' average trading volume. The abnormal trading volume of buyer-initiated call option is denoted by BC, seller-initiated call option by SC, buyer-initiated put option by BP, seller-initiated put option by SP, near-the-money buyer-initiated call by BC(NTM), near-the-money seller-initiated call by SC(NTM), out-of-the-money buyer-initiated call by BC(OTM), out-of-the-money seller-initiated call by SC(OTM), near-the-money buyer-initiated put by BP(NTM), near-the-money seller-initiated put by SP(NTM), out-of-the-money buyer-initiated put by BP(OTM), out-of-the-money seller-initiated put by SP(OTM), and the control variable is the VIX level 1-day prior to the announcement time, denoted by VIX. The t-statistics are reported in the parentheses which are calculated by using Newey-West standard errors. Panel A reports the regression results of full sample period from 2004 to 2016, and Panel B reports the regression results of excluding financial crisis period of 2008 to 2009.

Panel A: The regression results of full sample period: 2004 to 2016

	Dependent variable: dvix1h												
	Call volumes							Put volumes					
	(1)	(2)	(3)	(4)	(5)	(6)		(7)	(8)	(9)	(10)	(11)	(12)
BC	-0.046***						BP	0.013					
	(0.017)							(0.022)					
SC		(0.021)					SP		0.018				
		(0.020)							(0.027)				
BC(NTM)			-0.048***				BP(NTM)			0.019			
			(0.017)							(0.024)			
SC(NTM)				(0.020)			SP(NTM)				0.020		
				(0.020)							(0.027)		
BC(OTM)					0.981*		BP(OTM)					-0.392*	
					(0.585)							(0.209)	
SC(OTM)						(0.700)	SP(OTM)						(0.102)
						(0.678)							(0.258)
VIX	-0.045***	-0.042***	-0.044***	-0.041***	(0.013)	-0.052**		-0.035***	-0.035***	-0.034***	-0.035***	-0.057***	-0.044***
	(0.013)	(0.013)	(0.012)	(0.013)	(0.024)	(0.021)		(0.012)	(0.011)	(0.011)	(0.011)	(0.016)	(0.016)
Constant	0.230	0.266	0.208	0.262	(0.036)	0.495		0.321	0.324	0.319	0.326*	0.412*	0.354*
	(0.223)	(0.222)	(0.222)	(0.223)	(0.339)	(0.317)		(0.197)	(0.198)	(0.196)	(0.198)	(0.233)	(0.215)
Observations	104	104	104	104	104	104		104	104	104	104	104	104
Adjusted R2	0.152	0.131	0.154	0.131	0.148	0.128		0.126	0.129	0.128	0.13	0.148	0.124

Panel B: The regression results of excluding financial crisis period of 2008 to 2009

	Dependent variable: dvix1h												
	Call volumes							Put volumes					
	(1)	(2)	(3)	(4)	(5)	(6)		(7)	(8)	(9)	(10)	(11)	(12)
BC	-0.047**						BP	(0.009)					
	(0.022)							(0.022)					
SC		(0.030)					SP		0.003				
		(0.028)							(0.023)				
BC(NTM)			-0.048**				BP(NTM)			(0.004)			
			(0.022)							(0.023)			
SC(NTM)				(0.029)			SP(NTM)				0.004		
				(0.028)							(0.024)		
BC(OTM)					0.698		BP(OTM)					-0.464*	
					(1.263)							(0.241)	
SC(OTM)						(1.157)	SP(OTM)						(0.023)
						(1.058)							(0.329)
VIX	(0.029)	(0.026)	(0.029)	(0.026)	(0.015)	-0.034*		(0.025)	(0.021)	(0.023)	(0.021)	-0.045*	(0.023)
	(0.022)	(0.022)	(0.021)	(0.022)	(0.025)	(0.018)		(0.022)	(0.020)	(0.022)	(0.020)	(0.024)	(0.022)
Constant	(0.073)	(0.070)	(0.079)	(0.072)	(0.049)	0.141		0.019	0.017	0.016	0.018	0.118	0.019
	(0.316)	(0.330)	(0.314)	(0.329)	(0.345)	(0.294)		(0.332)	(0.325)	(0.328)	(0.326)	(0.363)	(0.317)
Observations	88	88	88	88	88	88		88	88	88	88	88	88
Adjusted R2	0.031	0.015	0.032	0.014	-0.003	0.002		-0.005	-0.006	-0.006	-0.006	0.035	-0.006

Table VII: Reverse Regressions of Abnormal Option Trading Volumes on Post-announcement Return and VIX Level Change

This table reports the regression results of joint test. The dependent variables are abnormal option trading volume of call option denoted by C, near-the-money call option by C(NTM), buyer-initiated call option by BC, near-the-money buyer-initiated call option by BC(NTM). There are two common independent variables in these regressions, the 1-hour post-FOMC announcement return, Ret_1h, and VIX level change, dvix1h.

Panel A: The regression results of full sample period: 2004 to 2016

	Dependent variable:					
	C	C(NTM)	BC	BC(NTM)	BC(OTM)	BP(OTM)
	(1)	(2)	(3)	(4)	(5)	(6)
Ret_1h	3.249**	3.256**	1.881**	1.885**	-0.004	0.219
	(1.291)	(1.273)	(0.838)	(0.827)	(0.079)	(0.143)
dvix1h	1.659	1.487	0.895	0.777	0.118	0.221
	(1.306)	(1.200)	(0.701)	(0.627)	(0.088)	(0.171)
Constant	-9.912***	-9.715***	-4.604***	-4.506***	-0.098**	-0.630***
	(1.217)	(1.189)	(0.574)	(0.559)	(0.039)	(0.125)
Observations	104	104	104	104	104	104
Adjusted R^2	0.015	0.018	0.026	0.032	0.144	0.033

Panel B: The regression results of excluding financial crisis period of 2008 to 2009

	Dependent variable:					
	C	C(NTM)	BC	BC(NTM)	BC(OTM)	BP(OTM)
	(1)	(2)	(3)	(4)	(5)	(6)
Ret_1h	2.302	2.209	1.211	1.181	0.031	0.159
	(1.791)	(1.769)	(1.290)	(1.280)	(0.023)	(0.122)
dvix1h	0.119	0.051	0.056	0.026	0.030	0.043
	(1.158)	(1.156)	(0.717)	(0.711)	(0.019)	(0.067)
Constant	-9.835***	-9.710***	-4.552***	-4.488***	-0.063***	-0.611***
	(1.333)	(1.314)	(0.617)	(0.608)	(0.020)	(0.130)
Observations	88	88	88	88	88	88
Adjusted R^2	0.013	0.013	0.014	0.015	0.005	-0.001
Note:						*p<0.1; **p<0.05; ***p<0.01

Table VIII: Vuong's Test of Alternative Models

This table reports the p-values of Vuong's test of alternative models, which is a likelihood ratio test of distinguishable models. Two models are considered in our test, and one nests another. The null hypothesis of this test is the large model fits as well as the small model, and the alternative hypothesis is the large model fits better than the small model.

Panel A: The test results of full sample period: 2004 to 2016

	C	C(NTM)	BC	BC(NTM)	BC(OTM)	BP(OTM)
Ret_1h	0.327	0.329	0.326	0.338	0.334	0.327
dvix1h	0.084	0.06	0.089	0.067	0.929	0.371

Panel B: The results of excluding financial crisis period of 2008 to 2009

Ret_1h	0.9	0.904	0.891	0.891	0.216	0.657
dvix1h	0.341	0.355	0.417	0.425	0.294	0.334

Figure 1: The Level of VIX around FOMC Announcements

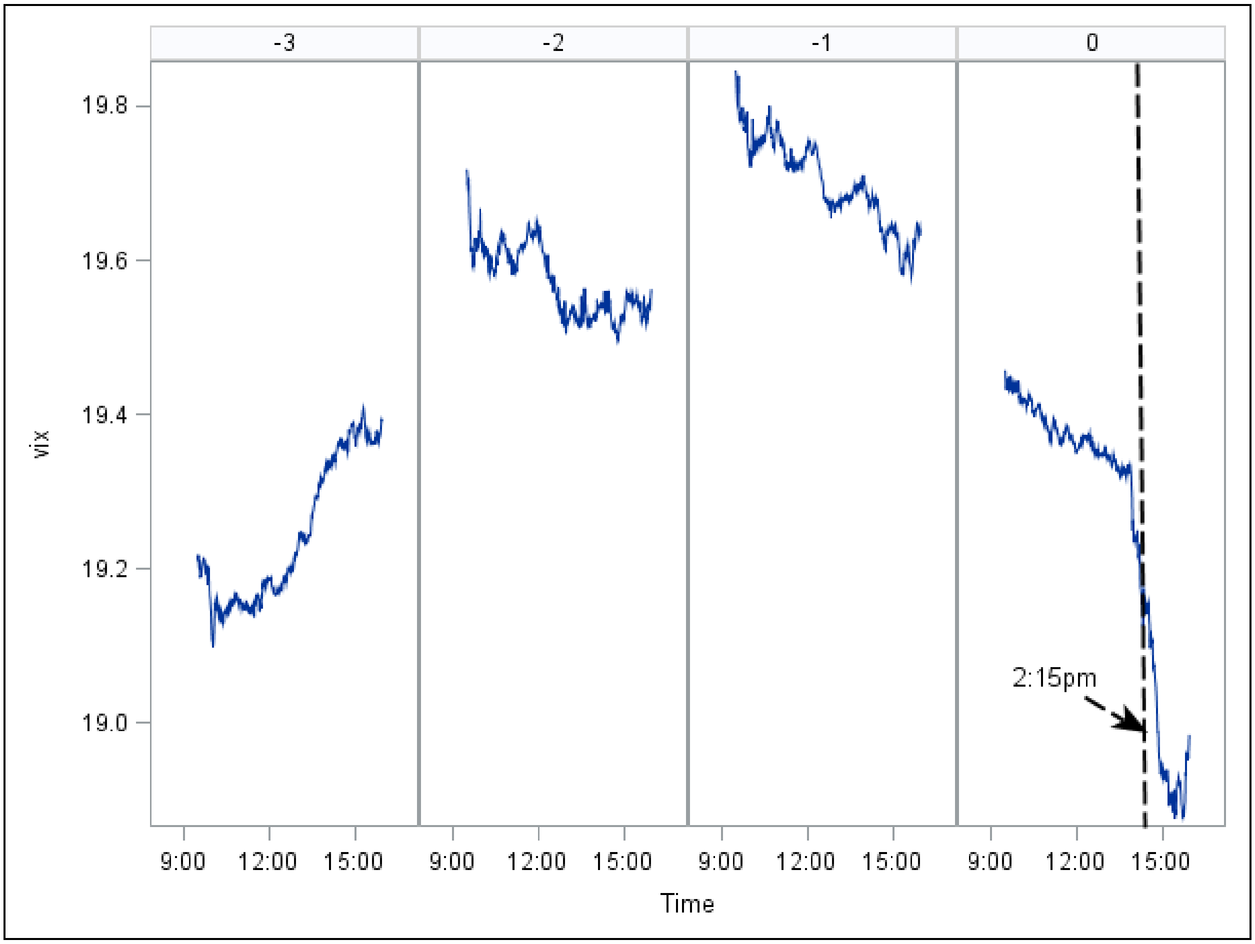


Figure 2: VIX daily time series: 2004 to 2016