Does Options Term Structures Reflects Risks? *

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April 2022

Abstract Information embedded in options market is commonly used to predict underlying stock returns and volatility. While implied volatility is well-studied in the literature, options' time-to-maturity (TTM) has received relatively little attention. This paper examines the TTM of single stock options and tests whether it reflects companys risks. By aggregating TTM using options' trading volume into volume-weighted maturity (VWM), we find that on average option investors tend to choose shorter term options if the perceived underlying stock has more uncertainty in the following trading day. When longer term options are traded at the aggregate level, the following underlying stock return would be larger on average.

Keywords: Options; Volume; Return predictability; Information; Center of mass; Risk
JEL Codes: G11, G12, G14, G17, G32

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1 Introduction

Implied volatility is widely used in pricing both options and the underlying stocks. This effect has been well documented by Cremers and Weinbaum (2010), Xing, Zhang, and Zhao (2010), Guo and Qiu (2014), An, Ang, Bali and Cakici (2014) and Baltussen, Van Bekkum, and Van Der Grient (2014). However, a related and important piece of information from the options market — time-to-maturity (TTM) — has received relatively little attention. In this paper, we have aggregated the options' TTM using their trading volume across all available contracts, which is the same method as Bernile, Gao and Hu (2019). This study complements Bernile, Gao and Hu (2019), as TTM is an orthogonal dimension to the previous paper's variable-of-interest the option moneyness ($VWKS$). We have also extended the study from focusing just on predicting future returns to predicting both future returns and returns volatility.

In another recent paper, Clements, Kalesnik, and Linnainmaa (2017) has compared the predictive power of implied volatility conditioned by the options' TTM. They find that implied volatility from long-dated options is a stronger predictor than implied volatility from short-dated options, as informed traders would typically maximize their information edge by choosing to trade longer-dated options. In comparison, my study focuses on the information content of options' TTM without associating or conditioning TTM with options' implied volatility.

To calculate volume-weighted TTM (VWM), we use the same aggregation method as Bernile, Gao and Hu (2018). First, we calculate TTM, which is the difference between observation date and the options' expiring date. Then, we weight TTM by the trading volume of all contracts on the same underlying stock on the same day, to derive the daily VWM for each stock from January 1, 1996 to August 31, 2013. We use options trading volume in aggregating TTM because volume has been found to be informative by Roll, Schwartz, Subrahmanyam (2009, 2010), Johnson and So (2012), and Ge, Lin, and Pearson (2016). The information content is different between call and put options, documented by Easley, O'Hara, and Srinivas (1998) and Pan and Poteshman (2006). Therefore, besides aggregating all trading volume, we have separated the trading volume by calls ($VWMCALL$) and puts ($VWMPUT$) to better understand the information content from options' TTM.

When we simplify the theory to adopt individual investors' preferences captured by a Lancaster-type utility function over the portfolio characteristics following Bemdt and Khaled (1979), the utility function can be described using a function of expected return Ret of the portfolio and its risk Vol:

$$U = U(Ret, Vol), \tag{1}$$

where $Ret = \sum_{i=1}^{n} X_i R_i$ and $Vol = \sum_{i=1}^{n} \sum_{j=1}^{n} X_i X_j Vol_{i,j}$, and X_i is the investors' proportion wealth invested in financial asset i. To maximize the utility function subject to $\sum_{i=1}^{n} X_i = 1$, we follow Aivazian et al (1983) to solve the first-order conditions that

$$U_{Ret} R_i + 2U_{Vol} \sum_{j=1}^{n} Vol_{i,j} X_j = \lambda, \tag{2}$$

and

$$1 - \sum_{i=1}^{n} X_i = 0. \tag{3}$$

While the utility function could be of various forms, the development of the mean-variance utility functions and the demand for risky assets depends on the volatility, in this paper, as a function of investors' estimated risks of the underlying assets, which is reflected through their choices in the options trading, including the term structure of the options.

In other words, the term Vol is a function of options TTM. Intuitively, options' VWM should shorten ahead of key events, as traders become more cautious of imminent price jumps. As such, we study the behavior of VWM before earnings announcements, 8-K filings, and permanent price jumps. We have also use transitory price jumps as a placebo test. Compared to non-event days, on average, we find that VWM is 16.7 days shorter one day before earnings announcements (t-statistic of -40.5), 4.4 days shorter before 8-K filings (t-statistic of -20.3), 2.9 days shorter before any permanent price jumps (t-statistic of -4.9) and 1.9 days shorter a day before transitory price jumps (t-statistic of -3.4). These event studies have confirmed option traders' preference of owning shorter contracts ahead of informational events.

We then study the behavior of VWM around volatility hikes using two proxies, the options implied volatility hike and the squared stock return hike. Compared to non-implied volatility-hike days, we find that on average, VWM is 1.1 days shorter a day before the hike (t-statistic of -2.8). Compared to non-squared return-hike days, VWM is 1.0 days shorter a day before the hikes (t-statistic of -8.2). These volatility hikes study further confirmed option traders' preference of owning shorter contracts ahead of future volatility hikes.

To test whether options' TTM predicts future stock volatility, we use Fama-MacBeth (1973) regressions. We control for five lags of options trading volume, implied volatility, underlying stock trading volume, bid-ask spread, and squared returns. The first lag of VWM is negative and statistically significant in predicting future implied volatility and squared returns. And the negative and significant predicting power holds for open interest-weighted TTM (OWM), as well as $VWMCALL$ and $VWMPUT$. In the implied volatility sensitivity to VWM test, we find before earnings announcements and 8K filings, VWM and its lags are on average shorter than non-event times.

A shorter VWM could be a signal of increase demand and trading activities of downside protections when market participants expect negative future returns. In contrast, a longer VWM could indicate higher level of confidence about a firm's future prospects and thus positive longer-term returns. Indeed, we find that VWM has a positive and statistically significant coefficient estimates after controlling for the effects of all other options market return predictors, stock return reversals, previous return variance, and liquidity effects (bid-ask spread and stock trading volume turnover). In other words, the term Ret can also be described as a function of options TTM in euqation (1). Interestingly, we find that the statistical significance of VWM is not diminished even when more control variables are added. This is likely due to the high level of correlations among the control variables, as six out of the ten return predictors are related to implied volatility. As such, we believe VWM contains information in an orthogonal dimension to common return predictors from option market, and could be additive to the predictors in the literature.

If VWM reflects informed trading, then its predictive power should be stronger on stocks with higher levels of information asymmetry and arbitrage costs. We divide the sample into sub-samples based on firm size, analyst coverage, institutional ownership, probability of informed trading (PIN), Amihud's (2002) illiquidity, bid-ask spread, idiosyncratic volatility, and the time period. VWM shows statistically significant difference between all sub-samples. VWM has more persistent and stronger predictive power for stocks with higher levels of information asymmetry, i.e. those with smaller market capitalization, fewer analyst coverage, lower institutional ownership, and larger PIN, and for stocks with higher arbitrage costs, i.e. those with lower liquidity, wider bid-ask spreads, higher idiosyncratic volatility, as well as in the first half of the sample period where markets could be less efficient. These results reinforce my hypothesis that VWM contains information.

The rest of the paper is organized as follows. Section 2 reviews the related literature and develops my hypotheses. Section 3 describes the data and sample selection. Section 4 reports my empirical results. Section 5 concludes.

2 Related literature and hypotheses

Hypothesis 1. The volume-weighted time-to-maturity, VWM, becomes smaller ahead of informational events and volatility hikes.

Information shocks can be observed around earnings announcements, supported by Pan and Poteshman (2006), Roll, Schwartz and Subrahmanyam (2010), Xing, Zhang, and Zhao (2010), Johnson and So (2012), and Ge, Lin, and Pearson (2016). The anticipated nature of such announcements can greatly increase expected volatility in the event window as shown by Cremers, Fodor, and Weinbaum (2015). Events such as mergers and acquisitions, spinoffs, stock splits and bankruptcy can have larger informational shock to the market. These events are studied by Cao, Chen, and Griffin (2005), Chan, Ge, and Lin (2015), and Augustin, Brenner, and Subrahmanyam (2016) for mergers and acquisitions, Hayunga and Lung (2014) for analyst revisions, Augustin, Brenner, Hu, and Subrahmanyam (2015) for spinoffs, Gharghori, Maberly, and Nguyen (2015) for stock splits, and Ge, Hu, Humphery-Jenner and Lin (2016) for bankruptcies. To include all types of unscheduled announcements in the analysis, we use the SEC's 8-K filings. The majority of such 8-K forms are non-scheduled and can serve as a more comprehensive set of information events where informed trader are likely to exploit their information advantage, as documented by Thompson and Sale (2003), Brochet (2010), Skaife, Veenman and Wangerin (2013), and Zhao (2016). There could be other information shocks not captured by earnings and 8-K filings. Based on the notion that significant information should lead to large price adjustment, we use extreme price jumps unrelated to earnings news and 8-K filings to identify additional information shocks. We divide these jumps into transitory hikes, which reverse quickly, and permanent jumps otherwise. As argued by Boehmer and Wu (2013), by definition, permanent jumps involve new information while transitory jumps do not. Lee and Mykland (2008) show that jumps are often associated with scheduled earnings announcements and other company-specific news events.

To relate the volatilities to options' TTM, we examine the behavior of VWM around volatility hikes. We have two proxies for volatility, the options implied volatility and squared returns of the underlying stocks. We calculate their daily changes and define the significant positive changes as volatility hikes. The idea is similar to price jumps except that we focus on the upside volatility jumps. The panel regression directly tests option traders' preferences of contract TTM around volatile period and leads to the second hypothesis on predicting stock volatility.

Hypothesis 2. The volume-weighted time-to-maturity, VWM, has a negative and permanent impact on future stock volatility.

We use both options implied volatility and squared returns of the underlying stocks as proxies for stock volatility. Without specify the return variance or volatility process, we test the hypothesis by Fama-MacBeth (1973) regression with Newey-West (1987) adjustment, controlling for past return variances and other previous significant volatility predictors. Guo and Qiu (2014) confirm the idiosyncratic volatility puzzle using the options implied volatility ($IVOL$). We follow Ni, Pan and Poteshman (2008) to control for the logarithm of option trading volume $LnOV$, the logarithm of underlying stock trading volume $LnSV$ and bid-ask spread ($SPREAD$). In the empirical tests, we include five lags of all the control variables as well as the previous return variances (V). The negative impact on future volatility from VWM implies that options traders prefer shorter-term contracts ahead of a risky event.

Intuitively, when a smaller VWM signals a risky event ahead, then the expected future return will be negative. In contrast, when a larger VWM signals option tradersćonfidence on the underlying stock then the expected future return will be positive. Therefore, we have the following hypothesis.

Hypothesis 3. The volume-weighted time-to-maturity, VWM, has a positive and permanent impact on the underlying stock returns.

We use Fama-MacBeth (1973) regression with Newey-West (1987) adjustment, controlling for previous significant return predictors. Bernile, Gao and Hu (2019) find that volume weighted strike-to-price ratios ($VWKS$) has a positive and robust predictive power on future returns. We follow their setting by controlling for put-call ratios (PC) by Pan and Poteshman (2006); total options volume to stock volume ratio (OS) by Roll, Schwartz and Subrahmanyam (2009); deviation from put-call parity (DEV) by Cremers and Weinbaum (2010); options-implied skewness ($SKEW$) by Xing, Zhang, and Zhao (2010); options implied volatility ($IVOL$) by Guo and Qiu (2014); the innovation of implied volatility from both call ($DCIVOL$) and put ($DPIVOL$) options by An, Ang, Bali and Cakici (2014); variance of implied volatility ($VOLVOL$) by Baltussen, Van Bekkum, and Van Der Grient (2014), as well as stock return reversals, bid-ask spread ($SPREAD$), turnover ratio ($TURN$) and previous return variances (V). The positive and significant predictive power from VWM implies that it contains information on future stock returns.

The effectiveness of an information measure can depend on a stock's information environment and trading costs of arbitrageurs. Holding everything else the same, informed trading is less likely to happen to transparent stocks and stocks with low arbitrage costs. We rely on several proxies for information asymmetry including firm size, analyst coverage, institutional ownership, and the probability of informed trading as in Easley, Kiefer, O'Hara, and Paperman (1996). We measure arbitrage costs using Amihud's (2002) illiquidity measure, relative bid-ask spread, idiosyncratic volatility as well as the time period. We compare all the return predictors from the options market in the first half of the sample (1996-2004) to those in the second half (2005-2013). As the market becomes more efficient over the past two decades, all the effective return predictors are expected to be less informative in predicting the future returns.

3 Data, sample selection and variable construction

Options data are from OptionMetrics, which provides daily option trading volumes, strike prices, expiration date of the option, and call and put flags starting from 1996. Equity returns, bid and ask spread, trading volume and shares outstanding data are from the Center for Research in Security Prices (CRSP). Earnings announcement dates and analyst coverage are from the Institutional Brokers Estimate System (IBES). 8K Filing data are from SEC Analytics Suite. The sample ends at August 2013. We exclude all indexes, units, ADRs, REITs, closed end funds, ETFs, and foreign firms and focus on common stocks only (CRSP share codes 10 and 11). We follow Jegadeesh and Titman (2001) and many others to exclude stocks whose closing prices are below \$5. After merging, the final sample has 3837 unique firms. On each trading day, there are on average 1400 firms.

We propose the volume-weighted time-to-maturity for firm i on day t, $VWM_{i,t}$, as the center of mass in the options volume distribution along time-to-maturity:

$$VWM_{i,t} = \frac{\sum_{j=1}^{n} volume_{i,t,j}(T_{i,t,j} - t)}{\sum_{j=1}^{n} volume_{i,t,j}}, \tag{4}$$

where $T_{i,t,j}$ is the expiration date contract j, $volume_{i,t,j}$ is the trading volume of contract j, n is the total number of unique options contracts available, and $T_{i,t,j}$ is the expiring date.

For ease of reporting, VWM is expressed in years instead of days. If there are no options traded on a particular day, VWM is set to be zero.

Table 1 reports the summary statistics for variables from both the options and equity markets. Both options and equity trading volumes are counted as number of shares traded. All the variables are winsorized at 0.5 and 99.5 percentiles every day to mitigate the effect of potential outliers.

[Table 1 about here]

On average, VWM is 0.188 year, with a maximum of 2.655 years and a standard deviation of 0.179. OWM is 0.264 year, with a maximum of 2.458 years and a standard deviation of 0.151. The logarithm of options trading volume ($LnOV$) has a mean of 4.257. We follow Guo and Qiu (2014) to compute options implied volatility $IVOL$ as the average implied volatility of ATM call and put options. It is a forward-looking measure of conditional variance and the mean is 0.478. Using CRSP data, we compute the percentage bid-ask spread ($SPREAD$) as the close ask minus close bid scaled by the midpoint of the bid and ask prices, whose mean is 0.580. The logarithm of underlying stocks trading volume ($LnSV$) has a mean of 9.196. The squared return V has a mean of 0.001. $QRET$ is mid quote returns calculated using closing bid-ask prices adjusted for stock splits and dividends. $AQRET$ is mid quote returns adjusted for Fama and French (1993) factors and liquidity and momentum factors. Their means are 0.001 and 0 respectively.

Table 2 provides time-series averages of cross-sectional correlations. The correlation between VWM and the following trading day's implied volatility is -0.740. Its correlation with the following trading day's squared return is -0.021. The contemporaneous correlation between VWM and implied volatility is -0.076. While the contemporaneous correlation between VWM and squared return is -0.008. The correlation between VWM and $LnOV$,

$SPREAD$, $LnSV$, $AQRET$ is 0.339, -0.058, -0.291 and -0.002, respectively. The positive relationship between VWM and $LnOV$ implies that when there are more options trading activities, traders prefers longer contracts.

[Table 2 about here]

4 Empirical results

4.1 Options' time-to-maturity on information shocks

To establish a concrete and unambiguous link between VWM and information flow, we study its behavior around earnings announcements, non-earnings 8-K filings and price jumps due to other reasons. We define four types of events. The first type is scheduled events, which is earnings announcements. It has been examined as an instrument of information shocks extensively in the literature. Information revealed in scheduled events is found to be associated with options implied uncertainty by Dubinsky and Johannes (2006). As required by SEC, "companies must report certain materiel corporate events on a more current basis", in the form of 8-K. There could be other information events not captured by these two types. We define unscheduled events as 8-K filings unrelated to earnings announcements. In the sample, we observe extreme price jumps, which are not related to either scheduled earnings announcements or 8-K filings. Extreme price jumps are identified either if the risk adjusted return is higher than 10% as in Savor (2012) or if the risk adjusted return is above two standard deviations as in Boehmer and Wu (2013). We further classify price jumps into transitory and permanent categories. A transitory jump ($tranjump$) is identified when the returns reverse within five days that completely offsets the initial jumps. A permanent price jump ($permjump$) survives the subsequent return reversal. The four types of events are mutually exclusive in the analysis.

To test if VWM exhibits any abnormal behavior around events, we estimate the following equation using ordinary least squares (OLS) regressions with the firm, year and week fixed effects:

$$VWM = \alpha + \beta_0 EVENT + \sum_{i=1}^{5} \beta_1^i PREEVENTi + \sum_{i=1}^{5} \beta_2^i POSTEVENTi + \theta X + \epsilon, \quad (5)$$

where $EVENT$ is a category variable with a value of 1 there is a corporate event on day t, and zero otherwise; $PREEVENTi$ is a pre-event category variable with a value of 1 if there is an event on day $t+i$, and zero otherwise; and $POSTEVENTi$ is a post-event category variable with a value of 1 if there is an event on day $t-i$, and zero otherwise. X contains year and week fixed effects and firm fixed effects. We cluster standard errors around firms. VWM in this table is in days instead of years.The results are reported in Table 3.

[Table 3 about here]

We find that before the scheduled events, all five pre-event category variables are negative and significant in predicting VWM in model [1]. Compared with days without scheduled events, on average VWM is 16.669 lower one day before a scheduled event, 8.765 lower two days before a scheduled event, 6.275 lower three days before a scheduled event, 4.512 lower four days before a scheduled event, and 1.265 lower five days before a scheduled event.All five pre-event category variables are significant at the 1% level, with t-statistics of -40.52, -21.84, -16.45, -12.58 and -3.70 respectively. In the second model, we find similar pattern for unscheduled events. Compared with days without unscheduled events, on average VWM is 4.417 lower one day before, 2.574 lower two days before, 2.004 lower three days before, 1.861 lower four days before, and 0.762 lower five days before an unscheduled event. All five pre-event category variables are significant at the 1% level, with t-statistics of -20.26, -12.11, -9.88, -9.77 and -4.27 respectively. In model [3] all five pre-event category variables for permanent price hikes are positive and significant in predicting VWM. Compared with days without price jumps, on average VWM is 2.888 lower one day before (t-statistic=-4.91), 1.226 lower two days before (t-statistic=-2.16), and 1.263 lower three days before a permanent price jump (t-statistic=-2.34). However, for transitory price jumps, the average slopes of pre-event category variables are -1.911, -0.766, -0.058, -0.205, and 0.259. Beside the one day before a transitory price jump, all the other category variables are statistically insignificant in predicting VWM in model [4]. In the fifth model, we combine the previous four events, and find all five pre-event category variables are negative and significant in predicting VWM. Compared with days without any events, on average VWM is 6.085 lower one day before, 3.136 lower two days before, 2.358 lower three days before, 1.991 lower four days before, and 0.595 lower five days before any events. All five pre-event category variables are significant at the 1% level, with t-statistics of -35.07, -18.55, -14.60, -13.02 and -4.08 respectively. Since permanent jumps involve new information while transitory jumps do not (Boehmer and Wu, 2013), the finding establishes a clear link between VWM and information shocks, supporting the first hypothesis.

4.2 Options' time-to-maturity on volatility hikes

To directly test the relationship between VWM and volatility, we use a similar approach to study its behavior around volatility hikes. We define two types of hikes, options implied volatility hike and the underlying stock squared return hike. We estimate the following equation using ordinary least squares (OLS) regressions with the firm, year and week fixed effects:

$$VWM = \alpha + \beta_0 HIKE + \sum_{i=1}^{5} \beta_1^i PREHIKEi + \sum_{i=1}^{5} \beta_2^i POSTHIKEi + \theta X + \epsilon, \qquad (6)$$

where $HIKE$ is a category variable with a value of 1 the implied volatility increases by more than 5% or squared return increases by more than 1% on day t, and zero otherwise; $PREHIKEi$ is a pre-event category variable with a value of 1 if there is an event on day $t+i$, and zero otherwise; and $POSTHIKEi$ is a post-event category variable with a value of 1 if there is an event on day $t-i$, and zero otherwise. X contains year and firm fixed effects. We cluster standard errors around firms. VWM in this table is in days and the results are reported in Table 4.

[Table 4 about here]

Compared with days without implied volatility hike, on average, VWM is 1.143 lower one day before implied volatility hike, 1.417 lower two days before implied volatility hike, 1.640 lower three days before implied volatility hike, 1.399 lower four days before implied volatility hike, and 1.426 lower five days before implied volatility hike. All five pre-event category variables are significant at the 1% level, with t-statistics of -2.79, -3.46, -4.01, -3.42 and -3.50 respectively. In the second model, we find similar pattern for $VWMCALL$. Compared with days without implied volatility hike, on average, $VWMCALL$ is 0.786 lower one day before implied volatility hike, 1.333 lower two days before implied volatility hike, 1.366 lower three days before implied volatility hike, 1.589 days lower four days before implied volatility hike, and 1.250 lower five days before implied volatility hike. All five pre-event category variables are significant at the 5% level and above, with t-statistics of -1.99, -3.39, -3.48, -4.04 and -3.19 respectively. Compared with days without implied volatility hike, $VWMPUT$ in the third model is on average is 0.532 lower one day before implied volatility hike, 0.372 lower two days before implied volatility hike, 0.750 lower three days before implied volatility hike, 0.521 lower four days before implied volatility hike, and 0.786 lower five days before implied volatility hike. The t-statistics of the five pre-event category variables are -1.36, -0.95, -1.92, -1.34 and -2.02 respectively.

Compared with days without squared return hike, on average, VWM is 1.019 lower one day before squared return hike, 0.799 lower two days before squared return hike, 0.704 lower three days before squared return hike, 0.882 lower four days before squared return hike, and 0.650 lower five days before squared return hike. All five pre-event category variables are significant at the 1% level, with t-statistics of -8.19, -6.42, -5.66, -7.09 and -5.22 respectively. In the second model, we find similar pattern for $VWMCALL$. Compared with days without squared returns hike, on average, $VWMCALL$ is 0.299 lower one day before squared return hike, 0.307 lower two days before squared return hike, 0.378 lower three days before squared return hike, 0.748 days lower four days before squared return hike, and 0.523 lower five days before squared return hike. All five pre-event category variables are significant at the 5% level and above, with t-statistics of -2.50, -2.57, -3.16, -6.25 and -4.38 respectively. Compared with days without squared return hike, $VWMPUT$ in the third model is on average is 0.361 lower one day before squared return hike, 0.695 lower two days before squared return hike, 0.691 lower three days before squared return hike, 0.767 lower four days before squared return hike, and 0.698 lower five days before squared return hike. The t-statistics of the five pre-event category variables are -3.04, -5.85, -5.82, -6.46 and -5.88 respectively. The results support our first hypothesis and are more significant if squared returns are used as a proxy for underlying stock volatility. In the following analysis, we focus on options implied volatility and use squared return as a robustness check.

4.3 Multivariate regression analysis on stock volatility

The multivariate regression analysis is to test the second hypothesis that VWM has a negative and permanent impact on the future stock volatility. The standard Fama-MacBeth (1973) regression has two stages. We first estimate the following model in the cross section for each trading day t:

$$VOL_{i,t} = \alpha + \sum_{l=1}^{5} \beta_l VWM_{i,t-l} + \sum_{l=1}^{5} \theta_l X_{i,t-l} + \epsilon, \tag{7}$$

where VOL is $IVOL$ in the first four models and V in the last model. The $X_{i,t-l}$ is a set of control variables on day t for firm i, including five lags of $LnOV$, $IVOL$, $SPREAD$, $LnSV$ and V. After obtaining a time series of the slope coefficients, we then examine the mean of these coefficients using Newey-West (1987) adjustment, allowing for autocorrelation structures. For ease of reporting, the VWM are expressed in years.

[Table 5 about here]

The first model contains one lag of VWM, which has an average slope coefficient of -0.084 for VWM (t-statistic = -35.23). The second model controls for all five lags of VWM. The first lag has a coefficient of -0.043 and a t-statistic of -32.78. The second lag has a coefficient of -0.038 and a t-statistic of -33.16. The third lag has a coefficient of -0.036 and a t-statistic of -32,37. The fourth lag has a coefficient of -0.036 and a t-statistic of -31.48. The fifth lag has a coefficient of -0.038 and a t-statistic of -29.52. The third model further controls for all previous volatility predictors and the first lag of VWM drops to -0.001 with a t-statistic of -4.79. The fourth model replaces VWM by OWM, the open interest-weighted maturity, whose first lag has a coefficient of -0.011 with a t-statistic of -1.97. In the fifth model, we examine VWM's predictive ability on future squared return. With full set of control variables, the first lag of VWM is -0.914 with a t-statistic of -8.45. The negative coefficients of VWM supports our second hypothesis that VWM has a negative impact on future stock volatility.

4.4 Separating calls and puts

To better understand the nature of the squared returns predictability, we analyze VWM using different types of options with the full set of control variables. We first compute volume weighted call options' TTM $VWMCALL$, and volume weighted put options' TTM $VWMPUT$. Then we use $VWMCALL$ and $VWMPUT$ in the Fama-Macbeth regressions, and report the results in Table 6.

[Table 6 about here]

The first three models examines VWM's predictive power on options implied volatility. In model [1], the first lag of $VWMCALL$ has a coefficient of -0.000 with a t-statistic of -2.80. In model [2], the first lag of $VWMPUT$ has a coefficient of -0.000 with a t-statistic of -1.77. The third models control for both $VWMCALL$ and $VWMPUT$. While their estimates are both -0.000, $VWMCALL$ has a t-statistic of -2.90 while $VWMPUT$ has a t-statistic of -1.57. With the full set of control variables, both $VWMCALL$ and $VWMPUT$ have negative and statistically significant impacts on future squared returns.

The next three models test VWM's predictive power on underlying stock squared return. In model [4], the first lag of $VWMCALL$ has a coefficient of -0.654 with a t-statistic of -6.81. In model [5], the first lag of $VWMPUT$ has a coefficient of -1.033 with a t-statistic of -10.46. The sixth model controls for both $VWMCALL$ and $VWMPUT$. The first lag of $VWMCALL$ has a coefficient of -0.522 with a t-statistic of -5.45 while the first lag of $VWMPUT$ has a coefficient of -0.983 with a t-statistic of -10.18. With the full set of control variables, both call and put VWM have negative and significant impact on future squared returns.

4.5 Sensitivity of implied volatility on informational events

Previous results show that on average, VWM becomes negative ahead of informational events and can predict future volatility. This section checks if VWM contains information on future stock by studying its sensitivity of implied volatility before earnings announcements and 8-K filings. Table 7 reports Fama-MacBeth (1973) regression with full controls on five lags of VWM if there will be an earnings announcement on the following day.

[Table 7 about here]

Compared with non-earnings days, on average, an 1% increase of the first lag of VWM before earnings announcements will shrink the implied volatility by 1.911% (t-statistic = -0.28). An 1% increase of the second lag will shrink the implied volatility by 8.075% (t-statistic = -2.04). If it happens on the third lag, we see the implied volatility decreases by 13.479% (t-statistic = -7.02). If it happens on the fourth lag, we see the implied volatility decreases by 13.227% (t-statistic = -6.93). And if it happens on the fifth lag, we see the implied volatility decreases by 8.235% (t-statistic = -3.91). The first lag of VWM in all five models are negative with coefficients less than -0.210, with t-statistics less than -4.30.

While earnings announcements are pre-scheduled, most of the 8K filings are unscheduled. Table 8 reports Fama-MacBeth (1973) regression with full controls on five lags of VWM if there is an 8K filing on the following day.

[Table 8 about here]

Compared with non-8K days, on average, an 1% increase of the first lag of VWM before earnings announcements will shrink the implied volatility by 2.178% (t-statistic = -6.16). An 1% increase of the second lag will shrink the implied volatility by 2.444% (t-statistic = -7.91). If it happens on the third lag, we see the implied volatility decreases by 2.611% (t-statistic = -7.61). If it happens on the fourth lag, we see the implied volatility decreases by 3.057% (t-statistic = -7.64). And if it happens on the fifth lag, we see the implied volatility decreases by 3.158% (t-statistic = -5.86). The first lag of VWM in all five models are negative with coefficients less than -0.168, with t-statistics less than -3.40.

Both sensitivity tests on earnings announcements and 8-K filings show that VWM contains information on future implied volatility.

4.6 Multivariate regression analysis on stock returns

If VWM contains future information, it can be reflected in predicting future stock returns using the following Fama-MacBeth (1973) regression:

$$AQRET_{i,t} = \alpha + \sum_{l=1}^{5} \beta_l VWM_{i,t-l} + \sum_{l=1}^{5} \theta_l X_{i,t-l} + \epsilon, \tag{8}$$

where $AQRET_{i,t}$ is the risk adjusted mid quote returns on day t for firm i scaled to percentages. X is a set of control variables including five lags of $VWKS$, PC, OS, DEV, $SKEW$, $IVOL$, $QRET$, $SPREAD$, $TURN$ and V. For ease of reporting, the returns are expressed as percentages.

[Table 9 about here]

Model [1] controls for one lag of VWM. The coefficient estimate is 0.047 with a t-statistic of 5.92. Model [2] controls five lags of VWM. The coefficient is 0.031 for the first lag

(t-statistic = 4.10), 0.017 for the second lag (t-statistic = 2.21), 0.004 for the third lag (t-statistic = 0.52), 0.021 for the fourth lag (t-statistic = 2.74), and 0.018 for the fifth lag (t-statistic = 2.47). The third model controls for all return predictors from the options market. The coefficient is 0.033 for the first lag (t-statistic = 3.93), 0.034 for the second lag (t-statistic = 4.04), 0.024 for the third lag (t-statistic = 2.71), 0.037 for the fourth lag (t-statistic = 4.48), and 0.030 for the fifth lag (t-statistic = 3.64). The fourth model further controls for risk adjusted mid quote returns, bid-ask spread and turnover ratio. While the first lag of VWM has a coefficient of 0.017 with a t-statistic of 2.05, all the other four lags have coefficient above 0.027 and significant at the 1% level. In the last model, we include the full set controls. Similarly to the previous model, while the first lag of VWM has a coefficient of 0.019 with a t-statistic of 2.25, all the other four lags have coefficient above 0.025 and significant at the 1% level.

To study the aggregate aggregate predictive power from VWM, we study the 5-day moving averages of all return predictors using the following Fama-MacBeth (1973) regression:

$$AQRET_{i,t} = \alpha + \beta VWM\_MA5_{i,t-1} + \theta X\_MA5_{i,t-1} + \epsilon, \tag{9}$$

where

$$VWM\_MA5_{i,t-1} = \sum_{l=1}^{5} VWKS_{i,t-l}/5, \tag{10}$$

and

$$X\_MA5_{i,t-1} = \sum_{l=1}^{5} X_{i,t-l}/5. \tag{11}$$

$AQRET_{i,t}$ is the risk adjusted mid quote return, $AQRET_{i,t}$. The X_MA5 contains the same set of control variables in Eq. (5). After obtaining a time series of the slope coefficients, we then examine the mean of these coefficients using Newey-West (1987) adjustment, allowing for autocorrelation structures.

[Table 10 about here]

The first model only contains VWM_MA5, which has an average slope coefficient of 0.087 for VWM_MA5 (t-statistic = 5.94). The second model controls for the other return predictors from the options market. VWM_MA5 has a coefficient of 0.159 and a t-statistic of 8.94. The third model controls for the stock market macrostructure variables. The coefficient of VWM_MA5 is 0.150 and the t-statistic is 8.66. The fourth model further adds V_MA5. The coefficient of VWM_MA5 is 0.151 and its t-statistic is 8.70. VWM_MA5, $VWKS\_MA5$, PC_MA5, OS_MA5, $SKEW\_MA5$, $DCIVOL\_MA5$, $AQRET\_MA5$, $SPREAD\_MA5$, $TURN\_MA5$ in the full model are significant at the 1% level. DEV_MA5 is significant at the 5%. $IVOL\_MA5$, $DPIVOL\_MA5$, $VOLVOL\_MA5$ and V_MA5 are insignificant. Even though DEV, $SKEW$, $IVOL$, $DPIVOL$ and $DCIVOL$ are measuring from different perspectives through options implied volatility, their 5-day MA share common information by definition, resulting in a decrease of significance level. VWM_MA5 are not affected when we add these return predictors from the options market.

Using moving averages of the past five trading days, Table 5 captures the permanent price impact from the examined return predictors, which is more relevant for our question of information arrival to financial markets. Results in both tables support the third hypothesis that VWM has a positive and permanent price impact on the underlying stock price at daily horizon.

We further test hypothesis 3 by checking whether VWM has stronger return predictability for stocks with higher levels of information asymmetry and greater arbitrage costs. Based on the four proxies for information asymmetry, we divide the sample by size (measured by market capitalization), analyst coverage, institutional ownership, probability of informed trading (PIN). Based on the proxies for arbitrage costs, we divide the sample by Amihud's (2002) illiquidity, relative bid-ask spread, idiosyncratic volatility, and sample time period. For each proxy, we divide the sample into terciles, and report the regression results for low (<33th percentile) group and high (>33th percentile) group. Table 11 reports the slope coefficients and t-statistics (in parentheses) for five lags of VWM in Eq (2) and VWM_MA5 in Eq (3), based on the full specification Fama-Macbeth regressions as in model [5] of Table **??** and model [4] of Table 5. The differences of VWM_MA5 between the low group and high group are reported in the last column of each panel in Table 11.

[Table 11 about here]

The conditioning variable is firm market capitalization ($Size$) in Panel A, analyst coverage ($Analyst$) in Panel B, fraction of institutional ownership ($Ownership$) in Panel C, the probability of informed trading (PIN) as of Easley, Kiefer, O'Hara, and Paperman (1996) in Panel D, illiquidity measured as in Amihud (2002) in Panel E, relative bid-ask spread ($Spread$) in Panel F, idiosyncratic stock volatility ($Idio$) in Panel G, and sample period ($Year$) in Panel H.

For large firms, all five lags of VWM are insignificant. For small firms, the first four lags are significant at the 1% level while the fifth lag is significant at the 5% level. Therefore, we see a more persistent predictive power for stocks in smaller firms. At the aggregate level, VWM_MA5 for smaller firms has a coefficient of 0.039 (t-statistic = 2.00) while VWM_MA5 for larger firms has a coefficient of 0.383 (t-statistic = 11.38). We then test the differences of VWM_MA5 between small and large firms and find VWM_MA5 is statistically more significant in smaller firms with a t-value of 9.32, at the 1% level.

For more analyst covered firms, only the fourth lag of VWM is significant, whose coefficient is 0.043 with a t-statistic of 3.06. For less analyst covered firms, the second, third and fourth lags of VWM are significant at the 1% level while the fifth lag is significant at the 5% level. At the aggregate level, VWM_MA5 for more analyst covered firms has a coefficient of 0.087 (t-statistic = 3.90) while VWM_MA5 for less analyst covered firms has a coefficient of 0.242 (t-statistic = 7.96). We then test the differences of VWM_MA5 between small and large firms and find VWM_MA5 is statistically more significant in smaller firms with a t-value of 4.46. Similarly, we find a more persistent predictive power for stocks with less analyst covered firms.

Firms with higher institutional ownership have less significant and persistent VWM. For low institutional ownership firms, the first, fourth and fifth lags of VWM are significant at the 5% level while the second and third lags are significant at 10% level. VWM_MA5 is significant at the 1% level for both samples, the lower institutional ownership sees a coefficient of 0.198 with a t-statistic of 7.10 while the higher institutional ownership sample sees a coefficient of 0.069 with a t-statistic of 2.919. The differences between the two subsamples are significant at the 1% level, with a t-value of 4.06.

For high PIN firms, all five lags are significant. The first lag has a coefficient of 0.040 and a t-statistic of 2.06. The fourth lag has a coefficient of 0.084 and a t-statistic of 4.39. The fifth lag has a coefficient of 0.044 and a t-statistic of 2.28. For low PIN firms, first lag is significant, with a coefficient of 0.121 and a t-statistic of 1.87. The estimate of the fifth lag is negative and insignificant. VWM_MA5 in both high PIN and low PIN firms are significant at the 1% and their differences are significant at the 1% level, with a t-value of -4.37.

More liquid firms have higher significance in VWM, but less persistent over multiple lags. Firms with higher illiquidity have statistically significant VWM for all its five lags at the 5% level and above. Firms with lower illiquidity see insignificant VWM at the first four lags. The fifth lag of VWM has a coefficient of 0.028 with a t-statistic of 2.22. VWM_MA5 are significant for both low and high liquid firms. The differences between liquid and illiquid firms are quite obvious with a t-value of -7.48, significant at the 1% level.

Firms with larger bid-ask spread see more significant and persistent predicting power from VWM. For larger spread firms, the second, third, fourth and fifth lags are significant at the 1% with a coefficient of 0.065, 0.089, 0.101 and 0.081, respectively. For smaller spread firms, only the fourth lag is significant with a coefficient of 0.025 and a t-value of 1.68. VWM_MA5 in smaller spread firms has a coefficient of 0.037 (t-value=2.26) while VWM_MA5 in larger spread firms has a coefficient of 0.319 (t-value=8.69). The t-value for low minus high sample is -7.46, significant at the 1% level.

Firms with more idiosyncratic risks see more significant and persistent VWM. The second, fourth and fifth lags of VWM are significant at the 1% level, with a coefficient of 0.093, 0.108 and 0.085. For firms with less idiosyncratic risks, only the first lag of VWM is significant, with a coefficient of 0.017 and a t-statistic of 2.01. VWM_MA5 in less idiosyncratic risks firms has a coefficient of 0.029 (t-value=1.99) while VWM_MA5 in more idiosyncratic risks firms has a coefficient of 0.340 (t-value=8.37). The t-value for low minus high sample is -7.90, significant at the 1% level.

Although VWM_MA5 are significant in both 1996-2004 and 2005-2013 subsample, its economic significance has decreased from 0.215 (t-statistic = 6.89) to 0.105 (t-statistic = 5.83). While four out of five lags of VWM are significant at the 1% level in the earlier sample period, four out of five lags of VWM are significant at the 10% level or above in the later sample period. The differences between the two sample periods are significant with a t-value of 3.42.

5 Conclusion

In this paper, we aggregate options' TTM using their trading volume into VWM, a variable which measures the hot spot in the distribution of TTM and could reflect the activity of informed traders. We first test this relationship using a series of event studies and document a close link between VWM and firms' future fundamental news (e.g. earnings, 8-K filings, and price jumps). We find that VWM exhibits abnormal run-ups before all of these corporate events. Before volatility hikes, VWM is significantly smaller than non-hike days. Using Fama-MacBeth (1973) regressions, we find that TTM is a strong predictor of cross-sectional implied volatility and squared returns, even after controlling for common options market variables including the five lags of logarithm of options trading volume and underlying stock trading volume, implied volatility, bid-ask spread and squared returns. In the implied volatility sensitivity test, we find that TTM is negative and significant one to five days before 8-K filings and two to five days before earnings announcements. The results suggest that VWM contains stock information.

Furthermore, we find that VWM has a positive and statistically significant relationship to future returns. This effect remains at the same significance level when more control variables are added. As such, we believe VWM contains information in an orthogonal dimension to common return predictors from options market, many of which are related to implied volatility, and could be additive to a larger set of return predictors currently found in the literature. Consistent with the possibility that some options traders utilizing insider information, we find that VWM has stronger return predictive power for stocks with higher levels of information asymmetry proxied by lower market capitalization, fewer analyst coverage, lower institutional ownership and larger PIN. VWM also has higher predictive power for stocks with greater arbitrage costs, measured by high Amihud illiquidity, larger bid-ask spread, higher idiosyncratic volatility and during the first half of the sample period.

For mean-variance utility function being described in equation (1), we can describe it as

$$U = U(Ret, Vol), \tag{12}$$

where $Ret = Ret(TTM)$ and $Vol = Vol(TTM)$ for individual investors. When individual's preferred TTM is not observable, we propose VWM to aggregate the information in the options market, which provides the wisdom of the crowd on underlying assets' returns and volatility.

For future research, it would be interesting to study the impact of VWM on other corporate events such as M&A and bankruptcy, where the value of longer-dated options could suffer large, often binary, hikes depending on the outcome of these events.

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Table 1: Summary statistics

This table reports descriptive statistics of the main variables in the analysis. We obtain daily stock and options data from CRSP and OptionMetrics between January 1, 1996 and August 31, 2013. Only common stocks with CRSP security code of 10 and 11 are included. We also exclude those stocks with prices below five dollars. There are 3837 unique firms in the sample with on average 1400 firms per day. VWM is the options volume weighted time-to-maturity. OWM is the options open interest weighted time-to-maturity.$LnOV$ is the logarithm of options volume. $IVOL$ is the options-implied volatility, calculated as the average implied volatility of at-the-money call and put options. $LnSV$ is the logarithm of underlying stock volume. $SPREAD$ is the percentage bid-ask spread calculated as the ask minus bid scaled by the midpoint of the bid and ask prices. V is the squared raw stock returns in CRSP. $QRET$ is mid quote returns calculated using closing bid-ask prices and adjusted for stock splits and dividends. $AQRET$ is the risk adjusted mid quote returns calculated using market return, high-minus-low, small-minus-big, and momentum factors. All variables are winsorized at the 0.5% and 99.5% levels.

Variable	N	Mean	Std Dev	Minimum	Maximum
VWM	6273198	0.188	0.179	0.000	2.655
OWM	6273198	0.264	0.151	0.000	2.458
$LnOV$	6273198	4.257	2.865	0.000	15.635
$IVOL$	6273198	0.478	0.231	0.071	2.291
$SPREAD$	6024263	0.580	0.926	0.005	100.388
$LnSV$	6273198	9.196	1.696	0.664	16.686
V	6273127	0.001	0.003	0.000	0.180
$QRET$	6149934	0.001	0.030	-0.333	0.436
$AQRET$	6149934	0.000	0.026	-0.354	0.435

Table 2: Correlations

This table reports the time-series averages of cross-sectional correlations between January 1996 and August 2013. VWM is the options-volume weighted time-to-maturity. $LnOV$ is the logarithm of options volume. $IVOL$ is the options-implied volatility, calculated as the average implied volatility of at-the-money call options and at-the-money put options. $IVOL1$ is $IVOL$ on the following day. $LnSV$ is the logarithm of underlying stock volume. $SPREAD$ is the percentage bid-ask spread calculated as the ask minus bid scaled by the midpoint of the bid and ask prices. V is the squared raw stock returns in CRSP. $V1$ is V on the following day. $AQRET$ is the risk adjusted mid quote returns calculated using market return, high-minus-low, small-minus-big, and momentum factors.

	IVOL1	*V1*	*VWM*	*LnOV*	*IVOL*	*SPREAD*	*LnSV*	*V*	*AQRET*
IVOL1	1.000								
V1	0.296	1.000							
VWM	-0.074	-0.021	1.000						
LnOV	0.046	0.063	0.339	1.000					
IVOL	0.959	0.295	-0.076	0.048	1.000				
SPREAD	0.254	0.079	-0.058	-0.231	0.254	1.000			
LnSV	-0.098	-0.020	-0.291	-0.069	-0.096	-0.084	1.000		
V	0.296	0.178	-0.008	0.138	0.299	0.082	0.030	1.000	
AQRET	-0.017	0.002	-0.002	0.031	-0.017	-0.004	0.004	0.153	1.000

Table 3: Center of options volume mass of TTM around corporate events

For each type of corporate event in each column, we present the pooled ordinary least squares results of the following equation:

$$VWM = \alpha + \beta_0 EVENT + \sum_{i=1}^{5} \beta_1^i PREEVENTi + \sum_{i=1}^{5} \beta_2^i POSTEVENTi + \theta X + \epsilon,$$

where $EVENT$ is a category variable with a value of 1 if there is a corporate event on the same day t, and zero otherwise. $PREEVENTi$ is a pre-event category variable with a value of 1 if there is an event on day $t+i$, and zero otherwise; and $POSTEVENTi$ is a post-event category variable with a value of 1 if there is an event on day $t-i$, and zero otherwise. We include the firm, year and week fixed effects (FE). Standard errors are clustered by firms. Scheduled events are those from earnings announcements. Unscheduled events are 8-K filings that are not related to earnings news. Jumps are identified if the risk adjusted return is higher than 10% based on Savor (2012) or if the risk adjusted return is above two standard deviations by Boehmer and Wu (2013), and are not related to either 8-K filings or earnings announcements. *permjump* are price hikes whose $CAR0$ has the same sign as the cumulative abnormal return on the following one to five days ($CAR5$). *tranjump* are price hikes that reverse within the following five trading days ($sign(CAR0 * CAR5) < 0$). Associated t-statistics are reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

VWM	*scheduled*	*unscheduled*	*permjump*	*tranjump*	*all events*
EVENT	-16.826***	-3.831***	-4.265***	-3.995***	-6.121***
	[-40.96]	[-17.47]	[-7.21]	[-7.01]	[-35.13]
PREEVENT1	-16.669***	-4.417***	-2.888***	-1.911***	-6.085***
	[-40.52]	[-20.26]	[-4.91]	[-3.37]	[-35.07]
PREEVENT2	-8.765***	-2.574***	-1.226**	-0.766	-3.136***
	[-21.84]	[-12.11]	[-2.16]	[-1.40]	[-18.55]
PREEVENT3	-6.275***	-2.004***	-1.263**	-0.058	-2.358***
	[-16.45]	[-9.88]	[-2.34]	[-0.11]	[-14.60]
PREEVENT4	-4.512***	-1.861***	-0.21	-0.205	-1.991***
	[-12.58]	[-9.77]	[-0.41]	[-0.41]	[-13.02]
PREEVENT5	-1.265***	-0.762***	0.252	0.259	-0.595***
	[-3.70]	[-4.27]	[0.51]	[0.55]	[-4.08]
POSTEVENT1	-6.837***	-0.989***	-1.625***	-0.17	-1.737***
	[-16.76]	[-4.54]	[-2.75]	[-0.30]	[-10.03]
POSTEVENT2	-0.708*	-0.141	-0.747	-0.689	-0.195
	[-1.79]	[-0.66]	[-1.31]	[-1.25]	[-1.16]
POSTEVENT3	0.618	0.153	-0.59	-0.131	0.222
	[1.64]	[0.75]	[-1.11]	[-0.26]	[1.38]
POSTEVENT4	1.304***	0.352*	0.232	-0.307	0.505***
	[3.67]	[1.84]	[0.46]	[-0.63]	[3.32]
POSTEVENT5	1.072***	-0.189	0.703	1.007**	0.253*
	[3.18]	[-1.06]	[1.49]	[2.21]	[1.75]
Year & Week FE	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES
Intercept	84.127***	84.144***	83.702***	83.687***	84.629***
	[2694.04]	[1747.77]	[3066.54]	[3030.70]	[1524.87]
R^2	0.300	0.300	0.299	0.299	0.300
Obs	5130705	5130705	5130290	5130113	5129698

Table 4: Center of options volume mass of TTM around volatility hikes

For volatility hikes in each column, we present the pooled ordinary least squares results of the following equation:

$$VWM = \alpha + \beta_0 HIKE + \sum_{i=1}^{5} \beta_1^i PREHIKEi + \sum_{i=1}^{5} \beta_2^i POSTHIKEi + \theta X + \epsilon,$$

where $HIKE$ is a category variable with a value of 1 if there is a volatility hike on the same day t, and zero otherwise. $PREHIKEi$ is a pre-HIKE category variable with a value of 1 if there is an HIKE on day $t+i$, and zero otherwise; and $POSTHIKEi$ is a post-HIKE category variable with a value of 1 if there is an HIKE on day $t-i$, and zero otherwise. We include the firm and year fixed effects (FE). Standard errors are clustered by firms. The first three columns reports the hikes if the implied volatility increases by 0.5. The last three columns reports the hikes if the squared return increases by 1%. Model [1] and [4] examines VWM. Model [2] and [5] examines $VWMCALL$. Model [3] and [6] examines $VWMPUT$. Associated t-statistics are reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

VWM	*[1]*	*[2]*	*[3]*	*[4]*	*[5]*	*[6]*
HIKE	-0.321	0.178	0.155	9.383***	11.234***	10.385***
	[-0.78]	[0.45]	[0.40]	[75.43]	[94.00]	[87.48]
PREHIKE1	-1.143***	-0.786**	-0.532	-1.019***	-0.299**	-0.361***
	[-2.79]	[-1.99]	[-1.36]	[-8.19]	[-2.50]	[-3.04]
PREHIKE2	-1.417***	-1.333***	-0.372	-0.799***	-0.307**	-0.695***
	[-3.46]	[-3.39]	[-0.95]	[-6.42]	[-2.57]	[-5.85]
PREHIKE3	-1.640***	-1.366***	-0.750*	-0.704***	-0.378***	-0.691***
	[-4.01]	[-3.48]	[-1.92]	[-5.66]	[-3.16]	[-5.82]
PREHIKE4	-1.399***	-1.589***	-0.521	-0.882***	-0.748***	-0.767***
	[-3.42]	[-4.04]	[-1.34]	[-7.09]	[-6.25]	[-6.46]
PREHIKE5	-1.426***	-1.250***	-0.786**	-0.650***	-0.523***	-0.698***
	[-3.50]	[-3.19]	[-2.02]	[-5.22]	[-4.38]	[-5.88]
POSTHIKE1	0.241	0.363	0.838**	8.823***	9.480***	8.543***
	[0.59]	[0.92]	[2.14]	[70.96]	[79.35]	[71.99]
POSTHIKE2	0.434	0.347	0.468	4.927***	5.093***	4.322***
	[1.06]	[0.88]	[1.19]	[39.64]	[42.65]	[36.43]
POSTHIKE3	-0.411	-0.454	0.157	3.261***	3.196***	2.723***
	[-1.00]	[-1.15]	[0.40]	[26.24]	[26.77]	[22.96]
POSTHIKE4	-0.426	-0.251	-0.333	2.031***	2.106***	1.469***
	[-1.04]	[-0.64]	[-0.85]	[16.36]	[17.66]	[12.40]
POSTHIKE5	-0.088	0.024	-0.054	1.310***	1.366***	0.784***
	[-0.27]	[0.08]	[-0.17]	[10.82]	[11.75]	[6.79]
Year FE	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES
Intercept	44.961***	39.394***	29.401***	44.624***	39.001***	29.079***
	[3268.58]	[2980.14]	[2239.40]	[3065.32]	[2788.59]	[2093.05]
adj. R2	0.372	0.376	0.366	0.373	0.377	0.367
Obs	8527857	8527857	8527857	8527857	8527857	8527857

Table 5: Multivariate Fama-MacBeth regressions on volatility

This table investigates daily volatility predictability from VWM, the options-volume weighted maturity. Presented are Fama-MacBeth regression results of the following equation:

$$VOL_{i,t} = \alpha + \sum_{l=1}^{5} \beta_l VWM_{i,t-l} + \sum_{l=1}^{5} \theta_l X_{i,t-l} + \epsilon,$$

where VOL is $IVOL$ in the first three models and V in the last three models on day t for firm i. $X_{i,t-l}$ is a set of control variables on day t for firm i, including five lags of $LnOV$, $IVOL$, $SPREAD$, $LnSV$ and V. $LnOV$ is the logarithm of options volume. $IVOL_{i,t}$ is the options-implied volatility, calculated as the average implied volatility of at-the-money call options and at-the-money put options. $LnSV$ is the logarithm of underlying stock volume. $SPREAD$ is the percentage bid-ask spread calculated as the ask minus bid scaled by the midpoint of the bid and ask prices. V is the squared raw stock returns in CRSP. In model [4] and [6], VWM is replaced by OWM, the options open interest weighted maturity. Standard errors are calculated with the Newey-West adjustment to four lags. Associated t-statistics are reported in parentheses ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

	[1]	*[2]*	*[3]*	*[4]*	*[5]*
L1VWM	-0.084***	-0.043***	-0.001***	-0.011**	-0.914***
	[-35.23]	[-32.78]	[-4.79]	[-1.97]	[-8.45]
L2VWM		-0.038***	0.000	0.000	-0.295***
		[-33.16]	[0.19]	[0.04]	[-3.08]
L3VWM		-0.036***	0.000	0.015*	-0.111
		[-32.37]	[0.24]	[1.75]	[-1.18]
L4VWM		-0.036***	0.000	0.009	0.114
		[-31.48]	[-0.09]	[0.99]	[1.17]
L5VWM		-0.038***	0.000	-0.014***	0.109
		[-29.52]	[0.75]	[-3.17]	[1.20]
L1LnOV			0.000***	0.000***	0.509***
			[3.80]	[3.68]	[27.61]
L2LnOV			-0.000***	-0.000***	-0.017
			[-7.47]	[-7.07]	[-1.49]
L3LnOV			-0.000***	-0.000***	-0.106***
			[-6.14]	[-6.02]	[-9.42]
L4LnOV			-0.000***	-0.000***	-0.103***
			[-4.04]	[-4.14]	[-8.01]
L5LnOV			0.000***	0.000***	-0.104***
			[4.66]	[4.22]	[-7.72]

Table 5 (continued):

	[1]	[2]	[3]	[4]	[5]
L1IVOL			0.612***	0.612***	21.859***
			[115.51]	[115.57]	[27.75]
L2IVOL			0.183***	0.183***	0.991*
			[76.84]	[76.85]	[1.76]
L3IVOL			0.075***	0.075***	-0.628
			[33.04]	[33.08]	[-1.14]
L4IVOL			0.048***	0.048***	0.051
			[24.90]	[25.00]	[0.10]
L5IVOL			0.057***	0.057***	0.793*
			[35.14]	[35.10]	[1.83]
L1SPREAD			0.004***	0.004***	1.349***
			[8.93]	[8.87]	[14.03]
L2SPREAD			0.003***	0.003***	0.093
			[7.05]	[7.01]	[1.36]
L3SPREAD			0.003***	0.003***	-0.015
			[6.94]	[6.88]	[-0.20]
L4SPREAD			0.003***	0.003***	-0.125*
			[6.58]	[6.54]	[-1.75]
L5SPREAD			0.003***	0.003***	-0.246***
			[6.08]	[6.12]	[-3.68]
L1lnSV			0.000	0.000**	0.299***
			[0.79]	[2.17]	[19.34]
L2lnSV			-0.000***	-0.000***	-0.025**
			[-5.72]	[-5.89]	[-2.08]
L3LnSV			-0.000***	-0.000***	-0.062***
			[-2.91]	[-3.20]	[-5.45]
L4LnSV			-0.000***	-0.000***	-0.059***
			[-4.84]	[-4.79]	[-4.23]
L5LnSV			0.000**	0.000	-0.028**
			[1.99]	[1.55]	[-2.09]
L1V			0.583***	0.580***	804.958***
			[13.68]	[13.49]	[55.85]
L2V			0.420***	0.416***	349.466***
			[12.20]	[12.19]	[31.07]
L3V			0.343***	0.349***	279.998***
			[9.72]	[9.84]	[25.47]
L4V			0.330***	0.338***	274.430***
			[10.30]	[10.54]	[23.23]
L5V			0.324***	0.328***	273.182***
			[10.23]	[10.34]	[25.35]
Intercept	0.494***	0.514***	0.011***	0.011***	-6.293***
	[114.66]	[119.05]	[25.08]	[25.72]	[-16.83]
adj. R2	0.009***	0.020***	0.939***	0.939***	0.126***
Obs	6034957	6034957	6034957	6034957	6034957

Table 6: VWM in call and put options on volatility

This table reports Fama-Macbeth estimates of volatility predictions using the following equation:

$$VOL_{i,t} = \alpha + \sum_{l=1}^{5} \beta_l VWMCALL_{i,t-l} + \sum_{l=1}^{5} \gamma_l VWMPUT_{i,t-l} + \sum_{l=1}^{5} \theta_l X_{i,t-l} + \epsilon,$$

where VOL is $IVOL$ in the first three models and V in the last three models on day t for firm i. $VWMCALL$ is the call options-volume weighted maturity. $VWMPUT$ is the put options-volume weighted maturity. $X_{i,t-l}$ is a set of control variables on day t for firm i, including five lags of $LnOV$, $IVOL$, $SPREAD$, $LnSV$ and V. $LnOV$ is the logarithm of options volume. $IVOL$ is the options-implied volatility, calculated as the average implied volatility of at-the-money call options and at-the-money put options. $LnSV$ is the logarithm of underlying stock volume. $SPREAD$ is the percentage bid-ask spread calculated as the ask minus bid scaled by the midpoint of the bid and ask prices. V is the squared raw stock returns in CRSP. Standard errors are calculated with the Newey-West adjustment to four lags. Associated t-statistics are reported in parentheses ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

	[1]	*[2]*	*[3]*	*[4]*	*[5]*	*[6]*
VWMCALL	-0.000***		-0.000***	-0.654***		-0.522***
	[-2.80]		[-2.90]	[-6.81]		[-5.45]
L2VWMCALL	0.000		0.000	-0.261***		-0.143
	[1.26]		[0.87]	[-2.91]		[-1.58]
L3VWMCALL	0.000		0.000	-0.002		0.090
	[0.18]		[0.04]	[-0.03]		[1.13]
L4VWMCALL	0.000		0.000	0.024		0.091
	[-0.96]		[-1.32]	[0.29]		[1.09]
L5VWMCALL	0.000		0.000	0.019		0.104
	[0.45]		[0.25]	[0.24]		[1.29]
VWMPUT		-0.000*	0.000		-1.033***	-0.983***
		[-1.77]	[-1.57]		[-10.46]	[-10.18]
L2VWMPUT		0.000	0.000		-0.330***	-0.279***
		[0.72]	[0.76]		[-4.16]	[-3.58]
L3VWMPUT		0.000	0.000		-0.194**	-0.185**
		[0.28]	[0.37]		[-2.51]	[-2.39]
L4VWMPUT		0.000*	0.000**		-0.042	-0.018
		[1.93]	[2.02]		[-0.52]	[-0.21]
L5VWMPUT		0.000	0.000		-0.117	-0.099
		[-0.33]	[-0.31]		[-1.47]	[-1.27]
L1LnOV	0.000***	0.000***	0.000***	0.509***	0.523***	0.527***
	[3.71]	[3.65]	[3.77]	[27.63]	[27.58]	[27.69]
L2LnOV	-0.000***	-0.000***	-0.000***	-0.018	-0.012	-0.012
	[-7.53]	[-7.53]	[-7.43]	[-1.56]	[-1.02]	[-1.01]
L3LnOV	-0.000***	-0.000***	-0.000***	-0.108***	-0.104***	-0.104***
	[-6.30]	[-6.39]	[-6.33]	[-9.63]	[-8.98]	[-9.06]
L4LnOV	-0.000***	-0.000***	-0.000***	-0.103***	-0.100***	-0.100***
	[-4.08]	[-4.30]	[-4.20]	[-7.99]	[-7.81]	[-7.70]

Table 6 (continued):

	[1]	[2]	[3]	[4]	[5]	[6]
L5LnOV	0.000***	0.000***	0.000***	-0.105***	-0.101***	-0.103***
	[4.62]	[4.57]	[4.58]	[-7.72]	[-7.50]	[-7.43]
L1IVOL	0.612***	0.612***	0.612***	21.879***	21.858***	21.833***
	[115.53]	[115.51]	[115.47]	[27.75]	[27.73]	[27.78]
L2IVOL	0.183***	0.183***	0.183***	0.996*	0.991*	0.999*
	[76.83]	[76.75]	[76.80]	[1.77]	[1.77]	[1.78]
L3IVOL	0.075***	0.075***	0.075***	-0.596	-0.617	-0.621
	[33.03]	[33.05]	[33.04]	[-1.07]	[-1.12]	[-1.12]
L4IVOL	0.048***	0.048***	0.048***	0.000	0.061	0.046
	[24.87]	[24.83]	[24.83]	[0.00]	[0.12]	[0.09]
L5IVOL	0.057***	0.057***	0.057***	0.832*	0.776*	0.770*
	[35.15]	[35.14]	[35.20]	[1.92]	[1.78]	[1.77]
L1SPREAD	0.004***	0.004***	0.004***	1.343***	1.342***	1.340***
	[8.95]	[8.91]	[8.89]	[13.95]	[13.91]	[13.93]
L2SPREAD	0.003***	0.003***	0.003***	0.091	0.086	0.094
	[7.02]	[7.02]	[7.02]	[1.34]	[1.27]	[1.38]
L3SPREAD	0.003***	0.003***	0.003***	-0.022	-0.029	-0.023
	[6.91]	[6.88]	[6.88]	[-0.31]	[-0.41]	[-0.32]
L4SPREAD	0.003***	0.003***	0.003***	-0.131*	-0.137*	-0.133*
	[6.57]	[6.53]	[6.57]	[-1.82]	[-1.90]	[-1.84]
L5SPREAD	0.003***	0.003***	0.003***	-0.245***	-0.252***	-0.242***
	[6.08]	[6.15]	[6.15]	[-3.66]	[-3.77]	[-3.63]
L1lnSV	0.000	0.000**	0.000	0.315***	0.325***	0.308***
	[1.62]	[2.12]	[1.61]	[20.28]	[21.38]	[19.93]
L2lnSV	-0.000***	-0.000***	-0.000***	-0.024**	-0.020*	-0.022*
	[-5.59]	[-5.83]	[-5.55]	[-2.10]	[-1.73]	[-1.95]
L3LnSV	-0.000***	-0.000***	-0.000***	-0.059***	-0.063***	-0.058***
	[-3.05]	[-3.15]	[-3.05]	[-5.27]	[-5.99]	[-5.27]
L4LnSV	-0.000***	-0.000***	-0.000***	-0.066***	-0.067***	-0.063***
	[-5.18]	[-4.81]	[-5.01]	[-4.94]	[-5.14]	[-4.69]
L5LnSV	0.000*	0.000*	0.000*	-0.035***	-0.039***	-0.033**
	[1.88]	[1.71]	[1.79]	[-2.74]	[-3.09]	[-2.53]
L1V	0.581***	0.583***	0.583***	804.554***	803.659***	803.564***
	[13.63]	[13.65]	[13.70]	[55.66]	[55.37]	[55.48]
L2V	0.417***	0.419***	0.418***	349.402***	347.893***	349.127***
	[12.15]	[12.25]	[12.19]	[31.06]	[30.87]	[31.01]
L3V	0.343***	0.343***	0.344***	279.269***	279.601***	279.029***
	[9.74]	[9.73]	[9.75]	[25.39]	[25.48]	[25.40]
L4V	0.331***	0.333***	0.331***	274.571***	273.683***	273.662***
	[10.31]	[10.39]	[10.36]	[23.21]	[23.16]	[23.11]
L5V	0.326***	0.325***	0.326***	274.030***	273.930***	273.041***
	[10.28]	[10.22]	[10.27]	[25.41]	[25.40]	[25.35]
Intercept	0.011***	0.011***	0.011***	-6.398***	-6.478***	-6.379***
	[25.20]	[25.37]	[24.98]	[-17.28]	[-17.76]	[-17.23]
adj. R^2	0.939	0.939	0.939	0.126	0.126	0.126
Obs	6034957	6034957	6034957	[119.33]	[119.79]	[119.59]

Table 7: Volatility sensitivity to VWM around earnings announcements

This table reports volatility sensitivity of $VWKS$ to earnings announcements by Fama-Macbeth regression:

$$IVOL_{i,t} = \alpha + \gamma_l VWM_{l,t-l} * EARN + \sum_{l=1}^{5} \beta_l VWM_{i,t-l} + \sum_{l=1}^{5} \theta_l X_{i,t-l} + \epsilon,$$

where $IVOL$ is the options-implied volatility, calculated as the average implied volatility of at-the-money call options and at-the-money put options on day t for firm i. $EARN$ equals one if there is an earnings announcement on the following trading day, and zero otherwise. $X_{i,t-l}$ is a set of control variables on day t for firm i, including five lags of $LnOV$, $IVOL$, $SPREAD$, $LnSV$ and V. $LnOV$ is the logarithm of options volume. $LnSV$ is the logarithm of underlying stock volume. $SPREAD$ is the percentage bid-ask spread calculated as the ask minus bid scaled by the midpoint of the bid and ask prices. V is the squared raw stock returns in CRSP. Standard errors are calculated with the Newey-West adjustment to four lags. Associated t-statistics are reported in parentheses ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

	[1]	*[2]*	*[3]*	*[4]*	*[5]*
*L1VWM*EARN*	-1.911				
	[-0.28]				
*L2VWM*EARN*		-8.075**			
		[-2.04]			
*L3VWM*EARN*			-13.479***		
			[-7.02]		
*L4VWM*EARN*				-13.227***	
				[-6.93]	
*L5VWM*EARN*					-8.235***
					[-3.91]
L1VWM	-0.214***	-0.228***	-0.228***	-0.228***	-0.228***
	[-4.34]	[-4.64]	[-4.65]	[-4.67]	[-4.66]
L2VWM	0.023	0.044	0.019	0.021	0.019
	[0.49]	[0.91]	[0.40]	[0.45]	[0.40]
L3VWM	0.010	0.010	0.032	0.011	0.011
	[0.21]	[0.21]	[0.65]	[0.21]	[0.23]
L4VWM	-0.056	-0.056	-0.056	-0.036	-0.058
	[-1.21]	[-1.20]	[-1.20]	[-0.77]	[-1.24]
L5VWM	-0.058	-0.061	-0.058	-0.06	-0.035
	[-1.22]	[-1.27]	[-1.22]	[-1.25]	[-0.73]
L1lnOV	0.000***	0.000***	0.000***	0.000***	0.000***
	[6.22]	[6.32]	[6.32]	[6.29]	[6.28]
L2LnOV	-0.000***	-0.000***	-0.000***	-0.000***	-0.000***
	[-5.76]	[-5.75]	[-5.75]	[-5.74]	[-5.75]
L3LnOV	-0.000***	-0.000***	-0.000***	-0.000***	-0.000***
	[-7.26]	[-7.27]	[-7.28]	[-7.27]	[-7.24]
L4LnOV	-0.000***	-0.000***	-0.000***	-0.000***	-0.000***
	[-4.21]	[-4.23]	[-4.25]	[-4.22]	[-4.23]
L5LnOV	0.000**	0.000**	0.000**	0.000**	0.000**
	[2.50]	[2.44]	[2.46]	[2.45]	[2.45]

Table 7 (continued):

	[1]	*[2]*	*[3]*	*[4]*	*[5]*
L1IVOL	0.611***	0.611***	0.611***	0.611***	0.611***
	[116.91]	[116.91]	[116.93]	[116.94]	[116.89]
L2IVOL	0.182***	0.183***	0.182***	0.183***	0.182***
	[83.45]	[83.45]	[83.45]	[83.53]	[83.42]
L3IVOL	0.076***	0.076***	0.076***	0.076***	0.076***
	[36.68]	[36.67]	[36.67]	[36.67]	[36.67]
L4IVOL	0.050***	0.050***	0.050***	0.050***	0.050***
	[27.95]	[27.96]	[27.97]	[27.95]	[27.97]
L5IVOL	0.057***	0.057***	0.057***	0.057***	0.057***
	[37.45]	[37.44]	[37.43]	[37.46]	[37.43]
L1SPREAD	0.004***	0.004***	0.004***	0.004***	0.004***
	[10.93]	[10.93]	[10.94]	[10.93]	[10.94]
L2SPREAD	0.003***	0.003***	0.003***	0.003***	0.003***
	[8.98]	[8.97]	[8.97]	[9.00]	[8.98]
L3SPREAD	0.002***	0.002***	0.002***	0.002***	0.002***
	[6.79]	[6.77]	[6.76]	[6.77]	[6.77]
L4SPREAD	0.003***	0.003***	0.003***	0.003***	0.003***
	[7.92]	[7.92]	[7.91]	[7.92]	[7.92]
L5SPREAD	0.003***	0.003***	0.003***	0.003***	0.003***
	[8.58]	[8.58]	[8.58]	[8.57]	[8.58]
L1lnSV	0.000***	0.000***	0.000***	0.000***	0.000***
	[2.69]	[2.74]	[2.72]	[2.73]	[2.72]
L2lnSV	-0.000***	-0.000***	-0.000***	-0.000***	-0.000***
	[-4.65]	[-4.65]	[-4.68]	[-4.67]	[-4.66]
L3LnSV	-0.000***	-0.000***	-0.000***	-0.000***	-0.000***
	[-3.93]	[-3.92]	[-3.93]	[-3.94]	[-3.90]
L4LnSV	-0.000***	-0.000***	-0.000***	-0.000***	-0.000***
	[-5.99]	[-6.02]	[-5.99]	[-5.99]	[-6.02]
L5LnSV	0.000	0.000	0.000	0.000	0.000
	[0.01]	[-0.02]	[0.00]	[-0.02]	[-0.02]
L1V	0.165***	0.165***	0.165***	0.165***	0.165***
	[8.40]	[8.38]	[8.37]	[8.38]	[8.38]
L2V	0.097***	0.097***	0.097***	0.097***	0.097***
	[6.66]	[6.65]	[6.66]	[6.66]	[6.68]
L3V	0.075***	0.075***	0.075***	0.075***	0.075***
	[5.26]	[5.25]	[5.25]	[5.24]	[5.24]
L4V	0.085***	0.085***	0.085***	0.085***	0.085***
	[6.29]	[6.27]	[6.25]	[6.27]	[6.26]
L5V	0.099***	0.099***	0.099***	0.099***	0.099***
	[7.87]	[7.89]	[7.86]	[7.86]	[7.88]
Intercept	0.011***	0.011***	0.011***	0.011***	0.011***
	[23.61]	[23.61]	[23.60]	[23.61]	[23.62]
adj. R2	0.940	0.940	0.940	0.940	0.940
Obs	6034957	6034957	6034957	6034957	6034957

Table 8: Volatility sensitivity to VWM around 8K filings

This table reports volatility sensitivity of $VWKS$ to earnings announcements by Fama-Macbeth regression:

$$IVOL_{i,t} = \alpha + \gamma_l VWM_{l,t-l} * 8K + \sum_{l=1}^{5} \beta_l VWM_{i,t-l} + \sum_{l=1}^{5} \theta_l X_{i,t-l} + \epsilon,$$

where $IVOL$ is the options-implied volatility, calculated as the average implied volatility of at-the-money call options and at-the-money put options on day t for firm i. $8K$ equals one if there is an 8K filing on the following trading day, and zero otherwise. $X_{i,t-l}$ is a set of control variables on day t for firm i, including five lags of $LnOV$, $IVOL$, $SPREAD$, $LnSV$ and V. $LnOV$ is the logarithm of options volume. $LnSV$ is the logarithm of underlying stock volume. $SPREAD$ is the percentage bid-ask spread calculated as the ask minus bid scaled by the midpoint of the bid and ask prices. V is the squared raw stock returns in CRSP. Standard errors are calculated with the Newey-West adjustment to four lags. Associated t-statistics are reported in parentheses ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

	[1]	*[2]*	*[3]*	*[4]*	*[5]*
*VWM*8K*	-2.178***				
	[-6.16]				
*L2VWM*8K*		-2.444***			
		[-7.91]			
*L3VWM*8K*			-2.611***		
			[-7.61]		
*L4VWM*8K*				-3.057***	
				[-7.64]	
*L5VWM*8K*					-3.158***
					[-5.86]
L1VWM	-0.169***	-0.226***	-0.227***	-0.228***	-0.229***
	[-3.43]	[-4.60]	[-4.65]	[-4.66]	[-4.68]
L2VWM	0.025	0.093*	0.025	0.022	0.024
	[0.53]	[1.90]	[0.53]	[0.46]	[0.50]
L3VWM	0.011	0.011	0.085*	0.011	0.012
	[0.23]	[0.23]	[1.68]	[0.23]	[0.24]
L4VWM	-0.056	-0.057	-0.056	0.02	-0.058
	[-1.20]	[-1.22]	[-1.20]	[0.42]	[-1.25]
L5VWM	-0.057	-0.058	-0.059	-0.06	0.022
	[-1.20]	[-1.22]	[-1.23]	[-1.25]	[0.46]
L1lnOV	0.000***	0.000***	0.000***	0.000***	0.000***
	[6.15]	[6.23]	[6.26]	[6.28]	[6.30]
L2LnOV	-0.000***	-0.000***	-0.000***	-0.000***	-0.000***
	[-5.80]	[-5.75]	[-5.73]	[-5.77]	[-5.78]
L3LnOV	-0.000***	-0.000***	-0.000***	-0.000***	-0.000***
	[-7.17]	[-7.22]	[-7.25]	[-7.19]	[-7.22]
L4LnOV	-0.000***	-0.000***	-0.000***	-0.000***	-0.000***
	[-4.19]	[-4.20]	[-4.20]	[-4.24]	[-4.19]
L5LnOV	0.000***	0.000**	0.000**	0.000**	0.000**
	[2.58]	[2.53]	[2.53]	[2.51]	[2.49]

Table 8 (continued):

	[1]	*[2]*	*[3]*	*[4]*	*[5]*
L1IVOL	0.611***	0.611***	0.611***	0.611***	0.611***
	[116.91]	[116.90]	[116.90]	[116.90]	[116.89]
L2IVOL	0.183***	0.182***	0.183***	0.183***	0.183***
	[83.48]	[83.44]	[83.46]	[83.51]	[83.47]
L3IVOL	0.076***	0.076***	0.076***	0.076***	0.076***
	[36.69]	[36.67]	[36.65]	[36.66]	[36.68]
L4IVOL	0.050***	0.050***	0.050***	0.050***	0.050***
	[27.99]	[27.99]	[27.98]	[27.98]	[27.95]
L5IVOL	0.057***	0.057***	0.057***	0.057***	0.057***
	[37.48]	[37.48]	[37.47]	[37.47]	[37.49]
L1SPREAD	0.004***	0.004***	0.004***	0.004***	0.004***
	[10.92]	[10.95]	[10.94]	[10.95]	[10.93]
L2SPREAD	0.003***	0.003***	0.003***	0.003***	0.003***
	[9.00]	[8.99]	[9.00]	[9.00]	[8.99]
L3SPREAD	0.002***	0.002***	0.002***	0.002***	0.002***
	[6.78]	[6.78]	[6.75]	[6.77]	[6.78]
L4SPREAD	0.003***	0.003***	0.003***	0.003***	0.003***
	[7.92]	[7.91]	[7.91]	[7.90]	[7.90]
L5SPREAD	0.003***	0.003***	0.003***	0.003***	0.003***
	[8.59]	[8.58]	[8.59]	[8.58]	[8.58]
L1lnSV	0.000***	0.000***	0.000***	0.000***	0.000***
	[2.66]	[2.65]	[2.69]	[2.71]	[2.70]
L2lnSV	-0.000***	-0.000***	-0.000***	-0.000***	-0.000***
	[-4.64]	[-4.56]	[-4.63]	[-4.65]	[-4.63]
L3LnSV	-0.000***	-0.000***	-0.000***	-0.000***	-0.000***
	[-3.85]	[-3.88]	[-3.83]	[-3.85]	[-3.89]
L4LnSV	-0.000***	-0.000***	-0.000***	-0.000***	-0.000***
	[-5.97]	[-5.97]	[-5.97]	[-5.95]	[-5.99]
L5LnSV	0.000	0.000	0.000	0.000	0.000
	[0.06]	[0.06]	[0.01]	[-0.02]	[0.06]
L1V	0.167***	0.166***	0.166***	0.166***	0.166***
	[8.48]	[8.44]	[8.43]	[8.45]	[8.46]
L2V	0.098***	0.098***	0.098***	0.098***	0.098***
	[6.74]	[6.72]	[6.71]	[6.73]	[6.74]
L3V	0.075***	0.076***	0.075***	0.075***	0.075***
	[5.30]	[5.32]	[5.30]	[5.29]	[5.29]
L4V	0.085***	0.085***	0.085***	0.085***	0.085***
	[6.26]	[6.28]	[6.26]	[6.25]	[6.26]
L5V	0.099***	0.099***	0.099***	0.099***	0.099***
	[7.87]	[7.86]	[7.87]	[7.88]	[7.85]
Intercept	0.011***	0.011***	0.011***	0.011***	0.011***
	[23.57]	[23.57]	[23.56]	[23.57]	[23.59]
adj. R2	0.940	0.940	0.940	0.940	0.940
Obs	6034957	6034957	6034957	6034957	6034957

Table 9: Multivariate Fama-MacBeth regressions

This table investigates daily risk adjusted mid quote return predictability from VWM, the options-volume weighted time-to-maturity. Presented are Fama-MacBeth regression results of the following equation:

$$AQRET_{i,t} = \alpha + \sum_{l=1}^{5} \beta_l VWM_{i,t-l} + \sum_{l=1}^{5} \theta_l X_{i,t-l} + \epsilon,$$

where $AQRET_{i,t}$ is the risk adjusted mid quote returns on day t for firm i scaled to percentages; $X_{i,t-l}$ is a set of control variables on day t for firm i, including five lags of $VWKS$, PC, OS, DEV, $SKEW$, $IVOL$, $QRET$, $SPREAD$, $TURN$ and V. $VWKS$ is the volume-weighted strike-to-price ratio. PC is the put-call ratio, calculated as the logarithm of put options volume over call options volume. OS is the logarithm of total options volume over underlying stock volume. DEV is the deviation from put-call parity, calculated as the average difference in implied volatilities between call options and put options. $SKEW$ is the options implied skewness, calculated as the difference between the implied volatilities of out-of-the-money puts and at-the-money calls. $IVOL$ is the options-implied volatility, calculated as the average implied volatility of at-the-money call options and at-the-money put options. $DCIVOL$ is the first difference of call options-implied volatility. $DPIVOL$ is the first difference of put options-implied volatility. $VOLVOL$ is the volatility of options-implied voatility. $AQRET$ is mid quote returns adjusted for market return, high-minus-low, small-minus-big and momentum factors. $SPREAD$ is the percentage bid-ask spread calculated as the ask minus bid scaled by the midpoint of the bid and ask prices. $TURN$ is the turnover ratio calculated as the total trading volume over the number of shares outstanding. V is the squared raw stock returns in CRSP. Standard errors are calculated with the Newey-West adjustment to four lags. Associated t-statistics are reported in parentheses ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 9 (continued):

	[1]	*[2]*	*[3]*	*[4]*	*[5]*
L1VWM	0.047***	0.031***	0.033***	0.017**	0.019**
	[5.92]	[4.10]	[3.93]	[2.05]	[2.25]
L2VWM		0.017**	0.034***	0.035***	0.033***
		[2.21]	[4.04]	[4.19]	[4.02]
L3VWM		0.004	0.024***	0.027***	0.025***
		[0.52]	[2.71]	[3.12]	[2.90]
L4VWM		0.021***	0.037***	0.042***	0.041***
		[2.74]	[4.48]	[5.11]	[5.00]
L5VWM		0.018**	0.030***	0.036***	0.035***
		[2.47]	[3.64]	[4.36]	[4.37]
L1VWKS			0.120***	0.067***	0.061***
			[8.06]	[4.87]	[4.48]
L2VWKS			0.118***	0.045***	0.041***
			[7.91]	[3.38]	[3.08]
L3VWKS			0.057***	0.042***	0.044***
			[3.85]	[2.97]	[3.11]
L4VWKS			0.030**	0.029**	0.031**
			[2.07]	[2.05]	[2.20]
L5VWKS			0.012	0.035**	0.034**
			[0.81]	[2.39]	[2.34]
L1PC			-0.002***	-0.003***	-0.003***
			[-6.94]	[-9.45]	[-9.19]
L2PC			0.000	-0.001***	-0.001***
			[0.08]	[-2.91]	[-2.93]
L3PC			0.000	0.000	0.000
			[0.33]	[-0.85]	[-0.96]
L4PC			0.000	0.000	0.000
			[0.81]	[0.10]	[0.03]
L5PC			0.000	0.000	0.000
			[0.23]	[0.67]	[0.48]
L1OS			-0.002***	-0.001	-0.001
			[-3.59]	[-1.58]	[-1.61]
L2OS			-0.002***	-0.002***	-0.002***
			[-3.54]	[-3.94]	[-3.75]
L3OS			-0.002***	-0.002***	-0.002***
			[-3.11]	[-3.96]	[-3.96]
L4OS			-0.002***	-0.003***	-0.003***
			[-3.23]	[-4.60]	[-4.64]
L5OS			-0.001**	-0.002***	-0.002***
			[-2.07]	[-3.84]	[-3.93]
L1DEV			0.172	0.144	0.161
			[1.08]	[0.91]	[1.02]
L2DEV			-0.083	-0.091	-0.092
			[-0.51]	[-0.55]	[-0.56]
L3DEV			-0.110	-0.118	-0.140
			[-0.68]	[-0.74]	[-0.87]
L4DEV			0.124	0.193	0.197
			[0.78]	[1.19]	[1.22]

Table 9 (continued):

	[1]	[2]	[3]	[4]	[5]
L5DEV			-0.011	-0.029	-0.023
			[-0.07]	[-0.20]	[-0.16]
LSKEW			-0.325***	-0.251***	-0.240***
			[-8.63]	[-6.80]	[-6.56]
L2SKEW			-0.121***	-0.087**	-0.093**
			[-3.17]	[-2.33]	[-2.49]
L3SKEW			0.081**	0.044	0.041
			[2.21]	[1.20]	[1.11]
L4SKEW			-0.025	-0.04	-0.037
			[-0.67]	[-1.05]	[-0.98]
L5SKEW			0.025	-0.009	-0.002
			[0.74]	[-0.27]	[-0.06]
L1VOL			-0.597	-0.582	-0.611
			[-1.08]	[-1.06]	[-1.09]
L2IVOL			0.739	0.468	0.525
			[1.07]	[0.71]	[0.78]
L3IVOL			-0.433	-0.421	-0.464
			[-0.62]	[-0.62]	[-0.70]
L4IVOL			1.000	0.965	1.000
			[1.63]	[1.58]	[1.60]
L5IVOL			-0.603	-0.411	-0.413
			[-1.13]	[-0.76]	[-0.77]
L1DCIVOL			0.397	0.282	0.26
			[1.21]	[0.87]	[0.79]
L2DCIVOL			0.171	0.162	0.131
			[0.47]	[0.46]	[0.37]
L3DCIVOL			0.479	0.513	0.53
			[1.38]	[1.49]	[1.54]
L4DCIVOL			-0.184	-0.184	-0.185
			[-0.60]	[-0.60]	[-0.60]
L5DCIVOL			0.130***	0.078**	0.066*
			[3.30]	[2.06]	[1.76]
LDPIVOL			0.766**	0.577*	0.603*
			[2.46]	[1.87]	[1.92]
L2DPIVOL			0.252	0.138	0.134
			[0.77]	[0.43]	[0.41]
L3DPIVOL			0.200	0.165	0.168
			[0.59]	[0.49]	[0.50]
L4DPIVOL			-0.121	-0.058	-0.070
			[-0.40]	[-0.19]	[-0.23]
L5DPIVOL			0.075**	0.066*	0.065*
			[1.99]	[1.79]	[1.77]
LVOLVOL			1.809***	1.328***	1.123**
			[3.80]	[2.83]	[2.42]
L2VOLVOL			-1.793**	-1.21	-0.828
			[-2.23]	[-1.53]	[-1.06]
L3VOLVOL			-0.025	0.046	-0.223
			[-0.03]	[0.06]	[-0.30]

Table 9 (continued):

	[1]	[2]	[3]	[4]	[5]
L4VOLVOL			-0.441	-0.531	-0.48
			[-0.63]	[-0.76]	[-0.68]
L5VOLVOL			0.539	0.393	0.422
			[1.33]	[0.98]	[1.03]
L1AQRET				-0.958***	-0.332**
				[-7.32]	[-2.41]
L2AQRET				-1.510***	-1.370***
				[-12.92]	[-11.06]
L3AQRET				-0.731***	-0.808***
				[-7.26]	[-7.22]
L4AQRET				-0.721***	-0.757***
				[-7.23]	[-6.84]
L5AQRET				-0.306***	-0.391***
				[-3.20]	[-3.69]
L1SPREAD				0.036***	0.039***
				[3.59]	[3.85]
L2SPREAD				0.026**	0.029***
				[2.56]	[2.87]
L3SPREAD				0.030***	0.031***
				[2.99]	[3.04]
L4SPREAD				0.020**	0.020**
				[2.04]	[2.01]
L5SPREAD				0.016*	0.017*
				[1.68]	[1.78]
L1TURN				0.089***	0.096***
				[23.03]	[25.90]
L2TURN				-0.024***	-0.021***
				[-7.29]	[-6.41]
L3TURN				-0.007**	-0.011***
				[-2.15]	[-3.23]
L4TURN				-0.004	-0.004
				[-1.16]	[-1.34]
L5TURN				-0.021***	-0.025***
				[-6.96]	[-8.00]
L1V					-5.417***
					[-2.69]
L2V					-6.551***
					[-3.88]
L3V					1.306
					[0.80]
L4V					-0.312
					[-0.19]
L5V					3.225**
					[2.11]
Intercept	-0.004	-0.012***	-0.132***	-0.255***	-0.262***
	[-1.19]	[-2.85]	[-10.24]	[-13.16]	[-13.34]
adj. R2	0.000	0.000	0.034	0.057	0.063
Obs	5466600	5466600	5466600	5466600	5466600

Table 10: Daily multivariate Fama-MacBeth regressions on returns

This table reports the time-series averages of the cross-sectional coefficients of the following equation:

$$AQRET_{i,t} = \alpha + \beta VWM\_MA5_{i,t-1} + \theta X\_MA5_{i,t-1} + \epsilon,$$

where $AQRET_{i,t}$ is the risk adjusted mid quote returns on day t for firm i scaled to percentages; VWM_MA5 is the 5-day moving average (MA) of options-volume weighted time-to-maturity calculated on day $t-1$; and X_MA5 is a set of control variables on day $t-1$. $VWKS\_MA5$ is the 5-day moving average (MA) of options-volume weighted strike price over underlying price minus one. PC_MA5 is the 5-day MA of the logarithm of put volume over call volume. OS_MA5 is the 5-day MA of logarithm of total options volume over underlying stock volume. DEV_MA5 is the 5-day MA of deviation from put-call parity, calculated as the average difference in implied volatility between call options and put options. $SKEW\_MA5$ is the 5-day MA of options implied skewness, calculated as the difference between the implied volatility of out-of-the-money puts and at-the-money calls. $IVOL\_MA5$ is the 5-day MA of options-implied volatility, calculated as the average implied volatility of at-the-money call options and at-the-money put options. $DCIVOL\_MA5$ is the 5-day MA of the first difference of call options-implied volatility. $DPIVOL\_MA5$ is the 5-day MA of the first difference of put options-implied volatility. $VOLVOL\_MA5$ is the 5-day MA of the volatility of options-implied volatility. $AQRET\_MA5$ is 5-day MA of mid quote returns adjusted for market return, high-minus-low, small-minus-big and momentum factors. $SPREAD\_MA5$ is the 5-day MA of percentage bid-ask spread. $TURN\_MA5$ is the 5-day MA of total trading volume over the number of shares outstanding. V_MA5 is the 5-day MA of squared raw stock returns in CRSP. Standard errors are calculated with the Newey-West adjustment. Associated t-statistics are reported in parentheses ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

	[1]	*[2]*	*[3]*	*[4]*
VWM_MA5	0.087***	0.159***	0.150***	0.151***
	[5.94]	[8.94]	[8.66]	[8.70]
VWKS_MA5		0.360***	0.241***	0.245***
		[11.33]	[8.00]	[8.13]
PC_MA5		-0.002***	-0.004***	-0.004***
		[-3.16]	[-6.42]	[-6.30]
OS_MA5		-0.009***	-0.010***	-0.010***
		[-8.43]	[-10.19]	[-10.13]
DEV_MA5		0.075*	0.083*	0.094**
		[1.66]	[1.87]	[2.10]
SKEW_MA5		-0.381***	-0.355***	-0.350***
		[-13.66]	[-13.09]	[-12.86]
IVOL_MA5		0.111***	0.029	0.022
		[4.95]	[1.22]	[0.92]
DCIVOL_MA5		1.510***	0.992***	0.917***
		[11.07]	[7.91]	[7.33]
DPIVOL_MA5		0.470***	0.174	0.188
		[3.56]	[1.34]	[1.45]
VOLVOL_MA5		0.063	-0.014	-0.011
		[1.09]	[-0.24]	[-0.19]
AQRET_MA5			-3.997***	-3.693***
			[-13.46]	[-12.37]
SPREAD_MA5			0.137***	0.138***
			[8.83]	[8.79]
TURN_MA5			0.030***	0.028***
			[7.82]	[7.37]
V_MA5				-0.059
				[-0.02]
Intercept	-0.013***	-0.140***	-0.253***	-0.243***
	[-3.03]	[-11.02]	[-13.02]	[-12.69]
adj. R2	0.001	0.018	0.028	0.030
Obs	6035002	6035002	6035002	6035002

Table 11: Subsample analysis

In each panel, the full sample is divided into tercile groups based on a proxy for information asymmetry: low (<33th percentile) and high (>33th percentile). The slope coefficients and t-statistics (in parentheses) are reported only for five lags of volume-weighted TTM (VWM) from the Fama-Macbeth regression, and coefficients of a 5-day moving average (MA) of VWM ($VWM\_MA5_{i,t-1}$), using the full set of control variables. The conditioning variable is firm market capitalization ($Size$) in Panel A, idiosyncratic stock volatility ($Idio$) in Panel B, illiquidity measured as in Amihud (2002) in Panel C, analyst coverage ($Analyst$) in Panel D, fraction of institutional ownership ($Ownership$) in Panel E, the probability of informed trading (PIN) as of Easley, Kiefer, O'Hara, and Paperman (1996) in Panel F, total options trading volume ($Volume$) in Panel G, and sample period ($Year$) in Panel H. $X_{i,t-l}$ is a set of control variables on day t for firm i, and $X\_MA5_{i,t-l}$ is the 5-day MA of $X_{i,t-l}$, and are defined the same as before. Standard errors are calculated with the Newey-West adjustment. Associated t-statistics are reported in parentheses ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. We further compare the coefficient estimates on $VWKS\_MA5$ between each pair of subsamples using the unpaired t-test.

	Panel A: *Size*		Panel B: *Analyst*	
	low	*high*	*low*	*high*
L1VWM	0.076***	-0.003	0.024	0.005
	[3.77]	[-0.25]	[1.32]	[0.38]
L2VWM	0.087***	0.020	0.059***	0.015
	[4.27]	[1.60]	[3.28]	[1.04]
L3VWM	0.066***	-0.005	0.047**	0.008
	[3.26]	[-0.38]	[2.52]	[0.52]
L4VWM	0.086***	0.015	0.069***	0.043***
	[4.23]	[1.09]	[3.84]	[3.06]
L5VWM	0.050**	0.014	0.043**	0.018
	[2.40]	[1.11]	[2.41]	[1.28]
VWKS_MA5	0.383***	0.039**	0.242***	0.087***
	[11.38]	[2.00]	[7.96]	[3.90]
low-high	0.344***		0.155***	
	[9.32]		[4.46]	

Table 11 (continued):

	Panel C: *Ownership*		Panel D: *PIN*	
	low	*high*	*low*	*high*
L1VWM	0.036**	0.010	0.121*	0.040**
	[2.10]	[0.71]	[1.87]	[2.06]
L2VWM	0.029*	0.007	0.091*	0.038*
	[1.74]	[0.48]	[1.68]	[1.92]
L3VWM	0.029*	-0.002	0.036	0.035*
	[1.66]	[-0.14]	[1.05]	[1.82]
L4VWM	0.045**	0.025	0.044	0.084***
	[2.52]	[1.64]	[0.73]	[4.39]
L5VWM	0.034**	0.021	-0.093	0.044**
	[2.00]	[1.38]	[-1.24]	[2.28]
VWKS_MA5	0.198***	0.069***	0.102***	0.254***
	[7.10]	[2.99]	[5.18]	[7.89]
low-high	0.129***		-0.152***	
	[4.06]		[-4.37]	

	Panel E: *Illiq*		Panel F: *Spread*	
	low	*high*	*low*	*high*
L1VWM	0.014	0.039**	0.010	0.026
	[1.05]	[1.97]	[0.77]	[1.11]
L2VWM	0.014	0.088***	0.014	0.065***
	[1.05]	[4.37]	[0.82]	[2.80]
L3VWM	-0.016	0.062***	-0.002	0.089***
	[-1.22]	[3.11]	[-0.17]	[3.79]
L4VWM	0.010	0.082***	0.025*	0.101***
	[0.71]	[4.05]	[1.68]	[4.49]
L5VWM	0.028**	0.055***	0.011	0.081***
	[2.22]	[2.76]	[0.52]	[3.47]
VWKS_MA5	0.057***	0.330***	0.037**	0.319***
	[2.94]	[9.76]	[2.26]	[8.69]
low-high	-0.273***		-0.282***	
	[-7.48]		[-7.46]	

Table 11 (continued):

	Panel G: *Idio*		Panel H: *Year*	
	low	*high*	*low*	*high*
L1VWM	0.017**	0.020	0.012	0.031***
	[2.01]	[0.81]	[0.83]	[3.33]
L2VWM	0.001	0.093***	0.057***	0.015*
	[0.12]	[3.76]	[3.84]	[1.74]
L3VWM	-0.006	0.055**	0.043***	0.008
	[-0.65]	[2.11]	[2.83]	[0.80]
L4VWM	0.000	0.108***	0.058***	0.033***
	[0.01]	[4.36]	[4.04]	[3.52]
L5VWM	0.008	0.085***	0.047***	0.022**
	[0.87]	[3.31]	[3.39]	[2.35]
VWKS_MA5	0.029**	0.340***	0.215***	0.105***
	[1.99]	[8.37]	[6.89]	[5.83]
low-high	-0.311***		0.110***	
	[-7.90]		[3.42]	