Cross Section of Option Returns and Volatility-of-Volatility*

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Abstract

This paper presents a robust new finding that there is a significantly negative relation between the monthly rebalanced equity option returns and the forward-looking volatility-of-volatility (VOV). This result cannot be explained by standard risk factors. Our finding is consistent with the stochastic volatility option pricing models and suggests that the VOV plays an important role in determining option prices. The investor is willing to pay a high premium to hold options on high VOV stocks. After controlling for numerous existing control variables, the VOV effect on option returns is still significantly negative.

Keywords: Volatility-of-volatility; option returns; cross section.

JEL Classifications: G12, G13.

1. Introduction

Volatility-based factors are the important determinant of the cross section of option returns (e.g., Goyal and Welch (2008); Cao and Han (2013); Vasquez (2017) and Hu and Jacobs (2017)). Huang and Shaliastovich (2014); Park (2015); Hollstein and Prokopczuk (2017); Agarwal, Arisoy, and Naik (2017) and Baltussen, Van Bekkum, and Van Der Grient (2017) have found that uncertainty about volatility can have important implications for pricing and portfolio decisions. This paper tests the hypothesis that whether there is a negative relation between the cross section of option returns and the volatility of volatility (VOV), which captures the risk of the uncertainty about volatility. The hypothesis is motivated by the theory of option pricing in a stochastic volatility model (e.g., Heston (1993); Broadie, Chernov, and Johannes (2009); Christoffersen, Heston, and Jacobs (2013); Chambers, Foy, Liebner, and Lu (2014); Huang and Wu (2004) and Park (2015)), in which option pricing is affected by the magnitude of the VOV (e.g., σ in Heston (1993)).

To test the hypothesis, we examine a cross section of equity option returns each month. We eliminate options with moneyness that is lower than 0.975 or higher than 1.025. At the end of each month, we collect a pair of options that are closest to being at-the-money (ATM), have shortest maturity among those with more than one month to expiration and have the same maturity. Finally, we obtain around 180,000 observations for both calls and puts. Option and stock trading involves significant costs, and strategies that hold over a certain period incur these costs only at initiation. In this paper, we consider monthly rebalanced delta-hedged option returns. At the end of each month, we construct one delta-hedged call (put) option portfolio that is long a call (put) option and short a delta number of stocks. This option portfolio is held until the end of the next month, so that the option returns are monthly rebalanced.

Empirically, we find that the higher the VOV, the more negative monthly rebalanced delta-hedged option returns. Fama and MacBeth (1973) regressions from 1996 to 2016 conclude that there is a significantly negative relation between the option returns and the VOV. This is the key new finding in this paper. A portfolio that buys the lowest decile ranked by the VOV and sells the highest decile earns about 3% per month. Our results are robust after controlling for numerous potential risk factors and control variables or using the alternative subsample, the alternative VOV and the alternative option returns.

This paper contributes to the finance literature in a number of ways. First, the paper extends the study of the forward-looking VOV. Previous literature has focused on the aggregate VOV. For example, Hollstein and Prokopczuk (2017) measure the aggregate VOV as the VIX Volatility (VVIX) index, which is identified in a model-free manner from the index and VIX option prices, and confirm that the VVIX index is priced in the stock market. It commands an economically substantial and statistically significant negative risk premium. Agarwal et al. (2017) measure the aggregate VOV as the monthly returns on a lookback straddle strategy written on the VIX and find that it is priced in the cross section of hedge fund returns. Instead of the cross-section of stock and hedge returns, Huang and Shaliastovich (2014) and Park (2015) show that the aggregate VOV, measured by the VVIX index, is a significant risk factor for both S&P 500 index option returns and VIX option returns. Arguably, similar to the market index option return, the individual option return should be affected by uncertainty about individual volatility. Therefore, in this paper, we examine the implications of the individual VOV for equity option returns.

To the best of our knowledge, ours is the first investigation to examine whether uncertainty about individual volatility is priced in the cross section of option returns.[1] The paper closest in spirit to our investigation is by Baltussen et al. (2017), who find that the VOV of individual stocks is an important factor in the cross section of stock returns. We follow their definition of the individual VOV and extend it to predict the cross section of option returns.[2]

Second, our paper contributes to the growing literature on the cross-section of option

[1] Cao, Han, Tong, and Zhan (2017) compute uncertainty in stock volatility (VOL-of-VOL) as the standard deviation of percentage change in the daily realized volatility over one month, in order to capture the model risk studied by Green and Figlewski (1999). Compared with our VOV, their VOL-of-VOL is not involved in option data so that it is not forward-looking. In line with Cao et al. (2017), we obtain estimates of daily volatility for each stock in each month by applying from the EGARCH (1,1) model to a rolling window of past 12-month daily stock returns and obtain VOL-of-VOL calculated from the standard deviation of percentage change in the daily realized volatility over one month. There is a comparison based on Fama and MacBeth (1973) regressions provided in Internet Appendix. It shows that the predictive power of VOV is almost not affected by controlling for VOL-of-VOL.

[2] The VOV in our paper is like the individual realized volatility of implied volatility, while the VVIX is the aggregate implied volatility of the implied volatility. Even though, Hollstein and Prokopczuk (2017) compare the realized volatility of VIX with the VVIX and find that the prediction power will be decreased or even vanish after controlling for the systematic risk, we have to use the realized volatility of implied volatility as our VOV measure due to the unavailability of individual implied volatility index option data.

returns. In particular, for the volatility-based option return predictors,[3] Goyal and Saretto (2009) find a zero-cost trading strategy of options, that is long (short) in the portfolio with a large positive (negative) realized-implied volatility spread, can produce an economically and statistically significant average monthly return. Cao and Han (2013) further document that the daily rebalanced delta-hedged equity option return decreases monotonically with an increase in the idiosyncratic volatility of the underlying stock. Hu and Jacobs (2017) analyze the relation between expected option returns and the volatility of the underlying securities and find that returns on call (put) option portfolios decrease (increase) with underlying stock volatility. In addition, Vasquez (2017) finds that the slope of the implied volatility term structure is positively related to future option returns. Those studies particularly focus on volatility. Their predictors do not get involved in the forward-looking volatility of volatility measure, i.e., the VOV. This paper fills this gap and tests whether there is a negative relation between the cross section of option returns and the VOV.

Third, this paper is also related to studies on stock index option pricing efficiency. Broadie et al. (2009); Constantinides, Jackwerth, and Savov (2013) and Chambers et al. (2014) give much evidence that the index options are mispriced. High index option returns are not consistent with the classic option pricing models, e.g., the Black and Scholes (1973) model and the Heston (1993) stochastic volatility model. This paper gives more evidence that the VOV is a separate risk factor, which affects the option returns. It suggests that option pricing models should consider the VOV risk (i.e., σ in Heston (1993) should be uncertain).

The remainder of our paper is organized as follows. Section 2 shows our data and variables construction. Section 3 studies the cross section of option returns, and Section 4 provides option trading strategies. Section 5 concludes.

[3] For other predictors, Bali and Murray (2013) find a strong negative relation between the risk-neutral skewness of stock returns and the skewness asset returns, comprised of two option positions (one long and one short) and a position in the underlying stock. Boyer and Vorkink (2014) provide a strong negative relationship between the risk-neutral skewness of option returns and the cross section of equity options. Byun and Kim (2016) investigate the relation between the option returns and the underlying stock's lottery-like characteristics. Furthermore, Muravyev (2016) shows that the inventory risk faced by market-makers has a first-order effect on option prices. Kanne, Korn, and Uhrig-Homburg (2016) and Christoffersen, Goyenko, Jacobs, and Karoui (2017) provide evidence of a strong effect of the underlying stock's illiquidity on option prices. Recently, Cao et al. (2017) have comprehensively studied the option return predictability and find that the cross-section of delta-hedged equity option returns can be predicted by a variety of underlying stock characteristics and firm fundamentals, including idiosyncratic volatility, past stock returns, profitability, cash holding, new share issuance, and dispersion of analyst forecasts.

2. Data

2.1 Option data

Option data are obtained from the Ivy DB database provided by OptionMetrics, from 04 January 1996 to 29 April 2016. The data include daily closing bid and ask prices, trading volume, option interest, implied volatility and delta. Closing option prices are calculated as the midpoint of the closing bid and ask prices. Following Goyal and Saretto (2009); Cao and Han (2013); Boyer and Vorkink (2014) and Byun and Kim (2016), we filter the option data based on Appendix A.1. Then we eliminate options with moneyness (S/K) lower than 0.975 or higher than 1.025. At the end of each month, we collect a pair of options that are closest to being at-the-money (ATM) and have the shortest maturity among those with more than one month to expiration. Following Cao and Han (2013), the maturity of the options we then pick each month has the same maturity. We therefore drop the options whose maturity is larger than that of the maturity. Finally, we have 178,786 observations for both calls and puts.

Panel A, Table 1 shows that the average moneyness of the chosen option is almost one, with a standard deviation of only 0.01. The average delta of call options is close to 0.5 and the average delta of put options is close to -0.5.In line with Cao and Han (2013), the time to maturity of the chosen options ranges from 47 to 52 calendar days across different months, with an average of 50 days. On average, the open interest and the trading volume of calls are greater than puts. These short-term options are the most actively traded. Following Cao and Han (2013), we calculate the bid-ask spread as the ratio of the difference between ask and bid quotes of options over the midpoint of bid and ask quotes at the end of each month, and measure demand by the option open interest at the end of each month scaled by monthly stock trading volume, i.e., (option open interest/stock volume)$\times 10^3$. The average bid-ask spreads of call and put options are same, around 0.16. Because of greater open interest, the demand of call options is higher than that of put options.

[Insert Table 1]

2.2 Option returns

Following Goyal and Saretto (2009) and Kanne et al. (2016), we define the monthly rebalanced delta-hedged option returns for calls and puts as

$$r^{C}_{t,t+T} = \frac{\max\left(S_{t+T} - K, 0\right) - \Delta^{C}_{t} S_{t+T} - \left(C_t - \Delta^{C}_{t} S_t\right) e^{r_t T}}{Abs(C_t - \Delta^{C}_{t} S_t)}, \tag{1}$$

$$r^{P}_{t,t+T} = \frac{\max\left(K - S_{t+T}, 0\right) - \Delta^{P}_{t} S_{t+T} - \left(P_t - \Delta^{P}_{t} S_t\right) e^{r_t T}}{Abs(P_t - \Delta^{P}_{t} S_t)}, \tag{2}$$

where T is the holding period length; K is the strike price; S_{t+T} is the stock price at time $t+T$; Δ^{C}_{t} (Δ^{P}_{t}) is the delta of the call (put) option at time t; C_t (P_t) is the call (put) option price at time t; and r_t is the risk-free rate at time t.

Hold-over-period returns are typically analyzed both in academic studies and in practice. Option and stock trading involves significant costs, and strategies that hold over a certain period incur these costs only at initiation. At the end of each month, we construct one delta-hedged call (put) option portfolio, that is long a call (put) option and short a delta number of stocks. This option portfolio is held until the end of the next month. Then the one-month return of this delta-hedged option portfolio is the portfolio's exercise value subtracted the future value of the initial cost at the end of month, scaled by the absolute value of the initial portfolio. We repeat this procedure each month during the sample period and then we get a time series of option returns for each equity. The stock prices, strikes and option prices are obtained from Ivy DB OptionMetrics. The monthly risk-free rate r_t is obtained from the Kenneth R. French Data Library.

Panel A, Table 1 shows that the mean and median of call and put option returns are both negative. The average monthly rebalanced delta-hedged call option return is -2.91% and the average monthly rebalanced delta-hedged put option return is -2.44%. Their median are -3.65% and -3.18%, respectively. The call and put option returns are highly correlated, with a correlation of 0.97, so that they have a similar pattern.

2.3 VOV measures

In line with Baltussen et al. (2017), we define the implied volatility (IV) as the average of the ATM call and put implied volatilities, using the volatility surface standardized options with a delta of 0.50 and maturity of 30 days. These data are obtained from Ivy DB OptionMetrics. For each month t, the VOV is defined as the standard deviation of the ATM 30-day IV, that is

$$VOV_t = sd(IV_d), \tag{3}$$

where IV_d is the daily IV in month t.

We require that there be at least 13 no-missing observations to calculate the VOV. As the IV is the implied volatility, the VOV is forward-looking. According to Baltussen et al. (2017), the VOV captures the uncertainty in investors' assessment of the risks that surround future stock prices. Epstein and Ji (2014) formulate a model to explain how investors' ambiguity on volatility affects the asset prices. The VOV does capture ambiguous volatility. Huang and Shaliastovich (2014); Park (2015) and Hollstein and Prokopczuk (2017) document that investors, who care the uncertainty on the volatility, are willing to pay a positive premium. Both theoretical and empirical evidence motivates us to explore whether the VOV is priced in the cross section of equity option returns.

According to Agarwal et al. (2017), an alternative way to define the VOV is as the difference between the maximum and the minimum of IV in month t,

$$VOV_t = \max(IV_d) - \min(IV_d). \tag{4}$$

Panel B, Table 1 shows that for each year, the median of the VOV across different stocks is around $1 - 4\%$, while, the median of the alternative VOV is around $6 - 12\%$. Across different years, the medians of the VOV and the alternative VOV are slightly different. For example, in 2008, both measures reach the maximal median during the sample period we use. Unsurprisingly, the two measures have a high correlation of 0.97.

2.4 Control variables

The daily and monthly stock returns, stock prices, trading volume and share outstanding are obtained from CRSP, and accounting and balance sheet data are obtained from COMPUSTAT, for calculating other control variables: the market beta (BETA), the log market capitalization (SIZE), the book-to-market ratio (BM), the return in the past month (REV), the cumulative return from month $t-12$ to month $t-2$ (MOM), the log illiquidity (LN_ILLIQ), the log turnover (LN_TURN), the maximum daily return (MAX) over the current month t, the idiosyncratic volatility (IVOL), the realized skewness (RSKEW) and the realized kurtosis (RKURT) based on daily returns over the most recent 12 months.

By using volatility surface data provided by Ivy DB OptionMetrics, we are able to calculate the model-free implied skewness (IS), the implied kurtosis (IK), the volatility term structures (VTS) and the implied volatility innovations (dCIV and dPIV). Finally, following Goyal and Saretto (2009), we calculate the realized-implied volatility spread (RV_IV) by using daily stock returns obtained from CRSP and the implied volatility obtained from Ivy DB OptionMetrics. The details of variable construction are provided in Appendix A.2. Following Cao and Han (2013) and Cao et al. (2017), we winsorize all independent variables each month at the 0.5% level in order to eliminate the outliers. The risk factors, including Fama and French (1993) three factors (MKT, SMB, HML), Carhart (1997) momentum factor (UMD) and Fama and French (2015) five factors (RMW, CMA), are obtained from the Kenneth R. French Data Library.

Panel C, Table 1 gives the summary statistics, which are close to the existing literature, e.g., Cao and Han (2013); Byun and Kim (2016); Cao and Han (2013); and Baltussen et al. (2017). Their correlations are given in Panel D, Table 1. The VOV, as a volatility-based variable, is correlated with IVOL, with a correlation of 0.55. In addition, we find there is a high correlation between the SIZE and the log ILLIQ, at the value of -0.91. It is intuitive, as the small size stocks have high illiquidity.

3. Empirical results

In this section, in order to test the hypothesis of whether there is a negative relation between the cross section of option returns and the VOV, we run the monthly Fama and MacBeth (1973) regressions, after controlling for existing popular determinants. The results are presented in Table 2. The dependent variable, which is the monthly rebalanced delta-hedged call option return, and the independent are predetermined at time t. The key variable of interest is the VOV.

[Insert Table 2]

As a benchmark, we present the univariate regression on the VOV in the first column of Table 2. It shows that the delta-hedged call option returns are negatively related to the VOV, without controls. The coefficient of the VOV is -0.34, with a significant t-statistic of -15.0. This negative relation is robust to the alternative subsample period, alternative VOV measure and alternative option returns. Section 3.5 reports robustness checks.

3.1 Controlling for firm-specific characteristics

The option returns are monthly rebalanced and scaled by the initial value of a delta-hedged portfolio. The underlying stock characteristics may affect the relation between the option returns and the VOV. Panel A, Table 2 reports the regression results after controlling for firm-specific characteristics, i.e., the market beta (BETA), the log market capitalization (SIZE), the book-to-market ratio (BM), the return in the past month (REV) and the cumulative return from month $t-12$ to month $t-2$ (MOM).

The coefficient of the VOV remains negative and highly significant in all regressions in Panel A, Table 2. Expect SIZE, other characteristics does not materially affect the magnitude and statistical significance of the VOV coefficient. Interestingly, the VOV coefficient is reduced from -0.34 to -0.27 after controlling for SIZE. Based on the negative correlation between the VOV and the SIZE in Panel D, Table 1, the VOV partially captures the size effect.

3.2 Controlling for return distribution characteristics

According to Cao and Han (2013), the idiosyncratic volatility (IVOL) as a proxy of arbitrage costs, is significantly and negatively related to the option returns. The higher premium investors have to pay is due to the arbitrage costs. Model 2 in Panel B, Table 2 provides a consistent observation of Cao and Han (2013) in that the IVOL coefficient is significant and negative. Comparing Model 1 and Model 2 in Panel B, we find the VOV coefficient reduced to -0.14. This is because of their high correlation. High IVOL stocks have high VOV. The VOV partially contains the IVOL information. Importantly, after the IVOL, the VOV coefficient is still statistically significant with a t-statistic of -6.62. The VOV, eliminating the IVOL effect, has some additional information, which is the uncertainty about volatility.

Byun and Kim (2016) suggest that call options written on the lottery-like stocks underperform. We control for the lottery demand factor, MAX, and find the VOV coefficient is not affected. Furthermore, the MAX coefficient is insignificant with a t-statistic of 0.39. We could not find Byun and Kim's (2016) observation in monthly rebalanced delta-hedged call option returns.

Based on the existing option pricing models (e.g., Pan (2002) and Carr and Wu (2004)), the jumps are the key factor for the option prices. We therefore control for the realized skewness (RSKEW) and the realized kurtosis (RKURT). First, based on Model 4 and Model 5, we indeed find a significant and negative relation between the option returns and jumps. This is consistent with the finding in Cao and Han (2013). Comparing those models with Model 1, we find the VOV coefficients do not decrease, after controlling for SKEW and KURT. This suggests that our results cannot be explained by jump premiums.

3.3 Controlling for limits to arbitrage

Cao and Han (2013) provide some evidence that the highly negative delta-hedge premium is related to the limits to arbitrage and that the IVOL can be partially explained by the limits to arbitrage. This is because their delta-hedge option portfolio is daily rebalanced. Following Cao and Han (2013), we consider four variables as proxies of limits to arbitrage, i.e., the demand (DEMAND), the bid-ask spread (BID_ASK), the log illiquidity (LN_ILLIQ) and the log turnover (LN_TURN).[4] Consistent with Cao and Han (2013), we find a significant and negative relation between the option returns and limits to arbitrage, based on Models 2-5 in Panel C, Table 2. In addition, the stock illiquidity is the most important among those four measures in weakening the VOV effect. The VOV coefficient decreases to -0.28 with a t-statistic of -13.0, after controlling for LN_ILLIQ. As we mentioned before, there is a much higher correlation between SIZE and log ILLIQ, at the value of -0.91. The potential source of the VOV therefore may be the illiquidity effect.

3.4 Controlling for option-based characteristics

Bali and Murray (2013) suggest that risk-neutral skewness (NSKEW) can predict the future returns of skewness assets. Goyal and Saretto (2009) find that the realized-implied volatility spread (RV_IV) can produce an economically and statistically significant average monthly option return. Recently, Vasquez (2017) has found that the slope of the implied volatility term structure (VTS) is positively related to future option returns. Furthermore, An, Ang, Bali, Cakici, et al. (2014) find that the implied volatility innovations (dCIV and dPIV) can predict the future stock returns. We are also interested in investigating the effects of the implied volatility innovations on the future option returns. We control for those option-based characteristics and present the results in Panel D, Table 2.

First, Model 2 shows the NSKEW coefficient is -0.021 with a t-statistic of -2.17. The option returns are negatively related to the NSKEW. This is identical to Bali and Murray (2013); Cao and Han (2013) and Cao et al. (2017). The positive and significant RV_IV coefficient in Model 4 suggests that the higher the realized-implied volatility spread, the higher the option returns. This is intuitive. Bakshi and Kapadia (2003) suggest that the returns of delta-hedged option portfolios can be a proxy of the variance risk premium. Additionally, the RV_IV is also highly correlated to the variance risk premium. This makes the option returns and the RV_IV have a positive relation. This is consistent with Bakshi and Kapadia (2003); Goyal and Saretto (2009); Cao and Han (2013) and Cao et al. (2017). The most influential

[4] As our delta-hedge option portfolio is monthly rebalanced, we do not consider the effect from the stock price as a proxy of transaction costs. The results are only slightly affected if we add the stock price as a control variable. For example, after controlling for the stock price, the VOV coefficient becomes -0.28 with a significant t-statistic of -12.75. In addition, after controlling for the above four variables of limits to arbitrage and the stock price, the VOV coefficient becomes -0.22 with a significant t-statistic of -11.04.

control variable is the VTS. The VTS coefficient is 0.099 with a significant t-statistic of -8.76, based on Model 5. Vasquez (2017) finds a significant and positive relation between the VTS and the straddle returns. Our results suggest there is also a significant and positive relation between the VTS and the delta-hedged option returns. Model 6 and Model 7 show that the implied volatility innovation from calls has a significant and negative coefficient, at value of -0.04 with a t-statistic of -5.21. Its effect on the option returns are opposite to the effect on the stock returns. Finally, based on all regressions in Panel D, we find the strength of the negative relation between the option returns and the VOV is not reduced, after controlling for those option-based characteristics.

3.5 Robustness checks

In this subsection, we provide several robustness checks on our results along three ways: alternative sample period, alternative VOV proxy and alternative option returns.

First, we divide the sample into two subsamples: January 1996 to December 2005 and January 2006 to April 2016. The results are provided in Table 3 and Table 4. In all regressions, we still find a significant VOV coefficient. Comparing Table 4 with Table 3, during the period from January 2006 to April 2016, the VOV effect is less reduced by the IVOL.

[Insert Table 3]

[Insert Table 4]

Second, we use an alternative VOV proxy and present the results in Table 5. In all regressions, the coefficients of the alternative VOV are still significantly negative. The alternative VOV can capture the similar information of the VOV.

[Insert Table 5]

Finally, we consider the delta-hedged call option returns over alternative periods, such as one week or time to maturity. Their summary statistics are given in the Internet Appendix. Table 6 shows there is a more significantly negative relation between the VOV and the one-week delta-hedged option returns. The t-statistics of all regressions are negatively higher than

−20. For the hold-to-expiration delta-hedged option returns, in Table 7, the VOV coefficients are smaller but all are still significantly negative. In addition, we consider the delta-hedged put option returns in Table 8. We find again a significantly negative relation between the delta-hedged put option returns and the VOV. The results of the delta-hedged put option returns over alternative periods are given in the Internet Appendix. They have same pattern as the delta-hedged call option returns.

[Insert Table 6]

[Insert Table 7]

[Insert Table 8]

4. Portfolio Formation and Trading Strategy

In this section, we study the relation between option returns and the VOV using the portfolio sorting approach, in order to confirm the previous results based on Fama and MacBeth (1973) regressions.

4.1 Univariate portfolios sorted on the VOV

At the end of each month, we rank the delta-hedged option portfolios into 10 deciles, based on the VOV, and then form the 10 portfolios. Their portfolio weights are equal-weighted, stock-value-weighted and option-value-weighted. After one month, we calculate the equal-weighted, stock-value-weighted and option-value-weighted monthly returns of those 10 portfolios, respectively. Table 9 reports the average returns of the 10 portfolios, each of which consists of long positions in monthly rebalanced delta-hedged calls, ranked in a given decile by the VOV. Table 9 also reports the difference in the average returns of the bottom and the top VOV decile portfolios in the "10-1" row.

[Insert Table 9]

Panel A, Table 9 shows that the average equal-weighted returns of the 10 portfolios decrease monotonically with an increase in the VOV, while Panels B and C, Table 9 show that the monotonically decreasing pattern is slightly violated. The average equal-weighted return of 10-1 portfolio is -3.16% with a t-statistic of -14.7, which is close to the average delta-hedged call option returns during our sample period. The average stock-value-weighted return of the 10-1 portfolio is less negative, at a value of -2.13 with a t-statistic of -5.90, while the average option-value-weighted return of the 10-1 portfolio is more negative, at a value of -3.56 with a t-statistic of -8.64. We use common risk factor models, i.e., the CAPM model, the Fama and French (1993) three-factor model, the Carhart (1997) four-factor model and the Fama and French (2015) five-factor model, to explain the raw returns of the 10 portfolios. The third to last columns in Table 9 give the results, which indicate that the common risk factors can only explain a tiny fraction of the returns of our option trading strategies.

4.2 Bivariate portfolios sorted on control variables and the VOV

In the previous subsection, after controlling for the existing option returns predictors, we use Fama and MacBeth (1973) regressions to show a significantly negative relation between the monthly rebalanced delta-hedged option returns and the VOV. Table 10 presents the equal-weighted returns of the 10 portfolios after controlling for the existing predictors. We first rank the delta-hedged option portfolios into 10 deciles, based on the controlling variable, and then sequentially rank each decile into another 10 deciles, based on the VOV. Finally, we calculate the average equal-weighted returns for each VOV decile across 10 control deciles.

[Insert Table 10]

Compared with the univariate sorting result (see Panel A in Table 9), the VOV effect is preserved after controlling for 19 variables in Table 10. Expect that after controlling for the IVOL, the 10-1 difference is around -2 to -3%, with a t-statistic of around -10. Corresponding to the previous results based on Fama and MacBeth (1973) regressions, the VOV partially contains the IVOL information. After controlling for the IVOL, the average equal-weighted raw return difference between the high VOV and low VOV deciles is -0.95 with a significant t-statistic of -6.72. The results after controlling for common risk factors are given in the Internet Appendix and they are similar to the raw returns.

5. Conclusion

This paper provides a comprehensive study of the relation between the monthly rebalanced delta-hedged option returns and the volatility-of-volatility (VOV). Based on Fama and MacBeth (1973) regressions and the portfolio sorting, we find a significantly negative relation between option returns and the VOV, which can be regarded as the main finding in this paper. This results is robust after controlling for numerous risk factors and control variables. For example, a portfolio of long the lowest decile ranked by the VOV and short the highest decile earns about 3% per month.

Our key finding shows that the VOV factor is priced by investors, with a negative market price of risk. Investors dislike increases in VOV, so they are willing to pay a high premium to hold options. In addition, our results suggest that it is important and fruitful to consider the VOV risk in option pricing models, e.g., Huang and Wu (2004).

A. Appendix

A.1 Option database screening procedure

1. Underlying Asset Is an Index: Optionmetrics "index flag" (index_flag) is nonzero.

2. Underlying Asset Is Not Common Stock: Optionmetrics "issue type" (issue_type) for underlying is nonzero.

3. AM Settlement: The option expires at the market open of the last trading day, rather than the close. Optionmetrics "am settlement flag"(am_set_flag) is nonzero.

4. Nonstandard Settlement: Optionmetrics "special settlement flag" (ss_flag) is nonzero.

5. Abnormal Price: The price is less than \$1/8; the bid price is zero or missing or is higher than the ask price; the price violates arbitrage bounds.

6. Abnormal Implied Volatility: Implied volatility is less than zero or missing;

7. Abnormal Delta: Delta is less than -1 or larger than $+1$.

8. Zero Open Interest: Open interest is zero or missing.

9. Mismatching between CRSP and OptionMetrics: The closing price for the underlying stock from CRSP is below 97% or above 103% of the closing price of the underlying stock from the OptionMetrics database.

A.2 Variable construction

A.2.1 Firm-specific characteristics

- BETA: We run the market model at the daily frequency in month t to obtain the monthly beta of an individual stock,

$$r_{i,d} - r_{f,d} = \alpha_i + \beta_{1,i} MKT_{d-1} + \beta_{2,i} MKT_d + \beta_{3,i} MKT_{d+1} + \varepsilon_{i,d}, \quad (5)$$

where $r_{i,d}$ is the return on stock i on day d, MKT_d is the market excess return on day d, and $r_{f,d}$ is the risk-free rate on day d. The sum of the estimated slop coefficients, $\hat{\beta}_{1,i} + \hat{\beta}_{2,i} + \hat{\beta}_{3,i}$, is the energy market beta of stock i in month t.

- SIZE: Firm size is measured as the natural logarithm of the market value of equity at the end of the month for each stock.

- Book-to-Market Ratio (BM): We compute the book-to-market ratio in month t of a firm using the market value of its equity at the end of December of the previous year and the book value of common equity plus balance-sheet deferred taxes for the firm's latest fiscal year ending in the prior calendar year, according to Fama and French (1993) and Davis, Fama, and French (2000).

- Short-Term Reversal (REV): Following Jegadeesh (1990) and Lehmann (1990), we define short-term reversal for each stock in month t as the return on the stock over the previous month from $t-1$ to t.

- Momentum (MOM): Following Jegadeesh and Titman (1993), the momentum variable for each stock in month t is defined as the cumulative return from month $t-12$ to month $t-2$.

A.2.2 Limit to arbitrage

- Option Bid-Ask Spread (BID-ASK): Option bid-ask spread is the ratio of the difference between ask and bid quotes of option over the midpoint of bid and ask quotes at the end of each month.

- Option Demand (DEMAND): Option demand is measured by option open interest at the end of each month scaled by monthly stock trading volume, according to Cao and Han (2013), i.e., (option open interest/stock volume)$\times 10^3$.

- Illiquidity (ILLIQ): Following Amihud (2002), the illiquidity, for each stock in month t is defined as the annual average of the ratio of the absolute daily stock return to its dollar trading volume over month t,

$$ILLIQ_{i,t} = 1/D_{i,t} \sum_{d=1}^{D_{i,t}} |R_{i,d}|/VOLD_{i,d} \times 10^6, \tag{6}$$

where $R_{i,d}$ is the return on stock i on day d; D_t is the number of trading days in month t; and $VOLD_{i,t}$ is the monthly trading volume of stock i in dollars.

- Turnover (TURN): Turnover ratio is defined as the average daily turnover ratio over month t. The daily turnover ratio equals the number of shares traded in stock i divided by the total shares outstanding.

A.2.3 Return distribution characteristics

- Maximum (MAX): MAX is the maximum daily return within a month, according to Bali, Cakici, and Whitelaw (2011).

- Idiosyncratic Volatility (IVOL): Following Ang, Hodrick, Xing, and Zhang (2006), we run the market model at the daily frequency,

$$r_{i,d} - r_{f,d} = \alpha_i + \beta_{i,MKT} MKT_d + \beta_{i,SMB} SMB_d + \beta_{i,HML} HML_d + \varepsilon_{i,d}, \tag{7}$$

where $r_{i,d}$ is the return on stock i on day d, MKT_d is the market return on day d, and $r_{f,d}$ is the risk-free rate on day d. Idiosyncratic volatility of each stock in month t is defined as the standard deviation of daily residuals in month t, $IVOL_{i,t} = sd(\varepsilon_{i,d})$.

- Realized Skewness (RS): Realized skewness of stock i in month t is defined as the skewness of daily returns over the most recent 12 months.

- Realized Kurtosis (RK): Realized kurtosis of stock i in month t is defined as the kurtosis of daily returns over most recent 12 months.

A.2.4 Option-based characteristics

- Implied Volatility (IV): Implied volatility is the average of the at-the-money (ATM) call and put implied volatilities, using the volatility surface standardized options with a delta of 0.50 and maturity of 30 days, $IV = \frac{CIV_{50}+PIV_{50}}{2}$, on the last trading day of each month.

- Implied Skewness (IS): Following Bali, Hu, and Murray (2016), the implied skewness is the difference between the ATM call and put implied volatilities with a delta of 0.25 and maturity of 30 days, $IS_{t,\tau} = CIV_{25} - PIV_{25}$, on the last trading day of each month.

- Implied Kurtosis (IK): Following Bali et al. (2016), the implied kurtosis is the difference between the sum of the 30-day ATM call and put implied volatilities with a delta of 0.25 and a delta of 0.50, $IK_{t,\tau} = (CIV_{25} + PIV_{25}) - (CIV_{50} + PIV_{50})$, on the last trading day of each month.

- Realized-Implied Volatility Spread (RV_IV): Following Goyal and Saretto (2009), realized-implied volatility spread is the difference between RV and IV, where the annualized realized volatility (RV) of stock i in month t is defined as the square root of 252 times the standard deviation of daily returns over month t, $RV_{i,t} = sd(R_{i,d}) \times \sqrt{252}$.

- Implied Volatility Innovation. According to An et al. (2014), implied volatility innovation of calls $dCIV_{i,t} = CIV_{i,t} - CIV_{i,t-1}$ and implied volatility innovation of puts $dPIV_{i,t} = PIV_{i,t} - PIV_{i,t-1}$, where CIV and PIV are the ATM call and put implied volatilities with a delta of 0.50 and maturity of 30 days, respectively.

- Volatility Term Structures (VTS): Following Vasquez (2017), $VTS = IV6M - IV$, where $IV6M$ is the average of the ATM call and put implied volatilities, using the volatility surface standardized options with a delta of 0.50 and maturity of six months. VTS in this paper captures the slope of the implied volatility term structure between one month and six months.

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Table 1: Summary Statistics

This table reports the descriptive statistics of option returns, the volatility-of-volatility (VOV) and control variables used to predict monthly rebalanced delta-hedged option returns. The option sample period is from January 1996 to April 2016. In Panel A, at the end of each month, we eliminate options with moneyness (S/K) lower than 0.975 or higher than 1.025 and then collect a pair of options that are closest to being at-the-money (ATM) and have the shortest maturity among those with more than one month to expiration. The maturity of the options we pick each month has the same maturity. We drop the options whose maturity is larger than that of the maturity. At the end of each month, we construct one delta-hedged call (put) option portfolio, that is long a call (put) option and short delta number of stocks. This option portfolio is held until the end of the next month. Then the one-month return of this delta-hedged option portfolio is the portfolio's exercise value subtracted the future value of the initial cost at the end of month, scaled by the absolute value of the initial portfolio. We repeat this procedure each month during the sample period and then we get a time series of option returns for each equity. The stock prices, strikes and option prices are obtained from Ivy DB OptionMetrics. The monthly risk-free rate is obtained from the Kenneth R. French Data Library. Days to maturity is the number of calendar days until the option expiration. Moneyness is the ratio of stock price to option strike price. Delta is the option delta according to the Black-Scholes model. The option bid-ask spread is the ratio of the difference between ask and bid quotes of option to the midpoint of the bid and ask quotes at the end of each month. Option demand is measured by option open interest at the end of each month scaled by monthly stock trading volume, i.e., (option open interest/stock volume)$\times 10^3$. In Panel B, the VOV is defined as the standard deviation of the ATM 30-day IV, and the alternative VOV is defined as the difference between the maximum and the minimum of IV in month t. Panel C reports the time-series average of the cross-sectional statistics of common predictors: the market beta (BETA), the log market capitalization (SIZE), the book-to-market ratio (BM), the return in the past month (REV), the cumulative return from month $t-12$ to month $t-2$ (MOM), the log illiquidity (LN_ILLIQ), the log turnover (LN_TURN), the maximum daily return (MAX) over the current month t, the idiosyncratic volatility (IVOL), the realized skewness (RSKEW) and the realized kurtosis (RKURT) based on daily returns over the most recent 12 months, the implied skewness (IS), the implied kurtosis (IK), the volatility term structures (VTS), the implied volatility innovations (dCIV and dPIV) and the realized-implied volatility spread (RV_IV). The details of variable construction are provided in Appendix A.2. All of these variables are winsorized each month at the 0.5% level. The daily and monthly stock returns, stock prices, trading volume and share outstanding are obtained from CRSP, and accounting and balance sheet data are obtained from COMPUSTAT. Panel D reports correlations among the VOV and all control variables.

Panel A: Option Returns							
	mean	p50	sd	p10	p25	p75	p90
Delta-hedged Calls							
r^C (%)	-2.91	-3.65	11.07	-12.01	-7.54	0.33	5.83
Days to maturity	50	50	2	47	50	51	52
Moneyness=S/K (%)	99.73	99.61	1.42	97.88	98.50	100.88	101.82
Trading volume	141.54	5.00	886.96	0.00	0.00	49.00	222.00
Open interest	1448.63	197.00	6536.37	11.00	45.00	836.00	2883.00
Delta	0.52	0.53	0.07	0.44	0.48	0.57	0.59
Bid-ask spread	0.16	0.11	0.19	0.04	0.06	0.19	0.33
Demand	0.04	0.01	0.09	0.00	0.00	0.03	0.09
Delta-hedged Puts							
r^P (%)	-2.44	-3.18	9.41	-10.23	-6.56	0.25	5.11
Days to maturity	50	50	2	47	50	51	52
Moneyness=S/K (%)	99.78	99.70	1.42	97.91	98.56	100.95	101.86
Trading volume	87.63	0.00	689.96	0.00	0.00	20.00	112.00
Open interest	932.17	99.00	5305.08	8.00	22.00	437.00	1676.00
Delta	-0.48	-0.47	0.07	-0.57	-0.52	-0.43	-0.41
Bid-ask spread	0.16	0.11	0.18	0.04	0.06	0.18	0.31
Demand	0.02	0.01	0.07	0.00	0.00	0.02	0.05
Correlation							
	r^C	r^P					
r^C	1.00						
r^P	0.97	1.00					

Table 1: Summary Statistics (cont'd)

Panel B: VOV						
	VOV (%)			Alternative VOV (%)		
Year	p10	p50	p90	p10	p50	p90
1996	0.72	1.91	5.89	2.72	6.91	19.96
1997	0.73	2.00	5.86	2.73	7.19	20.06
1998	0.83	2.32	7.31	3.07	8.27	25.13
1999	0.88	2.43	7.60	3.28	8.52	25.42
2000	1.14	3.29	9.94	4.19	11.40	33.12
2001	1.08	2.94	8.44	3.84	10.08	26.73
2002	1.10	2.95	7.85	3.95	10.03	26.05
2003	0.96	2.25	5.43	3.46	7.77	17.94
2004	0.79	1.79	4.55	2.87	6.34	15.82
2005	0.73	1.73	4.71	2.71	6.14	16.78
2006	0.80	1.88	4.80	2.86	6.60	16.55
2007	0.95	2.14	5.26	3.51	7.60	18.56
2008	1.49	3.87	10.67	5.41	13.64	38.67
2009	1.45	3.04	6.41	5.22	10.66	22.05
2010	1.17	2.40	5.22	4.22	8.60	18.65
2011	1.21	2.71	6.75	4.44	9.84	24.93
2012	1.09	2.26	5.48	3.98	8.02	19.18
2013	0.88	1.86	4.98	3.18	6.63	17.34
2014	0.92	2.20	5.91	3.34	7.71	20.40
2015	1.08	2.47	6.98	3.92	8.89	24.53
2016	1.50	3.36	8.20	5.15	11.78	29.45
Correlation						
VOV			1.00			
Alternative VOV			0.97			1.00

Table 1: Summary Statistics (cont'd)

Panel C: Control Variable Summary

	mean	p50	sd	p10	p25	p75	p90
BETA	1.22	1.09	1.40	-0.19	0.47	1.84	2.82
SIZE	15.22	15.17	1.56	13.21	14.09	16.31	17.26
BM	0.47	0.37	0.41	0.11	0.21	0.63	0.96
MOM	21.83	17.61	44.24	-23.40	-1.52	39.26	69.12
REV	1.71	1.32	12.27	-11.66	-4.69	7.37	15.05
IVOL	0.02	0.02	0.01	0.01	0.01	0.03	0.04
MAX	1.94	1.73	11.90	-11.12	-4.16	7.64	15.07
RSKEW	0.21	0.16	1.20	-0.81	-0.22	0.57	1.23
RKURT	9.26	5.75	10.72	3.64	4.31	9.35	17.82
LN_ILLIQ	-7.73	-7.87	1.76	-9.86	-9.03	-6.55	-5.34
LN_TURN	2.23	2.22	0.77	1.26	1.72	2.73	3.21
NSKEW	-0.04	-0.04	0.06	-0.10	-0.07	-0.02	0.01
NKURT	0.05	0.02	0.09	-0.01	0.01	0.05	0.12
RV_IV	-0.01	-0.03	0.15	-0.15	-0.08	0.04	0.14
VTS	-0.01	0.00	0.05	-0.06	-0.02	0.02	0.04
dCIV	0.00	0.00	0.08	-0.09	-0.04	0.03	0.08
dPIV	0.00	0.00	0.08	-0.09	-0.04	0.03	0.08

Table 1: Summary Statistics (cont'd)

Panel D: Correlations

	VOV	BETA	SIZE	BM	MOM	REV	IVOL	MAX	RSKEW	RKURT
VOV	1.00									
BETA	0.13	1.00								
SIZE	-0.27	-0.11	1.00							
BM	-0.02	0.00	-0.09	1.00						
MOM	0.04	0.09	0.00	-0.14	1.00					
REV	-0.09	-0.01	0.02	0.02	0.00	1.00				
IVOL	0.55	0.18	-0.40	-0.07	0.13	-0.04	1.00			
MAX	0.00	0.03	-0.07	0.02	-0.01	-0.02	0.10	1.00		
RSKEW	0.08	0.02	-0.05	-0.03	0.27	0.11	0.09	0.11	1.00	
RKURT	0.16	-0.01	-0.16	-0.06	0.03	0.01	0.13	0.02	0.26	1.00
DEMAND	-0.03	-0.04	-0.10	0.01	-0.03	0.03	-0.06	0.06	0.04	0.05
BID_ASK	0.17	-0.03	-0.39	0.12	-0.08	-0.03	0.01	-0.03	0.03	0.09
LN_ILLIQ	0.26	0.09	-0.91	0.08	-0.02	-0.04	0.42	0.02	0.04	0.09
LN_TURN	0.37	0.21	-0.27	-0.03	0.15	0.01	0.48	0.03	0.05	0.13
NSKEW	-0.19	-0.07	-0.02	-0.01	0.03	0.02	-0.12	-0.03	-0.03	0.02
NKURT	0.15	-0.03	-0.25	0.09	-0.07	-0.03	0.00	-0.02	0.00	0.07
RV_IV	0.26	0.14	0.05	-0.01	0.01	-0.08	0.57	0.15	0.02	0.05
VTS	-0.29	-0.06	0.10	0.02	0.00	0.05	-0.31	0.12	-0.03	-0.03
dCIV	-0.05	0.00	0.06	-0.03	0.04	0.08	-0.01	-0.34	-0.02	-0.01
dPIV	-0.03	0.01	0.06	-0.03	0.04	0.05	0.00	-0.30	-0.02	-0.01

	DEMAND	BID_ASK	LN_ILLIQ	LN_TURN	NSKEW	NKURT	RV_IV	VTS	dCIV	dPIV
DEMAND	1.00									
BID_ASK	0.02	1.00								
LN_ILLIQ	0.11	0.42	1.00							
LN_TURN	-0.14	-0.18	-0.03	1.00						
NSKEW	0.02	0.10	0.02	-0.17	1.00					
NKURT	0.05	0.50	0.26	-0.10	0.14	1.00				
RV_IV	-0.11	-0.03	-0.01	0.23	-0.05	0.02	1.00			
VTS	0.04	-0.02	-0.15	-0.12	0.17	0.08	0.07	1.00		
dCIV	-0.03	-0.06	-0.03	-0.01	0.02	-0.10	-0.18	-0.49	1.00	
dPIV	-0.02	-0.04	-0.02	-0.01	-0.12	-0.09	-0.16	-0.50	0.78	1.00

Table 2: Firm-level cross-sectional regressions

This table reports the average coefficients from monthly Fama and MacBeth (1973) regressions of delta-hedged call option returns until the end of month. The volatility of volatility (VOV) is defined as the standard deviation of the ATM 30-day IV and the details of control variable construction are provided in Appendix A.2. All independent variables are winsorized each month at the 0.5% level. The sample period is from January 1996 to April 2016. To adjust for serial correlation, robust Newey-West(1987) t-statistics are reported in parentheses. *, ** and *** indicates significance at the 10, 5 and 1% level.

Panel A: Firm-Specific Characteristics

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VOV	-0.34***	-0.32***	-0.27***	-0.35***	-0.35***	-0.34***	-0.27***
	(-15.0)	(-13.8)	(-11.8)	(-14.7)	(-15.2)	(-15.0)	(-11.9)
BETA		-0.0019***					-0.0019***
		(-3.57)					(-3.61)
SIZE			0.0041***				0.0035***
			(9.46)				(8.45)
BM				-0.00037			0.0022*
				(-0.21)			(1.65)
MOM					0.0010		0.0010
					(0.51)		(0.54)
REV						0.0042	-0.0024
						(0.62)	(-0.39)
R-squared	0.021	0.030	0.031	0.025	0.031	0.028	0.056

Panel B: Return Distribution Characteristics

	(1)	(2)	(3)	(4)	(5)	(6)
VOV	-0.34***	-0.14***	-0.34***	-0.35***	-0.34***	-0.15***
	(-15.0)	(-6.62)	(-15.6)	(-14.6)	(-14.0)	(-6.96)
IVOL		-0.75***				-0.76***
		(-12.9)				(-14.4)
MAX			0.0022			0.013**
			(0.39)			(2.13)
RSKEW				-0.0012***		-0.00089**
				(-2.61)		(-2.04)
RKURT					-0.00023***	-0.000092*
					(-3.57)	(-1.69)
R-squared	0.021	0.036	0.029	0.025	0.026	0.050

Panel C: Limits to Arbitrage

	(1)	(2)	(3)	(4)	(5)	(6)
VOV	-0.34***	-0.34***	-0.34***	-0.28***	-0.30***	-0.24***
	(-15.0)	(-15.2)	(-14.9)	(-13.0)	(-14.9)	(-12.0)
DEMAND		-0.026***				-0.012**
		(-3.50)				(-2.03)
BID_ASK			-0.019***			0.011*
			(-2.80)			(1.83)
LN_ILLIQ				-0.0041***		-0.0047***
				(-9.35)		(-10.7)
LN_TURN					-0.0038***	-0.0039***
					(-4.19)	(-4.33)
R-squared	0.021	0.024	0.025	0.031	0.029	0.045

Panel D:Option-based Characteristics

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VOV	-0.34***	-0.35***	-0.34***	-0.35***	-0.31***	-0.35***	-0.34***	-0.32***
	(-15.0)	(-16.1)	(-15.0)	(-15.6)	(-12.8)	(-13.2)	(-13.3)	(-11.6)
NSKEW		-0.021**						-0.026***
		(-2.17)						(-3.02)
NKURT			0.015*					0.0059
			(1.84)					(0.71)
RV_IV				0.014***				0.0078*
				(3.29)				(1.92)
VTS					0.099***			0.092***
					(8.76)			(5.71)
dCIV						-0.040***		-0.033***
						(-5.21)		(-2.98)
dPIV							-0.013	0.032***
							(-1.55)	(2.83)
R-squared	0.021	0.025	0.025	0.028	0.029	0.029	0.028	0.054

Table 3: Firm-level cross-sectional regressions during the subsample period from January 1996 to December 2005

This table reports the average coefficients from monthly Fama and MacBeth (1973) regressions of delta-hedged call option returns until the end of month. The volatility of volatility (VOV) is defined as the standard deviation of the ATM 30-day IV and the details of control variable construction are provided in Appendix A.2. All independent variables are winsorized each month at the 0.5% level. The sample period is January 1996 to December 2005. To adjust for serial correlation, robust Newey-West(1987) t-statistics are reported in parentheses. *, ** and *** indicates significance at the 10, 5 and 1% level.

Panel A: Firm-Specific Characteristics

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VOV	-0.34***	-0.30***	-0.24***	-0.34***	-0.34***	-0.33***	-0.24***
	(-8.85)	(-7.94)	(-6.74)	(-8.32)	(-8.71)	(-8.71)	(-6.92)
BETA		-0.0016**					-0.0024***
		(-2.28)					(-3.33)
SIZE			0.0051***				0.0040***
			(6.73)				(5.29)
BM				-0.0048			0.00056
				(-1.58)			(0.23)
MOM					0.0075***		0.0071**
					(2.70)		(2.60)
REV						0.021**	0.0092
						(2.48)	(1.10)
R-squared	0.019	0.029	0.032	0.024	0.032	0.026	0.058

Panel B: Return Distribution Characteristics

	(1)	(2)	(3)	(4)	(5)	(6)
VOV	-0.34***	-0.081***	-0.33***	-0.34***	-0.33***	-0.084***
	(-8.85)	(-2.66)	(-9.47)	(-8.23)	(-7.90)	(-3.10)
IVOL		-0.84***				-0.85***
		(-8.35)				(-9.40)
MAX			0.010			0.023***
			(1.25)			(2.79)
RSKEW				-0.0011		-0.00091
				(-1.26)		(-1.14)
RKURT					-0.00026**	-0.00011
					(-2.07)	(-1.00)
R-squared	0.019	0.038	0.027	0.025	0.025	0.053

Panel C: Limits to Arbitrage

	(1)	(2)	(3)	(4)	(5)	(6)
VOV	-0.34***	-0.34***	-0.33***	-0.26***	-0.29***	-0.22***
	(-8.85)	(-9.00)	(-9.00)	(-7.88)	(-8.65)	(-6.81)
DEMAND		-0.038***				-0.016*
		(-3.16)				(-1.78)
BID_ASK			-0.040***			0.0083
			(-3.49)			(0.71)
LN_ILLIQ				-0.0054***		-0.0057***
				(-7.43)		(-7.97)
LN_TURN					-0.0025	-0.0027*
					(-1.61)	(-1.75)
R-squared	0.019	0.022	0.024	0.032	0.029	0.048

Panel D:Option-based Characteristics

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VOV	-0.34***	-0.35***	-0.33***	-0.33***	-0.30***	-0.33***	-0.33***	-0.30***
	(-8.85)	(-9.40)	(-9.08)	(-9.46)	(-7.50)	(-8.36)	(-8.33)	(-7.89)
NSKEW		-0.035**						-0.039***
		(-2.26)						(-2.83)
NKURT			0.026*					0.015
			(1.75)					(1.04)
RV_IV				0.0064				0.0044
				(0.95)				(0.66)
VTS					0.098***			0.11***
					(5.97)			(5.29)
dCIV						-0.019**		-0.0055
						(-2.05)		(-0.37)
dPIV							0.0014	0.032**
							(0.12)	(2.08)
R-squared	0.019	0.023	0.024	0.027	0.027	0.026	0.026	0.054

Table 4: Firm-level cross-sectional regressions during the subsample period from January 2006 to April 2016

This table reports the average coefficients from monthly Fama and MacBeth (1973) regressions of delta-hedged call option returns until the end of month. The volatility of volatility (VOV) is defined as the standard deviation of the ATM 30-day IV and the details of control variable construction are provided in Appendix A.2. All independent variables are winsorized each month at the 0.5% level. The sample period is January 2006 to April 2016. To adjust for serial correlation, robust Newey-West(1987) t-statistics are reported in parentheses. *, ** and *** indicates significance at the 10, 5 and 1% level.

Panel A: Firm-Specific Characteristics

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VOV	-0.35***	-0.34***	-0.29***	-0.35***	-0.36***	-0.35***	-0.28***
	(-13.7)	(-13.0)	(-11.0)	(-13.9)	(-13.9)	(-14.0)	(-10.7)
BETA		-0.0021***					-0.0015*
		(-2.76)					(-1.98)
SIZE			0.0032***				0.0029***
			(9.81)				(8.93)
BM				0.0035***			0.0035***
				(2.68)			(3.04)
MOM					-0.0047**		-0.0043**
					(-2.46)		(-2.22)
REV						-0.012	-0.013
						(-1.41)	(-1.58)
R-squared	0.023	0.031	0.030	0.027	0.031	0.030	0.054

Panel B: Return Distribution Characteristics

	(1)	(2)	(3)	(4)	(5)	(6)
VOV	-0.35***	-0.21***	-0.35***	-0.35***	-0.34***	-0.20***
	(-13.7)	(-8.95)	(-13.4)	(-13.9)	(-13.5)	(-8.17)
IVOL		-0.67***				-0.69***
		(-12.7)				(-12.7)
MAX			-0.0055			0.0036
			(-0.75)			(0.45)
RSKEW				-0.0013***		-0.00086**
				(-3.19)		(-2.10)
RKURT					-0.00020***	-0.000080*
					(-4.16)	(-1.89)
R-squared	0.023	0.034	0.030	0.026	0.027	0.047

Panel C: Limits to Arbitrage

	(1)	(2)	(3)	(4)	(5)	(6)
VOV	-0.35***	-0.35***	-0.36***	-0.29***	-0.31***	-0.26***
	(-13.7)	(-13.7)	(-13.0)	(-11.3)	(-13.9)	(-11.4)
DEMAND		-0.014*				-0.0092
		(-1.79)				(-1.09)
BID_ASK			0.0012			0.014***
			(0.38)			(3.63)
LN_ILLIQ				-0.0029***		-0.0037***
				(-9.55)		(-9.68)
LN_TURN					-0.0051***	-0.0050***
					(-5.91)	(-6.06)
R-squared	0.023	0.025	0.026	0.030	0.029	0.042

Panel D:Option-based Characteristics

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VOV	-0.35***	-0.35***	-0.35***	-0.37***	-0.31***	-0.37***	-0.36***	-0.34***
	(-13.7)	(-15.2)	(-13.0)	(-13.4)	(-11.6)	(-10.5)	(-10.9)	(-8.66)
NSKEW		-0.0070						-0.015
		(-0.66)						(-1.43)
NKURT			0.0050					-0.0030
			(0.70)					(-0.39)
RV_IV				0.021***				0.011**
				(4.95)				(2.48)
VTS					0.10***			0.074***
					(6.32)			(3.13)
dCIV						-0.060***		-0.060***
						(-5.89)		(-4.28)
dPIV							-0.026**	0.033*
							(-2.43)	(1.91)
R-squared	0.023	0.027	0.026	0.028	0.030	0.032	0.030	0.054

Table 5: Firm-level cross-sectional regressions with the alternative VOV

This table reports the average coefficients from monthly Fama and MacBeth (1973) regressions of delta-hedged call option returns until the end of month. The alternative VOV is defined as the difference between the maximum and the minimum of IV in month t and the details of control variable construction are provided in Appendix A.2. All independent variables are winsorized each month at the 0.5% level. The sample period is January 1996 to April 2016. To adjust for serial correlation, robust Newey-West(1987) t-statistics are reported in parentheses. *, ** and *** indicates significance at the 10, 5 and 1% level.

Panel A: Firm-Specific Characteristics

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VOV	-0.10***	-0.096***	-0.081***	-0.10***	-0.10***	-0.10***	-0.080***
	(-15.4)	(-14.3)	(-12.5)	(-15.2)	(-15.7)	(-15.4)	(-12.7)
BETA		-0.0018***					-0.0019***
		(-3.46)					(-3.50)
SIZE			0.0040***				0.0033***
			(9.29)				(8.24)
BM				-0.00026			0.0022
				(-0.15)			(1.65)
MOM					0.00095		0.0010
					(0.49)		(0.54)
REV						0.0041	-0.0023
						(0.60)	(-0.38)
R-squared	0.022	0.031	0.031	0.026	0.031	0.029	0.056

Panel B: Return Distribution Characteristics

	(1)	(2)	(3)	(4)	(5)	(6)
VOV	-0.10***	-0.046***	-0.10***	-0.10***	-0.10***	-0.045***
	(-15.4)	(-7.64)	(-16.2)	(-15.0)	(-14.5)	(-7.93)
IVOL		-0.73***				-0.75***
		(-12.6)				(-14.0)
MAX			0.0023			0.013**
			(0.41)			(2.11)
RSKEW				-0.0012**		-0.00088**
				(-2.59)		(-2.04)
RKURT					-0.00023***	-0.000095*
					(-3.61)	(-1.74)
R-squared	0.022	0.036	0.029	0.026	0.027	0.050

Panel C: Limits to Arbitrage

	(1)	(2)	(3)	(4)	(5)	(6)
VOV	-0.10***	-0.10***	-0.10***	-0.084***	-0.093***	-0.074***
	(-15.4)	(-15.6)	(-15.3)	(-13.6)	(-15.5)	(-13.0)
DEMAND		-0.025***				-0.012**
		(-3.50)				(-2.00)
BID_ASK			-0.017**			0.013**
			(-2.49)			(2.11)
LN_ILLIQ				-0.0040***		-0.0046***
				(-9.16)		(-10.6)
LN_TURN					-0.0036***	-0.0036***
					(-3.85)	(-3.97)
R-squared	0.022	0.024	0.026	0.032	0.029	0.045

Panel D:Option-based Characteristics

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VOV	-0.10***	-0.11***	-0.10***	-0.11***	-0.093***	-0.10***	-0.10***	-0.097***
	(-15.4)	(-16.3)	(-15.5)	(-16.4)	(-13.3)	(-14.1)	(-14.0)	(-12.8)
NSKEW		-0.021**						-0.026***
		(-2.10)						(-2.96)
NKURT			0.019**					0.0092
			(2.24)					(1.12)
RV_IV				0.014***				0.0086**
				(3.56)				(2.16)
VTS					0.095***			0.089***
					(8.55)			(5.71)
dCIV						-0.037***		-0.033***
						(-4.99)		(-2.97)
dPIV							-0.011	0.034***
							(-1.35)	(3.00)
R-squared	0.022	0.026	0.026	0.028	0.029	0.030	0.028	0.054

Table 6: Firm-level cross-sectional regressions on one-week option returns

This table reports the average coefficients from monthly Fama and MacBeth (1973) regressions of delta-hedged call option returns over a one-week period. The volatility of volatility (VOV) is defined as the standard deviation of the ATM 30-day IV and the details of control variable construction are provided in Appendix A.2. All independent variables are winsorized each month at the 0.5% level. The sample period is from January 1996 to April 2016. To adjust for serial correlation, robust Newey-West(1987) *t*-statistics are reported in parentheses. *, ** and *** indicates significance at the 10, 5 and 1% level.

Panel A: Firm-Specific Characteristics							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VOV	-0.76***	-0.69***	-0.57***	-0.73***	-0.71***	-0.73***	-0.48***
	(-29.1)	(-28.9)	(-23.5)	(-29.7)	(-31.0)	(-31.0)	(-26.8)
BETA		-0.0064***					-0.0050***
		(-9.27)					(-9.06)
SIZE			0.010***				0.0096***
			(22.6)				(18.2)
BM				0.0072***			0.010***
				(4.39)			(6.45)
MOM					-0.0076***		-0.0068***
					(-3.53)		(-4.13)
REV						0.00066	-0.0057
						(0.14)	(-1.42)
R-squared	0.104	0.126	0.164	0.109	0.120	0.117	0.204

Panel B: Return Distribution Characteristics						
	(1)	(2)	(3)	(4)	(5)	(6)
VOV	-0.76***	-0.32***	-0.72***	-0.74***	-0.73***	-0.31***
	(-29.1)	(-20.7)	(-31.9)	(-29.8)	(-28.2)	(-20.1)
IVOL		-1.66***				-1.65***
		(-28.8)				(-32.0)
MAX			0.0075			0.023***
			(1.63)			(5.37)
RSKEW				-0.0019***		-0.0014***
				(-4.87)		(-5.09)
RKURT					-0.00022***	-0.000025
					(-4.13)	(-0.62)
R-squared	0.104	0.187	0.117	0.108	0.110	0.202

Panel C: Limits to Arbitrage						
	(1)	(2)	(3)	(4)	(5)	(6)
VOV	-0.76***	-0.75***	-0.76***	-0.63***	-0.54***	-0.42***
	(-29.1)	(-29.1)	(-29.7)	(-23.2)	(-28.7)	(-22.8)
DEMAND		-0.018***				-0.014***
		(-3.38)				(-3.51)
BID_ASK			0.017***			0.061***
			(3.43)			(7.06)
LN_ILLIQ				-0.0084***		-0.011***
				(-23.7)		(-22.4)
LN_TURN					-0.018***	-0.018***
					(-18.8)	(-18.7)
R-squared	0.104	0.107	0.109	0.154	0.151	0.217

Panel D:Option-based Characteristics								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VOV	-0.76***	-0.75***	-0.77***	-0.78***	-0.67***	-0.78***	-0.77***	-0.72***
	(-29.1)	(-28.1)	(-28.6)	(-30.5)	(-26.1)	(-31.1)	(-30.3)	(-28.1)
NSKEW		0.020**						0.011
		(2.02)						(1.37)
NKURT			0.042***					0.020***
			(4.76)					(2.97)
RV_IV				0.049***				0.035***
				(12.9)				(11.2)
VTS					0.22***			0.16***
					(11.4)			(6.60)
dCIV						-0.10***		-0.081***
						(-14.5)		(-9.36)
dPIV							-0.060***	0.048***
							(-7.52)	(6.82)
R-squared	0.104	0.113	0.110	0.123	0.135	0.127	0.119	0.174

Table 7: Firm-level cross-sectional regressions on hold-to-expiration option returns

This table reports the average coefficients from monthly Fama and MacBeth (1973) regressions of delta-hedged call option returns until maturity. The volatility of volatility (VOV) is defined as the standard deviation of the ATM 30-day IV and the details of control variable construction are provided in Appendix A.2. All independent variables are winsorized each month at the 0.5% level. The sample period is from January 1996 to April 2016. To adjust for serial correlation, robust Newey-West(1987) *t*-statistics are reported in parentheses. *, ** and *** indicates significance at the 10, 5 and 1% level.

Panel A: Firm-Specific Characteristics

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VOV	-0.14***	-0.14***	-0.11***	-0.16***	-0.16***	-0.14***	-0.16***
	(-4.23)	(-4.46)	(-3.26)	(-4.92)	(-5.01)	(-4.30)	(-5.14)
BETA		-0.000072					-0.00064
		(-0.11)					(-0.97)
SIZE			0.0011**				0.00041
			(2.01)				(0.83)
BM				-0.0015			0.00041
				(-0.55)			(0.17)
MOM					0.0046		0.0050*
					(1.62)		(1.90)
REV						0.0094	0.0023
						(0.98)	(0.25)
R-squared	0.011	0.019	0.016	0.017	0.022	0.019	0.044

Panel B: Return Distribution Characteristics

	(1)	(2)	(3)	(4)	(5)	(6)
VOV	-0.14***	-0.098***	-0.14***	-0.15***	-0.13***	-0.10***
	(-4.23)	(-3.09)	(-4.11)	(-4.41)	(-3.97)	(-3.38)
IVOL		-0.12				-0.13
		(-1.37)				(-1.54)
MAX			0.0064			0.0090
			(0.74)			(1.03)
RSKEW				-0.0013**		-0.00089*
				(-1.98)		(-1.71)
RKURT					-0.00026***	-0.00021**
					(-3.03)	(-2.54)
R-squared	0.011	0.019	0.018	0.016	0.016	0.033

Panel C: Limits to Arbitrage

	(1)	(2)	(3)	(4)	(5)	(6)
VOV	-0.14***	-0.14***	-0.13***	-0.11***	-0.21***	-0.17***
	(-4.23)	(-4.23)	(-3.99)	(-3.15)	(-6.70)	(-5.32)
DEMAND		-0.026***				-0.0060
		(-2.69)				(-0.77)
BID_ASK			-0.042***			-0.011
			(-3.44)			(-1.24)
LN_ILLIQ				-0.0021***		-0.0018***
				(-3.66)		(-3.29)
LN_TURN					0.0058***	0.0055***
					(3.85)	(3.95)
R-squared	0.011	0.014	0.017	0.017	0.019	0.031

Panel D:Option-based Characteristics

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VOV	-0.14***	-0.15***	-0.13***	-0.15***	-0.099***	-0.13***	-0.14***	-0.098***
	(-4.23)	(-4.92)	(-3.93)	(-4.77)	(-2.90)	(-3.72)	(-3.92)	(-2.73)
NSKEW		-0.043***						-0.047***
		(-3.54)						(-4.00)
NKURT			-0.00077					-0.011
			(-0.075)					(-0.99)
RV_IV				0.0083*				0.0012
				(1.66)				(0.25)
VTS					0.11***			0.11***
					(8.89)			(6.50)
dCIV						-0.043***		-0.028**
						(-4.89)		(-2.33)
dPIV							-0.022***	0.022*
							(-2.68)	(1.79)
R-squared	0.011	0.016	0.015	0.016	0.017	0.017	0.016	0.038

Table 8: Firm-level cross-sectional regressions on put option returns

This table reports the average coefficients from monthly Fama and MacBeth (1973) regressions of delta-hedged put option returns until the end of month. The volatility of volatility (VOV) is defined as the standard deviation of the ATM 30-day IV and the details of control variable construction are provided in Appendix A.2. All independent variables are winsorized each month at the 0.5% level. The sample period is from January 1996 to April 2016. To adjust for serial correlation, robust Newey-West(1987) t-statistics are reported in parentheses. *, ** and *** indicates significance at the 10, 5 and 1% level.

Panel A: Firm-Specific Characteristics							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VOV	-0.28***	-0.26***	-0.22***	-0.28***	-0.29***	-0.28***	-0.23***
	(-14.3)	(-13.5)	(-11.2)	(-14.3)	(-14.8)	(-14.5)	(-12.4)
BETA		-0.0011**					-0.0012***
		(-2.52)					(-2.76)
SIZE			0.0032***				0.0026***
			(8.91)				(7.67)
BM				-0.0025*			-0.00028
				(-1.69)			(-0.26)
MOM					0.0029*		0.0025
					(1.86)		(1.59)
REV						0.0036	-0.0016
						(0.69)	(-0.33)
R-squared	0.019	0.028	0.028	0.024	0.029	0.025	0.051

Panel B: Return Distribution Characteristics						
	(1)	(2)	(3)	(4)	(5)	(6)
VOV	-0.28***	-0.13***	-0.28***	-0.28***	-0.27***	-0.13***
	(-14.3)	(-7.17)	(-15.0)	(-13.9)	(-13.5)	(-7.64)
IVOL		-0.57***				-0.57***
		(-11.5)				(-12.6)
MAX			-0.0035			0.0048
			(-0.73)			(0.94)
RSKEW				-0.00088**		-0.00058
				(-2.25)		(-1.53)
RKURT					-0.00018***	-0.000069
					(-3.32)	(-1.52)
R-squared	0.019	0.032	0.026	0.023	0.024	0.044

Panel C: Limits to Arbitrage						
	(1)	(2)	(3)	(4)	(5)	(6)
VOV	-0.28***	-0.28***	-0.28***	-0.23***	-0.26***	-0.21***
	(-14.3)	(-14.4)	(-14.1)	(-12.4)	(-15.8)	(-12.3)
DEMAND		-0.039***				-0.018*
		(-3.36)				(-1.91)
BID_ASK			-0.014***			0.012**
			(-2.85)			(2.43)
LN_ILLIQ				-0.0033***		-0.0037***
				(-9.43)		(-10.5)
LN_TURN					-0.0018**	-0.0019**
					(-2.16)	(-2.37)
R-squared	0.019	0.023	0.023	0.029	0.026	0.042

Panel D:Option-based Characteristics								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VOV	-0.28***	-0.27***	-0.28***	-0.29***	-0.26***	-0.28***	-0.29***	-0.25***
	(-14.3)	(-13.5)	(-14.2)	(-15.1)	(-12.8)	(-13.0)	(-12.8)	(-10.6)
NSKEW		0.051***						0.029***
		(7.06)						(4.19)
NKURT			0.0048					-0.0028
			(0.74)					(-0.45)
RV_IV				0.011***				0.0071**
				(3.08)				(2.04)
VTS					0.067***			0.060***
					(7.38)			(4.87)
dCIV						0.0032		0.060***
						(0.44)		(6.39)
dPIV							-0.034***	-0.058***
							(-5.57)	(-6.24)
R-squared	0.019	0.025	0.023	0.025	0.026	0.025	0.027	0.050

Table 9: Univariate portfolios sorted on the VOV

This table reports the average return of holding delta-hedged option portfolios on the volatility of volatility (VOV). At the end of each month, we rank the delta-hedged option portfolios into 10 deciles, based on the controlling variable, and then sequentially rank each decile into another 10 deciles, based on the VOV. The portfolio weights are equal-weighted, stock-value-weighted (weight by the market capitalization of the underlying stock) and option-value-weighted (weight by the market value of option open interest at the beginning of the period). After one month, we calculate the equal-weighted, stock-value-weighted and option-value-weighted monthly returns of those 10 portfolios, respectively. This table reports the difference in the average returns of the bottom and the top VOV decile portfolios in the "10-1" row. The VOV is defined as the standard deviation of the ATM 30-day IV. The risk-adjusted average returns are also reported in the column 3 to column 6. The risk factors including Fama and French (1993) three factors (MKT, SMB, HML), Carhart (1997) momentum factor (UMD) and Fama and French (2015) five factors (RMW, CMA) are obtained from the Kenneth R. French Data Library. The sample period is from January 1996 to April 2016. The robust Newey-West(1987) t-statistics of the 10-1 portfolios are reported in parentheses.

	Raw return	CAPM alpha	Three-Factor alpha	Four-Factor alpha	Five-Factor alpha
Panel A: Equal-Weighted					
1	-2.05	-2.05	-2.05	-2.14	-2.02
2	-2.50	-2.49	-2.50	-2.55	-2.42
3	-2.54	-2.52	-2.54	-2.59	-2.51
4	-2.79	-2.79	-2.83	-2.88	-2.75
5	-2.83	-2.82	-2.83	-2.90	-2.78
6	-3.22	-3.23	-3.23	-3.23	-3.14
7	-3.35	-3.33	-3.35	-3.38	-3.29
8	-3.60	-3.60	-3.62	-3.67	-3.62
9	-4.06	-4.07	-4.07	-4.08	-4.01
10	-5.21	-5.25	-5.24	-5.21	-5.14
10-1	-3.16	-3.20	-3.19	-3.07	-3.12
	(-14.7)	(-14.1)	(-13.5)	(-10.7)	(-11.9)
Panel B: Stock-Value-Weighted					
1	-1.84	-1.86	-1.88	-1.97	-1.78
2	-2.23	-2.23	-2.23	-2.29	-2.19
3	-2.18	-2.19	-2.21	-2.29	-2.09
4	-2.12	-2.14	-2.15	-2.15	-2.04
5	-2.33	-2.36	-2.36	-2.43	-2.35
6	-2.59	-2.62	-2.62	-2.67	-2.56
7	-2.82	-2.83	-2.85	-2.87	-2.82
8	-2.36	-2.36	-2.42	-2.47	-2.41
9	-3.38	-3.43	-3.41	-3.42	-3.37
10	-3.97	-4.06	-4.08	-4.01	-3.90
10-1	-2.13	-2.21	-2.21	-2.04	-2.12
	(-5.90)	(-5.76)	(-5.79)	(-4.61)	(-5.24)
Panel C: Option-Value-Weighted					
1	-1.87	-1.90	-1.90	-2.01	-1.85
2	-2.71	-2.72	-2.74	-2.80	-2.75
3	-2.49	-2.48	-2.52	-2.60	-2.41
4	-2.20	-2.20	-2.23	-2.25	-2.17
5	-2.61	-2.60	-2.59	-2.67	-2.55
6	-2.90	-2.95	-2.94	-2.98	-2.93
7	-3.51	-3.54	-3.54	-3.60	-3.54
8	-3.07	-3.03	-3.06	-3.07	-2.93
9	-3.69	-3.74	-3.75	-3.82	-3.73
10	-5.43	-5.54	-5.51	-5.58	-5.29
10-1	-3.56	-3.64	-3.61	-3.57	-3.44
	(-8.64)	(-8.26)	(-8.19)	(-7.44)	(-7.50)

Table 10: Bivariate portfolios sorted on control variables and the VOV

This table reports the average return of holding delta-hedged option portfolios on the volatility of volatility (VOV). At the end of each month, we rank the delta-hedged option portfolios into 10 deciles, based on the VOV, and then form the 10 portfolios. The portfolio weights are equal-weighted, stock-value-weighted (weight by the market capitalization of the underlying stock) and option-value-weighted (weight by the market value of option open interest at the beginning of the period). After one month, we calculate the equal-weighted, stock-value-weighted and option-value-weighted monthly returns of those 10 portfolios, respectively. This table reports the difference in the average returns of the bottom and the top VOV decile portfolios in the "10-1" column. The VOV is defined as the standard deviation of the ATM 30-day IV and the details of control variable construction are provided in Appendix A.2. All independent variables are winsorized each month at the 0.5% level. The sample period is from January 1996 to April 2016. The robust Newey-West(1987) t-statistics of the 10-1 portfolios are reported in parentheses.

	1	2	3	4	5	6	7	8	9	10	10-1	t
BETA	-2.45	-2.60	-2.73	-3.06	-2.84	-3.21	-3.27	-3.56	-3.86	-4.72	-2.27	(-10.8)
SIZE	-2.36	-2.75	-2.90	-2.96	-2.97	-3.20	-3.32	-3.54	-3.69	-4.60	-2.24	(-9.62)
BM	-2.08	-2.36	-2.64	-2.64	-2.96	-3.23	-3.29	-3.74	-3.89	-5.31	-3.22	(-13.5)
MOM	-2.26	-2.41	-2.62	-2.79	-3.00	-3.18	-3.31	-3.49	-4.17	-4.91	-2.64	(-9.97)
REV	-2.32	-2.57	-2.74	-2.91	-2.99	-3.02	-3.36	-3.45	-4.00	-4.97	-2.65	(-11.7)
IVOL	-2.86	-3.05	-2.94	-3.14	-3.17	-3.11	-3.25	-3.30	-3.58	-3.81	-0.95	(-6.72)
MAX	-2.35	-2.79	-2.75	-2.82	-2.94	-3.12	-3.37	-3.54	-3.81	-4.86	-2.51	(-13.7)
RSKEW	-2.12	-2.48	-2.79	-2.77	-2.91	-3.14	-3.37	-3.51	-4.06	-5.03	-2.91	(-11.2)
RKURT	-2.11	-2.59	-2.68	-2.79	-3.08	-3.04	-3.25	-3.64	-3.93	-5.05	-2.93	(-10.9)
DEMAND	-2.08	-2.45	-2.55	-2.78	-2.92	-3.23	-3.41	-3.64	-4.05	-5.27	-3.19	(-16.0)
BID_ASK	-2.08	-2.43	-2.59	-2.92	-2.99	-3.13	-3.24	-3.74	-4.11	-5.15	-3.08	(-13.6)
LN_ILLIQ	-2.27	-2.56	-2.95	-2.90	-2.99	-3.34	-3.27	-3.55	-3.69	-4.86	-2.60	(-12.9)
LN_TURN	-2.45	-2.62	-2.61	-2.93	-3.00	-3.22	-3.36	-3.57	-3.70	-4.87	-2.42	(-13.3)
NSKEW	-2.24	-2.55	-2.65	-2.93	-2.92	-3.14	-3.32	-3.74	-3.99	-4.87	-2.64	(-14.5)
NKURT	-2.13	-2.46	-2.74	-2.85	-2.94	-3.11	-3.45	-3.69	-3.95	-5.07	-2.94	(-13.6)
RV_IV	-2.35	-2.60	-2.73	-2.90	-3.16	-3.16	-3.34	-3.45	-3.83	-4.83	-2.48	(-13.8)
VTS	-2.32	-2.61	-2.70	-2.90	-3.07	-3.26	-3.16	-3.68	-4.08	-4.49	-2.17	(-11.5)
dCIV	-2.53	-2.60	-2.79	-2.71	-2.98	-3.09	-3.16	-3.61	-4.03	-4.73	-2.20	(-9.59)
dPIV	-2.45	-2.54	-2.82	-2.91	-3.10	-2.90	-3.37	-3.45	-3.97	-4.73	-2.28	(-11.1)

Internet Appendix

Table IA.1: Firm-level cross-sectional regressions after controlling for VOL-of-VOL in Cao et al. (2017)

This table reports the average coefficients from monthly Fama and MacBeth (1973) regressions of delta-hedged call option returns until the end of month. The volatility of volatility (VOV) is defined as the standard deviation of the ATM 30-day IV and the details of control variable construction are provided in Appendix A.2. In line with Cao et al. (2017), we obtain estimates of daily volatility for each stock in each month by applying from the EGARCH (1,1) model to a rolling window of past 12-month daily stock returns and VOL-of-VOL is measured as the standard deviation of percentage change in the daily realized volatility over one month. All independent variables are winsorized each month at the 0.5% level. The sample period is from January 1996 to April 2016. To adjust for serial correlation, robust Newey-West(1987) t-statistics are reported in parentheses. *, ** and *** indicates significance at the 10, 5 and 1% level.

	(1)	(2)	(3)
VOV	-0.34***		-0.34***
	(-15.0)		(-13.3)
VOL-of-VOL		-0.000015***	-0.0000025
		(-3.22)	(-0.56)

Table IA.2: Summary Statistics: Alternative option returns

This table reports the descriptive statistics of alternative option returns with a different holding period for calls and puts. The option sample period is from January 1996 to April 2016. One-week (hold-to-expiration) option returns are calculated from the monthly rebalanced delta-hedged option portfolio held over a one-week period (maturity). The stock prices, strikes and option prices are obtained from Ivy DB OptionMetrics. The monthly risk-free rate is obtained from the Kenneth R. French Data Library.

	mean	p50	sd	p10	p25	p75	p90
Delta-hedged Call Option Returns (%)							
One-week	-7.38	-6.56	7.44	-14.95	-10.21	-3.76	-1.39
Hold-to-expiration	0.29	-1.67	14.28	-10.79	-6.20	4.00	12.63
Delta-hedged Put Option Returns (%)							
One-week	-6.26	-5.74	5.92	-12.56	-8.81	-3.33	-1.30
Hold-to-expiration	0.30	-1.50	12.04	-9.28	-5.41	3.46	10.99

Table IA.3: Firm-level cross-sectional regressions on one-week put option returns

This table reports the average coefficients from monthly Fama and MacBeth (1973) regressions of delta-hedged put option returns over a one-week period. The volatility of volatility (VOV) is defined as the standard deviation of the ATM 30-day IV and the details of control variable construction are provided in Appendix A.2. All independent variables are winsorized each month at the 0.5% level. The sample period is from January 1996 to April 2016. To adjust for serial correlation, robust Newey-West(1987) t-statistics are reported in parentheses. *, ** and *** indicates significance at the 10, 5 and 1% level.

Panel A: Firm-Specific Characteristics

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VOV	-0.57***	-0.53***	-0.42***	-0.56***	-0.54***	-0.55***	-0.36***
	(-33.7)	(-30.9)	(-28.3)	(-34.2)	(-35.5)	(-33.9)	(-27.5)
BETA		-0.0045***					-0.0035***
		(-10.2)					(-9.89)
SIZE			0.0082***				0.0076***
			(25.4)				(21.4)
BM				0.0033***			0.0061***
				(2.94)			(5.54)
MOM					-0.0041***		-0.0038***
					(-2.63)		(-3.35)
REV						0.00048	-0.0043
						(0.14)	(-1.53)
R-squared	0.093	0.112	0.152	0.097	0.105	0.104	0.185

Panel B: Return Distribution Characteristics

	(1)	(2)	(3)	(4)	(5)	(6)
VOV	-0.57***	-0.25***	-0.55***	-0.56***	-0.55***	-0.24***
	(-33.7)	(-20.7)	(-34.0)	(-35.0)	(-33.9)	(-20.4)
IVOL		-1.26***				-1.24***
		(-31.6)				(-33.9)
MAX			-0.0011			0.011***
			(-0.33)			(3.22)
RSKEW				-0.0013***		-0.00082***
				(-4.44)		(-4.03)
RKURT					-0.00018***	-0.000031
					(-4.80)	(-0.98)
R-squared	0.093	0.166	0.104	0.096	0.098	0.178

Panel C: Limits to Arbitrage

	(1)	(2)	(3)	(4)	(5)	(6)
VOV	-0.57***	-0.57***	-0.57***	-0.46***	-0.42***	-0.31***
	(-33.7)	(-33.0)	(-33.0)	(-28.0)	(-28.6)	(-23.5)
DEMAND		-0.057***				-0.041***
		(-9.74)				(-7.51)
BID_ASK			0.0043			0.039***
			(1.01)			(5.80)
LN_ILLIQ				-0.0069***		-0.0082***
				(-26.7)		(-25.7)
LN_TURN					-0.013***	-0.013***
					(-20.4)	(-22.7)
R-squared	0.093	0.098	0.098	0.144	0.132	0.199

Panel D:Option-based Characteristics

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VOV	-0.57***	-0.55***	-0.58***	-0.60***	-0.51***	-0.59***	-0.59***	-0.55***
	(-33.7)	(-31.0)	(-33.1)	(-35.4)	(-26.7)	(-34.2)	(-33.5)	(-26.5)
NSKEW		0.071***						0.047***
		(10.5)						(7.66)
NKURT			0.033***					0.018***
			(5.93)					(4.24)
RV_IV				0.038***				0.028***
				(13.4)				(12.5)
VTS					0.15***			0.10***
					(12.6)			(6.99)
dCIV						-0.042***		0.026***
						(-6.26)		(3.45)
dPIV							-0.068***	-0.046***
							(-12.6)	(-8.59)
R-squared	0.093	0.106	0.098	0.110	0.118	0.105	0.111	0.155

Table IA.4: Firm-level cross-sectional regressions on hold-to-expiration put option returns

This table reports the average coefficients from monthly Fama and MacBeth (1973) regressions of delta-hedged put option returns until maturity. The volatility of volatility (VOV) is defined as the standard deviation of the ATM 30-day IV and the details of control variable construction are provided in Appendix A.2. All independent variables are winsorized each month at the 0.5% level. The sample period is from January 1996 to April 2016. To adjust for serial correlation, robust Newey-West(1987) t-statistics are reported in parentheses. *, ** and *** indicates significance at the 10, 5 and 1% level.

Panel A: Firm-Specific Characteristics

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VOV	-0.13***	-0.13***	-0.11***	-0.14***	-0.15***	-0.13***	-0.15***
	(-4.90)	(-5.35)	(-4.00)	(-5.73)	(-5.85)	(-5.09)	(-6.35)
BETA		0.00025					-0.00029
		(0.44)					(-0.51)
SIZE			0.00058				-0.000015
			(1.27)				(-0.036)
BM				-0.0033			-0.0015
				(-1.38)			(-0.77)
MOM					0.0059**		0.0058**
					(2.49)		(2.56)
REV						0.0083	0.0024
						(1.07)	(0.32)
R-squared	0.010	0.018	0.015	0.016	0.020	0.017	0.042

Panel B: Return Distribution Characteristics

	(1)	(2)	(3)	(4)	(5)	(6)
VOV	-0.13***	-0.10***	-0.13***	-0.13***	-0.12***	-0.11***
	(-4.90)	(-3.91)	(-4.90)	(-5.06)	(-4.65)	(-4.32)
IVOL		-0.080				-0.081
		(-1.12)				(-1.21)
MAX			0.00062			0.0026
			(0.087)			(0.37)
RSKEW				-0.00096*		-0.00066
				(-1.75)		(-1.44)
RKURT					-0.00020***	-0.00016**
					(-2.82)	(-2.37)
R-squared	0.010	0.017	0.017	0.014	0.014	0.029

Panel C: Limits to Arbitrage

	(1)	(2)	(3)	(4)	(5)	(6)
VOV	-0.13***	-0.13***	-0.12***	-0.10***	-0.20***	-0.17***
	(-4.90)	(-4.87)	(-4.52)	(-3.80)	(-8.42)	(-6.62)
DEMAND		-0.030**				-0.0051
		(-2.11)				(-0.44)
BID_ASK			-0.028***			-0.00064
			(-3.04)			(-0.090)
LN_ILLIQ				-0.0015***		-0.0015***
				(-3.25)		(-3.13)
LN_TURN					0.0060***	0.0058***
					(4.62)	(4.85)
R-squared	0.010	0.014	0.015	0.016	0.018	0.030

Panel D:Option-based Characteristics

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VOV	-0.13***	-0.12***	-0.12***	-0.13***	-0.10***	-0.12***	-0.13***	-0.078**
	(-4.90)	(-4.47)	(-4.36)	(-5.52)	(-3.69)	(-4.29)	(-4.64)	(-2.59)
NSKEW		0.043***						0.024***
		(5.59)						(2.95)
NKURT			-0.015*					-0.024***
			(-1.76)					(-2.69)
RV_IV				0.0065				0.0016
				(1.55)				(0.40)
VTS					0.078***			0.081***
					(7.80)			(5.48)
dCIV						0.0012		0.060***
						(0.15)		(6.00)
dPIV							-0.041***	-0.061***
							(-6.16)	(-6.14)
R-squared	0.010	0.015	0.014	0.014	0.015	0.015	0.015	0.035

Table IA.5: Bivariate portfolios sorted on control variables and the VOV: risk-adjusted average returns, adjusted by the CAPM model

This table reports the risk-adjusted average return of holding delta-hedged option portfolios on the volatility of volatility (VOV), adjusted by the CAPM model. At the end of each month, we rank the delta-hedged option portfolios into 10 deciles, based on the VOV, and then form the 10 portfolios. The portfolio weights are equal-weighted, stock-value-weighted (weight by the market capitalization of the underlying stock) and option-value-weighted (weight by the market value of option open interest at the beginning of the period). After one month, we calculate the equal-weighted, stock-value-weighted and option-value-weighted monthly returns of those 10 portfolios, respectively. This table reports the difference in the average returns of the bottom and the top VOV decile portfolios in the "10-1" column. The VOV is defined as the standard deviation of the ATM 30-day IV and the details of control variable construction are provided in Appendix A.2. All independent variables are winsorized each month at the 0.5% level. The sample period is from January 1996 to April 2016. The robust Newey-West(1987) t-statistics of the 10-1 portfolios are reported in parentheses.

	1	2	3	4	5	6	7	8	9	10	10-1	t
BETA	-2.45	-2.59	-2.73	-3.06	-2.80	-3.21	-3.29	-3.56	-3.86	-4.75	-2.29	(-11.0)
SIZE	-2.35	-2.71	-2.91	-2.94	-2.95	-3.20	-3.31	-3.58	-3.68	-4.66	-2.31	(-8.98)
BM	-2.09	-2.34	-2.64	-2.61	-2.97	-3.22	-3.29	-3.74	-3.91	-5.35	-3.26	(-13.1)
MOM	-2.26	-2.40	-2.61	-2.79	-3.00	-3.17	-3.33	-3.50	-4.17	-4.92	-2.66	(-9.45)
REV	-2.31	-2.58	-2.70	-2.89	-3.01	-3.01	-3.38	-3.46	-3.99	-5.01	-2.70	(-10.9)
IVOL	-2.84	-3.06	-2.90	-3.14	-3.19	-3.11	-3.25	-3.29	-3.58	-3.84	-1.00	(-7.03)
MAX	-2.34	-2.79	-2.74	-2.80	-2.91	-3.13	-3.37	-3.54	-3.84	-4.89	-2.55	(-13.6)
RSKEW	-2.11	-2.48	-2.79	-2.75	-2.91	-3.14	-3.36	-3.51	-4.06	-5.07	-2.96	(-10.8)
RKURT	-2.12	-2.59	-2.67	-2.77	-3.07	-3.04	-3.26	-3.66	-3.93	-5.07	-2.95	(-10.7)
DEMAND	-2.09	-2.43	-2.53	-2.77	-2.92	-3.23	-3.41	-3.65	-4.05	-5.32	-3.23	(-15.2)
BID_ASK	-2.09	-2.41	-2.59	-2.92	-2.99	-3.13	-3.21	-3.76	-4.13	-5.19	-3.10	(-13.2)
LN_ILLIQ	-2.27	-2.54	-2.93	-2.89	-3.01	-3.32	-3.27	-3.55	-3.68	-4.94	-2.67	(-12.3)
LN_TURN	-2.45	-2.61	-2.60	-2.88	-3.03	-3.24	-3.36	-3.58	-3.70	-4.91	-2.46	(-13.4)
NSKEW	-2.22	-2.53	-2.64	-2.95	-2.92	-3.12	-3.33	-3.74	-4.02	-4.90	-2.68	(-14.1)
NKURT	-2.12	-2.45	-2.73	-2.84	-2.92	-3.11	-3.45	-3.69	-3.97	-5.09	-2.97	(-12.7)
RV_IV	-2.35	-2.61	-2.71	-2.90	-3.14	-3.17	-3.34	-3.47	-3.82	-4.84	-2.49	(-13.2)
VTS	-2.32	-2.62	-2.70	-2.89	-3.06	-3.26	-3.17	-3.66	-4.08	-4.53	-2.21	(-11.2)
dCIV	-2.52	-2.62	-2.76	-2.69	-2.97	-3.09	-3.17	-3.63	-4.04	-4.74	-2.22	(-9.33)
dPIV	-2.43	-2.51	-2.81	-2.90	-3.10	-2.91	-3.40	-3.45	-4.00	-4.74	-2.31	(-10.3)

Table IA.6: Bivariate portfolios sorted on control variables and the VOV: risk-adjusted average returns, adjusted by the three-factor model

This table reports the risk-adjusted average return of holding delta-hedged option portfolios on the volatility of volatility (VOV), adjusted by the three-factor model. At the end of each month, we rank the delta-hedged option portfolios into 10 deciles, based on the VOV, and then form the 10 portfolios. The portfolio weights are equal-weighted, stock-value-weighted (weight by the market capitalization of the underlying stock) and option-value-weighted (weight by the market value of option open interest at the beginning of the period). After one month, we calculate the equal-weighted, stock-value-weighted and option-value-weighted monthly returns of those 10 portfolios, respectively. This table reports the difference in the average returns of the bottom and the top VOV decile portfolios in the "10-1" column. The VOV is defined as the standard deviation of the ATM 30-day IV and the details of control variable construction are provided in Appendix A.2. All independent variables are winsorized each month at the 0.5% level. The sample period is from January 1996 to April 2016. The robust Newey-West(1987) t-statistics of the 10-1 portfolios are reported in parentheses.

	1	2	3	4	5	6	7	8	9	10	10-1	t
BETA	-2.47	-2.60	-2.76	-3.08	-2.82	-3.22	-3.30	-3.59	-3.87	-4.73	-2.26	(-10.2)
SIZE	-2.36	-2.72	-2.92	-2.97	-2.99	-3.19	-3.33	-3.58	-3.68	-4.68	-2.33	(-8.86)
BM	-2.10	-2.35	-2.67	-2.63	-2.99	-3.25	-3.32	-3.74	-3.91	-5.36	-3.26	(-12.2)
MOM	-2.27	-2.43	-2.64	-2.82	-3.01	-3.19	-3.34	-3.47	-4.19	-4.95	-2.68	(-9.77)
REV	-2.31	-2.59	-2.72	-2.91	-3.03	-3.04	-3.39	-3.47	-4.01	-5.01	-2.70	(-10.8)
IVOL	-2.84	-3.08	-2.92	-3.17	-3.20	-3.13	-3.28	-3.31	-3.58	-3.84	-0.99	(-6.63)
MAX	-2.35	-2.80	-2.77	-2.81	-2.94	-3.13	-3.38	-3.56	-3.83	-4.90	-2.55	(-12.7)
RSKEW	-2.12	-2.50	-2.81	-2.79	-2.90	-3.17	-3.38	-3.51	-4.08	-5.09	-2.97	(-10.4)
RKURT	-2.13	-2.61	-2.68	-2.81	-3.09	-3.05	-3.26	-3.65	-3.99	-5.07	-2.94	(-9.94)
DEMAND	-2.10	-2.45	-2.56	-2.79	-2.93	-3.25	-3.41	-3.66	-4.06	-5.31	-3.22	(-14.5)
BID_ASK	-2.09	-2.42	-2.61	-2.95	-3.01	-3.15	-3.22	-3.78	-4.12	-5.19	-3.10	(-13.3)
LN_ILLIQ	-2.27	-2.56	-2.94	-2.90	-3.03	-3.34	-3.28	-3.59	-3.67	-4.94	-2.67	(-11.9)
LN_TURN	-2.46	-2.64	-2.60	-2.90	-3.04	-3.26	-3.37	-3.60	-3.71	-4.91	-2.45	(-13.1)
NSKEW	-2.23	-2.56	-2.66	-2.96	-2.93	-3.13	-3.33	-3.76	-4.02	-4.90	-2.67	(-13.7)
NKURT	-2.13	-2.46	-2.76	-2.85	-2.95	-3.13	-3.45	-3.71	-3.98	-5.09	-2.96	(-12.2)
RV_IV	-2.36	-2.63	-2.74	-2.92	-3.14	-3.17	-3.35	-3.49	-3.83	-4.85	-2.49	(-13.2)
VTS	-2.31	-2.63	-2.72	-2.91	-3.09	-3.27	-3.18	-3.67	-4.10	-4.52	-2.21	(-11.0)
dCIV	-2.53	-2.65	-2.78	-2.71	-3.00	-3.10	-3.19	-3.62	-4.04	-4.76	-2.23	(-9.60)
dPIV	-2.45	-2.53	-2.82	-2.92	-3.12	-2.92	-3.39	-3.47	-3.99	-4.77	-2.32	(-10.3)

Table IA.7: Bivariate portfolios sorted on control variables and the VOV: risk-adjusted average returns, adjusted by the four-factor model

This table reports the risk-adjusted average return of holding delta-hedged option portfolios on the volatility of volatility (VOV), adjusted by the four-factor model. At the end of each month, we rank the delta-hedged option portfolios into 10 deciles, based on the VOV, and then form the 10 portfolios. The portfolio weights are equal-weighted, stock-value-weighted (weight by the market capitalization of the underlying stock) and option-value-weighted (weight by the market value of option open interest at the beginning of the period). After one month, we calculate the equal-weighted, stock-value-weighted and option-value-weighted monthly returns of those 10 portfolios, respectively. This table reports the difference in the average returns of the bottom and the top VOV decile portfolios in the "10-1" column. The volatility of VOV is defined as the standard deviation of the ATM 30-day IV and the details of control variable construction are provided in Appendix A.2. All independent variables are winsorized each month at the 0.5% level. The sample period is from January 1996 to April 2016. The robust Newey-West(1987) t-statistics of the 10-1 portfolios are reported in parentheses.

	1	2	3	4	5	6	7	8	9	10	10-1	t
BETA	-2.53	-2.67	-2.79	-3.13	-2.82	-3.29	-3.33	-3.59	-3.88	-4.75	-2.22	(-8.73)
SIZE	-2.43	-2.76	-2.97	-3.02	-3.04	-3.22	-3.36	-3.61	-3.71	-4.65	-2.21	(-6.97)
BM	-2.18	-2.40	-2.73	-2.68	-3.02	-3.30	-3.35	-3.74	-3.92	-5.33	-3.16	(-9.92)
MOM	-2.32	-2.49	-2.70	-2.88	-3.03	-3.22	-3.38	-3.50	-4.21	-4.94	-2.62	(-7.89)
REV	-2.38	-2.66	-2.76	-2.94	-3.07	-3.10	-3.42	-3.49	-4.02	-4.99	-2.61	(-9.25)
IVOL	-2.90	-3.11	-2.96	-3.20	-3.25	-3.18	-3.33	-3.35	-3.57	-3.84	-0.93	(-5.92)
MAX	-2.42	-2.85	-2.82	-2.87	-2.99	-3.17	-3.39	-3.58	-3.84	-4.92	-2.51	(-10.8)
RSKEW	-2.19	-2.56	-2.88	-2.83	-2.93	-3.23	-3.39	-3.55	-4.08	-5.08	-2.89	(-8.77)
RKURT	-2.20	-2.66	-2.75	-2.86	-3.16	-3.06	-3.32	-3.65	-4.01	-5.03	-2.82	(-8.17)
DEMAND	-2.17	-2.49	-2.60	-2.86	-2.98	-3.28	-3.46	-3.66	-4.06	-5.32	-3.14	(-12.1)
BID_ASK	-2.16	-2.47	-2.68	-3.02	-3.03	-3.17	-3.26	-3.78	-4.13	-5.18	-3.02	(-11.2)
LN_ILLIQ	-2.35	-2.62	-2.98	-2.95	-3.04	-3.38	-3.29	-3.64	-3.70	-4.89	-2.54	(-9.14)
LN_TURN	-2.52	-2.70	-2.63	-2.93	-3.10	-3.29	-3.41	-3.62	-3.70	-4.93	-2.40	(-12.8)
NSKEW	-2.31	-2.62	-2.73	-2.98	-2.97	-3.18	-3.38	-3.75	-4.05	-4.89	-2.58	(-11.8)
NKURT	-2.20	-2.53	-2.81	-2.90	-2.99	-3.16	-3.49	-3.71	-4.01	-5.07	-2.87	(-10.5)
RV_IV	-2.43	-2.68	-2.74	-2.91	-3.18	-3.23	-3.39	-3.54	-3.85	-4.90	-2.47	(-12.1)
VTS	-2.39	-2.67	-2.77	-2.96	-3.15	-3.32	-3.21	-3.67	-4.11	-4.50	-2.11	(-8.66)
dCIV	-2.59	-2.70	-2.81	-2.72	-3.06	-3.14	-3.21	-3.68	-4.04	-4.79	-2.20	(-8.79)
dPIV	-2.50	-2.58	-2.82	-2.96	-3.17	-2.98	-3.44	-3.52	-4.00	-4.82	-2.33	(-10.0)

Table IA.8: Bivariate portfolios sorted on control variables and the VOV: risk-adjusted average returns, adjusted by the five-factor model

This table reports the risk-adjusted average return of holding delta-hedged option portfolios on the volatility of volatility (VOV), adjusted by the five-factor model. At the end of each month, we rank the delta-hedged option portfolios into 10 deciles, based on the VOV, and then form the 10 portfolios. The portfolio weights are equal-weighted, stock-value-weighted (weight by the market capitalization of the underlying stock) and option-value-weighted (weight by the market value of option open interest at the beginning of the period). After one month, we calculate the equal-weighted, stock-value-weighted and option-value-weighted monthly returns of those 10 portfolios, respectively. This table reports the difference in the average returns of the bottom and the top VOV decile portfolios in the "10-1" column. The volatility of VOV is defined as the standard deviation of the ATM 30-day IV and the details of control variable construction are provided in Appendix A.2. All independent variables are winsorized each month at the 0.5% level. The sample period is from January 1996 to April 2016. The robust Newey-West(1987) t-statistics of the 10-1 portfolios are reported in parentheses.

	1	2	3	4	5	6	7	8	9	10	10-1	t
BETA	-2.39	-2.52	-2.71	-3.04	-2.73	-3.15	-3.23	-3.50	-3.83	-4.76	-2.36	(-9.35)
SIZE	-2.32	-2.66	-2.86	-2.89	-2.96	-3.13	-3.25	-3.60	-3.61	-4.53	-2.21	(-8.49)
BM	-2.06	-2.27	-2.61	-2.55	-2.95	-3.21	-3.26	-3.70	-3.82	-5.18	-3.12	(-11.0)
MOM	-2.21	-2.40	-2.57	-2.74	-2.94	-3.15	-3.25	-3.33	-4.12	-4.87	-2.66	(-8.56)
REV	-2.26	-2.53	-2.61	-2.80	-3.01	-3.04	-3.33	-3.45	-3.94	-4.90	-2.64	(-9.52)
IVOL	-2.82	-3.04	-2.83	-3.12	-3.11	-3.05	-3.26	-3.26	-3.46	-3.77	-0.95	(-5.55)
MAX	-2.31	-2.71	-2.71	-2.75	-2.90	-3.07	-3.34	-3.48	-3.77	-4.82	-2.51	(-12.0)
RSKEW	-2.06	-2.45	-2.79	-2.72	-2.77	-3.10	-3.35	-3.48	-3.98	-4.96	-2.90	(-9.29)
RKURT	-2.07	-2.54	-2.63	-2.74	-3.05	-2.90	-3.23	-3.65	-3.91	-4.91	-2.84	(-8.68)
DEMAND	-2.05	-2.38	-2.51	-2.77	-2.85	-3.15	-3.35	-3.63	-4.02	-5.20	-3.16	(-13.2)
BID_ASK	-2.03	-2.35	-2.59	-2.87	-2.90	-3.10	-3.18	-3.82	-3.99	-5.08	-3.05	(-11.4)
LN_ILLIQ	-2.20	-2.56	-2.86	-2.86	-2.94	-3.30	-3.21	-3.58	-3.63	-4.77	-2.57	(-9.98)
LN_TURN	-2.43	-2.57	-2.56	-2.85	-2.96	-3.24	-3.27	-3.54	-3.59	-4.84	-2.41	(-12.1)
NSKEW	-2.19	-2.49	-2.64	-2.91	-2.82	-3.18	-3.23	-3.66	-4.03	-4.72	-2.53	(-11.1)
NKURT	-2.09	-2.38	-2.70	-2.83	-2.89	-3.05	-3.32	-3.70	-3.94	-5.00	-2.91	(-11.0)
RV_IV	-2.29	-2.57	-2.69	-2.85	-3.02	-3.10	-3.31	-3.46	-3.77	-4.81	-2.52	(-12.4)
VTS	-2.25	-2.58	-2.61	-2.82	-3.08	-3.19	-3.10	-3.67	-4.10	-4.41	-2.16	(-9.24)
dCIV	-2.50	-2.61	-2.70	-2.62	-2.93	-3.06	-3.09	-3.54	-4.03	-4.68	-2.18	(-9.61)
dPIV	-2.38	-2.49	-2.76	-2.84	-3.03	-2.84	-3.29	-3.47	-3.92	-4.79	-2.41	(-10.7)