Informed Options Trading on the Implied Volatility Surface: A Cross-sectional Approach

Haehean Park[a] Baeho Kim[b] Dahae Kim[0]

Abstract

This paper investigates the cross-sectional implication of informed options trading *across different strikes and maturities*. We adopt well-known option-implied volatility measures showing stock return predictability to explore the term-structure perspective of the one-way information transmission from options to stock markets. Using equity options data for U.S. listed stocks covering 2000 to 2013, we find that the shape of the long-term implied volatility curve exhibits extra predictive power for subsequent month stock returns even after orthogonalizing the short-term components and existing predictors based on stock characteristics. Our finding indicates that the inter-market information asymmetry rapidly disappears prior to the expiration of long-term option contracts.

Key words: Implied volatility surface; Equity options; Stock return; Predictability; Informed options trading;

JEL classification: G12; G13; G14

[a] Southwestern University of Finance and Economics (SWUFE), 55 Guanghuacun St, Chengdu, Sichuan 610074, China; hhpark@swufe.edu.cn.

[b] Corresponding author: Korea University Business School, Anam-dong, Sungbuk-Gu, Seoul 136-701, Republic of Korea; baehokim@korea.ac.kr; phone +82-2-3290-2626; fax +82-2-922-7220; http://biz.korea.ac.kr/~baehokim.

[0] Department of Finance, Sungkyunkwan University, Seoul, Republic of Korea; dahea86@gmail.com; Phone 82+02+760+0951;

1 Introduction

The widespread use of various financial instruments across different maturities enables investors to construct profitable strategies, as the instruments shed light on the market's expectations for future economic states and market conditions over different investment horizons. For example, it is widely accepted that the shape of a yield curve extracted from short- and long-term bond prices integrates the market's anticipation of future interest rates and economic growth across time; see Harvey (1988), Harvey (1991), Fama and French (1993) and Boudoukh and Richardson (1993) among many others. Hendrik and Bessembinder (1995) examine the term structure perspective of the futures market and find that mean reversion in asset prices occurs as an equilibrium phenomenon in the futures markets. Han and Zhou (2011) examine the term structure of single-name CDS spreads and show its negatively predictive power for future stock returns. Research on the market *volatility* term structure has intensified as well. Merton (1973) claims in his Intertemporal Capital Asset Pricing Model (ICAPM) that changes in the volatility term structure should be priced in the cross-section of risky asset returns. Campbell and Viceira (2005) further generalize the relevance of risk horizon effects on asset allocation by exploring the term-structure of the risk–return tradeoff.

In this study, we consider the term structure of the *option-implied* volatility curve *across different strikes and maturities*, as it reflects expected trends in the *realized* volatility of different horizons in a forward-looking manner. An option-implied volatility surface is a function of both moneyness and time-to-maturity. Thus, the time-varying implied volatility curve and term structure are reflective of fluctuations in expectations of the risk-neutral distribution of underlying asset returns based on the dynamics of the investment opportunity set in the market. Both academics and practitioners have a long-standing interest in the options market, as it provides informed investors with opportunities to capitalize on their information advantage. For example, Jin, Livnat, and Zhang (2012) find that options traders are better able to process less-anticipated information than are equity traders by analyzing the shape of implied volatility curves. Although a considerable literature has grown around the theme of informed trading in the options market, few studies have investigated stock return predictability in terms of the *moneyness* and *maturity* dimensions at the same time. This paper fills this gap by examining the time-varying term structure of option-implied volatility curves.

For the *moneyness* dimension, Xing, Zhang, and Zhao (2010) propose an implied volatility smirk (IV smirk) measure by showing its significant predictability for the cross-section of future equity returns. Jin, Livnat, and Zhang (2012) find that options traders are better able to process less-anticipated information than are equity traders by analyzing the slope of option-implied volatility curves. Using the spread between the ATM call and put option-implied volatilities (IV spread) as a proxy of the average size of the jump in stock price dynamics, Yan (2011) find a negative predictive relationship between IV spread and future stock returns. Constructing an implied volatility convexity (IV convexity) measure, Park, Kim and Shim (2016) find that their proposed IV convexity shows a cross-sectional predictive power for future stock returns in the subsequent month, even after the slope of the implied volatility curve is taken out.

Remarkably, most studies examining the implied volatility curve use short-term (usually one-month) maturity options when calculating the implied volatility shape measures. By contrast, this paper contributes to the literature by studying the informational content of the term structure of the options-implied volatility curve at the firm level and examining its predictive power for the cross-section of stock returns. In the broader context, however, a considerable body of literature has grown up around the theme of asset return predictability from the *term structure* perspective. For instance, Xie (2014) finds that stocks with high sensitivities to changes in the VIX slope exhibit high returns on average, as a downward sloping VIX term structure anticipates a potential long disaster. Vasquez (2015) reports that the slope of the implied volatility term structure is positively related to future option returns. Furthermore, Jones and Wang (2012) examine the relationship between the slope of the implied volatility term structure and future option returns and find that implied volatility slopes are positively correlated with the future returns on short-term straddles while no clear relationship is observed for the returns on longer-term straddles. Andries, Eisenbach, Schmalz and Wang (2015) investigate the price per unit of volatility risk at varying maturities and find that the price per unit of volatility risk parameters are negative and decrease in absolute value with maturity. Their finding is inconsistent with the standard asset pricing assumption of constant risk aversion across maturities but confirms the horizon-dependent risk aversion asset pricing modeling approach. Using index option data, Andries, Eisenbach and Schmalz (2014) show that the preferences of horizon-dependent risk aversion generate a decreasing term structure of risk premia if and only if volatility is stochastic; they argue that the price of risk depends on the horizon and the horizon-dependent risk appetite has a meaningful impact on asset pricing. Vogt (2014) investigates the term structures of variance risk premium using the VIX index and finds that the term structure of the variance risk premium is dominated by compensation for bearing short-run variance risk. Johnson (2016) finds that the changes in the shape of the VIX term structure contain information about time-varying variance risk premia rather than expected changes in the VIX, thus rejecting the expectation hypothesis. We notice that most studies focus on the term structure of the option- implied volatility on the at-the-money level and overlook the importance of the changes in the *shape* of the implied volatility curve across different strike prices over time.

To the best of our knowledge, this study is the first to consider both the implied volatility smile (smirk) and its term structure at the same time in the context of informed options trading relative to equity trading. By adopting well-known option-implied volatility measures showing stock return predictability, we explore the term-structure perspective of informed trading in the options market. Whereas prior studies typically measure the slope of the implied volatility term structure, we devise our measure by orthogonalizing short-term volatility from long-term volatility movements. Unlike with the simple difference between long- and short-term components, our proposed measure corrects for the fact that implied volatility curves tend to flatten as time-to-maturity increases, *ceteris paribus*. It is widely observed that the volatility term structure is differently curved across different moneyness points, as the volatility implied by short-dated option prices changes faster than that implied by longer-term options, partly because of the mean-reversion effect of the (potentially) stochastic volatility process.

Using equity options data for U.S. listed stocks covering 2000 to 2013, we find that the shape of the long-term implied volatility curve shows extra predictive power for subsequent months' stock returns even after we take out their short-term components and existing predictors based on stock characteristics. Specifically, the average return differential between the lowest and highest *orthogonalized* implied volatility spread/smirk/convexity quintile portfolios exceeds a range of 0.38% to 0.52% per month, which is both economically and statistically significant on a risk-adjusted basis. Our finding indicates that the transmission of long-term private information from the options market to the stock market occurs prior to the expiration of the options. Thus, informed long-term options trading contributes to the short-term price discovery process, as the equity market updates its valuation by digesting the information prevailing in the options market prior to the expiration of the options. Our findings are robust across different term spreads and various holding periods.

The rest of this paper is organized as follows. Section 2 describes our dataset and variable definitions. Section 3 presents the empirical results for the main hypotheses. Section 4 provides additional tests as robustness checks, and Section 5 concludes the paper.

2 Data and Construction of Variables

This section describes our dataset and the methodology used to calculate the term structure of implied volatility spread orthogonalized by one-month implied volatility spread (*Ortho Spread*, hereafter), the term structure of implied volatility smirk orthogonalized by one-month implied volatility smirk (*Ortho Smirk*, hereafter), and the term structure of implied volatility convexity orthogonalized by one-month implied volatility convexity (*Ortho Convexity*, hereafter). We then test whether each of *Ortho Spread*, *Ortho Smirk*, and *Ortho Convexity* exhibits significant predictive power for future stock returns even if these variables are orthogonalized by one-month component from long-term, six-month, implied volatility spread (smirk, convexity).

2.1 Data Description

The data for our study come from three primary sources: the OptionMetrics, the Center for Research in Securities Prices (CRSP), and Compustat. We begin our sample selection with the U.S. equity and index option data from the OptionMetrics database covering January 2000 to July 2013.

As the raw data include individual equity options in the American style, the OptionMetrics applies the binomial tree model of Cox, Ross, and Rubinstein (1979) to estimate the option-implied volatility curve to account for the possibility of an early exercise with discrete dividend payments over the lives of the options, and OptionMetrics computes the interpolated implied volatility surface separately for puts and calls using a kernel smoothing algorithm employing options with various strikes and maturities.

Employing a kernel smoothing technique, OptionMetrics offers a volatility surface dataset containing the implied volatilities for a list of standardized options for constant maturities and deltas. Specifically, we obtain the fitted implied volatilities on a grid of fixed time-to-maturities (30 days, 60 days, 90 days, 180 days, and 360 days) and option deltas (0.2, 0.25, …, 0.8 for calls and -0.8, -0.75, … , -0.2 for puts), respectively. In our empirical analyses, we then select the options with 180-day time-to-maturity as a representative value for long-term options and 30-day time-to-maturity as a representative value for short-term options to estimate *Ortho Spread, Ortho Smirk,* and *Ortho Convexity.*

[Insert Table 1 about here.]

Panel A of Table 1 shows the summary statistics of the fitted implied volatility and fixed deltas of the individual equity options with one-month (30 days), two-month (60 days), three-month (91 days), and six-month (182 days) time-to-maturity chosen at the end of each month. We can clearly observe a positive convexity in the option-implied volatility curve as a function of the option's delta, in that the implied volatilities from in-the-money (ITM; calls for delta in the range of 0.55 to 0.80, puts for delta of -0.80 to -0.55) options and OTM (calls for delta of 0.20 to 0.45, puts for delta of -0.45 to -0.20) options are greater on average than those near the ATM options (calls for delta of 0.50, puts for delta of -0.50). Panel B of Table 1 presents the unique number of firms by industry each year. Each firm is placed into one of the 12 Fama−French industry (FF1-12) classifications based on the SIC code. There are 2,900 unique firms in 2000, rising to 4,159 in 2013. We obtain daily and monthly individual common stock (shrcd of 10 or 11) returns from the Center for Research in Security Prices (CRSP) for stocks traded on the NYSE (exchcd=1), Amex (exchcd=2), and NASDAQ (exchcd=3). Accounting data are obtained from Compustat. We obtain both daily and monthly data for each factor from Kenneth R. French's website (http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html).

2.2. Variable Construction

The option-implied volatility curve is a function not only of moneyness but also of time-to expiration. The term structure of the option-implied volatility curve may convey useful information about investors' horizon-dependent risk aversion or expectations for asset prices. Moreover, the slope of the option-implied volatility curve term structure contributes to the prediction of realized higher moments of underlying assets over the life of options and delivers crucial information about future stock prices. In contrast to the previous studies, which look into the term structure of the options implied volatility at the ATM level and overlook the importance of the change in implied volatility across moneyness over the life of options, we consider implied volatility curve in an aspect of both the term structure and the moneyness characteristics and study the informational content of the term structure of options implied volatility curve at the individual firm level and examine their predictive power for the cross-section of stock returns.

To verify the relationship between the term structure of the option-implied volatility curve and the expected equity return, we introduce three measures for the term-structure perspective of the implied volatility curve—*Ortho Spread, Ortho Smirk,* and *Ortho Convexity*—representing the change in the implied volatility curve over the life of options. We first calculate variables related to daily long- and short-term option-implied volatility curves following Yan (2011), Xing, Zhang and Zhao (2010), and Park, Kim and Shim (2016). We chose options with six-month time-to-maturity as a benchmark of long-term options and options with one-month time-to-maturity as a benchmark of short-term options. These variables are defined as follows:

$$Spread_{6m\ (or\ 1m)} = \mathrm{IV}_{\mathrm{put},6m\ (or\ 1m)}(\Delta= -0.5) - \mathrm{IV}_{\mathrm{call},6m\ (or\ 1m)}(\Delta= 0.5) \quad (1)$$

$$Smirk_{6m\ (or\ 1m)} = \mathrm{IV}_{\mathrm{put},6m\ (or\ 1m)}(\Delta= -0.2) - \mathrm{IV}_{\mathrm{call},6m\ (or\ 1m)}(\Delta= 0.5) \quad (2)$$

$$Convexity_{6m\ (or\ 1m)} = \mathrm{IV}_{\mathrm{put},6m\ (or\ 1m)}(\Delta= -0.2) + \mathrm{IV}_{\mathrm{put},6m\ (or\ 1m)}(\Delta= -0.8) - 2 \times \mathrm{IV}_{\mathrm{call},6m\ (or\ 1m)}(\Delta= 0.5) \quad (3)$$

where $IV_{put}(\Delta)$ and $IV_{call}(\Delta)$ refer to the fitted put and call option-implied volatilities with six months (or one month) to expiration, and Δ is the options' delta. Note that using an option's delta is common industry practice to measure moneyness, as it is sensitive to the option's intrinsic and time values at the same time. As proposed by Yan (2011), $Spread_{6m\ (or\ 1m)}$ is the slope of the option-implied volatility curve that captures the effect of the average jump size (μ_J) in the SVJ model framework; this measure contains information about the *ex-ante* 3rd moment in the option-implied distribution of the stock returns over the life (six months or one month) of the options. Following Xing et al. (2010), $Smirk_{6m\,(or\ 1m)}$ is defined as the OTM ($\Delta = -0.2$) put implied volatility less the ATM ($\Delta = 0.5$) call implied volatility. This measure contains information on both the 3rd and 4th moments of the stock return in a mixed manner. Next, $Convexity_{6m\,(or\ 1m)}$, proposed by Park et al. (2016), is defined as the average of the sum of OTM and ITM put implied volatilities minus double the ATM call implied volatility. $Convexity_{6m\,(or\ 1m)}$ is a simple proxy for the volatility of stochastic volatility (σ_v) and jump size volatility (σ_J) in SV and SVJ framework. The authors argue that the information delivered by $Convexity_{6m\,(or\ 1m)}$ incorporates the market's expectation of the future tail-risk aversion of the underlying stock return over the lifetime of the option.

The previous studies employ all the variables above based on one-month options and thus capture the effect of the one-month implied volatility curve alone, not the effect of the longer-term (six-month) implied volatility curve, on the implied distribution of the underlying stock returns. Viewed in this vein, the main research question in this paper is whether the long-term implied volatility spread still carries extra predictability for future stock returns even after we remove the short-term component from it.

OptionMetrics provides the fitted implied volatilities on a grid of fixed time-to-maturities of 30 days, 60 days, 90 days, 180 days, and 360 days. We consider 180-day (six-month) options as long-term implied volatility and 30-day (one-month) options as short-term implied volatility. Alternative definitions for the term structure of implied volatility curve-related variables across different time-to-maturities do not materially change our main results.

Using daily $Spread_{6m}$ ($Smirk_{6m}$, $Convexity_{6m}$) and $Spread_{1m}$ ($Smirk_{1m}$, $Convexity_{1m}$), we conduct time series regressions for each month to decompose $Spread_{6m}$ ($Smirk_{6m}$, $Convexity_{6m}$) into the predictive component and orthogonalized component by $Spread_{1m}$ ($Smirk_{1m}$, $Convexity_{1m}$) to disentangle the slope of the term structure of the implied volatility curve from the information on the long-term implied volatility curve as follows:

$$Spread_{6m,i,t-30\sim t} = \alpha_i + b_i Spread_{1m,i,t-30\sim t} + \varepsilon_{i,t} \quad (4)$$

$$Smirk_{6m,i,t-30\sim t} = \alpha_i + b_i Smirk_{1m,i,t-30\sim t} + \varepsilon_{i,t} \quad (5)$$

$$Convexity_{6m,i,t-30\sim t} = \alpha_i + b_i Convexity_{1m,i,t-30\sim t} + \varepsilon_{i,t} \quad (6)$$

The residual terms at the end of each month are defined as $Ortho\ Spread_{6m,1m}$, $Ortho\ Smirk_{6m,1m}$, and $Ortho\ Convexity_{6m,1m}$, respectively. To reduce the impact of infrequent trading on estimates, a minimum of 10 trading days in a month is required. $Ortho\ Spread_{6m,1m}$ $(Ortho\ Smirk_{6m,1m}, Ortho\ Convexity_{6m,1m})$ is the term structure of the option-implied volatility curve orthogonalized by the one-month option-implied volatility curve. This variable contains the information about how *Spread (Smirk, Convexity)* will fluctuate from long- to short-term options' time intervals and how it will change over the life of the options. This decomposition enables us to investigate whether the term structure of implied volatility curve-related variables (from six- to one-month) and implied volatility curve-related variables (one-month) has a distinct impact on a cross-section of future stock returns, which determines whether $Ortho\ Spread_{6m,1m}$ $(Ortho\ Smirk_{6m,1m}, Ortho\ Convexity_{6m,1m})$ carries extra predictive power for future stock returns, controlling for the return predictability of $Spread_{1m}$ ($Smirk_{1m}$, $Convexity_{1m}$) of stock return distribution, as identified by Yan (2011), Xing et al. (2010), and Part et al. (2016).

We define a firm's size (Size) as the natural logarithm of market capitalization (prc × shrout × 1000), which is computed at the end of each month using CRSP data. When computing book-to-market ratio (BTM), we match the yearly book value of equity, or BE (book value of common equity [CEQ] plus deferred taxes and investment tax credit [txditc]) for all fiscal years ending in June at year t to returns starting in July of year t-1, and divide this BE by the market capitalization at month t-1. Hence, the book-to-market ratio is computed on a monthly basis. Market betas (β) are estimated with rolling regressions using the previous 36 monthly returns available up to month t-1 (a minimum of 12 months) given by

$$(\mathrm{R_i} - \mathrm{R_f})_k = \alpha_i + \beta_i (\mathrm{MKT} - \mathrm{R_f})_k + \varepsilon_{i,k}, \quad (7)$$

where $t-36 \leq k \leq t-1$ on a monthly basis. Following Jegadeesh and Titman (1993), we compute momentum (MOM) using cumulative returns over the past six months, skipping one month between the portfolio formation period and the computation period to exclude the reversal effect. Momentum is also rebalanced every month and assumed to be held for the next one month. Short-term reversal (REV) is estimated based on the past one-month return, as in Jegadeesh (1990) and Lehmann (1990). Motivated by Amihud (2002) and Hasbrouck(2009), we define illiquidity (ILLIQ) as the average of the absolute value of the stock return divided by the trading volume of the stock in thousand USD using the past one-year's daily data up to month t.

Adopting Ang, Hodrick, Xing, and Zhang (2006), we compute idiosyncratic volatility using daily returns. The daily excess returns of individual stocks over the last 30 days are regressed on Fama and French's (1993, 1996) three factors daily and momentum factors monthly, where the regression specification is given by

$$(R_i - R_f)_k = \alpha_i + \beta_{1i}(MKT - R_f)_k + \beta_{2i}SMB_k + \beta_{3i}HML_k + \beta_{4i}WML_k + \varepsilon_k, \qquad (8)$$

where $t-30 \leq k \leq t-1$ on a daily basis. Idiosyncratic volatility is computed as the standard deviation of the regression residuals in every month. To reduce the impact of infrequent trading on idiosyncratic volatility estimates, a minimum of 15 trading days in a month for which CRSP reports both a daily return and non-zero trading volume is required.

We estimate systematic volatility using the method suggested by Duan and Wei (2009): $v_{sys}^2 = \beta^2 v_M^2 / v^2$ for every month. We also compute idiosyncratic implied variance as $v_{idio}^2 = v^2 - \beta^2 v_M^2$ on a monthly basis, where v_M is the implied volatility of the S&P500 index option, following Dennis, Mayhew, and Stivers (2006).

[Insert Table 2 about here.]

Panel A of Table 2 shows the descriptive statistics of $Spread_{6m}$ ($Smirk_{6m}$, $Convexity_{6m}$), $Spread_{1m}$ ($Smirk_{1m}$, $Convexity_{1m}$), and $Ortho\ Spread_{6m,1m}$ ($Ortho\ Smirk_{6m,1m}$, $Ortho\ Convexity_{6m,1m}$). The average values for each variable are the following: $Spread_{1m}$ ($Spread_{6m}$) has 0.009(0.011), $Smirk_{1m}$ ($Smirk_{6m}$) 0.069 (0.058) and

$Convexity_{1m}(Convexity_{1m})$ 0.095 (0.063). The standard deviation of $Spread_{1m}$ $(Spread_{6m})$ is 0.124 (0.086), that of $Smirk_{1m}$ ($Smirk_{6m}$) is 0.142 (0.097), and that of $Convexity_{1m}(Convexity_{1m})$ is 0.279 (0.184). Concerning the end-of-month observations for $Ortho\ Spread\ (Smirk, Convexity)_{6m,1m}$, the mean value of $Ortho\ Spread\ _{6m,1m}$ $(Ortho\ Smirk_{6m,1m}, Ortho\ Convexity\ _{6m,1m})$ is 0 (0, -0.002), and the standard deviation of $Ortho\ Spread\ _{6m,1m}$ $(Ortho\ Smirk\ _{6m,1m},\ Ortho\ Convexity\ _{6m,1m})$ is 0.041, (0.052, 0.086).

Panel B of Table 2 reports the descriptive statistics of the quintile portfolios sorted by each firm characteristic variable (Size, BTM, Market β, MOM, REV, ILLIQ, and Coskew). The mean and median of SIZE are 19.4607 and 19.3757, respectively, and BTM has a right-skewed distribution, with a mean of 0.9186 and a median of 0.5472.

3 Empirical Analysis

3.1 Portfolio Analysis

The first empirical examination is whether $Ortho\ Spread\ _{6m,1m}$ ($Ortho\ Smirk_{6m,1m}$, $Ortho\ Convexity\ _{6m,1m}$) can account for the cross-sectional variation of expected equity return. To examine the relationship between $Ortho\ Spread\ _{6m,1m}$ ($Ortho\ Smirk\ _{6m,1m}$, $Ortho\ Convexity\ _{6m,1m}$) and future stock returns, we form five portfolios based on the value of $Ortho\ Spread\ (Ortho\ Smirk, Ortho\ Convexity)_{6m,1m}$ at the end of each month.

Quintile 1 is composed of stocks with the lowest $Ortho\ Spread\ _{6m,1m}$ $(Ortho\ Smirk\ _{6m,1m},\ Ortho\ Convexity\ _{6m,1m})$ while Quintile 5 is composed of stocks with the highest $Ortho\ Spread\ _{6m,1m}$ $(Ortho\ Smirk_{6m,1m}, Ortho\ Convexity\ _{6m,1m})$. These portfolios are equally weighted, rebalanced every month, and assumed to be held for the subsequent one-month period.

[Insert Table 3 about here.]

Panel A presents the average number of firms, means, and standard deviations of the $Spread_{6m}$, $Spread_{1m}$, $Ortho\ Spread_{6m,1m}$ quintile portfolios and the average portfolio monthly returns over the entire sample period. Examining the average returns across quintiles for

$Spread_{6m}$, the long-term implied volatility spread, reveals that stocks (Q1) with the lowest $Spread_{6m}$ provide 0.0149 of expected return per month on average and stocks (Q5) with the highest $Spread_{6m}$ provide -0.0003, suggesting that the average returns on the quintile portfolios sorted by $Spread_{6m}$ decrease monotonically in portfolio rank. In addition, the average monthly return of the arbitrage portfolio buying the lowest $Spread_{6m}$ portfolio Q1 and selling highest $Spread_{6m}$ portfolio Q5 is significantly positive (0.0152, with t-statistics of 8.12).

Moreover, examining the portfolios sorted by $Spread_{1m}$, the short-term implied volatility spread, shows that their average returns decrease monotonically from 0.0143 for quintile portfolio Q1 to 0.0012 for quintile portfolio Q5, and the average return difference between Q1 and Q5 amounts to 0.013, with t-statistics of 7.44. These results confirm Yan's (2011) empirical finding that low $Spread_{1m}$ stocks outperform high $Spread_{1m}$ stocks. Overall, we find significant evidence that stocks with lower quintiles have higher expected returns than do stocks with higher quintiles for both long- and short-term implied volatility spreads. This result implies that not only short-term implied volatility spread, $Spread_{1m}$, but also long-term implied volatility spread, $Spread_{6m}$, has explanatory power in capturing stock return variation. As shown in Yan (2011), there is a definitely negative predictive relationship between $Spread_{1m}$ and future stock returns.

The main research question of this paper is whether the long-term implied volatility spread still carries extra predictability for future stock returns even after we remove the short-term component from it. To address it, we employ $Ortho\,Spread_{6m,1m}$, the term structure of the option-implied volatility curve orthogonalized by the one-month option-implied volatility curve, and examine whether $Ortho\,Spread_{6m,1m}$ still carries extra predictability for future stock returns beyond $Spread_{1m}$. The six right-hand columns are the results using portfolios sorted by $Ortho\,Spread_{6m,1m}$. Although the arbitrage portfolio return is somewhat small (the value is 0.0044) compared to that of $Spread_{6m}$ ($Spread_{1m}$), the average returns of the quintile portfolios sorted by $Ortho\,Spread_{6m,1m}$ are decreasing in $Ortho\,Spread_{6m,1m}$, and the returns of the zero-investment portfolios (Q1–Q5) are all positive and statistically significant, confirming that $Ortho\,Spread_{6m,1m}$, which contains information about how the ex-ante skewness of the underlying stock return will fluctuate over the options' lifetime, has additional explanatory power for future stock returns beyond $Spread_{1m}$.

Panel B in Table 3 shows the average number of firms, means, and standard deviations of the $Smirk_{6m}$, $Smirk_{1m}$, and $Ortho\ Smirk_{6m,1m}$ quintile portfolios and the average portfolio monthly returns over the entire sample period. Our empirical results show that the long-term smirk measure, $Smirk_{6m}$, generates a monotone decreasing pattern of the average quintile portfolio returns, from 0.0147 per month for the bottom quintile to 0.0005 per month for the top quintile, and that the realized returns of the arbitrage portfolio (Q1−Q5) has a positive value (0.0142) with statistical significance (with a t-statistic of 6.92).

The average returns of the quintile portfolio sorted by short-term smirk measure, $Spread_{1m}$, also decline monotonically, going from quintile 1 to quintile 5, and the difference between average returns on the portfolio with the highest and lowest $Spread_{1m}$ is around 0.0104, with a t-statistics of 5.16 per month. These results are consistent with Xing et al.'s (2010) empirical findings that low $Smirk_{1m}$ stocks outperform high $Smirk_{1m}$ stocks. Overall, we find significant evidence that both short-term implied volatility smirk, $Smirk_{1m}$, and long-term implied volatility smirk, $Smirk_{6m}$, have predictive power in forecasting future equity returns and that, as shown in Xing et al. (2010), a definitely negative predictive relationship exists between $Smirk$ and future stock returns.

In the case of $Ortho\ Smirk_{6m,1m}$, the long-short zero investment portfolio of Q1−Q5 has an average return of 0.0044 over the next month, with a t-statistics of 3.98. This long-short portfolio return is smaller than that of $Spread_{6m}$ ($Spread_{1m}$). $Ortho\ Smirk_{6m,1m}$ is a forward-looking measure capturing the change of higher moments in the implied distribution of stock returns during the long- to the short-term options' time intervals and how it changes over the lifetime of the options. So these empirical results imply that $Ortho\ Smirk_{6m,1m}$ delivers crucial additional explanatory information for future stock returns beyond $Smirk_{1m}$.

We next reconcile the relationship between the convexity of an option-implied volatility curve, *Convexity*, and future stock returns. As Park et al. (2016) suggested, *Convexity* is a forward-looking measure of excess tail-risk contribution to the perceived variance of underlying equity returns. Panel C in Table 3 reports the average number of firms, means, and standard deviations of the $Convexity_{6m}$, $Convexity_{1m}$, and $Ortho\ Convexity_{6m,1m}$ quintile portfolios and the average portfolio monthly returns over the entire sample. In the results for average returns across *Convexity* quintile, the average returns of the quintile portfolios decline monotonically, and stocks with the lowest $Convexity_{6m}$ ($Convexity_{1m}$) provide 0.0149 (0.0136) of the expected average returns, and stocks with the highest $Convexity_{6m}$ ($Convexity_{1m}$) provide -0.0007 (0.018). In addition, the average monthly return of the arbitrage portfolio buying the lowest $Convexity_{6m}$ ($Convexity_{1m}$) portfolio Q1 and selling the highest $Convexity_{6m}$ ($Convexity_{1m}$) portfolio Q5 are significantly positive values. (0.0156, with a t-statistic of 8.56, for $Convexity_{6m}$ and 0.0119, with a t-statistic of 7.07, for $Convexity_{1m}$). This empirical result indicates that both short-term implied volatility convexity, $Convexity_{1m}$, and long-term implied volatility convexity, $Convexity_{6m}$, have predictive ability in forecasting future equity returns, thus confirming Park et al. (2016), who find that the average return differential between the lowest and highest *convexity* quintile portfolios exceeds 1% per month, which is both economically and statistically significant on a risk-adjusted basis.

Next, we decompose the information extracted from the six-month option-implied volatility convexity into a predictive component and orthogonalized component by $Convexity_{1m}$ and empirically verify that $Ortho\ Convexity_{6m,1m}$, has a significant predictive power for the cross-section of future stock returns. The $Convexity_{1m}$ measure proposed by Park et al. (2016) captures the effect of the one-month implied volatility convexity, but not the effect of the longer-term (six-month) implied volatility convexity, on the implied distribution of underlying stock returns. The empirical evidence indicates that $Ortho\ Convexity_{6m,1m}$ carries additional forecasting power for future stock returns even after we remove the information of short-term component convexity from long-term convexity.

[Insert Figure 2 about here.]

The left-hand side of Panel A (Panel B, Panel C) in Figure 2 shows the monthly average $Ortho\ Spread_{6m,1m}$ ($Ortho\ Smirk_{6m,1m}$, $Ortho\ Convexity_{6m,1m}$) value for each quintile portfolio, while the right-hand side plots the monthly average return of the arbitrage portfolio formed by taking a long position in the lowest quintile and a short position in the highest quintile portfolios (Q1–Q5). The time-varying average monthly returns of the long-short portfolios based on $Ortho\ Spread_{6m,1m}$ ($Ortho\ Smirk_{6m,1m}, Ortho\ Convexity_{6m,1m}$) are mostly positive, confirming the results reported in Table 3.

3.2 Time-series Analysis

In this section, we examine whether the existing risk factor models can explain the negative relationship between $Ortho\ Spread_{6m,1m}$ ($Ortho\ Smirk_{6m,1m}, Ortho\ Convexity_{6m,1m}$) and stock return. If financial markets perfectly and completely function well and the mean-variance efficiency of the market portfolio holds, market β is the only risk factor that can explain the cross-sectional variations in expected returns, as argued in the capital asset pricing model (CAPM).

As investors cannot hold perfectly diversified portfolios, Fama and French (1996) find that CAPM's measure of systematic risk is unreliable in practice and that firm size and book-to-market ratio are more valid. They argue that the three-factor model in Fama and French (1993) can capture the cross-sectional variations in equity returns better than the CAPM model. The Fama and French (1993) model has three factors: (i) $R_m - R_f$ (the excess return on the market), (ii) SMB (the difference in returns between small stocks and big stocks), and (iii) HML (the difference in returns between high book-to-market stocks and low book-to-market stocks).

To test whether the existing risk factor models can explain our result that $Ortho\ Spread_{6m,1m}$ ($Ortho\ Smirk_{6m,1m}, Ortho\ Convexity_{6m,1m}$) provides a negative prediction of the cross-section of future stock returns, we conduct a time-series test based on CAPM and the Fama-French three factor model, respectively. In addition to CAPM and Fama-French three factor model, we also conduct time-series analysis using an extended four-factor model (Carhart, 1997) that includes a momentum factor (UMD) suggested by Jegadeesh and Titman (1993; FF4).

[Insert Table 4 about here.]

Table 4 presents the coefficient of the CAPM, the three-factor model proposed in Fama and French, and the four-factor model proposed in Carhart (1997), time-series regressions for monthly excess returns on five portfolios sorted by $Ortho\ Spread_{6m}$ ($Ortho\ Smirk_{1m}$, $Ortho\ Convexity_{6m,1m}$). The six left-hand columns are the results using a portfolio sorted by $Ortho\ Spread_{6m,1m}$. The result shows that the estimated intercepts in the Q2 and Q3 $Ortho\ Spread_{6m,1m}$ portfolio ($\hat{\alpha}_{Q2}, \hat{\alpha}_{Q3}$) are statistically significant; we observe negative patterns with respect to portfolios formed by $Ortho\ Spread_{6m,1m}$. A trading strategy of buying the lowest and selling the highest (Q5) portfolio using $Ortho\ Spread_{6m,1m}$ ($\hat{\alpha}_{Q5} - \hat{\alpha}_{Q1}$) generates about 0.0037 alpha per month (t-statistic = 3.91) for CAPM, 0.0137 alpha per month (t-statistic = 3.75) for FF3, and 0.0136 alpha per month (t-statistic =3.74) for FF4. Following Gibbons, Ross, and Shanken (1989), we test the null hypothesis that all estimated intercepts are simultaneously equal to zero ($\hat{\alpha}_{Q1} = \cdots = \hat{\alpha}_{Q5} = 0$). The results show that this null hypothesis is rejected with a p-value < 0.001 in the CAPM, FF3, and FF4 model specifications. The pattern of alphas from the three different factor specifications implies that the abnormal returns of Q1-Q5 $Ortho\ Spread_{6m,1m}$ portfolios are not specific to asset pricing models and confirms that the widely accepted existing factors ($\mathrm{R_m} - R_f$, SMB, HML, UMD) cannot fully capture and explain the negative portfolio return patterns sorted by $Ortho\ Spread_{6m,1m}$. We may thus argue that the existing systematic risk factors cannot capture the information of $Ortho\ Spread_{6m,1m}$. Therefore, we argue that $Ortho\ Spread_{6m,1m}$ has additional explanatory power for capturing the cross-sectional variations in equity returns that cannot be fully explained by existing models (CAPM, FF3, and FF4).

When we conduct a time-series test using portfolios sorted by $Ortho\ Smirk_{6m,1m}$ to see whether the effect of $Ortho\ Smirk_{6m,1m}$ can be explained by existing risk factors, the alphas of the quintile portfolios sorted by $Ortho\ Smirk_{6m,1m}$ decline monotonically, from 0.0038 (0.0012, 0.0019) per month for the bottom quintile to -0.0005 (-0.0032, -0.0025) per month for the top quintile for the CAPM (FF3, FF4) model. The $Ortho\ Smirk_{6m,1m}$ portfolio with long stocks in the bottom $Ortho\ Smirk_{6m,1m}$ quintile and short stocks in the top quintile has a monthly alpha of 0.0043 (t-statistic = 3.62), 0.0044 (t-statistic = 3.91), and 0.0044 (t-statistic = 3.95) with respect to the CAPM, the Fama–French three-factor, and the Carhart four-factor model, respectively. The joint tests from Gibbons, Ross, and Shanken (1989) examining whether the model explains the average portfolio returns sorted by $Ortho\ Smirk_{6m,1m}$ are strongly rejected with a p-value < 0.001 for the CAPM, FF3, and FF4 models. This result implies that $Ortho\ Smirk_{6m,1m}$ is not explained by existing systematic risk factors. Thus, we infer that it is difficult to explain the decreasing pattern of portfolio returns shown in $Ortho\ Smirk_{6m,1m}$ using existing traditional risk-based factor models and that $Ortho\ Smirk_{6m,1m}$ can capture the cross-sectional variations in equity returns that cannot be fully explained by existing models (CAPM, FF3, and FF4).

As shown in the six right-hand columns, similar economically and statistically significant results are obtained for the monthly returns on $Ortho\ Convexity_{6m,1m}$ portfolios. The alpha differences between the lowest $Ortho\ Convexity_{6m,1m}$ and highest $Ortho\ Convexity_{6m,1m}$ portfolios are in the range of 0.0050 to 0.0052 per month, and are significant. For example, the CAPM alpha of the Q1−Q5 $Ortho\ Convexity_{6m,1m}$ is 0.0050 per month with 4.14 t-statistics, and the four-factor alpha is 0.0052 per month with 4.46 t-statistics.

3.3. Fama−Macbeth Regression

Having found the significance of the $Ortho\ Spread_{6m,1m}$ ($Ortho\ Smirk_{6m,1m}$, $Ortho\ Convexity_{6m,1m}$) as a determinant of the expected equity returns at the portfolio level, we turn to address additional aspect of $Ortho\ Spread_{6m,1m}$ ($Ortho\ Smirk_{6m,1m}$, $Ortho\ Convexity_{6m,1m}$) measurements for robustness. We conduct a Fama–Macbeth (1973) regression analysis at the firm level with various control variables to document the robustness of the cross-sectional negative relationship between $Ortho\ Spread_{6m,1m}$ ($Ortho\ Smirk_{6m,1m}$, $Ortho\ Convexity_{6m,1m}$) and the expected stock returns and investigate whether *IV convexity* has sufficient explanatory power beyond others suggested in the literature. In a Fama–Macbeth regression, the dependent variable is one-month ahead monthly returns.

We control for Market β (estimated following Fama and French [1992]), log market capitalization (*ln_mv*), book-to-market ratio (*btm*), momentum (*MOM*), reversal (*REV*), illiquidity (*ILLIQ*), options volatility slope (*IV spread* and *IV smirk*), and idiosyncratic risk (*idio_risk*) as common measures of risks that explain stock returns. We also include the measure of the option-implied volatility-related variables, implied volatility level (*IV level*), systematic implied volatility

(v_{sys}^2), and idiosyncratic implied variance (v_{idio}^2), as suggested by Duan and Wei (2009) and Dennis, Mayhew, and Stivers (2006). We run the monthly cross-sectional regression of individual stock returns of the subsequent month on $Spread_{1m}$ ($Smirk_{1m}$, $Convexity_{1m}$), $Ortho\ Spread_{6m,1m}$($Ortho\ Smirk_{6m,1m}$, $Ortho\ Convexity_{6m,1m}$) and other known measures of risks presented above.

[Insert Table 5 about here.]

Panel A in Table 5 reports the time-series averages of the coefficients from the regressions of expected stock returns on the $Spread_{1m}$, $Ortho\ Spread_{6m,1m}$, beta, size, book-to-market ratio, momentum, short-term reversal, illiquidity, idiosyncratic risk, *IV level*, and v_{sys}^2 v_{idio}^2 with the Newey–West adjusted t-statistics for the time-series average of coefficients with a lag of 3 over the sample period of 2000 to 2013. The column of Model 1 shows that the coefficient on $Spread_{1m}$ is significantly negative, confirming Yan's (2011) finding demonstrating the negative predictive relationship between $Spread_{1m}$ and future stock returns. When we include both $Spread_{1m}$ and $Ortho\ Spread_{6m,1m}$ as shown in Model 2, the coefficients on $Ortho\ Spread_{6m,1m}$ are significantly negative, indicating that $Ortho\ Spread_{6m,1m}$ has additional explanatory power for stock returns that $Spread_{1m}$ cannot fully capture. This result suggests that not only $Spread_{1m}$ but $Ortho\ Spread_{6m,1m}$ exhibits significant predictive power for stock returns, confirming the univariate sorting results in Table 3. The column of Model 3 and 4 shows the Fama–Macbeth regression results using market β and other stock fundamentals including firm-size (*ln_mv*), book-to-market ratio (*btm*), other systematic risks, *MOM*, *REV*, and *ILLIQ*. These variables are widely accepted stock characteristics that can capture the cross-sectional variation in stock returns. When the six control variables are included in the regression, not only the coefficient on $Spread_{1m}$ but also that on $Ortho\ Spread_{6m,1m}$ has negative values with negative significance. This result from cross-sectional regressions shows strong corroborating evidence for an economically and statistically significant negative relationship between the degree of $Ortho\ Spread_{6m,1m}$ and the expected stock returns.

Model 5 and Model 6 represent the Fama–Macbeth regression result using market β, *ln_mv*, *btm*, *MOM*, *REV*, *ILLIQ*, and idiosyncratic risk. The estimated coefficient on idiosyncratic risk suggested by Ang, Hodrick, Xing, and Zhang (2006) has a negative value and is significant. If an ideal asset pricing model can fully captures the cross-sectional variation in stock return, idiosyncratic risk should not be significantly priced. The relationship between idiosyncratic risk and stock returns is inconclusive and a matter of controversy among researchers. Ang, Hodrick, Xing, and Zhang (2006) show that stocks with low idiosyncratic risk earn higher average returns compared to high idiosyncratic risk portfolios and that the arbitrage portfolio for long high idiosyncratic risk and short low idiosyncratic risk earns significantly negative returns. However, other researchers argue that this relationship does not persist when different sample periods and equal-weighted returns are employed. Fu (2009) finds a significantly positive relationship between idiosyncratic risk and stock returns, whereas Bali and Cakici (2008) show no significant negative relationship but insignificant positive relationships when they form equal-weighted portfolios. Panel A of Table 6 shows that the estimated coefficient on the idiosyncratic risk has a negative value with statistical significance. This result implies that idiosyncratic risk is priced and that there may be other risk factors besides Market β, *ln_mv*, *btm*, *MOM*, *REV*, and *ILLIQ*. When looking at the coefficient on $Spread_{1m}$ and $Ortho\ Spread_{6m,1m}$, as in Model 5 and Model 6, We find a strong negative $Spread_{1m}$ and $Ortho\ Spread_{6m,1m}$ effect on returns, even after controlling for Market β, *ln_mv*, *btm*, *MOM*, *REV*, *ILLIQ* and idiosyncratic risk. Regarding this observation, we may conjecture that both $Spread_{1m}$ and $Ortho\ Spread_{6m,1m}$ explain the cross-sectional variation in returns that cannot be fully explained by Market β, *ln_mv*, *btm*, *MOM*, *REV*, *ILLIQ* or idiosyncratic risk; it is noteworthy that the statistical significance of $Ortho\ Spread_{6m,1m}$ remains, even after including both $Spread_{1m}$ and $Ortho\ Spread_{6m,1m}$ in Model 6.

In Models 7 and 8, we use alternative ex-ante volatility measures such as implied volatility level (*IV level*), systematic volatility (v_{sys}^2), and idiosyncratic implied variance (v_{idio}^2) in the model. The results show that the sign and significance for the $Spread_{1m}$ and $Ortho\ Spread_{6m,1m}$ coefficients remain unchanged; they still have significantly negative coefficients, confirming that the predictive power of $Ortho\ Spread_{6m,1m}$ for future stock return is independent of that of $Spread_{1m}$ and that $Ortho\ Smirk_{6m,1m}$ has sufficient explanatory power for future stock returns beyond $Spread_{1m}$. All in all, it can be inferred that there is no evidence that the existing risk factors suggested by previous studies can explain the negative return patterns in $Spread_{1m}$ and $Ortho\ Spread_{6m,1m}$ and that both $Spread_{1m}$ and $Ortho\ Spread_{6m,1m}$ may capture the cross-sectional variations in returns not explained by existing models.

In a similar way, we conduct additional Fama–MacBeth (1973) regression analyses using $Smirk_{1m}$ ($Convexity_{1m}$) and $Ortho\ Smirk_{6m,1m}$ ($Ortho\ Convexity_{6m,1m}$) to investigate whether the term-structure (from six months to one month) of implied volatility Smirk (Convexity) and short-term (one-month) implied volatility Smirk (Convexity) has distinct impacts on a cross-section of future stock returns. We also investigate whether $Ortho\ Smirk_{6m,1m}$ ($Ortho\ Convexity\ _{6m,1m}$) carries extra predictability for forecasting future stock returns even when controlling for the return predictability of the $Smirk_{1m}$ ($Convexity_{1m}$) of stock return distribution, as identified by Xing et al. (2010) and Part et al. (2016). Notice that we do not include the co-skewness factor in the Fama–Macbeth (1973) regression. Harvey and Siddique (2000) argue that co-skewness is related to the momentum effect, as the low momentum portfolio returns tend to have higher skewness than high momentum portfolio returns. Thus, we exclude co-skewness from the Fama–Macbeth regression specification to avoid the multicollinearity problem with the momentum factor.

As reported in Panel B of Table 5, the regressions of $Smirk_{1m}$ and $Ortho\ Smirk_{6m,1m}$ in Model 2 show that the estimated coefficients on $Smirk_{1m}$ and $Ortho\ Smirk_{6m,1m}$ are significantly negative (-0.024 and -0.059 with t-statistics of -4.78 and -3.81, respectively), confirming our previous findings from the portfolio formation approach in Panel B in Table 3. As shown in Models 3 to 6, the coefficients on the $Smirk_{1m}$ and $Ortho\ Smirk_{6m,1m}$ maintain their statistical significance even after controlling for Market β, *ln_mv*, *btm*, *MOM*, *REV*, and idiosyncratic risk. In Model 3 and Model 5, $Smirk_{1m}$ has a significantly negative average coefficient, confirming Xing et al.'s (2010) empirical findings. When adding the $Ortho\ Smirk_{6m,1m}$ variables in the model, as in Model 4 and Model 6, we can observe that both $Smirk_{1m}$ and $Ortho\ Smirk_{6m,1m}$ have negative values and keep their statistical significance. Our findings suggest that not only $Smirk_{1m}$ but $Ortho\ Smirk_{6m,1m}$ can exhibit significant predictive power for future stock returns, even after we control for the risk factors suggested by the literature. The statistical significance of both $Smirk_{1m}$ and $Ortho\ Smirk_{6m,1m}$ is intact even after including alternative ex-ante volatility measures such as implied volatility level (*IV level*), systematic volatility (v_{sys}^2), and idiosyncratic implied variance (v_{idio}^2) in Model 7 and Model 8, respectively. We observe similar results, confirming that the cross-sectional predictive power of $Smirk_{1m}$ and $Ortho\ Smirk_{6m,1m}$ is statistically significant. These results provide more evidence that, although $Ortho\ Smirk_{6m,1m}$ does not contain the information of the one-month *Smirk*, the negative relationship between $Ortho\ Smirk_{6m,1m}$ and stock return persists, confirming that $Ortho\ Smirk_{6m,1m}$ has additional forecasting power for cross-section variations of future stock returns beyond $Smirk_{1m}$ even after controlling for the existing risk factors suggested by prior studies.

Finally, Panel C of Table 5 presents the result of Fama–MacBeth regressions using $Convexity_{1m}$ and $Ortho\ Convexity_{6m,1m}$. The univariate regressions of $Convexity_{1m}$ in Model 1 show that the estimated coefficients on $Convexity_{1m}$ are significantly negative (-0.014 with t-statistics of -6.73), confirming Park et al.'s (2016) empirical findings. The regression results of $Convexity_{1m}$ and $Ortho\ Convexity_{6m,1m}$ in Model 2 show that the estimated coefficients on $Convexity_{1m}$ and $Ortho\ Convexity_{6m,1m}$ have negative values (-0.014 and -0.038) with t-statistics of -6.73 and -3.51, respectively, confirming our previous findings from the portfolio formation approach in Panel C in Table 3. These results also suggest that the information of term-structure of implied volatility convexity and that of short-term implied volatility convexity has distinct effects on a cross-section of future stock returns. Furthermore, we find that the predictive power of $Ortho\ Convexity_{6m,1m}$ is independent of that of $Convexity_{1m}$, and that $Ortho\ Convexity_{6m,1m}$ has extra explanatory power for future stock return variations over $Convexity_{1m}$. Note that the coefficients on $Convexity_{1m}$ and $Ortho\ Convexity_{6m,1m}$ keep their statistical significance even after controlling for Market β, *ln_mv*, *btm*, *MOM*, *REV*, and idiosyncratic risk, as shown in Models 3 to 6. In Model 3 and Model 5, $Convexity_{1m}$ has a significantly negative average coefficient, confirming Park et al.'s (2016) empirical findings. We can also observe that both $Convexity_{1m}$ and $Ortho\ Convexity_{6m,1m}$ have negative values and keep their statistical significance even when adding $Ortho\ Convexity_{6m,1m}$ variables in the model, as in Model 4 and Model 6. These findings suggest that not only $Convexity_{1m}$ but

$Ortho\ Convexity_{6m,1m}$ can exhibit significant predictive power for future stock returns, even after we control for the existing risk factors suggested by existing literature.

Model 7 and Model 8 show the result of adding alternative ex-ante volatility measures, implied volatility level (*IV level*), systematic volatility (v_{sys}^2), and idiosyncratic implied variance (v_{idio}^2) as control variables in the model. The results show that the sign and significance of $Convexity_{1m}$ and $Ortho\ Convexity_{6m,1m}$ coefficients remain unchanged and that they still have significantly negative coefficients. These results confirm that the predictive power of $Ortho\ Convexity_{6m,1m}$ for future stock returns is independent of that of $Convexity_{1m}$ and that $Ortho\ Convexity_{6m,1m}$ has sufficient explanatory power for future stock returns beyond $Convexity_{1m}$. There is seemingly no evidence that the existing risk factors proposed by previous studies can explain the positive profits from the zero-cost portfolio formed by $Spread_{1m}$ (or $Ortho\ Spread_{6m,1m}$); both $Convexity_{1m}$ and $Ortho\ Convexity_{6m,1m}$ may capture the cross-sectional variations in returns left unexplained by existing models.

3.4. Different Holding Periods

We turn to examine how long the arbitrage strategy based on $Ortho\ spread_{6m,1m}$ ($ortho\ smirk_{6m,1m}$, $ortho\ convexity_{6m,1m}$) portfolios continues to generate profits by varying investment horizons.

[Insert Table 6 about here.]

Table 6 reports the average risk-adjusted monthly returns (using Cahart four-factor model) of the quintile portfolios formed on $Ortho\ spread_{6m,1m}$ ($ortho\ smirk_{6m,1m}$, $ortho\ convexity_{6m,1m}$) for holding periods ranging from one month to six months, where "Q1–Q5" denotes a long-short arbitrage portfolio that buys a low-convexity portfolio and sells a high-convexity portfolio. The t-statistics are computed using the Newey–West procedure to adjust the serially correlated returns of overlapping samples. Though the decreasing patterns in the $Ortho\ spread_{6m,1m}$ ($ortho\ smirk_{6m,1m}$, $ortho\ convexity_{6m,1m}$) portfolio returns are slightly distorted and the decreasing patterns are less pronounced as the holding period increases, a trading strategy with a long position in low $Ortho\ spread_{6m,1m}$ ($ortho\ smirk_{6m,1m}$,

$ortho\ convexity_{6m,1m}$) stocks and a short position in high $Ortho\ spread_{6m,1m}$ ($ortho\ smirk_{6m,1m}$, $ortho\ convexity_{6m,1m}$) stocks still yields significantly positive profits. Note that the arbitrage $Ortho\ spread_{6m,1m}$ portfolio return decreases from 0.0036 (t-statistic = 3.74) for a one-month holding period to 0.0007 (t-statistic = 1.34) for a six-month holding period. For the $ortho\ smirk_{6m,1m}$ and $ortho\ convexity_{6m,1m}$ variables, similar results are observed: the arbitrage $Ortho\ Smirk_{6m,1m}$ portfolio return decreases from 0.0044 (t-statistic = 3.95) for a one-month holding period to 0.0011 (t-statistic = 2,59) for a six-month holding period, and the arbitrage $Ortho\ Convexity_{6m,1m}$ portfolio return decreases from 0.0052 (t-statistic = 4.46) for a one-month holding period to 0.0011 (t-statistic = 2.50) for a six-month holding period. These results imply that the opportunity to create arbitrage profits using $Ortho\ spread_{6m,1m}$ ($ortho\ smirk_{6m,1m}$, $ortho\ convexity_{6m,1m}$) information can be realized in the first month for the most part and then gradually disappears as portfolios are held for up to six months.

4. Conclusion

This study finds that the term structure of the shape of option-implied volatility curves contains meaningful information for predicting the future returns of underlying stocks. By adopting well-known measures showing stock return predictability such as *IV spread*, *IV smirk*, and *IV convexity* extracted from the market-observed equity option prices across different strikes and maturities, we explore the implication of informed options trading on the implied volatility surfaces. Using equity options data for U.S. listed stocks during the period from 2000 to 2013, we find that the investment horizon of options trading is informative, as the shape of the long-term implied volatility curve exhibits extra predictive power for subsequent months' stock returns even after we orthogonalize the short-term components and existing predictors based on stock characteristics. This observation suggests that the informed long-term options trading does capture new perceptions of higher moment risk that have not yet flowed through to the stock market and thereby contributes to the short-term price discovery process, as the equity market updates its valuation by digesting the extra information prevailing in the options market prior to the expiration of options. Our findings are robust across different term spreads and various holding periods.

References

Amihud, Yakov, 2002, Illiquidity and stock returns: Cross-section and time-series effects, *Journal of Financial Markets* 5, 31–56.

Andries, Marianne, et al. “The term structure of the price of variance risk.” *FRB of New York Working Paper No. FEDNSR736* (2015).

Andries, Marianne, Thomas M. Eisenbach, and Martin C. Schmalz. “Asset pricing with horizon-dependent risk aversion.” *FRB of New York Staff Report* 703 (2015).

Ang, Andrew, Robert Hodrick, Yuhang Xing, and Xiaoyan Zhang, 2006, The cross-section of volatility and expected returns, *Journal of Finance* 61, 259–299.

Bali, Turan G., and Nusret Cakici, 2008, Idiosyncratic volatility and the cross-section of expected returns, *Journal of Financial and Quantitative Analysis* 43, 29–58.

Bessembinder, Hendrik, et al. "Mean reversion in equilibrium asset prices: evidence from the futures term structure." *The Journal of Finance* 50.1 (1995): 361-375.

Boudoukh, Jacob, and Matthew Richardson. "Stock returns and inflation: A long-horizon perspective." *The American Economic Review* 83.5 (1993): 1346-1355.

Campbell, John Y., and Luis M. Viceira. "The term structure of the risk-return trade-off." *Financial Analysts Journal* 61.1 (2005): 34-44.

Cox, John C., Jonathan E. Ingersoll Jr, and Stephen A. Ross. "A theory of the term structure of interest rates." *Econometrica: Journal of the Econometric Society* (1985): 385-407.

Cox, John C., Stephen A. Ross, and Mark Rubinstein. "Option pricing: A simplified approach." *Journal of financial Economics* 7.3 (1979): 229-263.

Christoffersen, Peter, Steven Heston, and Kris Jacobs. "The shape and term structure of the index option smirk: Why multifactor stochastic volatility models work so well." *Management Science* 55.12 (2009): 1914-1932.

Das, Sanjiv Ranjan, and Rangarajan K. Sundaram. "Of smiles and smirks: A term structure perspective." *Journal of financial and quantitative analysis* 34.02 (1999): 211-239.

Day, Theodore E., and Craig M. Lewis. "Stock market volatility and the information content of stock index options." *Journal of Econometrics* 52.1-2 (1992): 267-287.

Dennis, Patrick, Stewart Mayhew, and Chris Stivers. "Stock returns, implied volatility innovations, and the asymmetric volatility phenomenon." *Journal of Financial and Quantitative Analysis* 41.02 (2006): 381-406.

Duan, Jin-Chuan, and Jason Wei. "Systematic risk and the price structure of individual equity options." *Review of Financial Studies* 22.5 (2009): 1981-2006.

Fama, Eugene F., and Kenneth R. French. "Common risk factors in the returns on stocks and bonds." *Journal of Financial Economics* 33.1 (1993): 3-56.

Fama, Eugene F., and Kenneth R. French. "Multifactor explanations of asset pricing anomalies." *The journal of finance* 51.1 (1996): 55-84.

Fama, Eugene F., and James D. MacBeth. "Risk, return, and equilibrium: Empirical tests." *The journal of political economy* (1973): 607-636.

Gibbons, Michael R., Stephen A. Ross, and Jay Shanken. "A test of the efficiency of a given portfolio." *Econometrica: Journal of the Econometric Society* (1989): 1121-1152.

Han, Bing, Avanidhar Subrahmanyam and Yi Zhou. "Term structure of credit default swap spreads and cross-section of stock returns." SSRN

Harvey, Campbell R. "The real term structure and consumption growth." *Journal of Financial Economics* 22.2 (1988): 305-333.

Harvey, Campbell R. "The world price of covariance risk." *The Journal of Finance* 46.1 (1991): 111-157.

Hasbrouck, Joel. "Trading costs and returns for US equities: Estimating effective costs from daily data." *The Journal of Finance* 64.3 (2009): 1445-1477.

Heston, Steven L. "A closed-form solution for options with stochastic volatility with applications to bond and currency options." *Review of financial studies* 6.2 (1993): 327-343.

Jegadeesh, Narasimhan, and Sheridan Titman. "Returns to buying winners and selling losers: Implications for stock market efficiency." *The Journal of finance* 48.1 (1993): 65-91.

Jin, Wen, Joshua Livnat, and Yuan Zhang. "Option prices leading equity prices: Do option traders have an information advantage?" *Journal of Accounting Research* 50.2 (2012): 401-432.

Johnson, Travis L. "Risk premia and the VIX term structure." *Available at SSRN 2548050* (2016).

Jones, C., and Tong Wang. "The term structure of equity option implied volatility." *Unpublished working paper. University of Southern California* (2012).

Keim, Donald B., and Robert F. Stambaugh. "Predicting returns in the stock and bond markets." *Journal of financial Economics* 17.2 (1986): 357-390.

Lamoureux, Christopher G., and William D. Lastrapes. "Forecasting stock-return variance: Toward an understanding of stochastic implied volatilities." *Review of Financial Studies* 6.2 (1993): 293-326.

Lehmann, Bruce. "Fads, martingales, and market efficiency." (1988).

Lettau, Martin, and Sydney Ludvigson. "Time-varying risk premia and the cost of capital: An alternative implication of the Q theory of investment." *Journal of Monetary Economics* 49.1 (2002): 31-66.

Merton, Robert C. "Theory of rational option pricing." *The Bell Journal of Economics and Management Science* (1973): 141-183.

Park, Hye-hyun, Baeho Kim, and Hyeongsop Shim. "A smiling bear in the equity options market and the cross-section of stock returns." *Available at SSRN 2632763* (2015).

Stock, James H., and Mark W. Watson. "New indexes of coincident and leading economic indicators." *NBER Macroeconomics Annual 1989, Volume 4*. MIT press, 1989. 351-409.

Vasquez, Aurelio. "Equity volatility term structures and the cross-section of option returns." *Available at SSRN 1944298* (2015).

Vogt, Erik. "Option-implied term structures." *Available at SSRN 2541954* (2014).

Xie, Chen. "Asset pricing implications of volatility term structure risk." *Available at SSRN 2517868* (2014).

Xing, Yuhang, Xiaoyan Zhang, and Rui Zhao. "What does the individual option volatility smirk tell us about future equity returns?" (2010): 641-662.

Xu, Xinzhong, and Stephen J. Taylor. "The term structure of volatility implied by foreign exchange options." *Journal of Financial and Quantitative Analysis* 29.01 (1994): 57-74.

Yan, Shu. "Jump risk, stock returns, and slope of implied volatility smile." *Journal of Financial Economics* 99.1 (2011): 216-233.

Table 1. Descriptive Statistics: Option-implied volatilities and sample distribution by year and industry

Panel A reports the summary statistics of the fitted implied volatilities and fixed deltas of the individual equity options with one month (30 days), two months (60 days), three months (91 days), and six months (182days) to expiration at the end of the month obtained from OptionMetrics. DS measures the degree of accuracy in the fitting process at each point and is computed by the weighted average standard deviations. The sample period covers Jan 2000 to Dec 2013. Panel B reports the unique number of firms each year and industry. Using SIC code, we assign every firm to the respective Fama–French 12-industry (FF12) classification industry.

Panel A. Summary statistics of the fitted implied volatilities

		Call												
Maturity	delta	20	25	30	35	40	45	50	55	60	65	70	75	80
30 days	Mean	0.4942	0.4817	0.4739	0.4696	0.4677	0.4676	0.4694	0.4730	0.4779	0.4841	0.4917	0.5019	0.5157
	stdev	0.2774	0.2764	0.2755	0.2746	0.2735	0.2724	0.2722	0.2732	0.2744	0.2763	0.2783	0.2808	0.2840
	DS	0.0502	0.0397	0.0306	0.0244	0.0208	0.0190	0.0182	0.0181	0.0190	0.0213	0.0258	0.0334	0.0436
60 days	Mean	0.4748	0.4671	0.4626	0.4607	0.4606	0.4619	0.4644	0.4683	0.4734	0.4795	0.4868	0.4961	0.5081
	stdev	0.2670	0.2660	0.2651	0.2645	0.2639	0.2635	0.2637	0.2649	0.2664	0.2681	0.2699	0.2719	0.2742
	DS	0.0328	0.0264	0.0206	0.0166	0.0145	0.0135	0.0133	0.0135	0.0144	0.0162	0.0196	0.0252	0.0329
91 days	Mean	0.4562	0.4518	0.4498	0.4497	0.4510	0.4533	0.4566	0.4609	0.4660	0.4720	0.4792	0.4879	0.4989
	stdev	0.2552	0.2537	0.2526	0.2519	0.2517	0.2518	0.2525	0.2537	0.2550	0.2566	0.2586	0.2607	0.2630
	DS	0.0269	0.0220	0.0178	0.0151	0.0135	0.0128	0.0127	0.0130	0.0138	0.0153	0.0181	0.0229	0.0298
182 days	Mean	0.4398	0.4385	0.4384	0.4394	0.4414	0.4442	0.4477	0.4521	0.4574	0.4634	0.4704	0.4783	0.4874
	stdev	0.4398	0.4385	0.4384	0.4394	0.4414	0.4442	0.4477	0.4521	0.4574	0.4634	0.4704	0.4783	0.4874
	DS	0.0178	0.0159	0.0141	0.0129	0.0122	0.012	0.0121	0.0126	0.0134	0.0146	0.0166	0.0198	0.0241

		Put												
Maturity	delta	-80	-75	-70	-65	-60	-55	-50	-45	-40	-35	-30	-25	-20
30 days	Mean	0.4958	0.4855	0.4788	0.4755	0.4745	0.4755	0.4784	0.4831	0.4893	0.4970	0.5067	0.5199	0.5381
	stdev	0.2976	0.2919	0.2876	0.2846	0.2821	0.2803	0.2796	0.2797	0.2803	0.2813	0.2823	0.2836	0.2844
	DS	0.0452	0.0369	0.0289	0.0231	0.0197	0.0181	0.0178	0.0183	0.0198	0.0228	0.0285	0.0382	0.0514
60 days	Mean	0.4805	0.4741	0.4700	0.4684	0.4687	0.4705	0.4738	0.4785	0.4845	0.4918	0.5008	0.5123	0.5279
	stdev	0.2843	0.2801	0.2765	0.2741	0.2723	0.2713	0.2709	0.2713	0.2723	0.2736	0.2751	0.2767	0.2778
	DS	0.0315	0.0261	0.0208	0.0168	0.0144	0.0133	0.013	0.0134	0.0145	0.0166	0.0207	0.0278	0.0379
91 days	Mean	0.4667	0.4627	0.4606	0.4602	0.4613	0.4636	0.4671	0.4717	0.4775	0.4845	0.4930	0.5038	0.5178
	stdev	0.2729	0.2691	0.2658	0.2631	0.2613	0.2602	0.2599	0.2603	0.2611	0.2623	0.2641	0.2660	0.2679
	DS	0.0275	0.0228	0.0185	0.0154	0.0136	0.0127	0.0126	0.0129	0.0138	0.0156	0.0189	0.0247	0.0334
182 days	Mean	0.4521	0.4508	0.4505	0.4513	0.4530	0.4556	0.4592	0.4638	0.4695	0.4763	0.4843	0.4940	0.5060
	stdev	0.2565	0.2541	0.2519	0.2502	0.2488	0.2480	0.2477	0.2480	0.2490	0.2505	0.2523	0.2547	0.2574
	DS	0.0191	0.0167	0.0146	0.0131	0.0122	0.0119	0.0120	0.0125	0.0134	0.0149	0.0174	0.0214	0.0270

Panel B. Number of firms

Year	FF1	FF2	FF3	FF4	FF5	FF6	FF7	FF8	FF9	FF10	FF11	FF12
2000	121	59	214	94	56	700	165	81	263	229	332	586
2001	86	49	167	90	50	641	145	71	219	233	290	518
2002	91	45	170	88	58	539	94	73	235	246	333	493
2003	90	47	165	82	55	476	77	73	235	233	349	479
2004	89	49	178	100	53	515	94	79	248	271	372	522
2005	93	50	200	122	56	521	95	82	258	281	466	558
2006	102	54	231	138	68	529	97	87	279	298	597	620
2007	104	63	248	156	74	545	105	96	287	303	734	704
2008	113	63	246	157	75	517	101	105	276	278	823	703
2009	110	56	232	154	70	460	87	110	283	269	794	705
2010	120	56	237	168	70	479	88	113	285	282	823	795
2011	126	58	254	190	76	521	90	115	294	293	903	913
2012	123	56	251	198	73	493	84	116	297	292	934	978
2013	131	63	252	203	75	493	91	115	295	287	1069	1085

Table 2. Descriptive Statistics

Panel A reports the descriptive statistics of $Spread\ (Smirk, Convexity)_{6m}$, $Spread\ (Smirk, Convexity)_{1m}$ and $Ortho\ Spread\ (Smirk, Convexity)_{6m,1m}$. Option-implied volatility spread is defined by $Spread_{6m\ (or\ 1m)} = \mathrm{IV}_{\mathrm{put,\ 6m\ (or\ 1m)}}(-0.5) - \mathrm{IV}_{\mathrm{call,\ 6m\ (or\ 1m)}}(0.5)$. Option-implied volatility smirk is defined as $smirk_{6m\ (or\ 1m)} = \mathrm{IV}_{\mathrm{put,\ 6m\ }(or\ 1m)}(-0.2) - \mathrm{IV}_{\mathrm{call,\ 6m\ }(or\ 1m)}(0.5)$, $convexity_{6m\ (or\ 1m)} = \mathrm{IV}_{\mathrm{put,\ 6m\ }(or\ 1m)}(-0.2) + \mathrm{IV}_{\mathrm{put,\ 6m\ }(or\ 1m)}(-0.8) - 2 \times \mathrm{IV}_{\mathrm{call,\ 6m\ }(or\ 1m)}(0.5)$, respectively.

Using daily $Spread_{6m}$ ($Smirk_{6m}$, $Convexity_{6m}$) and $Spread_{1m}$ ($Smirk_{1m}$, $Convexity_{1m}$), we conduct time series regressions every each month to decompose $Spread_{6m}$ ($smirk_{6m}$, $convexity_{6m}$) into the predictive and orthogonalized components given by:

$$Spread\ (or\ Smirk, Convexity)_{i,6m,t-30\sim t} = \alpha_i + b_i Spread\ \ (or\ Smirk, Convexity)_{i,1m,t-30\sim t} + \varepsilon_{i,t}$$

The predictive values and the residual terms at the end of each month are defined as $ortho\ spread_{6m,1m}$ ($ortho\ smirk_{6m,1m}$, $ortho\ convexity_{6m,1m}$), respectively. To reduce the impact of infrequent trading on estimates, a minimum of 10 trading days in a month is required.

Panel B shows the descriptive statistics of firm characteristic variables. Size (ln_mv) is computed at the end of each month and we define size as natural logarithm of the market capitalization. When computing book-to-market ratio (BTM), we match the yearly BE (book value of common equity (CEQ) plus deferred taxes and investment tax credit (txditc)) for all fiscal years ending at year t-1 to returns starting in July of year t, and this BE is divided by market capitalization at month t-1. Beta (β) is estimated from time-series regressions of raw stock excess returns on the Rm-Rf by month-by-month rolling over past three-year (36 months) returns (a minimum of 12 months). Momentum (MOM) is computed based on past cumulative returns over the past 5 months (t-6 to t-2) following Jegadeesh and Titman (1993). Reversal (REV) is computed based on past one-month return (t-1) following Jegadeesh (1990) and Lehmann(1990). Illiquidity (ILLIQ) is the average of the absolute value of stock return divided by the trading volume of the stock in thousand USD calculated using past one month daily data following Amihud (2002). The sample period covers from Jan 2000 to Dec 2013.

Panel A. Option-implied volatility spread, term convexity, the predictive term spread, and orthogonalized term spread

	End of Month						Daily			End of Month		
	$Spread_{1m}$	$Smirk_{1m}$	$Convexity_{1m}$	$Spread_{6m}$	$Smirk_{6m}$	$Convexity_{6m}$	$Ortho\ spread_{6m,1m}$	$Ortho\ smirk_{6m,1m}$	$Ortho\ convexity_{6m,1m}$	$Ortho\ spread_{6m,1m}$	$Ortho\ smirk_{6m,1m}$	$Ortho\ convexity_{6m,1m}$
Mean	0.009	0.069	0.095	0.011	0.058	0.063	0.000	0.000	0.000	0.000	0.000	-0.002
Median	0.005	0.052	0.059	0.005	0.046	0.038	0.000	0.000	0.000	0.000	0.000	-0.001
Q1	-0.012	0.022	0.002	-0.005	0.026	0.009	-0.005	-0.007	-0.016	-0.006	-0.009	-0.02
Q3	0.024	0.098	0.153	0.02	0.075	0.086	0.005	0.007	0.016	0.005	0.008	0.016
Stdev	0.124	0.142	0.279	0.086	0.097	0.184	0.039	0.048	0.081	0.041	0.052	0.086

Panel B. Firm Characteristic Variables

Size			BTM			Beta (β)			MOM			REV			ILLIQ($\times 10^6$)			Coskew		
Mean	Median	Stdev	Mean	Median	Stdev	Mean	Median	Stdev	Mean	Median	Stdev	Mean	Median	Stdev	Mean	Median	Stdev	Mean	Median	Stdev
19.4607	19.3757	2.1054	0.9186	0.5472	2.3613	1.1720	0.9808	1.1860	0.0966	0.0461	0.4515	0.0187	0.0080	0.1701	0.7808	0.0183	5.2832	-1.3516	-0.5745	15.2483

Table 3. Average returns sorted by term spread

Panel A reports the average portfolio monthly returns sorted by $Spread_{6m}$, $Spread_{1m}$ and $Ortho\ Spread_{6m,1m}$. We calculate $Spread_{6m\ (or\ 1m)} = \mathrm{IV}_{\mathrm{put,\ 6m\ (or\ 1m)}}(-0.5) - \mathrm{IV}_{\mathrm{call,\ 6m\ (or\ 1m)}}(0.5)$. $Ortho\ Spread_{6m,1m}$ is estimated by regressing $Spread_{6m}$ on $Spread_{1m}$ using over the last 30 days as below:

$$Spread_{6m,i,t-30\sim t} = \alpha_i + b_i Spread_{1m,i,t-30\sim t} + \varepsilon_{i,t}$$

$Ortho\ Spread_{6m,1m}$ is defined by the residual term at the end (last trading day) of each month. To reduce the impact of infrequent trading on estimates, a minimum of 10 trading days in a month is required. Panel B presents the corresponding results from the quintile portfolios of $Smirk_{6m}$, $Smirk_{1m}$ and $Ortho\ Smirk_{6m,1m}$. Panel C presents the corresponding results from the quintile portfolios of $Convexity_{6m}$, $Convexity_{1m}$ and $Ortho\ Convexity_{6m,1m}$.Options implied volatility smirk is defined as $smirk_{6m\ (or\ 1m)} = \mathrm{IV}_{\mathrm{put,\ 6m\ }(or\ 1m)}(-0.2) - \mathrm{IV}_{\mathrm{call,\ 6m\ }(or\ 1m)}(0.5)$, $convexity_{6m\ (or\ 1m)} = \mathrm{IV}_{\mathrm{put,\ 6m\ }(or\ 1m)}(-0.2) + \mathrm{IV}_{\mathrm{put,\ 6m\ }(or\ 1m)}(-0.8) - 2 \times \mathrm{IV}_{\mathrm{call,\ 6m\ }(or\ 1m)}(0.5)$, respectively. $Ortho\ Smirk_{6m,1m}$ and $Ortho\ Conovexity_{6m,1m}$ is estimated in a similar way when estimating $Ortho\ Spread_{6m,1m}$. On the last trading day of every each month, all firms are assigned to one of five portfolio groups based on $Spread\ (Smirk,\ Convexity)_{6m}$, $Spread\ (Smirk,\ Convexity)_{1m}$ and $Ortho\ Spread\ (Ortho\ Smirk,\ Ortho\ Convexity)_{6m,1m}$and we assume stocks are held for the next one-month-period. This process is repeated for every month. Monthly stock returns are obtained from the Center for Research in Security Prices (CRSP) with stocks traded on the NYSE (exchcd=1), Amex (exchcd=2) and NASDAQ (exchcd=3). We use only common shares (shrcd in 10, 11). The sample excludes stocks with a price of less than three dollars. "Q1–Q5" denotes an arbitrage portfolio that buys a low option-implied convexity portfolio (Q1) and sells a high *IV convexity* portfolio (Q5). The sample period covers Jan 2000 to Dec 2013. Numbers in parentheses indicate t-statistics.

Panel A. $Spread_{6m}$, $Spread_{1m}$ and $Ortho\ spread_{6m,1m}$

	Spread											
	$Spread_{6m}$				$Spread_{1m}$				$Ortho\ Spread_{6m,1m}$			
Quintile	Avg # of firms	Mean	Stdev	Unadjusted Return	Avg # of firms	Mean	Stdev	Unadjusted Return	Avg # of firms	Mean	Stdev	Unadjusted Return
Q1 (Low)	379	-0.0452	0.094	0.0149	379	-0.0797	0.1422	0.0143	363	-0.0313	0.0574	0.0102
Q2	401	-0.0026	0.0074	0.0105	383	-0.0086	0.0117	0.0103	365	-0.0048	0.0035	0.0094
Q3	390	0.0056	0.0065	0.0081	374	0.005	0.01	0.0078	370	-0.0002	0.0018	0.0079
Q4	346	0.0162	0.0104	0.0065	349	0.0207	0.0161	0.0068	363	0.0044	0.0034	0.0071
Q5 (High)	308	0.0911	0.1457	-0.0003	341	0.1146	0.1893	0.0012	358	0.0306	0.0519	0.0064
Q1-Q5				0.0152				0.013				0.0038
t-statistic				[8.12]				[7.44]				[3.72]

Panel B. $Smirk_{6m}$, $Smirk_{1m}$ and $Ortho\ smirk_{6m,1m}$

	Smirk											
	$Smirk_{6m}$				$Smirk_{1m}$				$Ortho\ Smirk_{6m,1m}$			
Quintile	Avg # of firms	Mean	Stdev	Unadjusted Return	Avg # of firms	Mean	Stdev	Unadjusted Return	Avg # of firms	Mean	Stdev	Unadjusted Return
Q1 (Low)	351	-0.0155	0.092	0.0147	378	-0.0494	0.1384	0.0136	367	-0.0413	0.0611	0.0104
Q2	385	0.033	0.0158	0.0115	379	0.0298	0.017	0.01	364	-0.0074	0.0047	0.0089
Q3	384	0.0478	0.0191	0.008	371	0.0537	0.02	0.0068	365	-0.0005	0.003	0.0085
Q4	358	0.0659	0.0244	0.0064	362	0.086	0.0279	0.0067	362	0.006	0.0049	0.0071
Q5 (High)	347	0.1561	0.1471	0.0005	335	0.2201	0.1895	0.0032	362	0.0416	0.0733	0.006
Q1-Q5				0.0142				0.0104				0.0044
t-statistic				[6.92]				[5.16]				[3.98]

Panel C. $Convexity_{6m}$, $Convexity_{1m}$ and $Ortho\ convexity_{6m,1m}$

	Convexity											
	$Convexity_{6m}$				$Convexity_{1m}$				$Ortho\ Convexity_{6m,1m}$			
Quintile	Avg # of firms	Mean	Stdev	Unadjusted Return	Avg # of firms	Mean	Stdev	Unadjusted Return	Avg # of firms	Mean	Stdev	Unadjusted Return
Q1 (Low)	380	-0.0699	0.1754	0.0149	389	-0.1378	0.2755	0.0136	367	-0.0779	0.1042	0.0102
Q2	395	0.0158	0.0187	0.0115	377	0.0155	0.0321	0.0103	364	-0.0162	0.0102	0.01
Q3	379	0.0401	0.0214	0.0083	367	0.064	0.0398	0.0079	364	-0.0018	0.0059	0.0087
Q4	347	0.0736	0.0352	0.0062	356	0.1334	0.0666	0.0067	363	0.0121	0.0094	0.0069
Q5 (High)	325	0.2578	0.2886	-0.0007	336	0.4043	0.3698	0.0018	361	0.0761	0.1029	0.005
Q1-Q5				0.0156				0.0119				0.0052
t-statistic				[8.56]				[7.07]				[4.68]

Table 4. Time series tests of 3- and 4-factor models using $Ortho\ sp_{6m,1m}$ ($ortho\ smirk_{6m,1m}$, $ortho\ convexity_{6m,1m}$) quintiles

This table presents the coefficient estimates of CAPM, Fama–French three- (four-) factor models for monthly excess returns on *IV convexity* quintiles portfolios. Fama–French factors [$R_M - R_f$], small market capitalization minus big (SMB), and high book-to-market ratio minus low (HML), and momentum factor (UMD)] are obtained from Kenneth French's website. $Ortho\ sp_{6m,1m}$ ($ortho\ smirk_{6m,1m}$, $ortho\ convexity_{6m,1m}$) quintiles are formed as in Table 3. The sample period covers Jan 2000 to Dec 2013 with stocks traded on the NYSE (exchcd=1), Amex (exchcd=2) and NASDAQ (exchcd=3). Stocks with a price of less than three dollars are excluded from the sample, and Newey–West (1987) adjusted t-statistics are reported in square brackets. The last row in each model labeled "Joint test p-value" reports a Gibbons, Ross, and Shanken (1989) result of testing the null hypothesis that all intercepts are jointly zero or $\hat{\alpha}_{Q1} = \cdots = \hat{\alpha}_{Q5} = 0$.

Model	Factor sensitivities		$Ortho\ spread_{6m,1m}$						$Ortho\ smirk_{6m,1m}$						$Ortho\ convexity_{6m,1m}$					
		Statistics	Q1	Q2	Q3	Q4	Q5	Q1-Q5	Q1	Q2	Q3	Q4	Q5	Q1-Q5	Q1	Q2	Q3	Q4	Q5	Q1-Q5
CAPM	Alpha	Coefficient	0.0034	0.0038	0.0023	0.0017	-0.0003	0.0037	0.0038	0.0033	0.0030	0.0013	-0.0005	0.0043	0.0036	0.0043	0.0031	0.0013	-0.0015	0.0050
		t-stat	(1.52	2.62	1.74	1.14	-0.13	3.91	1.63	2.33	2.15	0.94	-0.22	3.62	1.48	3.11	2.33	0.98	-0.71	4.14
	MKTRF	Coefficient	1.5129	1.2922	1.2783	1.2702	1.5122	0.0007	1.5287	1.2876	1.2433	1.2773	1.5210	0.0077	1.5463	1.2721	1.2470	1.2788	1.5165	0.0298
		t-stat	(32.08	43.42	40.59	46.57	32.03	0.03	28.18	36.46	39.68	40.52	35.70	0.28	26.96	43.74	42.09	48.02	34.52	0.83
	$\overline{Adj}\ R^2$		0.8386	0.9004	0.9004	0.9142	0.8439	0.0000	0.8371	0.8982	0.9145	0.9127	0.8401	0.0000	0.8262	0.9047	0.9161	0.9166	0.8437	0.0028
	Joint test: p-value				(<.0001)						(<.0001)						(<.0001)			
FF3	Alpha	Coefficient	0.0008	0.0015	0.0008	-0.0002	-0.0029	0.0037	0.0012	0.0014	0.0011	-0.0005	-0.0032	0.0044	0.0010	0.0023	0.0014	-0.0006	-0.0041	0.0050
		t-stat	0.49	1.55	0.78	-0.16	-1.83	3.75	0.72	1.28	0.98	-0.51	-2.01	3.91	0.56	2.46	1.37	-0.66	-2.59	4.31
	MKTRF	Coefficient	1.3656	1.1846	1.1947	1.1846	1.3731	-0.0075	1.3790	1.1787	1.1715	1.1938	1.3739	0.0052	1.3925	1.1671	1.1730	1.1936	1.3723	0.0202
		t-stat	27.30	43.11	47.57	42.21	29.17	-0.29	25.16	36.04	40.45	41.56	31.59	0.19	24.05	51.30	41.34	46.57	30.87	0.58
	SMB	Coefficient	0.6690	0.5120	0.3787	0.4050	0.6383	0.0308	0.6741	0.4920	0.3572	0.3981	0.6727	0.0014	0.6885	0.4861	0.3564	0.4122	0.6545	0.0341
		t-stat	4.62	7.99	5.70	5.04	4.58	0.80	4.98	7.53	4.38	4.74	5.15	0.03	4.86	7.33	4.43	5.25	5.17	0.80
	HML	Coefficient	0.0873	0.1281	0.0461	0.0963	0.1001	-0.0128	0.0729	0.0567	0.1284	0.1008	0.0990	-0.0262	0.0632	0.0889	0.1000	0.1200	0.0842	-0.0210
		t-stat	1.01	3.14	0.79	2.25	1.10	-0.33	0.79	1.30	2.22	2.26	1.22	-0.62	0.60	1.96	1.93	3.01	1.05	-0.36
	$\overline{Adj}\ R^2$		0.9166	0.9664	0.9562	0.9574	0.9155	0.0000	0.9165	0.9622	0.9490	0.9537	0.9188	0.0000	0.9067	0.9675	0.9505	0.9605	0.9195	0.0015
	Joint test: p-value				(<.0001)						(<.0001)						(<.0001)			
FF4	Alpha	Coefficient	0.0015	0.0017	0.0012	0.0001	-0.0021	0.0036	0.0019	0.0016	0.0015	-0.0002	-0.0025	0.0044	0.0018	0.0025	0.0018	-0.0004	-0.0034	0.0052
		t-stat	1.17	2.12	1.36	0.13	-1.85	3.74	1.56	1.56	1.55	-0.23	-2.10	3.95	1.40	3.10	2.10	-0.50	-2.73	4.46
	MKTRF	Coefficient	1.2091	1.1214	1.1135	1.1197	1.2069	0.0022	1.2146	1.1313	1.0878	1.1263	1.2087	0.0059	1.2065	1.1115	1.0898	1.1477	1.2135	-0.0070
		t-stat	24.05	43.70	37.78	38.88	32.97	0.08	26.84	34.15	34.40	36.38	28.58	0.21	23.32	50.33	37.41	38.39	29.22	-0.22
	SMB	Coefficient	0.7727	0.5539	0.4324	0.4480	0.7483	0.0244	0.7830	0.5233	0.4127	0.4428	0.7821	0.0009	0.8117	0.5230	0.4116	0.4426	0.7596	0.0521
		t-stat	6.55	10.88	8.98	6.81	7.20	0.65	7.44	9.28	6.37	6.48	7.95	0.02	7.33	9.89	6.65	6.66	7.86	1.11
	HML	Coefficient	0.0582	0.1164	0.0310	0.0842	0.0692	-0.0110	0.0423	0.0479	0.1128	0.0883	0.0683	-0.0260	0.0286	0.0786	0.0845	0.1115	0.0546	-0.0260
		t-stat	0.98	4.07	0.69	2.15	1.38	-0.30	0.78	1.18	2.42	2.63	1.62	-0.63	0.45	2.21	2.09	2.93	1.19	-0.49
	UMD	Coefficient	-0.2733	-0.1104	-0.1417	-0.1133	-0.2902	0.0168	-0.2872	-0.0826	-0.1461	-0.1179	-0.2884	0.0012	-0.3247	-0.0972	-0.1454	-0.0802	-0.2772	-0.0475
		t-stat	-5.95	-7.09	-6.50	-6.28	-7.11	0.61	-6.98	-4.26	-5.92	-4.07	-6.40	0.04	-6.55	-5.31	-7.51	-3.48	-5.68	-1.11
	$\overline{Adj}\ R^2$		0.9536	0.9749	0.9716	0.9668	0.9563	0.0000	0.9552	0.9669	0.9654	0.9637	0.9584	0.0000	0.9545	0.9743	0.9667	0.9650	0.9565	0.0250
	Joint test: p-value				(<.0001)						(<.0001)						(<.0001)			

Table 5. Fama-MacBeth regressions

Panel A reports the averages of month-by–month Fama and Macbeth (1973) cross-sectional regression coefficient estimates for individual stock returns on $Ortho\ spread_{6m,1m}$ ($ortho\ smirk_{6m,1m}$, $ortho\ convexity_{6m,1m}$) and control variables. The cross-section of expected stock returns is regressed on control variables. Control variables include market β estimated following Fama and French (1992), size (*ln_mv*), book-to-market (*btm*), momentum (MOM), reversal (REV), illiquidity (ILLIQ), *IV slope (IV spread, IV convexitys)*, idiosyncratic risk (*idio_risk*), implied volatility level (*IV level*), systematic volatility (v_{sys}^2), idiosyncratic implied variance (v_{isio}^2). Market β is estimated from time-series regressions of raw stock excess returns on the Rm-Rf by month-by-month rolling over the past three year (36 months) returns (a minimum of 12 months). Following Ang, Hodrick, Xing, and Zhang (2006), daily excess returns of individual stocks are regressed on the four Fama-–French (1993, 1996) factors daily in every month as:

$$(R_i - R_f)_k = \alpha_i + \beta_{1i}(MKT \; - R_f)_k + \beta_{2i}SMB_k + \beta_{3i}HML_k + \beta_{4i}WML_k + \varepsilon_k, \quad \text{where } t - 30 \le k \le \; t - 1$$

on a daily basis. The idiosyncratic volatility of a stock is computed as the standard deviation of the regression residuals. Daily stock returns are obtained from the Center for Research in Security Prices (CRSP). Momentum (MOM) is computed based on the past six months skipping one month between the portfolio formation period and the computation period to exclude the reversal effect following Jegadeesh and Titman (1993). Reversal (REV) is computed based on past one-month return following Jegadeesh (1990) and Lehmann (1990). Illiquidity (ILLIQ) is defined as the absolute monthly stock return divided by the dollar trading volume in the stock (in $thousands) following Amihud (2002). Systematic volatility is estimated by the method suggested by Duan and Wei (2009) as $v_{sys}^2 = \beta^2 v_m^2 / v^2$. Idiosyncratic implied variance as $v_{idio}^2 = v^2 - \beta^2 v_M^2$, where v_m is the implied volatility of S&P500 index option, is also computed following Dennis, Mayhey and Stivers (2006). The daily factor data are downloaded from Kenneth R. French's website. To reduce the impact of infrequent trading on idiosyncratic volatility estimates, a minimum of 15 trading days in a month for which CRSP reports both a daily return and non-zero trading volume are required. The sample period covers Jan 2000 to Dec 2013 with stocks traded on the NYSE (exchcd=1), Amex (exchcd=2) and NASDAQ (exchcd=3) and stocks with a price of less than three dollars are excluded from the sample. Newey–West adjusted t-statistics for the time-series average of coefficients using lag3 are reported. Numbers in parentheses indicate t -statistics.

Panel A. $Ortho\ Spread_{6m,1m}$

Variable	MODEL1	MODEL2	MODEL3	MODEL4	MODEL5	MODEL6	MODEL7	MODEL8
IV spread	-0.042***	-0.042***	-0.036***	-0.037***	-0.035***	-0.036***	-0.037***	-0.037***
.	(-6.00)	(-6.31)	(-5.70)	(-5.89)	(-5.56)	(-5.76)	(-5.67)	(-5.81)
$\boldsymbol{Ortho\ spread_{6m,1m}}$		-0.056***		-0.049**		-0.048**		-0.052***
.		(-2.62)		(-2.40)		(-2.38)		(-2.62)
Beta			-0.001	-0.001	-0.000	-0.000	0.000	0.000
.			(-0.31)	(-0.32)	(-0.06)	(-0.06)	(0.21)	(0.20)
Log[MV]			-0.001	-0.001	-0.001*	-0.001*	-0.002**	-0.002**
.			(-1.22)	(-1.21)	(-1.94)	(-1.92)	(-2.38)	(-2.37)
BTM			0.003	0.003	0.002	0.002	0.002	0.002
.			(1.57)	(1.53)	(1.45)	(1.42)	(1.31)	(1.27)
MOM			0.003	0.003	0.003	0.003	0.003	0.003
.			(0.85)	(0.85)	(0.90)	(0.90)	(1.06)	(1.05)
REV			-0.015***	-0.015***	-0.015***	-0.015***	-0.016***	-0.016***
.			(-2.71)	(-2.72)	(-2.89)	(-2.90)	(-3.08)	(-3.08)
ILLIQ			-0.020	-0.022	-0.014	-0.015	-0.001	-0.002
.			(-1.05)	(-1.12)	(-0.72)	(-0.79)	(-0.05)	(-0.12)
Idiosyncratic risk					-0.198***	-0.198***		
.					(-3.33)	(-3.33)		
IV level							-0.005	-0.005
.							(-0.47)	(-0.48)
v_{sys}^2							-0.003***	-0.003***
.							(-3.01)	(-3.08)
v_{idio}^2							-0.012**	-0.012**
.							(-2.15)	(-2.13)
$\overline{Adj}\ R^2$	0.002	0.003	0.059	0.060	0.063	0.063	0.070	0.071

Panel B. $Ortho\ Smirk_{6m,1m}$

Variable	MODEL1	MODEL2	MODEL3	MODEL4	MODEL5	MODEL6	MODEL7	MODEL8
IV smirk	-0.025***	-0.024***	-0.023***	-0.023***	-0.024***	-0.024***	-0.026***	-0.026***
.	(-4.78)	(-4.78)	(-4.59)	(-4.60)	(-4.74)	(-4.76)	(-4.64)	(-4.65)
$\boldsymbol{Ortho\ smirk_{6m,1m}}$		**-0.059*** **		**-0.056*** **		**-0.054*** **		**-0.052*** **
.		**(-3.81)**		**(-3.74)**		**(-3.77)**		**(-3.56)**
Beta			-0.001	-0.001	-0.000	-0.000	0.000	0.000
.			(-0.34)	(-0.34)	(-0.08)	(-0.09)	(0.19)	(0.17)
Log(MV)			-0.001	-0.001	-0.001**	-0.001*	-0.002**	-0.002**
.			(-1.22)	(-1.18)	(-1.98)	(-1.92)	(-2.55)	(-2.48)
BTM			0.003	0.003	0.003	0.003	0.002	0.002
.			(1.63)	(1.60)	(1.51)	(1.48)	(1.36)	(1.33)
MOM			0.003	0.003	0.003	0.003	0.004	0.004
.			(0.91)	(0.90)	(0.96)	(0.96)	(1.11)	(1.11)
REV			-0.014***	-0.015***	-0.015***	-0.015***	-0.016***	-0.016***
.			(-2.68)	(-2.73)	(-2.86)	(-2.91)	(-3.07)	(-3.12)
ILLIQ			-0.023	-0.022	-0.016	-0.015	-0.002	-0.001
.			(-1.17)	(-1.13)	(-0.84)	(-0.80)	(-0.09)	(-0.05)
Idiosyncratic risk					-0.206***	-0.203***		
.					(-3.48)	(-3.45)		
IV level							-0.007	-0.007
.							(-0.66)	(-0.60)
v_{sys}^2							-0.003***	-0.003***
.							(-2.98)	(-3.03)
v_{idio}^2							-0.012**	-0.012**
.							(-2.10)	(-2.12)
$\overline{Adj}\ R^2$	0.002	0.002	0.059	0.060	0.063	0.063	0.070	0.071

Panel C. $Ortho\ Convexity_{6m,1m}$

name	MODEL1	MODEL2	MODEL3	MODEL4	MODEL5	MODEL6	MODEL7	MODEL8
IV convexity	-0.014***	-0.014***	-0.014***	-0.014***	-0.014***	-0.014***	-0.015***	-0.015***
.	(-6.73)	(-6.73)	(-6.40)	(-6.36)	(-6.50)	(-6.45)	(-6.84)	(-6.82)
$\boldsymbol{Ortho\ convexity_{6m,1m}}$		-0.038***		-0.033***		-0.033***		-0.032***
.		(-3.57)		(-3.41)		(-3.43)		(-3.36)
Beta			-0.001	-0.001	-0.000	-0.000	0.000	0.000
.			(-0.34)	(-0.34)	(-0.08)	(-0.08)	(0.18)	(0.14)
Log(MV)			-0.001	-0.001	-0.001**	-0.001*	-0.002***	-0.002**
.			(-1.26)	(-1.22)	(-2.00)	(-1.94)	(-2.63)	(-2.56)
BTM			0.003	0.003	0.003	0.003	0.002	0.002
.			(1.62)	(1.60)	(1.51)	(1.48)	(1.36)	(1.33)
MOM			0.003	0.003	0.003	0.003	0.003	0.003
.			(0.81)	(0.80)	(0.86)	(0.85)	(0.99)	(0.99)
REV			-0.015***	-0.015***	-0.016***	-0.016***	-0.016***	-0.016***
.			(-2.74)	(-2.79)	(-2.92)	(-2.96)	(-3.13)	(-3.17)
ILLIQ			-0.023	-0.023	-0.016	-0.017	-0.001	-0.002
.			(-1.17)	(-1.19)	(-0.84)	(-0.87)	(-0.07)	(-0.11)
Idiosyncratic risk					-0.200***	-0.198***		
.					(-3.38)	(-3.38)		
IV level							-0.007	-0.007
.							(-0.65)	(-0.61)
v_{sys}^2							-0.003***	-0.003***
.							(-2.95)	(-2.96)
v_{idio}^2							-0.012**	-0.013**
.							(-2.15)	(-2.16)
$\overline{Adj}\ R^2$	0.002	0.003	0.060	0.060	0.063	0.064	0.071	0.071

Table 6. Different holding period returns

This table reports the average risk-adjusted monthly returns (using the four-factor model) of the quintile portfolios formed on $Ortho\ spread_{6m,1m}$ ($ortho\ smirk_{6m,1m}$, $ortho\ convexity_{6m,1m}$) for holding period of one month to six months. 'Q1–Q5' denotes a long-short arbitrage portfolio that buys a low $Ortho\ spread_{6m,1m}$ ($ortho\ smirk_{6m,1m}$, $ortho\ convexity_{6m,1m}$) portfolio and sells a high $Ortho\ spread_{6m,1m}$ ($ortho\ smirk_{6m,1m}$, $ortho\ convexity_{6m,1m}$) portfolio. The t-statistics are computed using the Newey–West procedure to adjust the serially-correlated returns of overlapping samples.

	$Ortho\ spread_{6m,1m}$						$Ortho\ smirk_{6m,1m}$						$Ortho\ convexity_{6m,1m}$					
	Q1 (Low)	Q2	Q3	Q4	Q5 (High)	Q1-Q5	Q1 (Low)	Q2	Q3	Q4	Q5 (High)	Q1-Q5	Q1 (Low)	Q2	Q3	Q4	Q5 (High)	Q1-Q5
One month	0.0015	0.0017	0.0012	0.0001	-0.0021	0.0036	0.0019	0.0016	0.0015	-0.0002	-0.0025	0.0044	0.0018	0.0025	0.0018	-0.0004	-0.0034	0.0052
						[3.74]						[3.95]						[4.46]
Two months	0.0089	0.009	0.0079	0.0077	0.0072	0.0018	0.0095	0.009	0.009	0.0076	0.0071	0.0024	0.0093	0.0093	0.0089	0.0078	0.0068	0.0025
	1.49	1.81	1.66	1.6	1.18	[1.89]						[2.81]						[3.16]
Three months	0.0093	0.009	0.0081	0.0078	0.0073	0.002	0.0092	0.0091	0.009	0.0082	0.0071	0.0021	0.0094	0.0092	0.0091	0.0078	0.0072	0.0022
						[2.98]						[3.20]						[3.32]
Four months	0.0089	0.0092	0.0084	0.0078	0.0076	0.0013	0.0093	0.0093	0.0089	0.0082	0.0075	0.0018	0.0093	0.0093	0.0092	0.0078	0.0076	0.0017
						[2.16]						[3.17]						[3.00]
Five months	0.0087	0.009	0.0086	0.008	0.0079	0.0008	0.0092	0.0092	0.0091	0.0083	0.0078	0.0014	0.0093	0.0092	0.0092	0.0081	0.0078	0.0015
						[1.42]						[2.87]						[3.05]
Six months	0.0088	0.009	0.0088	0.0081	0.0081	0.0007	0.0094	0.0093	0.0091	0.0083	0.0082	0.0011	0.0094	0.0092	0.0091	0.0082	0.0083	0.0011
						[1.34]						[2.59]						[2.50]

Referee only Table R1 (but not in the text). Average returns sorted by term spread with different-period

Panel A reports the average portfolio monthly returns sorted by $Ortho\ Spread_{2m(3m),1m}$, $Ortho\ Smirk_{2m(3m),1m}$, $Ortho\ Conovexity_{2m(3m),1m}$. $Ortho\ Spread_{2m(3m),1m}$ ($Ortho\ Smirk_{2m(3m),1m}$, $Ortho\ Conovexity_{2m(3m),1m}$) is estimated by regressing $Spread_{2m(3m)}$ $\left(Smirk_{2m(3m)}, Convexity_{2m(3m)}\right)$ on $Spread_{1m}$ $(Smirk_{1m}, Convexity_{1m})$ using over the last 30days as below:

$$Spread_{2m(3m),i,t-30\sim t} = \alpha_i + b_i Spread_{1m,i,t-30\sim t} + \varepsilon_{i,t}$$
$$Smirk_{2m(3m),i,t-30\sim t} = \alpha_i + b_i Smirk_{1m,i,t-30\sim t} + \varepsilon_{i,t}$$
$$Convexity_{2m(3m),i,t-30\sim t} = \alpha_i + b_i Convexity_{1m,i,t-30\sim t} + \varepsilon_{i,t}$$

$Ortho\ Spread_{2m(3m),1m}$ ($Ortho\ Smirk_{2m(3m),1m}$, $Ortho\ Conovexity_{2m(3m),1m}$) is defined by the residual term at the end (last trading day) of each month. To reduce the impact of infrequent trading on estimates, a minimum of 10 trading days in a month is required. Panel B presents the corresponding results from the quintile portfolios of $Ortho\ Spread_{9m(1y),1m}$ ($Ortho\ Smirk_{9m(1y),1m}$, $Ortho\ Conovexity_{9m(1y),1m}$). On the last trading day of every each month, all firms are assigned to one of five portfolio groups based on $Ortho\ Spread$ ($Ortho\ Smirk$, $Ortho\ Convexity)_{2m(or\ 3m,9m\ ,1y),1m}$ and we assume stocks are held for the next one-month-period. This process is repeated for every month. Monthly stock returns are obtained from Center for Research in Security Prices (CRSP) with stocks traded on the NYSE (exchcd=1), Amex (exchcd=2) and NASDAQ (exchcd=3). We use only common shares (shrcd in 10, 11). The sample excludes stocks with a price of less than three dollars. “Q1–Q5” denotes an arbitrage portfolio that buys a low option-implied convexity portfolio (Q1) and sells a high *IV convexity* portfolio (Q5). The sample period covers Jan 2000 to Dec 2013. Numbers in parentheses indicate t-statistics.

Panel A. $Ortho\ Spread_{2m(3m),1m}$ ($Ortho\ Smirk_{2m(3m),1m}$, $Ortho\ Conovexity_{2m(3m),1m}$)

	2 month orthogonalized by 1 month									3 month orthogonalized by 1 month								
	s_yan_2m_1m			*s_xing_2m_1m*			*curv_2m_1m*			*s_yan_3m_1m*			*s_xing_3m_1m*			*curv_3m_1m*		
Quintile	Mean	Stdev	Return	Mean	Stdev	Return	Mean	Stdev	Return	Mean	Stdev	Return	Mean	Stdev	Return	Mean	Stdev	Return
Q1 (Low)	-0.028	0.050	0.009	-0.045	0.057	0.010	-0.087	0.101	0.009	-0.0328	0.0567	0.0088	-0.0469	0.0631	0.0096	-0.0911	0.1100	0.0096
Q2	-0.004	0.002	0.008	-0.009	0.005	0.009	-0.020	0.011	0.009	-0.0050	0.0032	0.0087	-0.0084	0.0047	0.0088	-0.0200	0.0115	0.0088
Q3	0.000	0.001	0.010	-0.001	0.002	0.009	-0.003	0.005	0.008	-0.0001	0.0014	0.0098	-0.0006	0.0027	0.0098	-0.0026	0.0060	0.0093
Q4	0.003	0.002	0.009	0.006	0.004	0.008	0.012	0.009	0.009	0.0044	0.0030	0.0081	0.0066	0.0047	0.0075	0.0130	0.0096	0.0083
Q5 (High)	0.027	0.053	0.005	0.043	0.065	0.006	0.079	0.103	0.007	0.0320	0.0534	0.0061	0.0457	0.0717	0.0059	0.0855	0.1091	0.0058
Q1-Q5			0.004			0.003			0.002			0.0026			0.0038			0.0039
t-statistic			[3.89]			[2.86]			[2.34]			[3.11]			[3.48]			[4.06]

Panel B. $Ortho\ Spread_{9m(1y),1m}$ ($Ortho\ Smirk_{9m(1y),1m}$, $Ortho\ Conovexity_{9m(1y),1m}$)

	9 month orthogonalized by 1 month									1 year orthogonalized by 1 month								
	s_yan_9m_1m			*s_xing_9m_1m*			*curv_9m_1m*			*s_yan_1y_1m*			*s_xing_1y_1m*			*curv_1y_1m*		
Quintile	Mean	Stdev	Return	Mean	Stdev	Return	Mean	Stdev	Return	Mean	Stdev	Return	Mean	Stdev	Return	Mean	Stdev	Return
Q1 (Low)	-0.0335	0.0613	0.0103	-0.0439	0.0666	0.0106	-0.0811	0.1146	0.0104	-0.0342	0.0622	0.0098	-0.0443	0.0672	0.0108	-0.0814	0.1160	0.0102
Q2	-0.0049	0.0036	0.0090	-0.0076	0.0049	0.0088	-0.0163	0.0106	0.0093	-0.0051	0.0038	0.0090	-0.0076	0.0050	0.0087	-0.0162	0.0109	0.0094
Q3	-0.0002	0.0018	0.0086	-0.0005	0.0030	0.0091	-0.0017	0.0059	0.0092	-0.0002	0.0020	0.0089	-0.0005	0.0031	0.0095	-0.0017	0.0062	0.0093
Q4	0.0044	0.0036	0.0077	0.0061	0.0050	0.0073	0.0121	0.0097	0.0076	0.0046	0.0038	0.0079	0.0061	0.0051	0.0071	0.0122	0.0101	0.0073
Q5 (High)	0.0328	0.0561	0.0061	0.0436	0.0763	0.0057	0.0785	0.1096	0.0051	0.0334	0.0574	0.0060	0.0441	0.0769	0.0056	0.0791	0.1116	0.0055
Q1-Q5			0.0042			0.0049			0.0053			0.0038			0.0053			0.0048
t-statistic			[4.11]			[4.61]			[4.60]			[3.65]			[4.71]			[4.18]

Figure 1. The Term structure of Implied Volatility Curves

This figure shows the term structure of implied volatility curve of call and put options. We use the average implied volatilities with one month (30 days), two months (60 days), three months (91 days), and six months (182 days) to expiration and the delta points in Table 1.

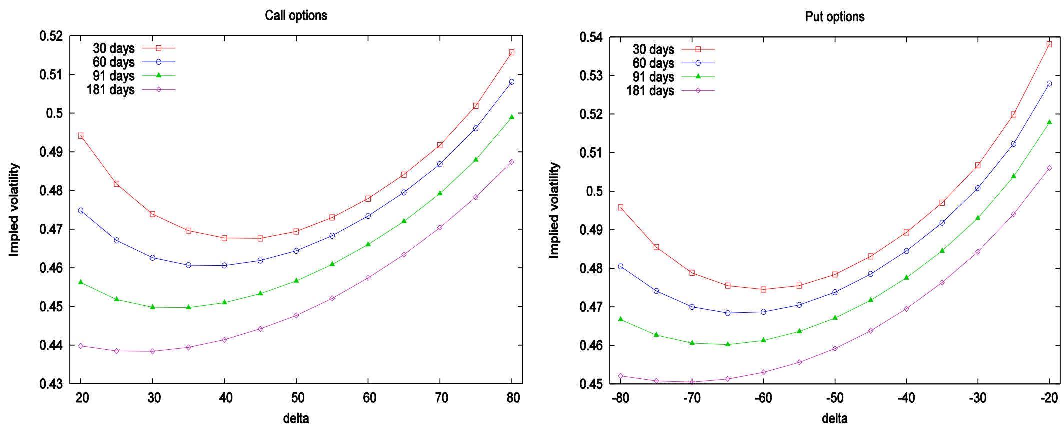
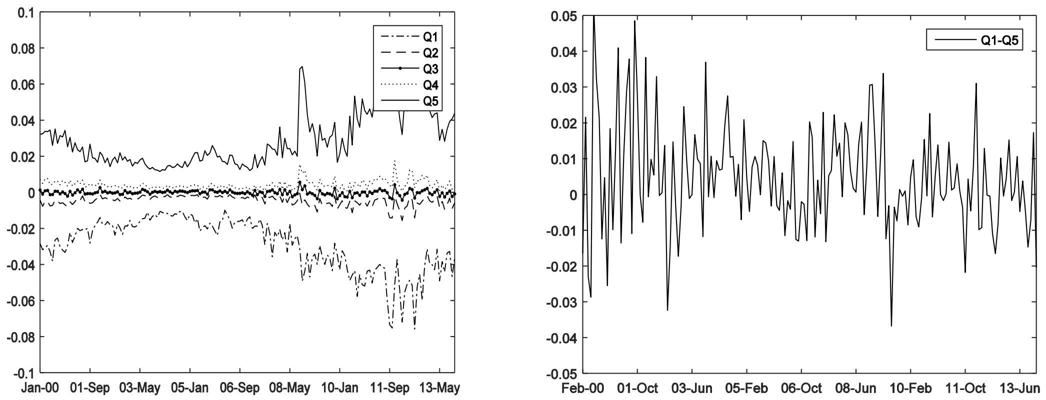


Figure 2. Average *IV convexity* and quintile portfolio returns

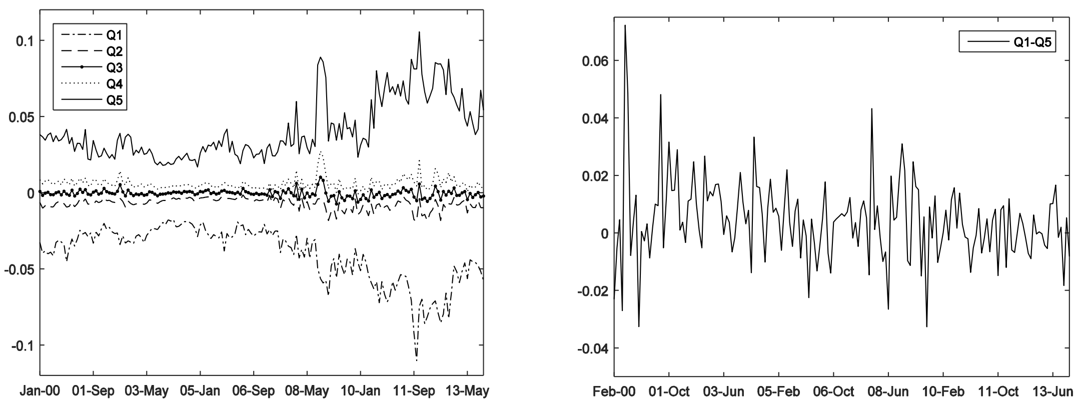
This figure shows the time-series behavior of the average $Ortho\ spread_{6m,1m}$ ($Ortho\ smirk_{6m,1m}$, $Ortho\ convexity_{6m,1m}$) and returns of quintile portfolios from Jan 2000 to Dec 2013. Panel A plots the monthly average $Ortho\ spread_{6m,1m}$ of the quintile portfolios and the monthly average returns of the long-short $Ortho\ spread_{6m,1m}$ portfolios Q1-Q5.

Panel B plots the monthly average $Ortho\ smirk_{6m,1m}$ of the quintile portfolios and the monthly average returns of the long-short $Ortho\ smirk_{6m,1m}$ portfolios Q1-Q5. Panel C plots the monthly average $Ortho\ convexity_{6m,1m}$ of the quintile portfolios and the monthly average returns of the long-short $Ortho\ convexity_{6m,1m}$ portfolios Q1-Q5.

Panel A. Average $Ortho\ spread_{6m,1m}$ of quintile portfolios and average returns of Q1-Q5



Panel B. Average $Ortho\ smirk_{6m,1m}$ of quintile portfolios and average returns of Q1-Q5



Panel C. Average $Ortho\ convexty_{6m,1m}$ of quintile portfolios and average returns of Q1-Q5