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Cross section of option returns and idiosyncratic stock volatility ☆

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ABSTRACT

This paper presents a robust new finding that delta-hedged equity option return decreases monotonically with an increase in the idiosyncratic volatility of the underlying stock. This result cannot be explained by standard risk factors. It is distinct from existing anomalies in the stock market or volatility-related option mispricing. It is consistent with market imperfections and constrained financial intermediaries. Dealers charge a higher premium for options on high idiosyncratic volatility stocks due to their higher arbitrage costs. Controlling for limits to arbitrage proxies reduces the strength of the negative relation between delta-hedged option return and idiosyncratic volatility by about 40%.

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1. Introduction

Despite the tremendous growth in equity options in recent decades, little is known about the determinants of expected return in this market. Partly responsible for this could be the view that options are merely leveraged positions in the underlying stocks. Correspondingly, academic research on options has traditionally focused on no-arbitrage valuation of options relative to the underlying stocks. However, recent studies show that options are not redundant.[1] There are limits to arbitrage between options and stocks, and the no-arbitrage approach can only establish very wide bounds on equilibrium option prices (e.g., Figlewski, 1989; Figlewski and Green, 1999).

The main test hypothesis of this paper is a negative relation between option returns and the idiosyncratic

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[1] See, e.g., Buraschi and Jackwerth (2001), Coval and Shumway (2001), and Jones (2006). Options are traded because they are useful and, therefore, options cannot be redundant for all investors.

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volatility of the underlying stock. The hypothesis is motivated by theory of option pricing in imperfect market that emphasizes the role of constrained financial intermediaries (e.g., Bollen and Whaley, 2004, Garleanu, Pedersen, and Poteshman, 2009). When there are limits to arbitrage and it is costly to hedge or replicate the options, option prices are importantly affected by demand for options from the end-users and the costs of option dealers to supply options. We focus on the relation between option returns and stock idiosyncratic volatility, because idiosyncratic volatility is the most important proxy of arbitrage costs, as it is correlated with transaction costs and imposes a significant holding cost for arbitrageurs (e.g., Shleifer and Vishny, 1997; Pontiff, 2006).

To test the hypothesis, we examine a cross section of options on individual stocks each month. We pick one call (or put) option on each optionable stock that has a common time-to-maturity (about one and a half months) and is closest to being at-the-money. At-the-money options are most sensitive to changes in stock volatility. For each optionable stock and in each month, we evaluate the return over the following month of a portfolio that buys one call (or put), delta-hedged with the underlying stock. The delta-hedge is rebalanced daily so that the portfolio is not sensitive to stock price movement. We study option returns after hedging out the option exposure to the underlying stocks so that our results are not driven by determinants of the stock returns. Our results are obtained from about 210,000 delta-hedged option returns for six thousand underlying stocks.

Empirically, we find that, on average, delta-hedged options have negative returns, especially when the underlying stocks have high idiosyncratic volatility. Options on stocks with high idiosyncratic volatility on average earn significantly lower returns than options on low idiosyncratic volatility stocks. This is the key new finding of our paper. The same pattern holds for both call options and put options. A portfolio strategy that buys delta-hedged call options on stocks ranked in the bottom quintile by idiosyncratic volatility and sells delta-hedged call options on stocks from the top idiosyncratic volatility quintile earns about 1.4% per month.

Our finding is consistent with models of financial intermediation under constraints (e.g., capital constraints, informational asymmetries). On the one hand, options on stocks with high idiosyncratic volatility attract high demand from speculators. On the other hand, such options are more difficult to hedge. Financial intermediaries need extra compensation for supplying these options. Thus, options on stocks with high idiosyncratic volatility tend to be more expensive and have lower returns.

We also find that the average delta-hedged option return is significantly more negative when the underlying stocks or the options are less liquid and when the option open interests are higher. These results are consistent with option dealers charging a higher option premium when the options are more difficult to hedge and option demands are higher.

Limits to arbitrage also play an important role explaining the negative relation between delta-hedged option return and idiosyncratic volatility. This relation is stronger when it is more costly to arbitrage between options and stocks. Controlling for several limits to arbitrage proxies reduces the strength of the negative relation between delta-hedged option return and idiosyncratic volatility by about 40%.

Further supporting the limits to arbitrage explanation, we find that the profitability of our volatility-based option strategy crucially depends on option trading costs. Buying delta-hedged call options on stocks ranked in the bottom idiosyncratic volatility quintile and selling delta-hedged call options on stocks from the top idiosyncratic volatility quintile earns about 1.4% per month, when we assume options are traded at the midpoint of the bid and the ask quotes. If we assume the effective option spread is equal to 25% of the quoted spread, then the average return of our option strategy is reduced to 0.79%. If the effective option spread is equal to 50% of the quoted spread, then the profit of our option strategy is only 0.17%, which is no longer statistically or economically significant. Thus, the option pricing pattern we find lies within the no-trade region or no-arbitrage bound for most market participants except those who face sufficiently low transaction costs.

We explore a number of potential alternative explanations for our results. The first is that the profitability of our option strategy reflects compensation for bearing volatility risk. It is well known that stock return volatility is time-varying. Delta-hedged options are positively exposed to changes in the volatility, and their average returns could embed a volatility risk premium.

After we control for the volatility risk premium in Fama-MacBeth regressions with the delta-hedged option return as the dependent variable, the coefficient on idiosyncratic volatility remains negative and significant. Further, we run time-series regressions of the returns to our option strategy on several proxies of market volatility risk and common idiosyncratic volatility risk. Our portfolio strategy still has a significant positive alpha of about 1.32% per month, after controlling for these volatility-related risk factors in addition to the Fama-French three factors and the momentum factor. Thus, our results cannot be explained by the volatility risk premium.

Another potential explanation of our results is volatility-related option mispricing. Stocks with high current volatility could have experienced recent increase in volatility. If investors overreacted to recent change in volatility (Stein, 1989; Poteshman, 2001) and paid too much for options on stocks with high current volatility, then it could explain our result. However, after we control for recent changes in volatility, we still find a significant negative relation between delta-hedged option returns and the idiosyncratic volatility of the underlying stock. Our results are not simply manifestation of investor overreaction to changes in volatility.

Further, we control for the difference between the realized volatility and the at-the-money option implied volatility. Goyal and Saretto (2009) argue that large deviations of implied volatility from historical volatility are indicative of misestimation of volatility dynamics. Consistent with their paper, we find that delta-hedged options on stocks with large positive differences between historical volatility and implied volatility have higher returns.[2] However, after controlling for

[2] Unlike our study, Goyal and Saretto (2009) hold delta-hedged option positions for a month without daily rebalancing. We thank an

the difference between historical and option-implied volatility, we find a more negative relation between delta-hedged option return and idiosyncratic volatility. Thus, controlling for volatility-related option mispricing exacerbates instead of explains our results.

A voluminous literature has studied the cross section of stock returns, but papers that examine the cross section of option returns are sparse. Previous studies on option returns have focused on index options (e.g., Coval and Shumway, 2001). Duarte and Jones (2007) use delta-hedged options to study properties of individual stock volatility risk premium. They do not examine how delta-hedged stock option return is related to the idiosyncratic volatility of the underlying stock, which is the focus of our study. Goyal and Saretto (2009) link delta-hedged options to the difference between historical realized volatility and at-the-money option implied volatility. They are motivated by investors' misestimation of volatility dynamics and volatility-related option mispricing. We examine additional theory-motivated variables (not examined in previous studies) that are expected to be related to delta-hedged stock option returns, including proxies of option demand pressures and costs of arbitrage between stocks and options.

Two recent studies investigate the pricing of skewness in the stock options market. Boyer and Vorkink (2011) report a negative cross-sectional relation between returns on individual equity options and their ex ante skewness, consistent with investors' preference for skewness or gambling in options. Bali and Murray (forthcoming) construct skewness asset from a pair of option positions and a position in the underlying stock. They find a strong negative relation between risk-neutral skewness and the skewness asset returns. By design, their skewness assets are not exposed to changes in stock volatility, while the delta-hedged options we study are most sensitive to change in volatility. Further, the relation between option skewness and the underlying stock volatility is rather complex: it depends on the option moneyness and differs across calls and puts.[3] Thus, Boyer and Vorkink (2011) and Bali and Murray (forthcoming) complement our study. Their findings are distinct from ours and cannot explain our results.

Our paper proceeds as follows. We describe the data in Section 2 and present the main regression-based results and additional analysis in Section 3. Section 4 presents portfolio-sorting results and studies an option trading strategy taking into account realistic transaction costs. Section 5 concludes the paper.

2. Data and delta-hedged option returns

This section first introduces the data used in the empirical tests and then describes the measurement of key variable of interest, the delta-hedged option return.

2.1. Data

We use data from both the equity option and stock markets. For the January 1996 to October 2009 sample period, we obtain data on U.S. individual stock options from the Ivy DB database provided by OptionMetrics. The data fields we use include daily closing bid and ask quotes, trading volume and open interest of each option, implied volatility, and the option's delta computed by OptionMetrics based on standard market conventions. We obtain daily and monthly split-adjusted stock returns, stock prices, and trading volume from the Center for Research in Security Prices (CRSP). For each stock, we also compute the book-to-market ratio using the book value from Compustat. Further, we obtain the daily and monthly Fama-French factor returns and risk-free rates from Kenneth French's data library.[4]

At the end of each month and for each optionable stock, we collect a pair of options (one call and one put) that are closest to being at-the-money and have the shortest maturity among those with more than one month to expiration. We apply several filters to the extracted option data. First, our main analyses use call options whose stocks do not have ex-dividend dates prior to option expiration (i.e., we exclude an option if the underlying stock paid a dividend during the remaining life of the option).[5] Second, we exclude all option observations that violate obvious no-arbitrage conditions such as $S \geq C \geq \max(0, S - Ke^{-rT})$ for a call option price C, where S is the underlying stock price, K is the option strike price, T is time to maturity of the option, and r is the risk-free rate. Third, to avoid microstructure-related bias, we only retain options that have positive trading volume and positive bid quotes, with the bid price strictly smaller than the ask price, and the midpoint of bid and ask quotes being at least \$1/8. We keep only the options whose last trade dates match the record dates and whose option price dates match the underlying security price dates. Fourth, the majority of the options we pick each month has the same maturity. We drop the options whose maturity is longer than that of the majority of options.

Thus, we obtain, in each month, reliable data on a cross section of options that are approximately at-the-money with a common short-term maturity. Our final sample in each month contains, on average, options on 1514 stocks.

(*footnote continued*)
anonymous referee for pointing out that rebalancing could have an important impact on the performance of delta-hedged option positions, as a big difference in performance exists between an unrebalanced delta hedge and one that is rebalanced as a function of the stock's realized price path.

[3] For example, Fig. 2 of Boyer and Vorkink (2011) shows that higher stock volatility results in slightly higher skewness for in-the-money call options. However, the relation flips for out-of the money put options. Fig. 3 of Boyer and Vorkink (2011) shows that higher stock volatility leads to much lower skewness for out-of-the-money call options, but essentially no relation exists between stock volatility and skewness for in-the-money put options.

[4] The data library is available at http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/.

[5] For the short-maturity options used in our study, the early exercise premium is small. We verify that our results do not change materially when we include options for which the underlying stock paid a dividend before option expire.

Table 1
Summary statistics of options data.

This table reports the descriptive statistics of delta-hedged option returns for the pooled data. The option sample period is from January 1996 to October 2009. At the end of each month, we extract from the Ivy DB database of OptionMetrics one call and one put on each optionable stock. The selected options are approximately at-the-money with a common maturity of about one and a half month. We exclude the following option observations: moneyness is lower than 0.8 or higher than 1.2; option price violates obvious no-arbitrage option bounds; reported option trading volume is zero; option bid quote is zero or midpoint of bid and ask quotes is less than \$1/8; and the underlying stock paid a dividend during the remaining life of the option. Delta-hedged gain is the change (over the next month or until option maturity) in the value of a portfolio consisting of one contract of long option position and a proper amount of the underlying stock, re-hedged daily so that the portfolio is not sensitive to stock price movement. The call option delta-hedged gain is scaled by ($\Delta * S - C$), where Δ is the Black-Scholes option delta, S is the underlying stock price, and C is the price of call option. Days to maturity is the number of calendar days until the option expiration. Moneyness is the ratio of stock price over option strike price. Vega is the option vega according to the Black-Scholes model scaled by stock price. Total volatility (VOL) is the standard deviation of daily stock returns over the previous month. Idiosyncratic volatility (IVOL) is the standard deviation of the residuals of the Fama-French 3-factors model estimated using the daily stock returns over the previous month. Volatility risk premium (VRP) is the difference between the square root of realized variance estimated from intradaily stock returns over the previous month and the square root of a model free estimate of the risk-neutral expected variance implied from stock options at the end of the month. VOL_deviation is the log difference between VOL and Black-Scholes implied volatility for at-the-money options (IV). 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. Illiquidity is the average of the daily Amihud (2002) illiquidity measure over the previous month.

Variable	Mean	Median	Standard deviation	10th percentile	Lower quartile	Upper quartile	90th percentile
Panel A: Call options (213,640 observations)							
Delta-hedged gain until maturity/($\Delta * S-C$)(%)	−1.13	−1.29	8.07	−7.86	−4.05	1.09	4.87
Delta-hedged gain until month-end/($\Delta * S-C$) (%)	−0.81	−0.92	5.13	−5.47	−2.86	0.90	3.76
Days to maturity	50	50	2	47	50	51	52
Moneyness=S/K (%)	100.55	100.18	5.08	94.80	97.36	103.36	106.53
Vega	0.14	0.14	0.01	0.13	0.14	0.15	0.15
Panel B: Put options (199,198 observations)							
Delta-hedged gain until maturity/(P - $\Delta * S$) (%)	−0.82	−1.17	6.46	−6.68	−3.57	1.18	4.95
Delta-hedged gain until month-end/(P - $\Delta * S$) (%)	−0.35	−0.73	4.67	−4.55	−2.44	1.08	3.93
Days to maturity	50	50	2	47	50	51	52
Moneyness = S/K (%)	99.84	99.73	4.86	94.20	96.87	102.69	105.63
Vega	0.14	0.14	0.01	0.13	0.14	0.15	0.15
Panel C: Other variables							
Total volatility: VOL	0.50	0.44	0.24	0.24	0.32	0.62	0.82
Idiosyncratic volatility: IVOL	0.42	0.37	0.23	0.19	0.26	0.53	0.72
Volatility risk premium: VRP	0.05	−0.05	0.09	−0.15	−0.09	0.00	0.05
VOL deviation: Ln (VOL/IV)	−0.09	−0.08	0.29	−0.45	−0.27	0.10	0.28
(Option open interest/stock volume)$*10^3$	0.03	0.01	0.07	0.00	0.00	0.03	0.08
Option bid–ask spread	0.21	0.16	0.15	0.07	0.10	0.27	0.42
Ln (Illiquidity)	−6.33	−6.30	1.68	−8.56	−7.50	−5.15	−4.17

Panel D: Average delta-hedged gain until maturity scaled by ($\Delta * S-C$) for calls or ($P-\Delta * S$) for puts

Option type	Total stocks	mean > 0	t > −2	mean > 0	t > 2	10th percentile	25th percentile	50th percentile	75th percentile	90th percentile
Call	6,141	4,759	1,930	1,382	64	−3.75%	−1.85 %	−0.77%	−0.08%	0.77%
Put	6,065	3,926	1,371	2,139	104	−2.75%	−1.25 %	−0.36%	0.30%	1.40%

The pooled data have 213,640 observations for delta-hedged call returns and 199,198 observations for delta-hedged put returns. Table 1 shows that the average moneyness of the chosen options is one, with a standard deviation of only 0.05. The time to maturity of the chosen options ranges from 47 to 52 calendar days across different months, with an average of 50 days. These short-term options are the most actively traded. We utilize this option data to study the cross-sectional determinants of expected option returns.

Compared with the whole CRSP stock universe, our sample of stocks with traded options has larger market cap, more institutional ownership and analyst coverage. For stocks in our sample, the average market cap is 3.81 billion dollars, the average institutional ownership is 66.68%, and the average number of analyst coverage is 8.72. Our results are not driven by small or neglected stocks.

2.2. Delta-hedged option returns

To measure delta-hedged call option return, we first define delta-hedged option gain, which is change in the value of a self-financing portfolio consisting of a long call position, hedged by a short position in the underlying stock so that the portfolio is not sensitive to stock price movement, with the net investment earning risk-free rate. Our definition of delta-hedged option gain follows Bakshi and Kapadia (2003). Specifically, consider a portfolio of a call option that is hedged discretely N times over a period $[t,t+\tau]$, where the hedge is rebalanced at each of the dates t_n, $n=0,1,\ldots,N-1$ (where we define $t_0=t$, $t_N=t+\tau$). The discrete delta-hedged call option gain over the period $[t,t+\tau]$ is

$$\Pi(t,t+\tau)=C_{t+\tau}-C_t-\sum_{n=0}^{N-1}\Delta_{C,t_n}[S(t_{n+1})-S(t_n)] - \sum_{n=0}^{N-1}\frac{a_n r_{t_n}}{365}[C(t_n)-\Delta_{C,t_n}S(t_n)], \quad (1)$$

where Δ_{C,t_n} is the delta of the call option on date t_n, r_{t_n} is annualized risk-free rate on date t_n, and a_n is the number of calendar days between t_n and t_{n+1}.[6] Definition for the delta-hedged put option gain is the same as Eq. (1), except with put option price and delta replacing call option price and delta.

With a zero net investment initial position, the delta-hedged option gain $\Pi(t,t+\tau)$ in Eq. (1) is the excess dollar return of delta-hedged call option. Because option price is homogeneous of degree one in the stock price, $\Pi(t,t+\tau)$ is proportional to the initial stock price. We scale the dollar return $\Pi(t,t+\tau)$ by the absolute value of the securities involved (i.e., $\Delta_t S_t-C_t$) to make it comparable across stocks that could have large differences in market prices.[7] In Section 3, we refer to the scaled delta-hedged option gain $\Pi(t,t+\tau)/(\Delta_t S_t-C_t)$ as delta-hedged call option return.

3. Empirical results

This section presents Fama-MacBeth regression results and tests several potential explanations of our results.

3.1. Average delta-hedged option returns

First, we examine the time series average of delta-hedged option returns for individual stocks. Table 1 Panels A and B show that, for both call options and put options, the mean and median of the pooled delta-hedged option returns are negative. For example, the average delta-hedged at-the-money call option return is −0.81% over the next month and −1.13% if held until maturity (which is on average 50 calendar days). The median delta-hedged call option return is −0.92% (−1.29%) over the next month (until maturity). For put options, the median delta-hedged option return is −0.73% (−1.17%) over the next month (until maturity).

Table 1 Panel D reports the results of t-test for the time series mean of individual stock delta-hedged option returns. We have time series observations of call options on 6,141 stocks. About 78% of them have negative average delta-hedged call option returns and 32% of them have significantly negative average delta-hedged call option returns. In contrast, the average delta-hedged call option return is significantly positive for about only 1% of the cases. The pattern for the put options is similar.

3.2. Delta-hedged option returns, idiosyncratic volatility, and systematic volatility

Table 1 shows large variations in the delta-hedged option returns. We study the cross-sectional determinants of delta-hedged option returns using monthly Fama-MacBeth regressions. For Tables 2–6, the dependent variable in month t's regression is scaled return of delta-hedged call option held until maturity, i.e., $\Pi(t,t+\tau)/(\Delta_t S_t-C_t)$, where the common time to maturity τ is about one and a half months. The independent variables are all predetermined at time t. The key variable of interest is the idiosyncratic volatility of the underlying stock. Table 7 reports robustness checks for different holding periods (e.g., one week or one month) and for put options.

Table 2 Panel A shows that delta-hedged option return is negatively related to the total volatility of the underlying stock. Model 1 is the univariate regression of delta-hedged option returns on stock return volatility *VOL*, measured as the standard deviation of daily stock returns over the previous month. The *VOL* coefficient estimate is −0.0299, with a significant t-statistic of −8.72.

The significant negative relation between delta-hedged option returns and stock volatility is robust to alternative measures of stock volatility. In Model 2 of Table 2 Panel A, we measure stock volatility as the square root of average of daily returns squared over the previous month. In Model 3, volatility is estimated as the standard

[6] Following Carr and Wu (2009) as well as Goyal and Saretto (2009), our delta hedges rely on the Black-Scholes option implied volatility. We also compute option delta based on the GARCH volatility estimate and obtain similar results.

[7] Our results are qualitatively the same when we scale the delta-hedged gains by the initial stock price or option price.

Table 2
Delta-hedged option returns and stock volatility.

This table reports the average coefficients from monthly Fama-MacBeth regressions of call option delta-hedged gain until maturity scaled by ($\Delta * S - C$) at the beginning of the period. All volatility measures are annualized. Total volatility (VOL) is the standard deviation of daily stock returns over the previous month. VOL2 is the square root of average of daily returns squared over the previous month. VOL_month is the standard deviation of monthly stock returns over the past 60 months. IV is the at-the-money Black-Scholes option implied volatility at the end of each month. Idiosyncratic volatility (IVOL) is the standard deviation of the residuals of the Fama-French three-factors model estimated using the daily stock returns over the previous month. Systematic volatility (SysVOL) is the square root of ($VOL^2 - IVOL^2$). IVOL_month is the standard deviation of the residuals of the market index model estimated using monthly stock returns over the past 60 months. SysVOL_month is the square root of ($VOL\_month^2 - IVOL\_month^2$). Eidio_in is the fitted idiosyncratic volatility from a EGARCH (1,1) model estimated using all historical monthly returns. Eidio_out is the one-step ahead idiosyncratic volatility forecast from the EGARCH(1,1) model. All independent variables are winsorized each month at the 0.5% level. The sample period is from January 1996 to October 2009. To adjust for serial correlation, robust Newey-West (1987) *t*-statistics are reported in brackets.

Panel A: Delta-hedged call option returns and stock total volatility

Variables	Model 1	Model 2	Model 3	Model 4
Intercept	0.0024	0.0019	0.0063	0.0305
	(1.34)	(1.09)	(3.23)	(13.65)
VOL	−0.0299			
	(−8.72)			
VOL2		−0.0289		
		(−8.58)		
VOL_month			−0.0341	
			(−10.89)	
IV				−0.0823
				(−21.38)
Average adj. R^2	0.0194	0.0196	0.0215	0.0653

Panel B: Systematic vs. idiosyncratic volatility

Variables	Model 1	Model 2	Model 3	Model 4
Intercept	0.0015	0.0050	0.0045	0.0042
	(0.87)	(2.64)	(2.46)	(2.34)
IVOL	−0.0405			
	(−15.46)			
SysVOL	0.0160			
	(3.79)			
IVOL_month		−0.0452		
		(−12.92)		
SysVOL_month		0.0265		
		(4.28)		
Eidio_in			−0.0353	
			(−10.78)	
Eidio_out				−0.0345
				(−10.85)
Average adj. R^2	0.0245	0.0264	0.0182	0.0181

deviation of monthly stock returns over the past 60 months. In Model 4, we use at-the-money Black-Scholes option implied volatility *IV* at the beginning of the option holding period. The coefficients for all of these volatility measures are significantly negative.

Table 2 Panel B shows that the negative relation between delta-hedged option returns and the volatility of the underlying stock is entirely driven by the idiosyncratic volatility. In Model 1 of Table 2 Panel B, we decompose individual stock volatility into two components: idiosyncratic volatility *IVOL* and systematic volatility *SysVol*. We measure idiosyncratic volatility as the standard deviation of the residuals of the Fama and French three-factor model estimated using the daily stock returns over the previous month, and systematic volatility is $\sqrt{VOL^2 - IVOL^2}$. Our definitions of idiosyncratic volatility and systematic volatility follow Ang, Hodrick, Xing, and Zhang (2006) and Duan and Wei (2009), respectively. When both idiosyncratic volatility and systematic volatility are included as regressors, the estimated *IVOL* coefficient is −0.0405 with a *t*-statistic of −15.46. In contrast, the estimated coefficient of systematic volatility is 0.016 with a *t*-statistic of 3.79. Controlling for idiosyncratic volatility, delta-hedged option return increases with the systematic risk exposure of the underlying stock.

The opposite effects of idiosyncratic risk versus systematic risk on delta-hedged option return is not sensitive to the volatility measures. In Model 2 of Table 2 Panel B, we measure idiosyncratic volatility as the standard deviation of the residuals of the CAPM model estimated using monthly stock returns over the past 60 months. In Model 3, we estimate an EGARCH(1,1) model using all historical monthly returns and use the fitted volatility of residuals.[8] In Model 4, we estimate idiosyncratic volatility as the one-period ahead expected volatility of residuals of the EGARCH(1,1) model. The coefficients for all of these idiosyncratic volatility measures are significantly negative.

The impact of idiosyncratic volatility on scaled delta-hedged option return is not only statistically significant, but also economically significant. Based on the −0.0405 coefficient estimate for *IVOL* and its summary statistics reported in Table 1 Panel C, a 1 standard deviation increase in the idiosyncratic volatility would reduce the delta-hedged call option return on average by 0.93%. Moving from the 10th (25th) percentile of stocks ranked by idiosyncratic volatility to the 90th (75th) percentile, the delta-hedged option return can be expected to decrease by 2.14% (1.09%).

3.3. *Controlling for volatility risk and jump risk*

Under the Black-Scholes model, the call option can be replicated by trading the underlying stock and risk-free bond. In this case, the discrete delta-hedged gain in Eq. (1) has a symmetric distribution centered around zero (e.g., Bertsimas, Kogan, and Lo, 2000). When volatility is stochastic and volatility risk is priced, the mean of delta-hedged option gain would be different from zero, reflecting the volatility risk premium. For example, Bakshi and Kapadia (2003) show that under the stochastic volatility model, the expected delta-hedged option gain depends positively on the volatility risk premium. Existing option pricing models with stochastic volatility specify volatility risk premium as a function of the volatility level. For example, in Heston (1993), the volatility risk premium is linear in volatility. The negative relation between delta-hedged option return and stock volatility is consistent with a negative volatility risk premium whose magnitude increases with the volatility level.[9]

[8] Each month and for each stock in our sample, we estimate the EGARCH(1,1) model using all available historical monthly stock returns since 1963, if at least five years of historical data are available.

[9] Only a few papers have examined the volatility risk premium for individual stocks. Carr and Wu (2009) report that, out of the 35 individual stocks they study, only seven generate volatility risk premiums that are significantly negative. For stocks belonging to the S&P

Table 3
Controlling for volatility risk premium and jump risk.

This table reports the average coefficients from monthly Fama-MacBeth cross-sectional regressions. The dependent variable is call option delta-hedged gain till maturity scaled by (Δ*S−C) at the beginning of the period. Total volatility (VOL) is the standard deviation of daily stock returns over the previous month. Idiosyncratic volatility (IVOL) is the standard deviation of the residuals of the Fama-French three-factors model estimated using the daily stock returns over the previous month. Systematic volatility (SysVOL) is the square root of (VOL^2-$IVOL^2$). Volatility risk premium (VRP) is the difference between the square root of realized variance estimated from intradaily stock returns over the previous month and the square root of a model free estimate of the risk-neutral expected variance implied from stock options at the end of the month. All volatility measures are annualized. Option implied skewness and kurtosis are the risk-neutral skewness and kurtosis of stock returns inferred from a cross section of out of the money calls and puts at the beginning of the period. All independent variables are winsorized each month at the 0.5% level. The sample period is from January 1996 to October 2009. To adjust for serial correlation, robust Newey-West (1987) *t*-statistics are reported in brackets.

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Intercept	−0.0032	0.0009	−0.0048	−0.0036	0.0003	−0.0052
	(−1.78)	(0.60)	(−2.33)	(−2.02)	(0.21)	(−2.57)
VOL	−0.0131	−0.0095	−0.0098			
	(−3.08)	(−2.45)	(−2.62)			
IVOL				−0.0240	−0.0206	−0.0204
				(−7.25)	(−6.63)	(−8.17)
SysVOL				0.0195	0.0219	0.0183
				(4.30)	(5.12)	(3.62)
VRP		0.1055			0.1035	
		(22.87)			(20.88)	
Option implied skewness			−0.0037			−0.0036
			(−7.20)			(−7.30)
Option implied kurtosis			−0.1165			−0.1057
			(−8.76)			(−7.32)
Average adj. R^2	0.0117	0.0363	0.0389	0.0162	0.0395	0.0449

In Table 3, we control for the volatility risk premium to examine whether it can explain the negative relation between scaled delta-hedged option return and idiosyncratic volatility of the underlying stock. The volatility risk premium of stock i in month t is

$$VRP_{i,t} = \sqrt{RV_{i,t}} - \sqrt{IV_{i,t}} \quad (2)$$

where $RV_{i,t}$ is realized return variance over month t computed from high frequency return data and $IV_{i,t}$ is the risk-neutral expected variance extracted from a cross section of equity options on the last trading day of each month t (see Appendix A for details). Our estimate of risk-neutral expected variance IV follows Jiang and Tian (2005), Bollerslev, Tauchen, and Zhou (2009), and Drechsler and Yaron (2011). Due to data limitation and to ensure the reliability of the variance risk premium estimates, we compute the volatility risk premium only for a subset (about one-third) of our sample in Table 2.[10] Table 3 Model 1 is identical to Table 2 Panel A Model 1, and Table 3 Model 4 is identical to Table 2 Panel B Model 1, except the sample size is smaller in Table 3.

We find a significantly positive cross-sectional relation between the delta-hedged option return and the volatility risk premium of the underlying stock. Intuitively, delta-hedged options are positively exposed to volatility risk. Investors are willing to pay a premium for assets whose payoffs are high when volatility increases because investors' marginal utility is high in these states. Our result is consistent with the prediction of the stochastic volatility model in Bakshi and Kapadia (2003). They find evidence of negative volatility risk premium by studying the time series of delta-hedged index option returns and a cross section of index

Table 4
Controlling for volatility related mispricing.

This table reports the average coefficients from monthly Fama-MacBeth cross-sectional regressions. The dependent variable in month t's regression is call option delta-hedged gain until maturity scaled by (Δ*S−C) at the end of month $t-1$. Idiosyncratic volatility (IVOL) is the standard deviation of the residuals of the Fama-French three-factors model estimated using the daily stock returns over month $t-1$. Total volatility (VOL_{t-1}) is the standard deviation of daily stock returns over month $t-1$. VOL_deviation is the log difference between VOL_{t-1} and IV_{t-1}, the Black-Scholes implied volatility for at-the-money options at the end of month $t-1$. Change in volatility (ΔVOL) is the difference between VOL_{t-1} and the previous six months' average realized volatility. In addition to these lagged regressors, we control for contemporaneous change in option implied volatility $\mathrm{Ln}(IV_t/IV_{t-1})$. All volatility measures are annualized. All independent variables are winsorized each month at the 0.5% level. The sample period is from January 1996 to October 2009. To adjust for serial correlation, robust Newey-West (1987) *t*-statistics are reported in brackets.

Variables	Model 1	Model 2	Model 3	Model 4
Intercept	0.0005	0.0213	0.0197	0.0122
	(0.28)	(11.56)	(10.29)	(8.84)
IVOL	−0.0373	−0.0822	−0.0715	−0.0613
	(−15.78)	(−25.33)	(−17.70)	(−16.48)
SysVOL	0.0154	0.0288	0.0178	0.0174
	(3.54)	(4.39)	(3.14)	(3.23)
VOL_deviation		0.0604	0.0718	0.0561
		(17.12)	(15.81)	(14.44)
ΔVOL			−0.0353	−0.0226
			(−8.69)	(−6.21)
$\mathrm{Ln}(IV_t/IV_{t-1})$				0.0800
				(26.58)
Average adj. R^2	0.0242	0.0757	0.0822	0.1378

(*footnote continued*)
100 index, Driessen, Maenhout, and Vilkov (2009) find no evidence for the presence of a significant volatility risk premium in individual stock options.

[10] The set of stocks for which we estimate the variance risk premium is a subsample of all optionable stocks that have larger market cap, higher institutional ownership, and higher analyst coverage.

Table 5
Controlling for stock characteristics.

This table reports the average coefficients from monthly Fama-MacBeth cross-sectional regressions of call option delta-hedged gain till maturity scaled by ($\Delta * S - C$) at the beginning of the period. Idiosyncratic volatility (IVOL) is the standard deviation of the residuals of the Fama-French 3-factors model estimated using the daily stock returns over the previous month. $Ret_{(-1,0)}$ is the stock return in the prior month. $Ret_{(-12,-1)}$ is the cumulative stock return from the prior second through 12th month. $Ret_{(-36,-13)}$ is the cumulative stock return from the prior 13th through 36th month. ME is the product of monthly closing price and the number of outstanding shares in previous June. Book-to-market (BE/ME) is the fiscal year-end book value of common equity divided by the calendar year-end market value of equity. All independent variables are winsorized each month at the 0.5% level. The sample period is from January 1996 to October 2009. To adjust for serial correlation, robust Newey-West (1987) *t*-statistics are reported in brackets.

Variables	Model 1	Model 2	Model 3	Model 4	Model 5
Intercept	0.0019	0.0011	0.0014	0.0005	−0.0353
	(1.12)	(0.67)	(0.80)	(0.29)	(−8.31)
IVOL	−0.0429	−0.0410	−0.0411	−0.0438	−0.0307
	(−16.38)	(−16.25)	(−15.49)	(−17.71)	(−11.48)
SysVOL	0.0145	0.0096	0.0147	0.0063	0.0055
	(3.82)	(2.46)	(3.59)	(1.82)	(1.70)
$Ret_{(-1,0)}$	0.0233			0.0238	0.0237
	(5.98)			(6.40)	(6.66)
$Ret_{(-12,-1)}$		0.0072		0.0077	0.0075
		(4.42)		(4.74)	(4.87)
$Ret_{(-36,-13)}$			0.0020	0.0020	0.0016
			(4.16)	(4.19)	(3.70)
Ln (ME)					0.0043
					(8.90)
Ln (BE/ME)					0.0009
					(2.00)
Average adj. R^2	0.0291	0.0317	0.0260	0.0405	0.0503

Table 6
Controlling for limits to arbitrage.

This table reports the average coefficients from monthly Fama-MacBeth cross-sectional regressions of call option delta-hedged gain until maturity scaled by ($\Delta * S - C$) at the beginning of the period. Idiosyncratic volatility (IVOL) is the standard deviation of the residuals of the Fama-French three-factors model estimated using the daily stock returns over the previous month. Option open interest is the total number of option contracts that are open (i.e., contracts that have been traded but not yet liquidated) at the beginning of the period. Stock volume is the stock trading volume over the previous month. Option bid–ask spread is the ratio of bid–ask spread of option quotes over the midpoint of bid and ask quotes at the beginning of the period. Illiquidity is the average of the daily Amihud (2002) illiquidity measure over the previous month. Stock price is closing price at the beginning of the period. All independent variables are winsorized each month at the 0.5% level. The sample period is from January 1996 to October 2009. To adjust for serial correlation, robust Newey-West (1987) *t*-statistics are reported in brackets.

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Intercept	0.0015	0.0035	0.0084	−0.0326	−0.0195	−0.0216
	(0.87)	(2.02)	(4.63)	(−8.55)	(−8.90)	(−5.42)
IVOL	−0.0405	−0.0408	−0.0397	−0.0278	−0.0233	−0.0233
	(−15.46)	(−15.74)	(−15.45)	(−10.22)	(−8.65)	(−8.91)
SysVOL	0.0160	0.0147	0.0128	0.0133	0.0121	0.0101
	(3.79)	(3.54)	(3.10)	(3.47)	(3.30)	(2.79)
(Option open interest/		−0.0670				−0.0508
stock volume) $* 10^3$		(−8.31)				(−7.65)
Option bid–ask spread			−0.0348			−0.0071
			(−9.04)			(−2.32)
Ln (Illiquidity)				−0.0048		−0.0013
				(−8.85)		(−3.14)
Stock price					0.0005	0.0004
					(11.84)	(10.31)
Average adj. R^2	0.0245	0.0274	0.0305	0.0385	0.0454	0.0529

options with different moneyness (holding volatility constant). Because the volatility risk premium is negative, the positive coefficient on *VRP* implies that the delta-hedged option return is more negative when the underlying stock is more exposed to systematic volatility risk. Delta-hedged option positions on such stocks increase more in values during market downturn. Therefore, they serve as useful hedges for the market risk and should command lower expected returns.

Table 3 shows that our basic results are robust to controlling for the volatility risk premium. Just like in Table 2, delta-hedged call option return decreases with an

Table 7

Alternative measures of delta-hedged option returns.

This table reports the average coefficients from monthly Fama-MacBeth cross-sectional regressions, using alternative measures of delta-hedged option returns as the dependent variable, for both call options (Panel A) and put options (Panel B). The first model uses delta-hedged option gain until maturity defined in Eq. (2) scaled by (Δ*S−C) for call or scaled by (P−Δ*S) for put. In the second model, delta-hedged option positions are held for one month instead of until option maturity. In the third model, delta-hedged option positions are held for one week. All independent variables are the same as in Tables 2, 3, 4, 5, and 6, and winsorized each month at the 0.5% level. The sample period is from January 1996 to October 2009. To adjust for serial correlation, robust Newey-West (1987) *t*-statistics are reported in brackets.

Panel A: Delta-hedged call option returns

Dependent variable	Gain until maturity (Δ*S−C)	Gain until month-end (Δ*S−C)	Gain until next week (Δ*S−C)
Intercept	0.0447	0.0415	0.0127
	(15.12)	(18.46)	(10.47)
IVOL	−0.0927	−0.0705	−0.0175
	(−35.45)	(−33.75)	(−17.67)
SysVOL	0.0158	0.0129	0.0096
	(3.40)	(4.42)	(5.26)
$Ret_{(-1,0)}$	0.0053	0.0004	−0.0026
	(1.37)	(0.14)	(−2.04)
$Ret_{(-12,-1)}$	0.0036	0.0006	0.0002
	(2.83)	(0.92)	(0.78)
$Ret_{(-36,-13)}$	0.0012	0.0001	0.0002
	(3.09)	(0.55)	(1.63)
(Option open interest/stock volume)*10^3	−0.0369	−0.0274	−0.0006
	(−6.90)	(−6.88)	(−0.39)
Option bid–ask spread	−0.0234	−0.0152	−0.0037
	(−8.42)	(−7.24)	(−3.47)
Ln (Illiquidity)	−0.0039	−0.0012	−0.0003
	(−6.98)	(−3.67)	(−2.95)
Ln (ME)	−0.0051	−0.0033	−0.0010
	(−10.00)	(−11.08)	(−8.33)
VOL_deviation	0.0639	0.0512	0.0168
	(17.28)	(17.93)	(15.01)
Average adj. R^2	0.0941	0.1237	0.0594

Panel B: Delta-hedged put option returns

Dependent variable	Gain until maturity	Gain until month-end	Gain until next week
	(P−Δ*S)	(P−Δ*S)	(P−Δ*S)
Intercept	0.0268	0.0304	0.0087
	(9.43)	(14.43)	(13.11)
IVOL	−0.0658	−0.0533	−0.0123
	(−23.08)	(−25.96)	(−20.10)
SysVOL	0.0195	0.0113	0.0066
	(4.52)	(4.33)	(5.85)
$Ret_{(-1,0)}$	−0.0080	−0.0069	−0.0054
	(−2.53)	(−2.56)	(−4.69)
$Ret_{(-12,-1)}$	0.0021	0.0015	−0.0000
	(3.50)	(2.93)	(−0.15)
$Ret_{(-36,-13)}$	0.0011	0.0006	0.0003
	(3.82)	(3.98)	(3.88)
(Option open interest/stock volume)*10^3	−0.0342	−0.0237	0.0002
	(−6.43)	(−5.58)	(0.16)
Option bid–ask spread	−0.0019	−0.0044	−0.0006
	(−0.55)	(−1.85)	(−0.73)
Ln (Illiquidity)	−0.0035	−0.0012	−0.0005
	(−5.97)	(−3.76)	(−3.72)
Ln (ME)	−0.0043	−0.0027	−0.0009
	(−7.47)	(−8.27)	(−7.07)
VOL_deviation	0.0492	0.0390	0.0118
	(18.70)	(20.02)	(15.78)
Average adj. R^2	0.0940	0.0980	0.0509

increase in the total volatility of the underlying stock (Table 3 Model 1), and this result is entirely driven by the idiosyncratic volatility (Table 3 Model 4). After controlling for the idiosyncratic volatility, a positive relation exists between delta-hedged option return and the systematic volatility of the underlying stock. The coefficient estimates and their *t*-statistics do not change much in the presence of the volatility risk premium. Thus, our results

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cannot simply be explained by the volatility risk premium.[11]

The significant relation between scaled delta-hedged option return and stock's systematic risk exposure complements the key finding of Duan and Wei (2009) that after controlling for the underlying asset's total risk, systematic risk proportion can help differentiate the price structure across individual equity options. Duan and Wei (2009) focus on the level of option implied volatility and the slope of the implied volatility curve, while we study the option return. They conclude that some systematic risk factors (e.g., volatility risk) drive the wedge between the risk-neutral and physical distributions. Our results suggest that, in the same vein, these systematic risk factors also affect the expected option returns. Further, because the systematic volatility coefficient remains significant after controlling for the volatility risk premium (see Table 3), our results suggest that volatility risk by itself is insufficient, and some additional systematic risk factors are needed to better understand the option returns.

Table 3 Model 3 and 6 examine whether our result can be explained by a state-dependent jump risk premium. For example, in Pan (2002), the jump-arrival intensity is linear in the volatility level, and the jump-risk premium is linear in stock volatility *VOL*. Following Bakshi and Kapadia (2003), we control for the jump risk by including the option implied risk-neutral skewness and kurtosis of the underlying stock return. Appendix B provides details of these measures. The coefficients of risk-neutral skewness and kurtosis are negative and statistically significant. However, after controlling for these jump risk proxies, a significant negative relation still exists between delta-hedged option return and idiosyncratic volatility. Thus, our result cannot be explained by jump risk premium.

3.4. Controlling for volatility-related option mispricing

Another potential explanation of our result is volatility-related option mispricing. First, Goyal and Saretto (2009) provide evidence of volatility mispricing due to investors' failure to incorporate the information contained in the cross-sectional distribution of implied volatilities when forecasting individual stock's volatility. They argue that large deviations of implied volatility from historical volatility are indicative of misestimation of volatility dynamics. They find that options with high implied volatility (relative to the historical volatility) earn low returns.

Table 4 Model 2 controls for the log difference between historical and at-the-money option implied volatility, the same variable used by Goyal and Saretto (2009).[12] This variable has a significant positive coefficient, which is consistent with Goyal and Saretto (2009). More important, after controlling for this proxy of volatility-related option mispricing, the coefficient for idiosyncratic volatility remains statistically significant, and its magnitude more than doubles. The *IVOL* coefficient estimate is now −0.0822 (Model 2), compared with −0.0373 (Model 1) without controlling for the Goyal and Saretto variable.[13] Thus, volatility-related mispricing shown by Goyal and Saretto (2009) exacerbates instead of explains our result.

Second, stocks with high idiosyncratic volatility could have experienced an increase in volatility recently. If investors overreact to recent changes in volatility (Stein, 1989; Poteshman, 2001) and pay too much for options on high volatility stocks, then the subsequent returns of delta-hedged option positions would be low. In Table 4 Model 3, we control for the average change in stock volatility over the past six months. Delta-hedged option return tends to be lower after recent increase in volatility. This is consistent with the overreaction to volatility story. However, after controlling for recent change in volatility, we still find a significant negative relation between delta-hedged option return and the idiosyncratic volatility of the underlying stock. Thus, our result cannot be explained simply by investors' overreaction to recent change in volatility.

Table 4 Model 4 further controls for the change in the implied volatility of the same option over the same time period as the dependent variable, the delta-hedged option return. If the negative relation between delta-hedged option return and the stock volatility at the beginning of the period just reflects the correction of some volatility-related option mispricing, then it should become insignificant once we control for the contemporaneous change in the option implied volatility. We find a strong and significantly positive coefficient for the contemporaneous change in the option implied volatility.[14] However, we find that the *IVOL* coefficient continues to be highly significant, both statistically and economically, while the coefficient for systematic volatility is still positive.

3.5. Controlling for stock characteristics

The dependent variable in all of our regressions is the scaled returns of delta-hedged option positions. We rebalance the delta-hedges daily to minimize the influence of change in the underlying stock price for delta-hedged option position. Still, due to the imperfections in the delta-hedges, the strong link between delta-hedged option return and stock idiosyncratic volatility that we find could be related to some known pattern in the cross section of expected stock return. The regressions reported in Table 5 control for several stock characteristics that are

[11] As further robustness check, we find in unreported empirical work that, after we control for stocks' beta with respect to several proxies of systematic volatility risk factors, the regression coefficient of delta-hedged option return on idiosyncratic volatility does not change much and remains significant. The first volatility factor is the monthly change in the Chicago Board Options Exchange Market Volatility Index (VIX). The second factor is the zero-beta straddle return on the S&P 500 index. The third is the variance risk premium for the S&P 500 index. The fourth factor is the monthly change of the equal-weighted average idiosyncratic volatility of individual stocks.

[12] Our results do not change when we use the difference (instead of log difference) between historical and at-the-money option implied volatility.

[13] Table 4 Model 1 has the same specification as Table 2 Panel B Model 1, but the sample size is slightly smaller, because there are some missing values for the control variables in other models of Table 4.

[14] By definition, delta-hedged option return is positively related to contemporaneous change in the option implied volatility, even in the absence of volatility mispricing.

significant predictors of the cross section of stock returns, including size (*ME*), book-to-market ratio (*BE*/*ME*) of the underlying stock, and past stock returns. *ME* is the product of monthly closing stock price and the number of outstanding common shares in previous June. *BE*/*ME* is the previous fiscal year-end book value of common equity divided by the calendar year-end market value of equity.

The *IVOL* coefficient remains negative and highly significant in all regressions reported in Table 5. The *IVOL* coefficient is about −0.0410 to −0.0429 in the presence of the past stock returns. By comparison, the *IVOL* coefficient is −0.0405 without the past stock returns as additional regressors (see Table 2 Panel B Model 1). Thus, the strong negative relation between delta-hedged option return and idiosyncratic volatility is insensitive to controlling for past stock returns over various horizons, including past one month, between 12 months and one month ago, and between three years and one year ago. This is in stark contrast to the return-idiosyncratic volatility relation in the stock market. Huang, Liu, Ghee, and Zhang (2010) report that the volatility-return relation in the cross section of stocks becomes insignificant when past one-month return is used as a control variable. Controlling for size and book-to-market ratio does not materially affect the magnitude and statistical significance of the *IVOL* coefficient either.

In contrast to the result for idiosyncratic volatility, Table 5 Model 5 shows that, after controlling for stock characteristics (size, book-to-market ratio, and past stock returns), the coefficient for the systematic volatility gets reduced by more than half in magnitude and becomes insignificant. This suggests that the positive relation between delta-hedged option return and systematic volatility reflects a known pattern in the cross section of expected stock return as captured by stock characteristics.

Interestingly, Table 5 shows that delta-hedged call option return is significantly and positively related to the underlying stock return over past one year as well as between three years and one year ago. The same pattern holds for delta-hedged put option returns (see Table 7 Panel B). These findings are not a mere reflection of stock return predictability by past returns. First, delta-hedged options are not sensitive to stock price movement by construction. Second, past return between three years and one year ago is positively related to delta-hedged call option return but negatively related to stock return.

To summarize, we have shown that the negative (positive) cross-sectional relation between delta-hedged option return and idiosyncratic (systematic) volatility of the underlying stock cannot be explained by volatility risk premium or volatility related option mispricing. Our finding is robust and distinct from known results on the cross section of expected stock return.

3.6. Limits to arbitrage

In this subsection, we provide evidence that our result can be better understood under models of option valuation in imperfect market (e.g., limits to arbitrage between options and stocks). Traditionally, options are priced relative to the underlying stock by the no-arbitrage principle. Recent studies find that options are nonredundant and limits to arbitrage exist in the options market. The no-arbitrage approach can only establish wide bounds on equilibrium option prices (e.g., Figlewski, 1989). Idiosyncratic risk has been recognized as one of the most robust and strongest hindrances to arbitrage activity (e.g., Shleifer and Vishny, 1997; Pontiff, 2006).

Options on high idiosyncratic volatility stocks are more difficult to hedge. If an option dealer delta-hedges each option with the underlying stock, he needs to trade frequently in the stock to rebalance the delta hedge. This is more difficult to implement when the underlying stock has high idiosyncratic volatility, because such stocks tend to be small and illiquid. (See Spiegel and Wang, 2007 for an overview of why one expects idiosyncratic risk to be inversely related to a stock's liquidity.) Further, an option dealer could have hundreds or thousands of options positions on different underliers in his portfolio at any given time. Dynamically hedging a large portfolio of equity options, each with the underlying stock, would be an expensive and time-consuming process. It is easier and cheaper to hedge a portfolio of options using stock market index products. However, this cross-hedging of equity options creates slippage and exposes option dealers to the idiosyncratic movements of stock prices. The higher the idiosyncratic volatility of the underlying stock, the less effective is the cross-hedging.

Although it is more difficult for option market makers to supply options on high idiosyncratic volatility stocks, investors' demand for these options is likely to be high. High idiosyncratic volatility stocks attract speculators (e.g., Kumar, 2009; Han and Kumar, forthcoming), some of whom could trade in the options market because of the embedded leverage. As a result of the supply-demand considerations, option market makers charge a higher premium for options on high idiosyncratic volatility, which leads to a negative relation between delta-hedged option return and stock's idiosyncratic volatility.

Table 6 examines the impact of limits to arbitrage proxies on delta-hedged option returns. One proxy is option demand, measured by option's open interest at the end of the month scaled by monthly stock trading volume.[15] Table 6 Model 2 shows that delta-hedged option returns decrease with option open interest, which has a significantly negative coefficient of −0.067 (*t*-statistic −8.31). This supports the idea that, due to limits to arbitrage, option market makers charge higher premiums for options with large end-user demand. It is consistent with the demand-pressure effect shown in Bollen and Whaley (2004) and Garleanu, Pedersen, and Poteshman (2009).

We use option bid–ask spread as another proxy of limits to arbitrage. First, the option bid–ask spreads limit the arbitrage activities by creating a no-trade region. Second, Jameson and Wilhelm (1992) show that option market makers face unique risk in managing inventory (including the risk associated with the inability to rebalance delta hedges and uncertain volatility). They find that several variables that measure the limits to arbitrage (including

[15] Our results are qualitatively the same if we use option trading volume instead of open interest or if we scale by stock's total shares outstanding.

option vega and gamma) play a statistically and economically important role in determining the quoted option bid–ask spreads. We also control for various liquidity measures for the underlying stocks, such as stock price and the Amihud (2002) illiquidity measure.[16] The motivation is that arbitrage between stock and option is more difficult to implement when transaction costs in options are high and when the stocks are illiquid. These cases tend to be associated with high stock volatility as well.

Table 6 Model 3 shows that on average delta-hedged call option return is negatively related to option bid–ask spread. This is in sharp contrast to the positive relation between expected stock return and stock illiquidity in many previous studies in the equity literature. It highlights that important differences exist in the pricing of options versus stocks and illustrates that our results are not a mere reflection of the known results on the cross section of expected stock return. Table 6 Models 4 and 5 show that delta-hedged option returns are more negative when the underlying stock is less liquid and has a low price. These results confirm that delta-hedged option returns are affected by limits to arbitrage between stocks and options.

Limits to arbitrage play a key role in explaining the negative relation between scaled delta-hedged option return and stock idiosyncratic volatility. After controlling for the limits of arbitrage proxies, the magnitude of the *IVOL* coefficient is reduced by about 42% from −0.0405 (Table 6 Model 1) to −0.0233 (Model 6). The stock illiquidity measures are more important than the option bid–ask spread in weakening the idiosyncratic volatility effect. In Section 4.4, we provide further evidence on the importance of limits to arbitrage for our results.

3.7. Robustness checks

Table 7 reports several robustness checks on our results. In previous regression tables, the dependent variable, delta-hedged option return, is measured as changes in daily rebalanced delta-hedged option portfolio until maturity scaled by the initial value of the delta-hedged portfolio. In Table 7 Panel A, we use delta-hedged option return over alternative holding periods, such as one week or one month. Previous tables report the results for call options. In Table 7 Panel B, we rerun the regressions for put options. In all regressions, we still find a significant negative *IVOL* coefficient. The regression coefficient for systematic volatility is significantly positive, although its magnitude and *t*-statistic are much smaller than those of the idiosyncratic volatility.

We conduct additional robustness checks. First, our results are qualitatively the same when we scale the delta-hedged gains by the initial stock price or option price. Second, we also control for option theta. In univariate regression, option theta is negatively correlated with delta-hedged option return. In the presence of other control variables, theta loses its significance. In all regressions, the coefficient for idiosyncratic volatility is still significantly negative. Third, we reestimate our models using panel regressions (both OLS and with firm-time clustered standard errors). We find again a significantly negative relation between delta-hedged option returns and stock idiosyncratic volatility, consistent with the results from Fama-MacBeth cross-sectional regressions.

4. Volatility-based option trading strategy

This section studies the relation between delta-hedged option returns and stock idiosyncratic volatility using the portfolio sorting approach. We confirm the previous results obtained by the Fama-MacBeth regressions, propose a volatility-based option trading strategy, and examine the impact of liquidity and transaction costs on the profitability of our option strategy.

At the end of each month, we rank stocks with traded options into five quintiles based on their idiosyncratic volatility (we also repeat the exercise sorting on total volatility or systematic volatility). Our option strategy buys the delta-hedged call options on stocks ranked in the bottom volatility quintile and sells the delta-hedged call options on stocks ranked in the top volatility quintile.[17] We rebalance daily the delta-hedged option positions and track their performances over the next month.

A long delta-hedged option position involves buying one contract of call option and selling Δ shares of the underlying stock, where Δ is the Black-Scholes call option delta. A short delta-hedged option position involves selling one contract of call option against a long position of Δ shares of the underlying stock. In both cases, we adjust the delta-hedge each trading day by buying or selling the proper amount of stock, keeping the option position to be one contract until the end of the next month when it is closed out. The return to selling a delta-hedged call over one trading day $[t,t+1]$ is H_{t+1}/H_t-1, where $H_t=\Delta S_t-C_t$, with C and S denoting call option price and the underlying stock price. We compound the daily returns to compute the monthly return.

4.1. Average portfolio returns

Table 8 reports the average returns of five portfolios, each of which consists of short positions in daily-rebalanced delta-hedged calls on stocks ranked in a given quintile by the underlying stock's total volatility (Panel A) or by its idiosyncratic volatility (Panel B). Table 1 shows that the returns of delta-hedged options are negative on average. We use short positions in delta-hedged call options in Table 8 so that the average portfolio returns are positive. Table 8 also reports in the "5–1" column the difference in the average returns of the top and the bottom (idiosyncratic) volatility quintile portfolios, which is by definition exactly the return of our volatility-based option trading strategy.

[16] The Amihud illiquidity measure for stock i at month t is defined as

$$IL_{i,t}=\frac{1}{D_t}\sum_{d=1}^{D_t}|R_{i,d}|/VOLUME_{i,d},$$

where D_t is the number of trading days in month t and $R_{i,d}$ and $VOLUME_{i,d}$ are, respectively, stock i's daily return and trading volume in day d of month t.

[17] As in Section 3, for each optionable stock, we choose a call option that is closest to being at-the-money and has a time-to-maturity of about 50 days.

Table 8
Returns of selling delta-hedged calls: portfolio sorts by stock volatility.

This table reports the average return of selling short-maturity at-the-money call options on stocks of various volatility level. At the end of each month, we rank all stocks with options traded into five groups by their total volatility (VOL) or idiosyncratic volatility (IVOL). For each stock, we sell one contract of call option against a long position of Δ shares of the underlying stock, where Δ is the Black-Scholes call option delta. The delta-hedges are rebalanced daily. For each stock and in each month, we compound the daily returns of the rebalanced delta-hedged call option positions over the next month to arrive a monthly return. We use three weighting schemes in computing the average return of selling delta-hedged calls for a portfolio of stocks: equal weight, weight by the market capitalization of the underlying stock, and weight by the market value of option open interest at the beginning of the period. All returns in this table are expressed in percent. Total volatility (VOL) is the standard deviation of daily stock returns over the previous month. Idiosyncratic volatility (IVOL) is the standard deviation of the residuals of the Fama-French three-factors model estimated using the daily stock returns over the previous month. Systematic volatility (SysVOL) is the square root of ($VOL^2 - IVOL^2$). The sample period is from January 1996 to October 2009. To adjust for serial correlation, robust Newey-West (1987) *t*-statistics are reported in the brackets.

Quintile	1-low	2	3	4	5-high	5-1
Panel A: Return to selling delta-hedged calls, sorted by stock total volatility						
Equal-weighted	0.85	0.97	1.15	1.42	2.05	1.20
	(6.97)	(6.37)	(6.42)	(6.55)	(8.30)	(6.10)
Stock-value-weighted	0.73	0.73	0.81	0.84	1.28	0.54
	(5.87)	(5.07)	(4.62)	(3.51)	(4.46)	(2.13)
Option-value-weighted	0.96	1.07	1.34	1.51	2.36	1.40
	(8.85)	(7.33)	(7.94)	(6.04)	(7.38)	(4.64)
Panel B: Return to selling delta-hedged calls, sorted by stock idiosyncratic volatility						
Equal-weighted	0.80	0.92	1.12	1.41	2.20	1.40
	(6.42)	(5.94)	(5.97)	(6.53)	(9.62)	(8.11)
Stock-value-weighted	0.71	0.70	0.80	0.86	1.48	0.76
	(5.17)	(5.05)	(4.23)	(3.62)	(5.66)	(3.46)
Option-value-weighted	0.96	1.05	1.21	1.52	2.68	1.72
	(7.58)	(7.73)	(6.47)	(6.20)	(8.49)	(5.94)

Panel C: Subsample results: equal-weighted portfolio returns, sorted by IVOL							
	1-low	2	3	4	5-high	5-1	*t*-Stat.
Size quintile 1	1.82	2.06	2.38	2.43	3.45	1.63	(9.11)
Size quintile 2	1.12	1.19	1.29	1.28	2.03	0.91	(5.37)
Size quintile 3	0.87	0.86	0.81	1.06	1.60	0.73	(3.92)
Size quintile 4	0.75	0.74	0.77	0.87	1.20	0.45	(1.98)
Size quintile 5	0.62	0.60	0.63	0.58	0.94	0.32	(1.66)
January	0.75	1.06	1.27	1.46	2.90	2.15	(6.75)
February–December	0.80	0.90	1.10	1.40	2.14	1.34	(6.98)
1996–1999	0.74	0.82	1.04	1.42	2.27	1.53	(5.35)
2000–2003	0.86	1.00	1.11	1.36	1.87	1.01	(2.06)
2004–2006	0.76	1.00	1.29	1.62	2.49	1.72	(14.41)
2007–2009	0.82	0.86	1.06	1.23	2.28	1.45	(8.74)
Panel D: Controlling for systematic risk: equal-weighted portfolio returns, sorted by IVOL							
SysVOL quintile 1	0.93	0.89	0.94	1.23	1.74	0.82	(6.05)
SysVOL quintile 2	0.76	0.80	0.95	1.08	1.82	1.06	(7.18)
SysVOL quintile 3	0.69	0.87	0.94	1.15	1.67	0.98	(5.46)
SysVOL quintile 4	0.74	0.93	1.17	1.49	2.06	1.32	(8.65)
SysVOL quintile 5	0.75	0.94	1.20	1.57	2.82	2.07	(13.20)
Panel E: Controlling for IVOL: equal-weighted portfolio return, sorted by SysVOL							
IVOL quintile 1	0.93	0.87	0.76	0.72	0.70	−0.23	(−2.96)
IVOL quintile 2	0.96	0.97	0.85	0.86	0.77	−0.19	(−1.66)
IVOL quintile 3	1.24	1.06	0.98	1.00	0.85	−0.39	(−2.59)
IVOL quintile 4	1.56	1.30	1.28	1.35	0.95	−0.61	(−2.84)
IVOL quintile 5	2.05	1.82	2.19	2.01	2.08	0.03	(0.17)

We try three weighting schemes in computing the average portfolio return: equal weight, weighted by the market capitalization of the underlying stock, and weighted by the market value of total option open interests on each stock (at the initial formation of option portfolio). Our results are consistent across different weighting schemes.

Table 8 shows that the average return of selling delta-hedged calls is positive. Corresponding to the significant negative relation between delta-hedged option return and stock (idiosyncratic) volatility in the regressions, we find that the average return to selling delta-hedged calls on high (idiosyncratic) volatility stocks is significantly higher than

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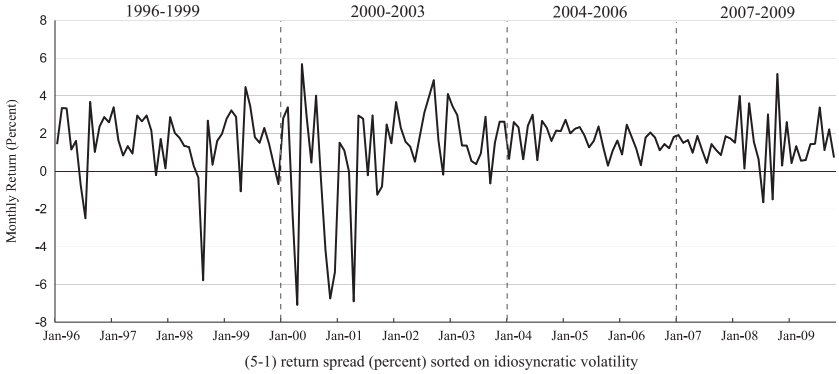

Fig. 1. Time series of returns of our volatility-based option trading strategy. This figure plots the monthly time series of the difference in the equal-weighted average returns of selling delta-hedged calls on stocks ranked in the top idiosyncratic volatility quintile and selling delta-hedged calls on stocks ranked in the bottom idiosyncratic volatility quintile. The delta-hedged option positions are rebalanced daily to be delta-neutral. Idiosyncratic volatility (IVOL) is the standard deviation of the residuals of the Fama-French 3-factors model estimated using the daily stock returns over the previous month. Our sample consists of short-term at-the-money call options on individual stocks. The sample period is from January 1996 to October 2009.

that on low (idiosyncratic) volatility stocks. For example, the average difference in returns between the equal-weighted portfolio of short positions in delta-hedged calls for stocks ranked in the top volatility quintile and that for stocks ranked in the bottom volatility quintile is 1.2%. The same result is stronger (1.4%) when we sort stocks by their idiosyncratic volatility. All of these return differences are significant both statistically and economically.

In both Panels A and B, the value-weighted portfolio return differences between the top and the bottom (idiosyncratic) volatility quintiles are only about half the magnitude as the corresponding equal-weighted results. This suggests that our results are stronger among smaller stocks. Table 8 Panel C confirms this. Each month, we first sort stocks into five quintiles by their market capitalization and then, within each size quintile, we sort further by stock's idiosyncratic volatility. We report the average returns of five portfolios and the difference in the average return of the high idiosyncratic volatility portfolio and that of the low idiosyncratic volatility portfolio (i.e., the mean profitability of our option strategy) separately for each size quintile.

The average return of our option strategy ranges from 1.63% for the bottom size quintile to 0.32% among the top size quintile. Our option strategy is profitable both in January and in the rest of the year. The average equal-weighted return to our option portfolio is over 1% per month in all subperiods: from 1996 to 1999, from 2000 to 2003, from 2004 to 2006, and from 2007 to 2009 (see Fig. 1).

4.2. Double sorts on idiosyncratic volatility and systematic volatility

Previously, we use Fama-MacBeth regressions to show that the negative relation between delta-hedged option return and stock volatility is entirely driven by the idiosyncratic volatility. Table 8 Panels D and E use conditional double sorts to highlight the differential impact of idiosyncratic volatility and systematic volatility on the delta-hedged option returns. In Panel D, we first sort stocks at the end of each month into five portfolios by their systematic volatility exposures and then within each systematic volatility quintile, we further sort stocks by their idiosyncratic volatility. In Panel E, we switch the order of double sorts, first sorting on idiosyncratic volatility and then on systematic volatility.

Table 8 Panel D shows that, in all five systematic volatility quintiles, selling delta-hedged calls on high idiosyncratic volatility stocks significantly outperforms selling delta-hedged calls on low idiosyncratic volatility stocks. The average outperformance ranges from 2.07% in the highest systematic volatility quintile to 0.82% in the lowest systematic volatility quintile. These findings are consistent with the negative relation between delta-hedged option return and idiosyncratic volatility. Further, this negative relation is significant after controlling for stock's systematic volatility exposure.

When we sort stocks by their systematic volatility exposures, the average portfolio returns to selling delta-hedged options show a pattern that is opposite to those when we sort stocks by their idiosyncratic volatility. Table 8 Panel E shows that selling delta-hedged options on stocks with high systematic volatility tends to underperform, not outperform, selling delta-hedged options on stocks with low systematic volatility. This is consistent with the positive regression coefficients on stock's systematic volatility in Table 2 Panel B and Table 3.

4.3. Controlling for common risk factors

Table 9 examines whether return of our option strategy can be explained by the systematic volatility risk factors. We regress the time series of equal-weighted monthly returns of our option strategy on several systematic volatility risk factors. The first is the zero-beta straddle return on the S&P 500 index, which proxies for the market volatility risk (e.g., Coval and Shumway, 2001; Carr and Wu, 2009). For robustness, we also measure the market volatility risk by change in the VIX index from the Chicago Board Options Exchange following Ang, Hodrick, Xing, and Zhang (2006). The third volatility risk factor is the common

Table 9
Return of option portfolio strategy and exposure to common risk factors.
This table reports the results of monthly time series regressions of the return to the strategy of selling delta-hedged calls on high idiosyncratic volatility stocks and buying delta-hedged calls on low idiosyncratic volatility stocks on several common risk factors. The risk factors include Fama-French (1993) three factors (MKT-Rf, SMB, HML), the momentum factor (Mom), the Coval and Shumway (2001) zero-beta straddle return of S&P 500 index option (ZB-STRAD-Index), the value-weighted zero-beta straddle returns of S&P 500 individual stock options (ZB-STRAD-Stock), and change in the Chicago Board Options Exchange Market Volatility Index (ΔVIX). The sample period is from January 1996 to October 2009.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Alpha	1.385	1.376	1.210	1.234	1.413	1.318
	(7.74)	(8.47)	(5.05)	(6.31)	(8.35)	(6.62)
MKT-Rf	0.057	0.049				−0.009
	(1.11)	(1.12)				(−0.18)
SMB		0.068				0.063
		(1.96)				(2.00)
HML		−0.079				−0.094
		(−1.07)				(−1.26)
MOM		0.053				0.071
		(2.06)				(2.83)
ZB-STRAD-Index			−0.012			0.011
			(−1.87)			(1.97)
ZB-STRAD-Stock				−0.033		−0.048
				(−2.87)		(−4.38)
ΔVIX					−0.085	−0.020
					(−1.68)	(−0.41)
Adj. R^2	0.0137	0.0931	0.0345	0.0706	0.0321	0.1589

individual stock variance risk used in Driessen, Maenhout, and Vilkov (2009). It is measured as value-weighted zero-beta straddle returns on the individual stocks that are components of the S&P 500 index. In addition, we include the Fama-French three factors and the momentum factor as additional regressors.

Table 9 shows that the estimated coefficients for the volatility risk factors are negative, but only the coefficient for the common individual stock variance risk is significantly negative in all specifications. In addition, our option strategy loads positively on the *SMB* factor and the momentum factor. More important, after controlling for the volatility risk factors and common risk factors from the stock markets, our option strategy still has a significant positive alpha of 1.318% per month, compared with the raw equal-weighted average return of 1.4% (Table 8 Panel B). Therefore, common risk factors explain only a tiny fraction of the profitability of our option strategy.

4.4. Accounting for transaction costs

For all of the previous results, we assume the options can be bought or sold at the midpoint of the bid and ask price quotes. Table 10 examines the impact of transaction cost on the profitability of our volatility-based option strategy. To take into account the costs associated with buying or selling options, we assume the effective option spread is equal to 10%, 25%, or 50% of the quoted spread. Effective spread is defined as twice the difference between the actual execution price and the market quote at the time of order entry. The column "MidP" in Table 10 Panel A corresponds to zero effective spread, i.e., transaction price equals the midpoint of the bid and ask quotes, as in all previous tables.

Table 10 Panel A shows that the average return to the equal-weighed portfolio strategy of selling delta-hedged calls on stocks ranked in the top idiosyncratic volatility quintile and buying delta-hedged calls on the bottom idiosyncratic volatility quintile stocks decreases monotonically with the transaction cost. It is 1.40% per month when evaluated at the midpoint of bid and ask quotes. When the effective option spread is 10% (25%) of the quoted spread, the average return of our option strategy is reduced to 1.16% (0.79%), although still statistically significant. When we buy an option at the average of the ask price and the midpoint of the quoted spread, and sell an option at the average of the bid price and the midpoint of the quoted spread (i.e., the effective spread is 50% of the quoted spread), the average return of our option strategy is only 0.17%, which is no longer significant statistically or economically. The results are similar when we consider the Fama-French three-factor alphas instead of the raw returns, or when we modify the trading strategy from "5 minus 1" to "10 minus 1" using the extreme deciles sorted by idiosyncratic volatility.[18] Hence, only market participants who face relatively low transaction costs can take advantage of our option strategy profitably.

Table 10 Panel B shows how the profitability of our option strategy varies with liquidity. Each month, we first sort the optionable stock sample into five quintiles by the stock price or its Amihud (2002) illiquidity measure. Then, within each quintile, we further sort by stock's idiosyncratic volatility. Panel B shows that the average return of our idiosyncratic volatility based option strategy is

[18] The average return of the "10 minus 1" strategy is still significantly positive when the effective spread is 50% of the quoted spread. But it becomes insignificant when the effective spread is 75% of the quoted spread.

Table 10
Impact of liquidity and transaction costs on the return of option portfolio strategy.

This table reports the impact of liquidity and transaction costs of stock options on the profitability of our option trading strategy based on stock volatility. Each month and for each optionable stock, we sell one contract of short-maturity at-the-money option, delta-hedged with the underlying stock, and rebalance the delta-hedges daily over the next month. In Panel A, each number of the columns under "5-1" (10-1) is the difference in the equal-weighted average returns of selling delta-hedged calls on stocks in the top idiosyncratic volatility quintile (decile) versus selling delta-hedged calls on stocks in the bottom idiosyncratic volatility quintile (decile). For the column "MidP", we assume the options are transacted at the midpoint of the bid and ask quotes (i.e., effective spread is zero). The other columns correspond to different assumptions on the ratio of effective bid–ask spread (ESPR) to the quoted bid–ask spread (QSPR). Panel B reports the average return spread between selling delta-hedged calls on high versus low idiosyncratic volatility stocks in various subsamples. Each month, we first sort our sample into five quintiles (G1–G5) by the Amihud (2002) stock illiquidity measure, stock price level, or option bid–ask spread. Then within each quintile, we further sort by stock's idiosyncratic volatility. All the numbers in this table are expressed in percent. The sample period is from January 1996 to October 2009. To adjust for serial correlation, robust Newey-West (1987) *t*-statistics are reported in the brackets.

Panel A: Equal-weighted portfolio returns (%) sorted on idiosyncratic volatility

	5-1				10-1			
		ESPR/QSPR				ESPR/QSPR		
	MidP	10%	25%	50%	MidP	10%	25%	50%
Average return	1.40	1.16	0.79	0.17	1.89	1.60	1.15	0.44
	(8.11)	(6.68)	(4.51)	(0.96)	(9.97)	(8.40)	(6.04)	(2.24)
FF-3 alpha	1.41	1.17	0.80	0.18	1.89	1.60	1.15	0.44
	(8.67)	(7.16)	(4.88)	(1.09)	(9.92)	(8.37)	(6.02)	(2.23)

Panel B: Equal-weighted (5-1) spread (%) sorted on idiosyncratic volatility

	Illiquidity	Stock price	Option bid–ask spread
G1-low	0.17	1.99	1.55
	(0.70)	(12.12)	(5.52)
G2	0.61	0.86	2.18
	(2.72)	(5.08)	(7.98)
G3	0.77	0.35	2.60
	(4.30)	(1.69)	(11.69)
G4	1.20	0.10	2.68
	(6.82)	(0.45)	(13.00)
G5-high	2.04	−0.09	2.83
	(12.04)	(−0.37)	(12.24)
G5–G1	1.87	−2.08	1.29
	(8.47)	(−8.15)	(3.51)

significantly higher for illiquid and low priced stocks.[19] For example, the average return of our option strategy is 2.04% among stocks ranked in the top quintile by the Amihud illiquidity measure and 1.99% among lowest priced stocks. In contrast, for stocks ranked in the bottom quintile by the Amihud illiquidity measure and for highest priced stocks, the average return of our option strategy is insignificant, both statistically and economically. These results highlight again that limits to arbitrage play a key role explaining the negative relation between delta-hedged option return and idiosyncratic volatility found in this paper.

4.5. Further discussion

A rapidly growing literature shows that low volatility stock portfolios earn high risk-adjusted returns (e.g., Ang, Hodrick, Xing, and Zhang, 2006; Bali and Cakici, 2008; Huang, Liu, Ghee, and Zhang, 2010; Boyer, Mitton, and Vorkink, 2010; Han and Kumar, forthcoming). The prospect of reducing risk without sacrificing return makes this new low-volatility investment style very attractive to investors, especially since the experience of the financial crises.[20] We contribute to this literature showing that the low volatility investment style works in the options market. By construction of delta-hedged option portfolio, the significant relation between delta-hedged option returns and idiosyncratic volatility of the underlying stock is distinct from and not driven by relation between stock return and idiosyncratic volatility.[21]

Existing theories for why assets with high volatility may have low average returns have difficulties explaining our results. One such explanation is investors' preference for positive skewness (e.g., Barberis and Huang, 2008;

[19] We also verify these results in unreported Fama-MacBeth regressions that include *IVOL*, stock price, and Amihud illiquidity measure, as well as *IVOL*× stock price and *IVOL*× Amihud measure as regressors.

[20] For example, MSCI launched a minimum volatility index in April 2008 to exploit volatility as an alpha source.

[21] For our sample of optionable stocks and for the 1996–2009 sample period, we find no significant relation between the average stock return and idiosyncratic volatility.

Boyer, Mitton, and Vorkink, 2010). Options have positively skewed returns. For at-the-money options, we verify that the skewness of call option return increases with the volatility of the underlying stock. However, put options on high volatility stocks offer lower, not higher, skewness. Thus, the skewness preference argument could not explain our results, because our results are strong and significant for both call options and put options.

Another explanation for why high volatility assets have low average returns is realization utility. Barberis and Xiong (2012) show that investors with realization utility hold onto risky asset until they have a sufficient gain. Our results are based on options with about one and a half months until maturity. Investors might not have the luxury of holding onto these short-term options until they have a gain. In addition, unlike stocks, options lose value over time. The time decay of option value is especially severe for high volatility stocks. Thus, it is unlikely that realization utility investors would find short-term options on high volatility stocks attractive. Finally, neither skewness preference nor realization utility can explain why delta-hedged option return is negatively related to underlying stock's idiosyncratic volatility but positively related to systematic risk exposure of the underlying stock.

Our finding is consistent with models of financial intermediation under constraints. Customers have high demand for certain type of options. Financial intermediaries need to be compensated for supplying these options. We argue that option market makers are more constrained from supplying options on stocks with high idiosyncratic volatility because they are more difficult to hedge. Another reason could be informed trading in options.[22] There is more private information in stocks with high idiosyncratic volatility (e.g., Durnev, Morck, Yeung, and Zarowin, 2003). Back (1993) shows that asymmetric information can make it impossible to price options by arbitrage. Market makers get hurt by the informed trading in options. Thus, they charge a higher premium for options on high idiosyncratic volatility stocks.

5. Conclusion

This paper provides a comprehensive study of individual stock option returns after delta-hedging the exposure to the underlying stocks. The key new finding is that the average delta-hedged option return is negative and decreases monotonically with an increase in the idiosyncratic volatility of the underlying stock. This holds for both call options and put options. It is robust and significant, both statistically and economically. For example, when equal-weighted, the portfolio of delta-hedged call options on stocks ranked in the top idiosyncratic volatility quintile on average under-performs the portfolio of delta-hedged call options on stocks ranked in the bottom idiosyncratic volatility quintile by 1.4% per month. In contrast, we find a positive relation between delta-hedged option return and systematic risk exposure of the underlying stock.

Our key finding is a new anomaly relative to the traditional models that value options under perfect markets and no-arbitrage. Our tests rule out explanations based on common stock market risk factors. Exposure to market volatility risk or common idiosyncratic volatility risk explains only a small portion of the under-performance of delta-hedged options on stocks with high idiosyncratic volatility. Our results are not a mere reflection of known patterns on the cross section of expected stock return.

Our key finding is consistent with models of financial intermediation under constraints. Market makers charge a higher premium for options on high idiosyncratic volatility stocks because these options are more difficult to hedge and have higher arbitrage costs. We find that several proxies of limits to arbitrage between stocks and options affect the cross section of delta-hedged option returns. Controlling for limits to arbitrage proxies reduces the strength of the negative relation between delta-hedged option return and idiosyncratic volatility by about 40%. We find only market participants who face relatively low transaction costs can take advantage of the option anomaly we document.

Another new empirical finding of this paper is that delta-hedged option returns for past winner stocks are on average significantly higher than those for past loser stocks. This option momentum pattern holds for both call options and put options on individual stocks. Further research is needed to better understand the cross section of equity option returns including this option momentum phenomenon. Our paper suggests that it is important and fruitful to consider the constraints of financial intermediaries and their impact on option prices.

Appendix A. Volatility risk premium

Our measure of volatility risk premium follows closely previous studies such as Jiang and Tian (2005), Carr and Wu (2009), and Bollerslev, Tauchen, and Zhou (2009). In each month t and for each stock i with options traded, we measure the stock's volatility risk premium as

$$VRP_{i,t} = \sqrt{RV_{i,t}} - \sqrt{IV_{i,t}} \quad (3)$$

where $RV_{i,t}$ is realized return variance computed from high frequency return data over all trading days in the month t and $IV_{i,t}$ is the risk-neutral expected variance extracted from equity options on the last trading day of each month t. Both $RV_{i,t}$ and $IV_{i,t}$ are annualized.

More precisely, we extract from TAQ intraday equity trading data spaced by $\Delta = 15$-minute interval.[23] Let p_j^i denote the logarithmic price of stock i at the end of the jth 15-minutes interval in the month t. The month t realized variance is measured as

$$RV_t^i = 12\sum_{j=1}^{n}[p_j^i - p_{j-1}^i]^2, \quad (4)$$

where n is the number of 15-minute intervals in month t. We multiply by 12 to get an annualized variance estimate

[22] For evidence of informed trading in options, see, e.g., Cao, Chen, and Griffin (2005) and Pan and Poteshman (2006).

[23] All of our results are robust when we estimate the realized variance using stock prices sampled every 30 minutes or every hour.

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that is comparable to the risk-neutral expected variance implied from the options data.

The one-month risk-neutral expected variance is

$$IV_{i,t} \equiv E^Q[\text{Return Variation } (t,t+1)_i]$$
$$= 2\int_0^\infty \frac{C_i(t,t+1,K)/B(t,t+1) - \max[0,S_{i,t}/B(t,t+1)-K]}{K^2}dK, \quad (5)$$

where $S_{i,t}$ denotes the price of stock i at t and $C_i(t,t+1,K)$ denotes the date t price of a call option with a strike price K and time-to-maturity of one month. $B(t,t+1)$ denotes the present value of a zero-coupon bond that pays off one dollar next month.[24]

In our empirical estimation, the integral in Eq. (5) is evaluated numerically. On the last trading day of each month t, we first extract the implied volatilities for one-month call options from the standardized Volatility Surface provided by OptionMetrics and then translate these implied volatilities into call option prices using the Black-Scholes model. We find that the number of strikes provided by the standardized Volatility Surface is fine enough so that the discretization in the numerical integration has minimal impact on the estimation of the risk-neutral expected variance.[25]

To estimate the variance risk premium for a stock in a given month, we require that, at the end of the month, there are at least five traded call options on the stock with maturity between 15 days and 60 days that survive the option data filters described in Section 2. Among these options, we further require that at least two are out-of-the-money, two are in-the-money, one is close to being at-the-money. This helps to ensure the reliability of the variance risk premium estimates. With these additional data filters, on average there are about 464 stocks in each month for which we estimate the volatility risk premium. The set of such stocks increases from about 350 in the beginning of our sample (1996–1997) to about 670 toward the end of the sample (2008–2009).

Appendix B. Risk-neutral skewness and kurtosis

We use a model-free and ex ante measure of risk-neutral skewness and kurtosis given by Bakshi, Kapadia, and Madan (2003). For each stock on date t, the skewness and kurtosis of the risk-neutral density of the stock return over the period $[t,t+\tau]$ can be inferred from the contemporaneous prices of out-of-the-money call options and put options as

$$Skew(t,\tau) = \frac{e^{r\tau}W(t,\tau) - 3\mu(t,\tau)e^{r\tau}V(t,\tau) + 2\mu(t,\tau)^3}{[e^{r\tau}V(t,\tau) - \mu(t,\tau)^2]^{3/2}}, \quad (6)$$

where

$$\mu(t,\tau) = e^{r\tau} - 1 - \frac{e^{r\tau}}{2}V(t,\tau) - \frac{e^{r\tau}}{6}W(t,\tau) - \frac{e^{r\tau}}{24}X(t,\tau), \quad (7)$$

and $V(t,\tau)$, $W(t,\tau)$, and $X(t,\tau)$ are the weighted sums of out-of-the-money call option prices $C(t,\tau,K)$ and put option prices $P(t,\tau,K)$, with time-to-maturity τ and strike price K, given the underlying asset price S_t:

$$V(t,\tau) = \int_{S_t}^\infty \frac{2\left(1-\ln\left(\frac{K}{S_t}\right)\right)}{K^2} C(t,\tau,K)\, dK + \int_0^{S_t} \frac{2\left(1+\ln\left(\frac{S_t}{K}\right)\right)}{K^2} P(t,\tau,K)\, dK, \quad (8)$$

$$W(t,\tau) = \int_{S_t}^\infty \frac{6\ln\left(\frac{K}{S_t}\right) - 3\left[\ln\left(\frac{K}{S_t}\right)\right]^2}{K^2} C(t,\tau,K)\, dK - \int_0^{S_t} \frac{6\ln\left(\frac{S_t}{K}\right) + 3\left[\ln\left(\frac{S_t}{K}\right)\right]^2}{K^2} P(t,\tau,K)\, dK, \quad (9)$$

$$X(t,\tau) = \int_{S_t}^\infty \frac{12\left[\ln\left(\frac{K}{S_t}\right)\right]^2 - 4\left[\ln\left(\frac{K}{S_t}\right)\right]^3}{K^2} C(t,\tau,K)\, dK + \int_0^{S_t} \frac{12\left[\ln\left(\frac{S_t}{K}\right)\right]^2 + 4\left[\ln\left(\frac{S_t}{K}\right)\right]^3}{K^2} P(t,\tau,K)\, dK. \quad (10)$$

The integrals are approximated in Eqs. (8)–(10) using the trapezoidal method. For accuracy, we require at least three out-of-the-money call options and three out-of-the-money put options. Due to this data constraint, the option implied skewness and kurtosis are available only for about half of the sample.

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[24] We also compute the model-free implied variance based on prices of put options and obtain virtually the same estimates as those based on the call options.

[25] OptionMetrics computes the implied volatility of a traded option from its price using a proprietary pricing algorithm. OptionMetrics uses a kernel smoothing technique to compute a surface of option implied volatilities for standard maturities and strikes based on the implied volatilities of traded options. The standard strikes correspond to call option deltas of 0.20, 0.25, 0.30, 0.35, 0.40, 0.45, 0.50, 0.55, 0.60, 0.65, 0.70, 0.75, and 0.80. For options with strike prices beyond the available range, we use the endpoint implied volatility to extrapolate their option value.

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