Skewness Premium and Index Option Returns

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First draft

Abstract

This paper presents a simple way to estimate the skewness premium implied in index option returns. Using a methodology proposed by Constantinides/Jackwerth/Savov (2013), we create option-based investment strategies with the same volatility and the same market exposure (of one) but different degrees of skewness. The resulting return series can be seen as index returns with controlled skewness. If skewness is relevant for pricing, it will be reflected in differences in the mean returns of the strategies. In an empirical analysis for SPX, ESX and DAX index options in the sample period 1995-2015, we find a remarkably close association of skewness and average returns that is consistent with a significantly negative skewness premium.

JEL classification: G12; G14

Keywords: Skewness, index options, higher moments, market risk premia

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1 Introduction

The objective of this paper is to estimate the skewness premium in stock market returns in a new way. We use index option strategies to construct a cross-section of return distributions that only differ with respect to the degree of skewness. The investment strategies involve the riskless asset and one index option at a time. The variation of skewness is achieved by using a cross-section of index options of different type (call and put options), different moneyness (0.9 to 1.05 in terms of strike to index level) and different time to maturity (30, 60, and 90 days). The options are unlevered so that their market exposure (beta) is one, and the investment is readjusted after a holding period of one day in order to hold the characteristics of the trading strategy constant over time.

When using *call* options, we have to hold a *long* position for a target beta of one. This means that returns will be convex. In contrast, to achieve the same beta with *put* options requires a *short* position, which implicates concave returns (negative convexity). The degree of convexity (positive or negative) tends to be stronger the deeper out-of-the money the options are and the shorter their time to maturity is. Positive convexity means that high positive index returns are reinforced while extreme negative returns are mitigated, which translates into higher skewness of the return distribution compared to the index. Inversely, negative convexity exacerbates extreme negative index returns and attenuates strongly positive returns, which produces lower skewness compared to the index. The dynamics of the smile pattern of index option prices tends to increase the convexity differences between the call- and put-based strategies because rising implied volatilities after a sharp index decrease are detrimental to the short put position while they are advantageous for the long call position.

Although the holding period is only one day, the size of convexity and skewness differences produced by the beta-one strategies is statistically and economically significant. It is all the more important as this is clearly the main systematic difference between the strategies. As the underlying asset is the same and the linear exposure to the index is also identical, it is the difference in the nonlinear exposure to the index which distinguishes the trading strategies. Therefore, the return series can be seen as index returns with controlled skewness. If skewness is relevant for pricing, it will be reflected in differences in the mean returns of the strategies. Thus, this methodology opens a simple way to estimate the skewness risk premium.

The methodology of creating a cross-section of beta-one option portfolios was proposed by Constantinides et al. (2013). The authors use the option portfolios as test assets in tests of multi-factor pricing models, arguing that the "standard linear factor methodology is applicable because the monthly portfolio returns have low skewness and are close to normal".[1] The low skewness with returns close to normal is emphasized as an important implication of the portfolio construction methodology: "The major advantage of this construction is to lower the variance and skewness of the monthly portfolio returns and render the returns close to normal (about as close to normal as the index return), thereby making applicable the standard linear factor pricing methodology."[2] We find, however, that the portfolio returns do indeed differ in skewness; one might even say that control over skewness is the main characteristic of the method. Therefore, in this paper, we propose to use the same portfolio strategies to study the skewness premium, which can be seen as an extension of Constantinides et al. (2013) focusing on an interesting but unexplored aspect of their work.

We present an empirical analysis for the three indices S&P 500 (SPX options), EuroStoxx 50 (ESX options) and DAX (DAX options) for the time periods Jan. 1996 to Sep. 2015 for SPX, 2000 to 2014 for ESX and 1995 to 2014 for DAX. In all three markets, we find a strongly negative and remarkably close association of skewness and average returns. It tends to be nonlinear in the sense that the risk premium increases with more intense negative skewness. We also show

[1] Constantinides et al. (2013), p. 229.

[2] Constantinides et al. (2013), p. 230. This statement is repeated several times:
"Unlike the earlier portfolio construction in Buraschi and Jackwerth (2001), we leverage-adjust the portfolios on a daily basis to maintain the targeted beta of one and gross up the daily returns to obtain monthly returns. This treatment has the effect of decreasing the volatility and skewness of returns and rendering them about as close to normal as the index itself." (p. 233);
"The second challenge is to generate portfolio returns that are stationary and only moderately skewed. We address this issue by deleveraging the portfolios to have a target market beta of one." (p. 234);
"We also revise the portfolios daily in a way that the moneyness, maturity, and leverage of each portfolio remain fairly constant. The procedure significantly reduces the variability and skewness of returns and produces returns about as close to normal as the index itself." (p. 235);
"An important methodological contribution of the paper is the construction (and public availability) of a panel of de-levered monthly returns of option portfolios split across type, maturity, and moneyness. This construction lowers the skewness of the monthly portfolio returns and renders them close to normal thereby allowing the future exploration of alternative linear factor models, as well as linear forecasting models." (p. 251).

that skewness is very similar to convexity measured by the loading of option returns on squared index returns. Thus, we can interpret our results in terms of a two-stage test of asset pricing models where squared index return is included as a risk factor in the time-series regressions and the squared-return loadings contribute to explaining the cross-sectional return differences.

The relevance of skewness for investor decisions and asset prices has been studied in a large body of prior literature. A preference for positive skewness is observed in lottery experiments (see the critical discussion in Vrecko et al. (2009)). Arditti (1967) shows that a preference for positive skewness follows if the utility function exhibits non-increasing absolute risk aversion in the Arrow-Pratt sense. However, portfolio optimization based on the first three moments of the return distribution is in general only consistent with Expected Utility maximization if a cubic utility function is assumed (for an extension, see Chiu (2010)). Kraus and Litzenberger (1976) derive a market equilibrium model in which systematic skewness is priced. Based on a related asset pricing model, Harvey and Siddique (2000) find an empirical risk premium for systematic skewness of 3.6% per year, which is statistically significant and economically important. In addition to the systematic component of skewness, total skewness of individual stocks also seems to be related to future stock returns (see Conrad et al. (2013)).

In a recent study, Chang et al. (2013) determine the market skewness implied in S&P 500 index option prices and estimate the exposure of a cross-section of stocks with respect to daily changes of implied skewness. The authors find that stocks with a high exposure to the skewness-related risk factor show low returns on average: "We find that the average return on the market skewness risk factor portfolio is 0.78% per month, or 9.36% per year, and this return cannot be explained by market beta, the size factor, the book-to-market factor, or the momentum factor."[3]

Another approach to measure the skewness risk premium is to compare realized skewness with options' implied skewness. In this vein, Kozhan et al. (2013) derive option implied skewness from a model-free dynamic strategy which creates a payoff equal to realized market skewness. They find that the strategy is highly exposed to variance risk. When this risk is hedged away, the skewness premium becomes insignificant.

[3] Chang et al. (2013), p. 47.

Other studies analyze risk factors which potentially contribute to skewness in returns, in particular volatility risk and jump risk. Andersen et al. (2015) exploit the movements of index option surfaces to study the relation between market risks and risk premia. A main finding is that the dynamics of the option risk premia cannot be explained by the dynamics of the underlying asset prices alone.

Our study is also related to the literature on a potential mispricing of put options because the methodology proposed by Constantinides et al. (2013) produces positive skewness for call-based strategies and negative skewness for put-based strategies. Rubinstein (1994) and Jackwerth and Rubinstein (1996) report that OTM puts are expensive compared to at-the-money (ATM) puts. Jones (2006) confirms that deep-OTM puts on S&P500 index futures are overpriced, generating negative abnormal returns even after taking volatility and jump risk premia into account. In contrast, Broadie et al. (2009) note that very high returns of deep-OTM puts alone are not inconsistent with standard option valuation models because individual option returns are extremely dispersed and highly skewed. Thus, they propose a different test approach based on market-neutral option portfolios. The main finding is that stochastic volatility alone is insufficient to explain returns of S&P 500 futures options, but models including estimation risk and jump risk premia are consistent with the data. Chambers et al. (2014) confirm this finding for the extended sample period of 1987-2012. Instead of market-neutral portfolios, the methodology of Constantinides et al. (2013) creates portfolios closely resembling the market, which facilitates the evaluation of abnormal returns in a mean-variance framework.

The paper proceeds as follows. The next section 2 explains how the beta-one option portfolios are created so that they span a substantial skewness range. Section 3 presents our data, describes the matching of option prices and index levels and provides descriptive statistics for our option portfolios. Section 4 examines the relationship between skewness and average returns in order to estimate the market skewness premium. The last section concludes.

2 Option-based strategy to generate skewed index returns

We implement the methodology proposed by Constantinides et al. (2013) in the following way. Let $\mathcal{C}$ denote the price of an option with strike price X, time to maturity T and underlying index level S. The option delta is the partial derivative $\partial\mathcal{C}/\partial S$. We determine the share ω of wealth invested in the option such that the elasticity of this position with respect to the index is 1:

$$\omega = \frac{1}{\frac{\partial\mathcal{C}}{\partial S}\frac{S}{\mathcal{C}}}. \tag{1}$$

The remaining share of $(1-\omega)$ of wealth is invested in the riskless asset with return r.

The option delta in Eq. (1) depends on the option pricing function. When estimating delta based on an implied volatility from the Black-Scholes model, we have to take into account that implied volatility changes with index movements. With σ_{imp} as implied volatility, the option delta is given by (see, e.g., Rosenberg (2000)):

$$\begin{aligned} \frac{d\mathcal{C}\left(S,\sigma_{imp}(S)\right)}{dS} &= \frac{\partial\mathcal{C}(S,\sigma_{imp}(S))}{\partial S} + \frac{\partial\mathcal{C}(S,\sigma_{imp}(S))}{\partial\sigma_{imp}}\cdot\frac{d\sigma_{imp}(S)}{dS} \\ &= \Delta_{BS} + \Lambda_{BS}\cdot\frac{d\sigma_{imp}(S)}{dS} \end{aligned} \tag{2}$$

where Δ_{BS} and Λ_{BS} are the option's delta and vega according to the Black/Scholes formula with volatility replaced by implied volatility. The adjustment term in the second summand of Eq. (2) captures the effect of index movements on implied volatility. The impact on implied volatility results from two effects. The first is that implied volatility of index options is typically a decreasing function of moneyness (smile or skew pattern)[4] so that an increase in the index level and the corresponding decrease in moneyness brings about an increase in implied volatility. The second effect is that the skew curve shifts in the opposite direction of index movements. The downward shift in case of a rising index offsets part of the first effect.

Therefore, in order to obtain an estimate of $d\sigma_{imp}(S)/dS$, we have to consider the structure and dynamics of the skew curve. A common way to model the implied volatility pattern is to use

[4] We use the terms "smile" and "skew" as synonyms for the strike price pattern of implied volatilities. Although "skew" better describes the downward sloping pattern typically observed in index option markets, "smile" is also commonly used.

the cubic regression function:

$$\sigma_{imp}(M) = \beta_0 + \beta_1 M + \beta_2 M^2 + \beta_3 D \cdot M^3 + \varepsilon, \tag{3}$$

where M is time to maturity adjusted moneyness defined as:

$$M = \frac{\ln(Xe^{-rT}/S)}{\sqrt{T}},$$

and β_i, $i = 0, 1, 2, 3$ are regression coefficients, ε is a random error, and D a dummy variable defined as:

$$D = \begin{cases} 0 \ , & M \leq 0 \\ 1 \ , & M > 0 \end{cases} .$$

The dummy variable term is included to capture the observation that implied volatility decreases less strongly or even rises at positive moneyness levels.

If the smile pattern does not shift ("sticky moneyness rule"), the second effect described above falls away and the change in implied volatility is fully due to the movement on the smile curve. For at-the-money options, we obtain:

$$\begin{aligned} \left.\frac{d\sigma_{imp}}{dS}\right|_{M=0} &= \left.\frac{d\sigma_{imp}}{dM}\right|_{M=0} \frac{dM}{dS} \\ &= \beta_1 \left(-\frac{1}{S\sqrt{T}}\right) \end{aligned} \tag{4}$$

where $\beta_1 < 0$ so that the adjustment to Δ_{BS} in Eq. (2) is positive.

If the smile pattern shifts in such a way that implied volatility for a given strike X is constant ("sticky strike rule"), the two effects compensate each other and we obtain $d\sigma_{imp}/dS = 0$. There is empirical evidence that the smile shifts even more strongly than the sticky strike rule suggests (Wallmeier (2015)) so that the adjustment term becomes negative. Combining this evidence with a β_1-estimate of -0.2, we use the estimate

$$\frac{d\sigma_{imp}(S)}{dS} = -\frac{0.1}{S\sqrt{T}} \tag{5}$$

for the adjustment in Eq. (4). Without this adjustment, the betas of our option portfolios would be less close to the target value of 1.

3 Data and descriptive statistics

Our sample period extends from 1996 to Sep. 2015 for SPX options and 1995 to 2014 for DAX options. ESX options were launched in January 2000 so that our sample period is shortened to 2000 to 2014. On each trading day, we estimate the skew in option prices using the cubic regression model (3). We run the regression separately for each time to maturity. For DAX and ESX options, the estimation is based on all daily transactions at Eurex. As transaction data are not available for SPX options, we use settlement data provided by Option Metrics. For settlement data, we infer the index level at settlement from put-call parity. The transaction data are synchronized with index future prices by milliseconds to avoid any relevant time mismatch, and the underlying index level is adjusted to account for put-call parity. For details, we refer to Wallmeier (2015). As the skew regression model describes the structure of option prices extremely well, we infer option prices for our option portfolios from the estimated smile curves.

Each of our beta-one portfolios is based on only one option at a time. The options differ in terms of time to maturity and moneyness. Following Constantinides et al. (2013), our time to maturity levels are $T \in \{30, 60, 90\}$ days. Constantinides et al. (2013) consider a range of strike to index ratios from 0.9 to 1.1 in steps of 0.25. We fix the upper limit at 1.05 because options with higher moneyness are not always actively traded during the sample period. Thus, in terms of simple moneyness $m = Xe^{-rT}/S$ we consider 7 levels $m \in \{0.9, 0.925, 0.95.0.975, 1.0, 1.025, 1.05\}$. Combining the time to maturity and moneyness levels with the option type $z \in \{call, put\}$, we obtain $3 \cdot 7 \cdot 2 = 42$ different options, each of which is used to create a beta-one strategy as described in Section 2.

More specifically, for a given combination (T_i, m_j, z_k), on day t of the sample period, we identify the option with a time to maturity closest to T_i. Options with time to maturity smaller than 15 days are not considered to avoid particular valuation effects near expiration. Based on the estimated smile regression for the chosen option on day t, we evaluate the option at moneyness

m_j and determine the weight ω of the option using Eq. (1) combined with Eqs. (2) and (5). The riskless asset holding is $(1-\omega)$. After a one-day holding period, we unwind the position based on the updated moneyness level and the new smile pattern and report the portfolio return. We enter inter a new position each day and thereby obtain a series of daily portfolio returns over the sample period. For the sake of simplicity, in the following we will refer to these particular return series as option returns or, more specifically, call and put option returns.

We inspect scatterplots of option returns versus index returns on a yearly basis in order to detect outliers. Less than 0.25% of the observations are identified as outliers and removed from the analysis. Most of these occur at moneyness levels of 1.025 and 1.05 when trading is relatively infrequent and the coefficient of the cubic element of the smile pattern is estimated with a high standard error.

– Insert Figures 1-3 (pp. 16-18) here –

For SPX options, we illustrate the relationship of daily index and option returns in Figures 1 ($T = 30$ days), 2 ($T = 60$ days) and 3 ($T = 90$ days). Calls are shown in the left panels, puts on the right, and moneyness increases from the top ($m = 0.9$) to the bottom panels ($m = 1.05$). The blue line shows the estimated linear regression of option return on index return, the quadratic regression line is shown in red.

As desired, the linear regression line is almost identical to the 45-degree line which indicates that the strategies were successful in achieving a target beta of 1. The difference in convexity of call option returns and put option returns is clearly visible. As expected, the degree of convexity is largest for deep out-of-the money options. It also tends to be higher for short-dated options.

– Insert Tables 1-3 (pp. 22-24) here –

Tables 1 (SPX), 2 (ESX) and 3 (DAX) show descriptive statistics for the 42 option portfolios. *Beta*, the estimated slope coefficient in the linear index regression model, is always close to 1. This is also true for *Beta1*, the first slope coefficient of the quadratic regression model. while the coefficient of the quadratic term, *Beta2*, is always significantly positive for calls and negative for puts (1% significance level). The average R^2-coefficients of the quadratic model across the 42 portfolios are 96.2%, 96.9% (ESX) and 96.8% (DAX). The volatility (*Vol*) is similar across the 42 portfolios; the differences between the highest and lowest annualized volatility are 1.90 (SPX), 2.42 (ESX) and 1.37 (DAX) percentage points. The last three columns show the Fisher-Pearson coefficient of skewness (*Skew*), the Pearson coefficient of kurtosis (*Kurt*) and the Sharpe ratio (*SR*). Skewness is clearly related to *Beta2,* with mostly positive values for call options and negative values for put options. The most obvious characteristic of the cross-section of Sharpe ratios is that they appear to be considerably higher for put option portfolios compared to call-based portfolios. This suggests a negative association of skewness and average returns which will be further explored in the next section.

– Insert Figure 4 (p. 19) here –

For a better illustration of the close association of skewness and convexity, the left panels of Figure 4 show scatterplots of *Skew* versus *Beta2* across our 42 portfolios for SPX (upper panel), ESX (middle) and DAX (lower panel). The index is positioned at the intersection point of the vertical and horizontal lines. The panels on the right of Figure 4 show how skewness is related to the option characteristics (puts vs. calls; moneyness; time to maturity). As expected, positive and negative skewness is more pronounced for out-of-the-money options. For in-the-money options, the effect of time to maturity (marker 1 for 30 days and 3 for 90 days) is negligible. For out-of-the-money options, skewness becomes more pronounced when the time to maturity is short.

4 Skewness and the cross-section of option returns

As a first illustration, in the left panels of Figure 5, we show plots of mean daily option returns versus skewness. The panels on the right of Figure 5 show t-statistics for testing the hypothesis that the expected option return is equal to the expected index return. As the index exposure is the same for all options, this test can be interpreted as a test of abnormal returns with respect to a linear one-factor market model. The horizontal lines indicate the 99% confidence interval around zero. Almost all put option portfolios achieve a significantly positive and almost all call portfolios a significantly negative abnormal return. The striking spread between call and put returns reflects the well-known observation that options are generally more expensive than option pricing models suggest. It is important to keep in mind that our strategy implies long call and short put positions in order to achieve the target beta-one market exposure. Therefore, the put-based strategies *profit* from a high general level of option prices, while the call-based strategies *suffer* from high option prices. The graphs also indicate that there is substantial variation of average returns within each option class (calls and puts).

– Insert Figure 5 (p. 20) here –

We propose three models to analyse the association of skewness and the cross-section of option returns. The first is a linear model with skewness as the sole explanatory variable of return. The second regression model is quadratic in skewness to allow for non-linearity in the skewness premium. In the third model, we include skewness and kurtosis as explanatory variables. We run the regressions separately for our two skewness measures *Skew* and *Beta2* as explained in Section 3. Formally:

$$\text{Model 1:} \qquad r_{pt} = \alpha + \beta x_{s,p} + \varepsilon_{pt} \tag{6}$$

$$\text{Model 2:} \qquad r_{pt} = \alpha + \beta x_{s,p} + \gamma x_{s,p}^2 + \varepsilon_{pt} \tag{7}$$

$$\text{Model 3:} \qquad r_{pt} = \alpha + \beta x_{s,p} + \gamma k_p + \varepsilon_{pt} \tag{8}$$

where r_{pt} is the excess daily log return of option portfolio p, $x_{s,p} \in \{Skew_p, Beta2_p\}$ is the skewness measure, k_p is the kurtosis measure, α, β, γ are regression coefficients and ε_{pt} is an error term. Our main interest is in the β-coefficients. The intercept α will correspond to the average market excess return because all portfolios have an index exposure of one and, as a consequence, achieve the market risk premium.

We also examine a modified version of models (6) to (8) where all variables are defined in excess to the index portfolio. Thus, the returns r_{pt} are defined as the spread between option return and index return, x_s becomes the difference of an option's skewness and the index skewness, and k_p

is differential kurtosis. In these regressions the intercept should be zero if skewness and kurtosis explain the cross-section of returns. We still include the intercept to test if it is statistically significant.

We apply the two-step GMM method of Hansen (1982) to estimate the models. As our explanatory variables are constant over time, the coefficient estimates of GMM are the same as the coefficients of an OLS regression of average returns on the explanatory variables, and these are the same as the estimates of a pooled OLS regression of cross-sectional and time-series data (see Cochrane (2005)). In estimating the standard errors, however, correcting for residual correlation as in the GMM method is important.

– Insert Table 4 (p. 25) here –

Table 4 shows our estimation results, Panel A for the base version of Models 1 to 3 and Panel B for the modified version with excess index levels. The upper part of each panel is based on $x_s = Skew$, the lower part on $x_s = Beta2$. The t-values based on GMM standard errors are reported in brackets. The R^2 coefficient is the cross-sectional R^2 measure of Jagannathan and Wang (1996), which is also employed by Lettau and Ludvigson (2001) and Petkova (2006).

The results suggest a significantly negative skewness premium. Its magnitude for SPX in Model 1 is -1.58E-04 in daily returns, which corresponds to -4% annual return for an increase of skewness by 1. It is even twice as high for ESX options. Therefore, the estimated premium is economically important. The evidence for a non-linear relationship according to Model 2 is mixed. The quadratic coefficient is always positive but rarely statistically significant. Kurtosis appears to have a weak positive effect on average returns which is clearly smaller than the effect of skewness.

It seems surprising that investors are willing to pay such a high premium for positive skewness, especially when considering daily returns. To evaluate these results, it is important to know whether skewness in daily returns carries over to longer return intervals. For index returns, Neuberger (2012) shows that skewness actually increases from a daily return frequency up to a one-year horizon. With the same persistence of skewness in option returns, it is plausible that even long-term investors might demand a substantial premium for negative skewness. The panels on the right-hand side of Figure 6, however, show a convergence of option returns' skewness to the level of index skewness (shown as red line) within a year. This convergence stems to a large extent from the put option portfolios which exhibit a peak of negative skewness at a horizon of approximately 20 to 50 days. The convergence appears to be particularly pronounced for ESX options while for SPX, the spread of skewness in the cross-section of option portfolios is still substantial at a one-year horizon. In view of the overall convergence pattern, our finding of a high skewness premium suggests a short investment horizon of the marginal investors in these option portfolios.

– Insert Figure 6 (p. 21) here –

5 Conclusion

Based on a methodology introduced by Constantinides et al. (2013), we create a sample of option-based investment strategies that represent market investments (market exposure of one) with different degrees of skewness. The possibility to control skewness using simple trading strategies allows us to study the skewness premium in a new way. This approach has the advantage that we can modify skewness on the market level and do not have to exploit small differences in systematic skewness of individual stocks. Another advantage is that the range of skewness spanned by our investment strategies is large compared to market skewness itself. For three of the most important index markets (S&P 500, EuroStoxx 50 and DAX), we provide evidence of a negative skewness premium that is statistically significant and economically important. Skewness explains approximately 90% of the variation of the investment strategies' average returns.

The close relationship between skewness and average returns found in our empirical analysis is not a mere reflection of the skew in option prices (implied volatilities decreasing in moneyness). Apart from the skew, the option returns are also affected by the overall level of option prices and the *dynamics* of the skew profile. In further work, the relative importance of these three factors could be examined more closely.

The skewness of the strategies' return distributions reflects the sensitivity of the strategies' returns with respect to squared market return. A positive sensitivity means that downward index jumps are mitigated and upward index jumps are enhanced. If we interpret this pattern as reduced jump risk, the skewness premium is, by definition, related to the premium for jump risk. The same holds true for volatility risk because volatility changes are typically associated with index changes. However, whatever the drivers of market return may be, ultimately the pricing of our investment strategies seems to be determined by the sensitivity with respect to squared market return and, therefore, the resulting skewness of the return distribution.

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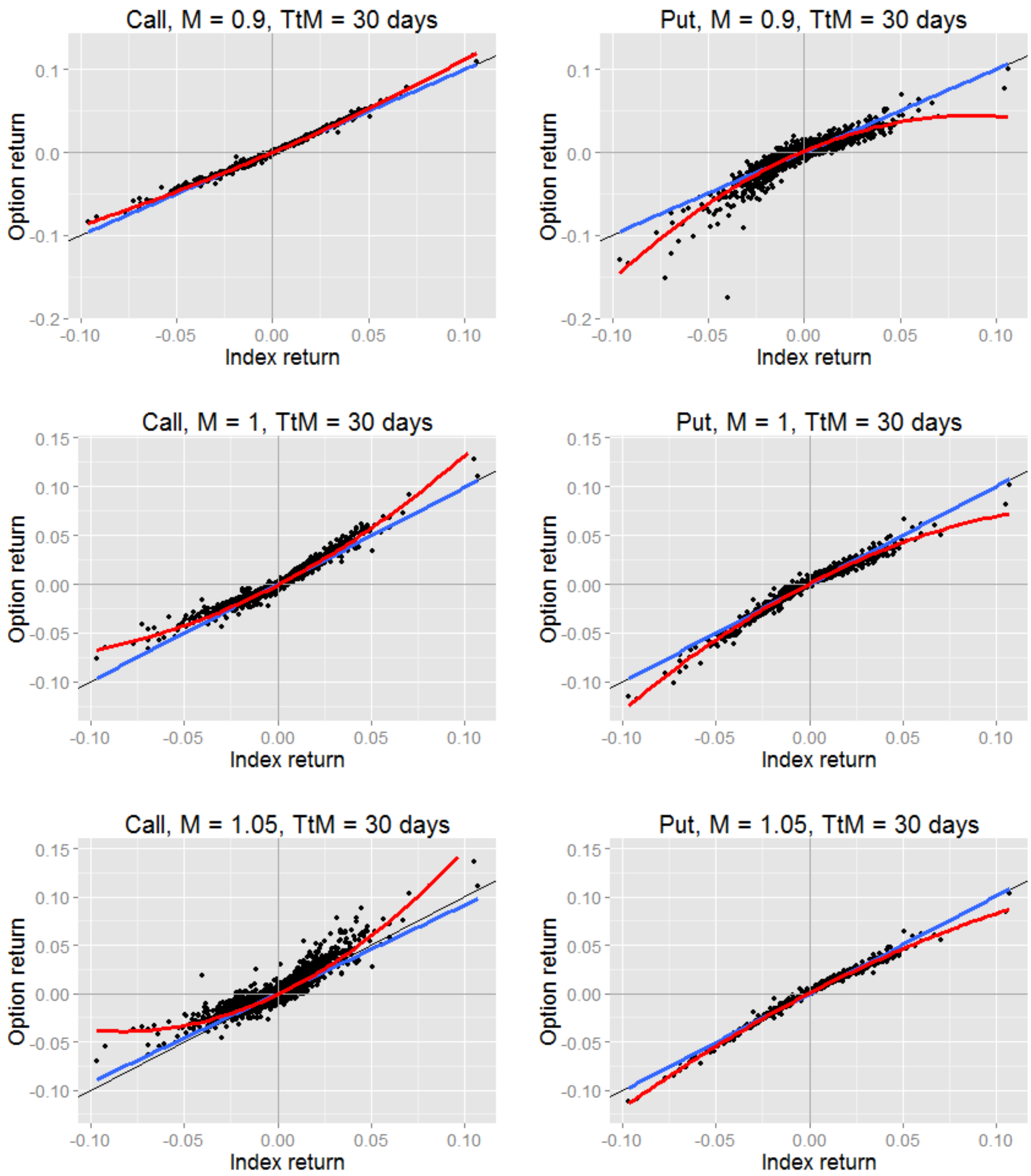

Figure 1: Scatterplots of daily option returns and index returns for selected SPX option portfolios over the sample period 1996-2015. M is moneyness, TtM time to maturity. The blue line illustrates the estimated linear regression, the red line the quadratic regression of option return on index return.

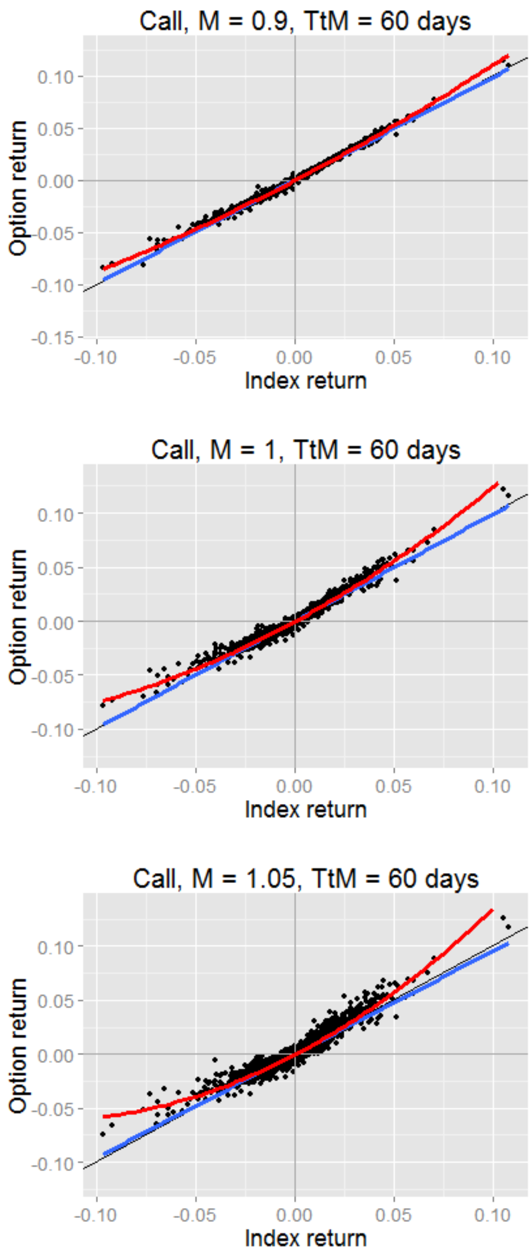

Figure 2: Scatterplots of daily option returns and index returns for selected SPX option portfolios over the sample period 1996-2015. M is moneyness, TtM time to maturity. The blue line illustrates the estimated linear regression, the red line the quadratic regression of option return on index return.

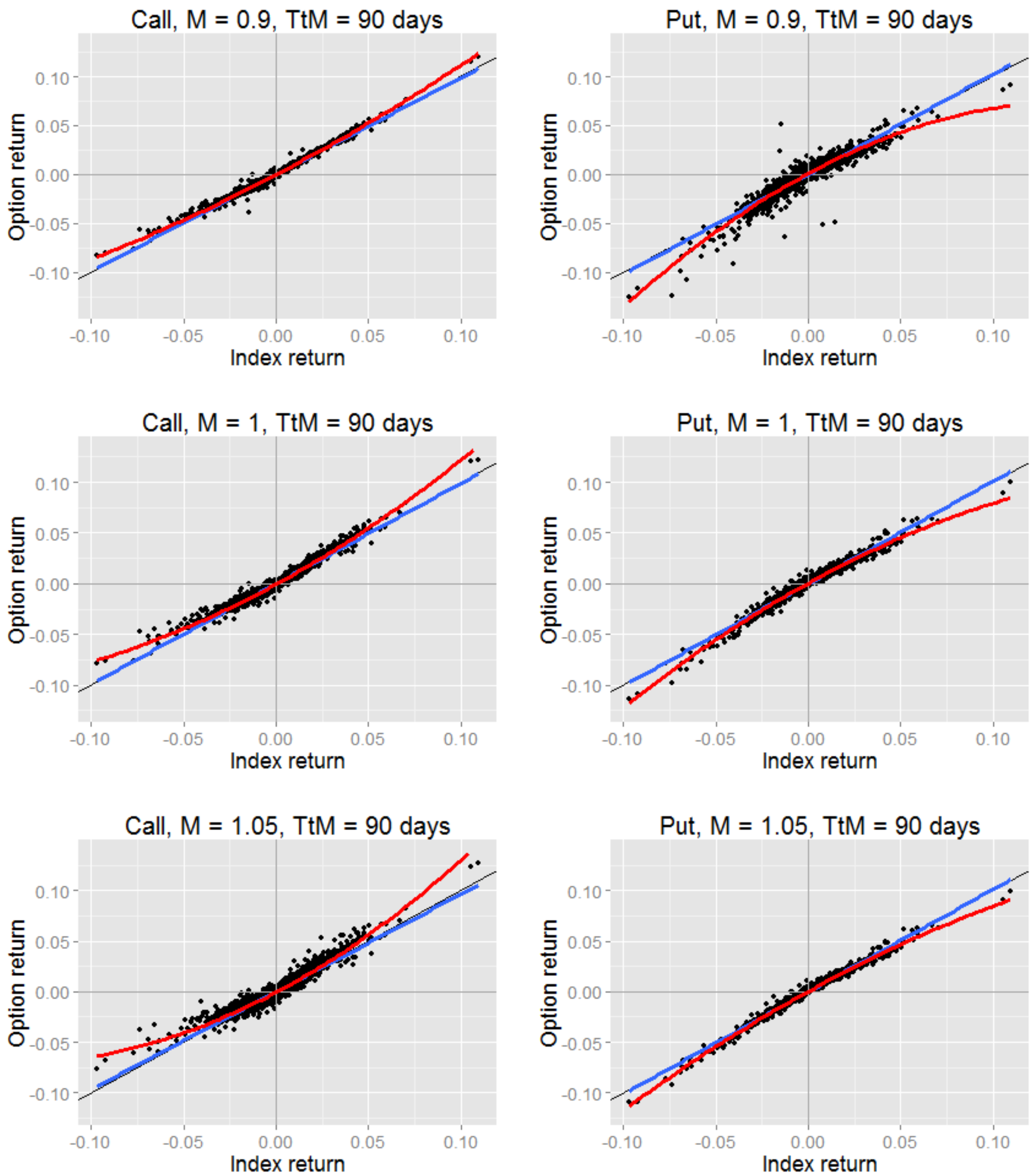

Figure 3: Scatterplots of daily option returns and index returns for selected SPX option portfolios over the sample period 1996-2015. M is moneyness, TtM time to maturity. The blue line illustrates the estimated linear regression, the red line the quadratic regression of option return on index return.

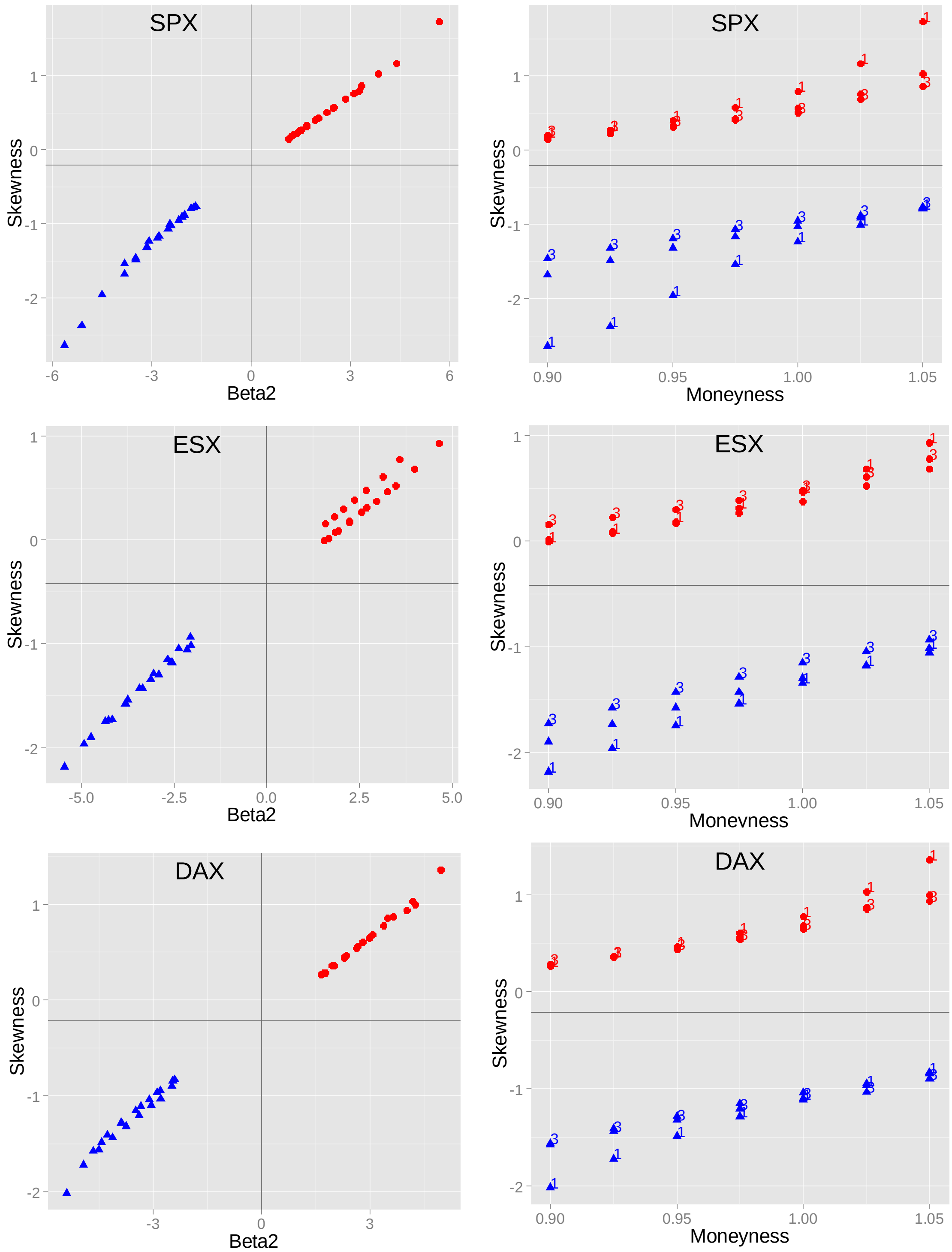

Figure 4: Each graph contains 42 data points for 21 call-based portfolios (red circles) and 21 put-based portfolios (blue triangles). Each portfolio is based on options with a particular moneyness (7 levels from 0.9 to 1.05) and time to maturity (3 levels). In the panels on the right, marker 1 denotes a time to maturity of 30 days, marker 3 a time to maturity of 60 days. All portfolios are constructed in such a way that their linear market exposure is 1. The additional vertical and horizontal lines indicate index level characteristics.

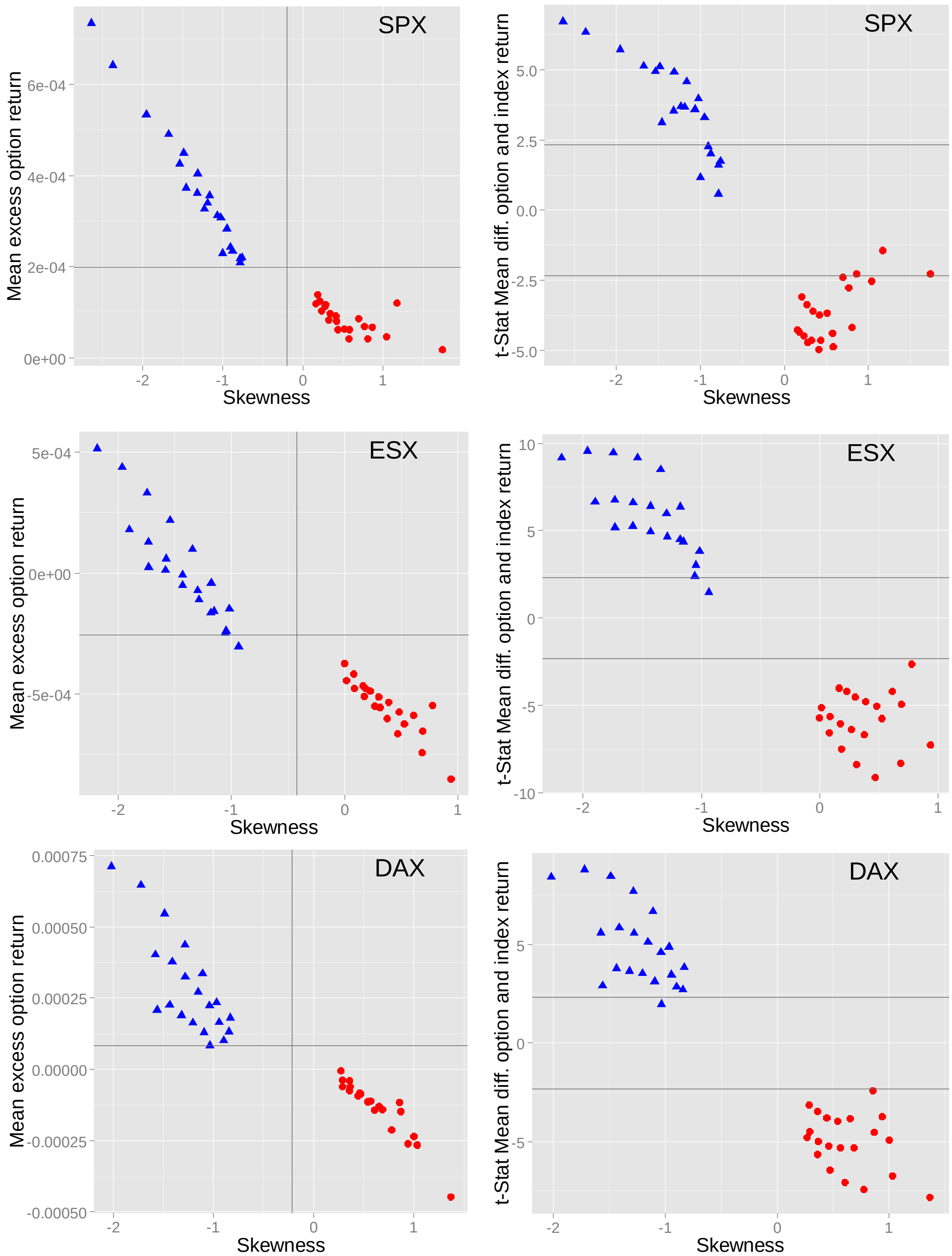

Figure 5: Each graph contains 42 data points for 21 call-based portfolios (red circles) and 21 put-based portfolios (blue triangles). Each portfolio is based on options with a particular moneyness (7 levels from 0.9 to 1.05) and time to maturity (3 levels). All portfolios are constructed in such a way that their linear market exposure is 1. On the left, the additional vertical and horizontal lines indicate index level characteristics. On the right, the horizontal lines indicate the thresholds for a 1% significance level of abnormal average returns.

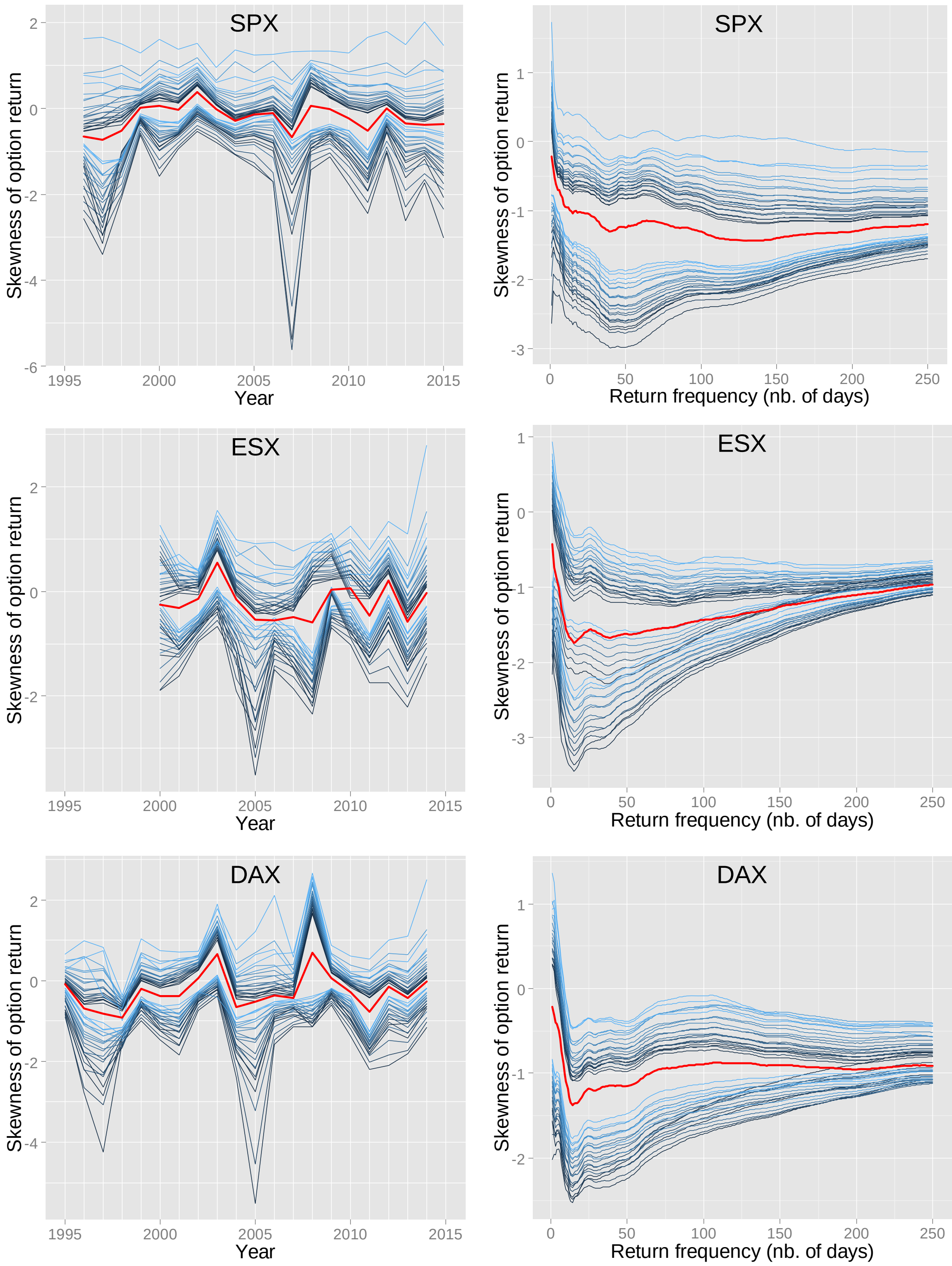

Figure 6: Left panels: Skewness of the 42 test portfolios (blue) and the index (red) in each year of the sample period (based on the 252 daily returns in the respective year). Right panels: Skewness for returns over different horizons (number of days n on the x-axis). All n-day intervals in the sample period are included in the estimation. Light blue lines: low moneyness options; dark blue lines: high moneyness options.

Table 1: Descriptive statistics SPX option returns

This table presents descriptive statistics for daily returns of option-based investment strategies using the SPX option from 1996 to Sept. 2015. The options are unlevered to achieve a target market exposure (Beta) of one. Type c referes to calls, type p to puts. M and TtM denote moneyness and time to maturity. Beta1 and Beta2 are the slope coefficients of a regression of option return on index return and squared index return; R2 is the R squared of this quadratic regression. Vol, Skew, Kurt and SR denote the volatility, the Fisher-Pearson coefficient of skewness, the Pearson coefficient of kurtosis and the Sharpe ratio, all based on the sample of daily returns of the option-based strategies over the full sample period.

No.	Option	Type	M	TtM	Beta	Beta1	Beta2	R2	Vol	Skew	Kurt	SR
1	SPX	c	0.9	30	0.995	0.998	1.192	0.996	0.01237	0.17644	3.71206	0.01120
2	SPX	c	0.9	60	0.991	0.993	1.133	0.994	0.01232	0.15211	3.85289	0.00969
3	SPX	c	0.9	90	0.990	0.993	1.265	0.991	0.01239	0.20266	4.16466	0.01011
4	SPX	p	0.9	30	0.993	0.982	-5.619	0.865	0.01352	-2.63613	19.04033	0.05429
5	SPX	p	0.9	60	1.024	1.016	-3.818	0.920	0.01335	-1.67669	10.10258	0.03674
6	SPX	p	0.9	90	1.024	1.017	-3.488	0.914	0.01343	-1.45778	8.12066	0.02774
7	SPX	c	0.925	30	0.995	0.997	1.513	0.994	0.01238	0.27629	3.74279	0.00953
8	SPX	c	0.925	60	0.990	0.993	1.371	0.992	0.01233	0.22790	3.89438	0.00838
9	SPX	c	0.925	90	0.989	0.992	1.456	0.990	0.01239	0.26458	4.16186	0.00914
10	SPX	p	0.925	30	1.004	0.994	-5.107	0.896	0.01337	-2.37029	16.94021	0.04799
11	SPX	p	0.925	60	1.021	1.014	-3.476	0.939	0.01315	-1.48498	8.62578	0.03419
12	SPX	p	0.925	90	1.021	1.015	-3.157	0.940	0.01320	-1.31877	7.48305	0.02739
13	SPX	c	0.95	30	0.994	0.997	1.935	0.990	0.01241	0.40602	3.81833	0.00740
14	SPX	c	0.95	60	0.990	0.993	1.664	0.988	0.01236	0.32047	3.93572	0.00680
15	SPX	c	0.95	90	0.989	0.992	1.681	0.987	0.01241	0.33531	4.15651	0.00792
16	SPX	p	0.95	30	1.008	0.999	-4.499	0.927	0.01315	-1.95364	12.33471	0.04060
17	SPX	p	0.95	60	1.017	1.010	-3.131	0.955	0.01297	-1.31436	7.52465	0.03115
18	SPX	p	0.95	90	1.018	1.012	-2.828	0.957	0.01302	-1.18971	6.91955	0.02608
19	SPX	c	0.975	30	0.993	0.998	2.495	0.983	0.01247	0.57610	3.95559	0.00501
20	SPX	c	0.975	60	0.990	0.994	2.025	0.983	0.01240	0.43248	3.97101	0.00503
21	SPX	c	0.975	90	0.989	0.993	1.948	0.982	0.01245	0.41664	4.14088	0.00653
22	SPX	p	0.975	30	1.007	1.000	-3.811	0.956	0.01289	-1.53804	8.63632	0.03303
23	SPX	p	0.975	60	1.012	1.006	-2.777	0.968	0.01280	-1.16297	6.74440	0.02779
24	SPX	p	0.975	90	1.014	1.009	-2.500	0.969	0.01287	-1.06602	6.43135	0.02428
25	SPX	c	1	30	0.995	1.001	3.246	0.970	0.01261	0.79932	4.14789	0.00333
26	SPX	c	1	60	0.992	0.997	2.469	0.974	0.01250	0.56584	3.98166	0.00333
27	SPX	c	1	90	0.990	0.995	2.267	0.974	0.01253	0.50981	4.09602	0.00514
28	SPX	p	1	30	1.003	0.998	-3.085	0.976	0.01267	-1.23238	7.00336	0.02576
29	SPX	p	1	60	1.007	1.002	-2.409	0.979	0.01266	-1.02423	6.17248	0.02428
30	SPX	p	1	90	1.010	1.005	-2.176	0.978	0.01274	-0.94955	6.02215	0.02222
31	SPX	c	1.025	30	0.980	0.988	4.386	0.934	0.01273	1.16714	4.73797	0.00944
32	SPX	c	1.025	60	0.984	0.990	3.096	0.957	0.01254	0.76130	4.06116	0.00555
33	SPX	c	1.025	90	0.985	0.991	2.833	0.961	0.01258	0.69217	4.53006	0.00690
34	SPX	p	1.025	30	1.008	1.003	-2.446	0.987	0.01262	-1.00229	6.07264	0.01816
35	SPX	p	1.025	60	1.010	1.006	-2.085	0.986	0.01263	-0.90477	5.72672	0.01919
36	SPX	p	1.025	90	1.010	1.006	-2.002	0.985	0.01270	-0.87827	5.55132	0.01846
37	SPX	c	1.05	30	0.919	0.929	5.671	0.852	0.01265	1.73802	7.46013	0.00149
38	SPX	c	1.05	60	0.957	0.965	3.825	0.925	0.01246	1.03472	4.93101	0.00374
39	SPX	c	1.05	90	0.966	0.973	3.318	0.937	0.01253	0.86088	4.83060	0.00544
40	SPX	p	1.05	30	1.011	1.007	-1.812	0.994	0.01259	-0.78602	5.17224	0.01664
41	SPX	p	1.05	60	1.013	1.010	-1.741	0.992	0.01262	-0.78160	5.16732	0.01725
42	SPX	p	1.05	90	1.014	1.011	-1.667	0.990	0.01270	-0.76216	5.18107	0.01729

Table 2: Descriptive statistics ESX option returns

This table presents descriptive statistics for daily returns of option-based investment strategies using the ESX option from 2000 to 2014. The options are unlevered to achieve a target market exposure (Beta) of one. Type c referes to calls, type p to puts. M and TtM denote moneyness and time to maturity. Beta1 and Beta2 are the slope coefficients of a regression of option return on index return and squared index return; R2 is the R squared of this quadratic regression. Vol, Skew, Kurt and SR denote the volatility, the Fisher-Pearson coefficient of skewness, the Pearson coefficient of kurtosis and the Sharpe ratio, all based on the sample of daily returns of the option-based strategies over the full sample period.

No.	Option	Type	M	TtM	Beta	Beta1	Beta2	R2	Vol	Skew	Kurt	SR
1	ESX	c	0.9	30	0.995	1.005	1.542	0.995	0.01386	-0.00594	1.02603	-0.02696
2	ESX	c	0.9	60	0.990	1.001	1.663	0.992	0.01394	0.01330	1.05037	-0.03187
3	ESX	c	0.9	90	0.993	1.000	1.585	0.988	0.01438	0.15900	1.42767	-0.03233
4	ESX	p	0.9	30	0.986	0.952	-5.451	0.913	0.01461	-2.18476	14.05049	0.03527
5	ESX	p	0.9	60	1.019	0.988	-4.741	0.934	0.01499	-1.90018	11.89559	0.01200
6	ESX	p	0.9	90	1.018	0.997	-4.165	0.923	0.01539	-1.73075	11.35401	0.00158
7	ESX	c	0.925	30	0.994	1.005	1.847	0.993	0.01387	0.07777	0.99979	-0.03004
8	ESX	c	0.925	60	0.989	1.002	1.922	0.990	0.01395	0.08521	1.05658	-0.03415
9	ESX	c	0.925	90	0.992	1.000	1.815	0.985	0.01439	0.22384	1.43936	-0.03387
10	ESX	p	0.925	30	1.000	0.969	-4.931	0.938	0.01456	-1.96361	11.58610	0.03005
11	ESX	p	0.925	60	1.019	0.991	-4.275	0.949	0.01482	-1.73439	10.11533	0.00873
12	ESX	p	0.925	90	1.015	0.997	-3.809	0.944	0.01517	-1.58214	9.84040	0.00076
13	ESX	c	0.95	30	0.992	1.006	2.223	0.990	0.01388	0.18181	1.00279	-0.03426
14	ESX	c	0.95	60	0.988	1.002	2.218	0.987	0.01396	0.16861	1.09397	-0.03646
15	ESX	c	0.95	90	0.992	1.001	2.069	0.983	0.01441	0.29802	1.48955	-0.03555
16	ESX	p	0.95	30	1.008	0.981	-4.359	0.955	0.01449	-1.74680	9.58025	0.02292
17	ESX	p	0.95	60	1.019	0.994	-3.813	0.962	0.01467	-1.57786	8.64624	0.00410
18	ESX	p	0.95	90	1.013	0.996	-3.431	0.958	0.01500	-1.43273	8.45751	-0.00331
19	ESX	c	0.975	30	0.990	1.007	2.687	0.985	0.01391	0.31013	1.05234	-0.03995
20	ESX	c	0.975	60	0.987	1.004	2.561	0.984	0.01399	0.26504	1.16105	-0.03933
21	ESX	c	0.975	90	0.991	1.003	2.353	0.981	0.01444	0.38331	1.59168	-0.03697
22	ESX	p	0.975	30	1.012	0.988	-3.752	0.970	0.01439	-1.54097	7.98967	0.01515
23	ESX	p	0.975	60	1.017	0.995	-3.358	0.974	0.01453	-1.43306	7.44516	-0.00050
24	ESX	p	0.975	90	1.012	0.997	-3.050	0.970	0.01486	-1.28791	7.21291	-0.00740
25	ESX	c	1	30	0.988	1.009	3.250	0.976	0.01398	0.46622	1.16285	-0.04740
26	ESX	c	1	60	0.986	1.006	2.956	0.978	0.01404	0.37488	1.25937	-0.04282
27	ESX	c	1	90	0.991	1.004	2.673	0.975	0.01450	0.48005	1.73959	-0.03947
28	ESX	p	1	30	1.012	0.993	-3.131	0.981	0.01427	-1.34608	6.71330	0.00700
29	ESX	p	1	60	1.015	0.995	-2.917	0.981	0.01442	-1.29711	6.43049	-0.00494
30	ESX	p	1	90	1.009	0.996	-2.677	0.978	0.01474	-1.15379	6.18109	-0.01065
31	ESX	c	1.025	30	0.977	1.001	3.984	0.957	0.01401	0.68228	1.46168	-0.05302
32	ESX	c	1.025	60	0.979	1.001	3.472	0.966	0.01406	0.52140	1.44844	-0.04427
33	ESX	c	1.025	90	0.985	1.000	3.120	0.961	0.01455	0.60666	1.97130	-0.04031
34	ESX	p	1.025	30	1.015	0.999	-2.583	0.988	0.01423	-1.17836	5.75963	-0.00288
35	ESX	p	1.025	60	1.016	0.999	-2.545	0.986	0.01438	-1.18178	5.64184	-0.01140
36	ESX	p	1.025	90	1.011	1.000	-2.381	0.982	0.01473	-1.04668	5.40859	-0.01623
37	ESX	c	1.05	30	0.946	0.975	4.650	0.907	0.01401	0.93342	2.17443	-0.06059
38	ESX	c	1.05	60	0.960	0.986	3.984	0.941	0.01402	0.68355	1.88813	-0.04661
39	ESX	c	1.05	90	0.970	0.987	3.578	0.930	0.01462	0.77396	2.43293	-0.03736
40	ESX	p	1.05	30	1.016	1.003	-2.049	0.991	0.01420	-1.01677	4.86963	-0.01046
41	ESX	p	1.05	60	1.018	1.004	-2.146	0.988	0.01437	-1.05636	4.81192	-0.01717
42	ESX	p	1.05	90	1.012	1.002	-2.066	0.983	0.01471	-0.93630	4.62794	-0.02062

Table 3: Descriptive statistics DAX option returns

This table presents descriptive statistics for daily returns of option-based investment strategies using the DAX option from 1995 to 2014. The options are unlevered to achieve a target market exposure (Beta) of one. Type c referes to calls, type p to puts. M and TtM denote moneyness and time to maturity. Beta1 and Beta2 are the slope coefficients of a regression of option return on index return and squared index return; R2 is the R squared of this quadratic regression. Vol, Skew, Kurt and SR denote the volatility, the Fisher-Pearson coefficient of skewness, the Pearson coefficient of kurtosis and the Sharpe ratio, all based on the sample of daily returns of the option-based strategies over the full sample period.

No.	Option	Type	M	TtM	Beta	Beta1	Beta2	R2	Vol	Skew	Kurt	SR
1	DAX	c	0.9	30	1.005	1.009	1.637	0.995	0.01382	0.26767	3.67902	-0.00034
2	DAX	c	0.9	60	1.001	1.005	1.712	0.993	0.01385	0.28555	3.59604	-0.00266
3	DAX	c	0.9	90	0.998	1.004	1.764	0.991	0.01400	0.28356	3.64577	-0.00432
4	DAX	p	0.9	30	0.947	0.933	-5.377	0.900	0.01396	-2.01656	9.57268	0.05105
5	DAX	p	0.9	60	0.988	0.976	-4.647	0.934	0.01427	-1.57637	5.67278	0.02820
6	DAX	p	0.9	90	0.999	0.985	-4.498	0.924	0.01469	-1.56110	5.81539	0.01417
7	DAX	c	0.925	30	1.005	1.010	1.947	0.993	0.01386	0.35769	3.94217	-0.00285
8	DAX	c	0.925	60	1.001	1.006	1.981	0.991	0.01388	0.36450	3.87063	-0.00431
9	DAX	c	0.925	90	0.998	1.005	2.006	0.989	0.01402	0.35611	3.90757	-0.00526
10	DAX	p	0.925	30	0.964	0.952	-4.917	0.929	0.01394	-1.72057	6.56009	0.04643
11	DAX	p	0.925	60	0.991	0.980	-4.255	0.950	0.01417	-1.41053	4.57184	0.02660
12	DAX	p	0.925	90	1.000	0.987	-4.115	0.950	0.01446	-1.43614	5.01157	0.01556
13	DAX	c	0.95	30	1.006	1.012	2.330	0.990	0.01390	0.46844	4.26511	-0.00610
14	DAX	c	0.95	60	1.002	1.008	2.294	0.988	0.01392	0.45562	4.19031	-0.00600
15	DAX	c	0.95	90	0.999	1.007	2.290	0.987	0.01406	0.44058	4.21859	-0.00659
16	DAX	p	0.95	30	0.978	0.966	-4.415	0.950	0.01393	-1.48567	4.81258	0.03926
17	DAX	p	0.95	60	0.993	0.983	-3.868	0.962	0.01408	-1.27991	3.76038	0.02305
18	DAX	p	0.95	90	1.000	0.988	-3.742	0.963	0.01433	-1.31879	4.27965	0.01325
19	DAX	c	0.975	30	1.007	1.014	2.801	0.984	0.01397	0.60502	4.66515	-0.01018
20	DAX	c	0.975	60	1.003	1.010	2.656	0.984	0.01398	0.56193	4.57288	-0.00791
21	DAX	c	0.975	90	1.000	1.008	2.615	0.983	0.01412	0.53885	4.58785	-0.00802
22	DAX	p	0.975	30	0.987	0.977	-3.883	0.966	0.01390	-1.28533	3.67282	0.03152
23	DAX	p	0.975	60	0.995	0.986	-3.480	0.972	0.01400	-1.15368	3.13026	0.01942
24	DAX	p	0.975	90	0.999	0.988	-3.390	0.972	0.01423	-1.20325	3.68708	0.01150
25	DAX	c	1	30	1.007	1.015	3.378	0.975	0.01407	0.77316	5.15270	-0.01504
26	DAX	c	1	60	1.004	1.012	3.071	0.978	0.01406	0.68485	5.03514	-0.00996
27	DAX	c	1	90	1.001	1.010	2.982	0.977	0.01419	0.65122	5.03174	-0.00913
28	DAX	p	1	30	0.993	0.985	-3.335	0.978	0.01386	-1.10859	2.88638	0.02430
29	DAX	p	1	60	0.995	0.987	-3.096	0.979	0.01393	-1.03738	2.63276	0.01603
30	DAX	p	1	90	0.999	0.989	-3.043	0.979	0.01415	-1.09475	3.18370	0.00919
31	DAX	c	1.025	30	0.996	1.007	4.176	0.956	0.01412	1.03043	6.20265	-0.01870
32	DAX	c	1.025	60	0.999	1.009	3.645	0.967	0.01411	0.86725	5.93273	-0.01038
33	DAX	c	1.025	90	0.995	1.007	3.486	0.954	0.01432	0.85401	5.93710	-0.00807
34	DAX	p	1.025	30	1.000	0.993	-2.882	0.986	0.01388	-0.96685	2.32166	0.01697
35	DAX	p	1.025	60	0.999	0.992	-2.801	0.985	0.01393	-0.94443	2.23335	0.01191
36	DAX	p	1.025	90	1.003	0.994	-2.786	0.975	0.01423	-1.03326	2.93661	0.00593
37	DAX	c	1.05	30	0.963	0.976	4.967	0.918	0.01401	1.36290	7.99224	-0.03181
38	DAX	c	1.05	60	0.983	0.994	4.245	0.938	0.01414	0.99808	7.34471	-0.01663
39	DAX	c	1.05	90	0.984	0.997	4.022	0.901	0.01462	0.93762	7.60189	-0.01773
40	DAX	p	1.05	30	1.005	0.999	-2.397	0.991	0.01388	-0.83027	1.90723	0.01303
41	DAX	p	1.05	60	1.003	0.997	-2.452	0.988	0.01394	-0.84296	1.88158	0.00947
42	DAX	p	1.05	90	1.005	0.997	-2.478	0.982	0.01420	-0.89718	2.33627	0.00715

Table 4: Cross-sectional analysis

This table shows cross-sectional regression results, Panel A for the base version of Models 1 to 3 (Eqs. 6-8) and Panel B for the modified version with excess index levels. The upper part of each panel is based on $x_s = Skew$, the lower part on $x_s = Beta2$. The t-values based on GMM standard errors are reported in brackets. The R^2 coefficient is the cross-sectional R^2 measure of Jagannathan and Wang (1996).

	Model 1			Model 2				Model 3			
Panel A: Excess option returns to risk-free, skewness and kurtosis											
	Interc	Skew	R^2	Interc	Skew	Skew^2	R^2	Interc	Skew	Kurt	R^2
SPX	1.66E-04	-1.58E-04	0.898	1.27E-04	-1.18E-04	4.43E-05	0.978	4.57E-05	-1.05E-04	2.26E-05	0.975
	(6.68)	(-6.17)		(3.90)	(-3.90)	(1.83)		(0.61)	(-2.88)	(1.72)	
ESX	-4.48E-04	-3.37E-04	0.921	-4.92E-04	-2.49E-04	7.63E-05	0.939	-5.07E-04	-2.56E-04	2.18E-05	0.929
	(-10.25)	(-7.91)		(-8.09)	(-2.79)	(1.09)		(-5.60)	(-2.25)	(0.75)	
DAX	1.99E-06	-2.42E-04	0.873	-2.97E-05	-2.19E-04	3.67E-05	0.881	-8.32E-05	-2.50E-04	1.85E-05	0.886
	(0.05)	(-6.63)		(-0.48)	(-4.22)	(0.63)		(-0.75)	(-6.46)	(0.81)	
	Interc	Beta2	R2	Interc	Beta2	Beta2^2	R2	Interc	Beta2	Kurt	R2
SPX	2.08E-04	-5.42E-05	0.846	1.40E-04	-5.04E-05	7.98E-06	0.962	4.94E-05	-3.37E-05	2.66E-05	0.974
	(8.53)	(-6.21)		(3.74)	(-5.82)	(2.30)		(0.66)	(-2.86)	(2.21)	
ESX	-3.03E-04	-1.01E-04	0.912	-3.79E-04	-9.43E-05	7.67E-06	0.931	-4.18E-04	-7.10E-05	2.67E-05	0.925
	(-7.42)	(-7.70)		(-4.74)	(-6.73)	(1.12)		(-3.16)	(-2.10)	(0.91)	
DAX	5.08E-05	-7.03E-05	0.857	5.48E-06	-6.76E-05	4.07E-06	0.867	-5.72E-05	-7.37E-05	2.38E-05	0.880
	(1.41)	(-6.51)		(0.07)	(-5.89)	(0.69)		(-0.52)	(-6.39)	(1.03)	
Panel B: Excess option returns to index, excess skewness and kurtosis compared to index											
	Interc	Skew	R^2	Interc	Skew	Skew^2	R^2	Interc	Skew	Kurt	R^2
SPX	1.24E-04	-1.58E-04	0.905	8.27E-05	-1.38E-04	4.07E-05	0.973	8.92E-05	-1.09E-04	2.06E-05	0.971
	(1.19)	(-14.25)		(-2.87)	(-11.46)	(3.47)		(-2.48)	(-6.36)	(3.42)	
ESX	7.88E-05	-3.36E-04	0.934	3.17E-05	-3.16E-04	5.41E-05	0.943	3.44E-05	-2.47E-04	2.39E-05	0.944
	(-0.78)	(-24.87)		(-3.11)	(-20.71)	(2.34)		(-3.35)	(-6.59)	(2.46)	
DAX	1.04E-04	-2.42E-04	0.901	7.45E-05	-2.36E-04	3.09E-05	0.907	6.33E-05	-2.50E-04	1.73E-05	0.914
	(0.56)	(-20.64)		(-1.47)	(-20.00)	(1.57)		(-2.16)	(-19.37)	(2.21)	
	Interc	Beta2	R2	Interc	Beta2	Beta2^2	R2	Interc	Beta2	Kurt	R2
SPX	1.34E-04	-5.41E-05	0.855	6.97E-05	-5.06E-05	7.45E-06	0.958	8.77E-05	-3.49E-05	2.47E-05	0.970
	(2.30)	(-14.29)		(-3.61)	(-13.20)	(4.41)		(-2.64)	(-6.53)	(4.45)	
ESX	9.37E-05	-1.01E-04	0.933	3.42E-05	-9.56E-05	5.99E-06	0.945	3.99E-05	-7.12E-05	2.65E-05	0.946
	(0.62)	(-25.21)		(-2.84)	(-22.59)	(2.79)		(-2.91)	(-6.78)	(2.87)	
DAX	9.89E-05	-7.01E-05	0.882	6.40E-05	-6.80E-05	3.14E-06	0.888	4.52E-05	-7.34E-05	2.26E-05	0.902
	(0.01)	(-20.81)		(-1.93)	(-19.47)	(1.65)		(-3.18)	(-19.46)	(2.82)	