The influence of volatility and moneyness on equity option returns - An empirical analysis

Peter Reichling* Juliane Selle† Anastasiia Zbandut†‡

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Abstract

This paper contributes to the literature analyzing the dynamics of equity options by determining the sensitivity of equity option returns to changes in systematic and idiosyncratic volatility (SVOL and IVOL) of the underlying on the EU and US markets. Total volatility is split into its two components by applying the Fama-French-Carhart model, resulting in an average SVOL of about 20 percent and an average IVOL of about 30 percent. Alternatively, we implement an exponential GARCH model that shows average IVOL estimates between 30 percent and 45 percent. Since we aim to consider the cross-sectional and time-series dimensions of the option returns separately, a two-stage Fama-MacBeth-Campbell regression is implemented accounting for varying moneyness levels and nonlinearities. In the first stage, cross-sectional regressions are run for each day in the sample. On average, the net effect of IVOL on call option returns is significantly negative for ATM and ITM options but positive for sufficiently OTM options. The average net effect of SVOL on call returns is negative for ATM options as well but its behavior for OTM and ITM options varies within the observed markets. For put option returns, the signs of the IVOL and SVOL coefficients are consistently opposite to those for calls. The second stage is a global time-series analysis where the first-stage coefficients are used as explanatory variables. Here, we determine their explanatory power and estimate their corresponding risk premia. Overall, the results suggest a clearly positive SVOL premium and show mixed results for the IVOL premium, which is negative when the regression is applied to single options and positive when applied to portfolios.

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*Faculty of Economics and Management, Otto-von-Guericke University Magdeburg.

†Audit and Assurance Department, Deloitte Germany.

‡Corresponding author, email anastasiia.zbandut@ovgu.de, phone +49 391 67 52302, mailing address Universitätsplatz 2, 39106, Magdeburg.

1 Introduction and literature review

According to data collected by FIA – the leading global trade organization for futures, options and centrally cleared derivatives – trading activities on the option market have vastly grown in the past years. The number of option contracts traded worldwide exploded since 2013 and increased by 461 percent to 54.53 billion contracts traded in 2022 (the number of equity option contracts increased by 479 percent to 49.32 billion contracts traded in 2022). Most of the growth can be attributed to the option markets in Brazil, China and India. However, the US market for equity options also expanded by 158 percent to 10.54 billion contracts in 2022 (the EU market for equity options decreased by 8 percent to 0.76 billion contracts traded in 2022) and continues to account for the majority of trading activities worldwide. Together with the EU market, it accounts for almost 78 percent of global open interest with 0.68 billion contracts outstanding (global open interest amounts to 0.88 billion contracts outstanding).[1]

A vast strand of scientific research has been devoted to analyzing option price dynamics. Since Black and Scholes (1973) and Merton (1973) (BSM from here) developed a formula to determine option values, the validity of those theoretically predicted prices and the sensitivity to its determinants, such as stock and strike prices or volatility of the underlying, has been extensively examined with empirically observed data. A major criticism towards the BSM model is its assumption of a constant volatility of the underlying. Empirical research showed that the observed dynamics on the option market deviate from the one predicted by the BSM model. To overcome this issue, Heston (1993) derived a closed-form solution for the price of European call options that incorporates stochastic volatility but still keeps most of the characteristics featured in the BSM model.

A far less extensive portion of the scientific literature is focused on analysing option returns. Rubinstein (1984) was among the first to calculate the expected return of a European-style call option over a holding period which might be shorter than its remaining time-to-maturity. His assumptions were that the market participants agree upon a constant interest rate and assume a log-normally distributed price of the underlying stock, where he assumes that the market price of the call option equals the value obtained with the BSM formula at all times. Coval and Shumway (2001) provide empirical evidence about the dynamics of index option returns. They use two different data sets and analyse two separate forms of option risk. Firstly, they consider the leverage effect[2] which, according to the BSM model, is reflected in option betas. Their empirical analysis shows that call options on securities with expected returns higher than the risk-free rate on average earn higher returns than the respective underlying security. Secondly, they consider the curvature effect, i.e., nonlinearity of option pay-offs. In contrast to the BSM model, they provide robust empirical evidence that options are not redundant assets and that they earn a risk premium net of the leverage effect. Broadie et al. (2009) empirically show that expected option returns are highly sensitive to stock volatility, that this relationship is concave and varies across different strike prices.

Recently, several papers started developing a theoretical foundation of how volatility influences option returns.[3] Chaudhury (2017) derives a general formula for return vegas,[4] which considers the effects of systematic (SVOL) and idiosyncratic (IVOL) volatility separately. Both analytically and with numerical simulations, the author demonstrates that an increase in IVOL leads to lower call (higher put) option returns. At the same time, there exists a counteracting effect from changes in SVOL. The intuition behind

[1] See https://www.fia.org/fia/etd-tracker.

[2] Here, leverage refers to the fact that the option price usually changes more strongly in relative terms than the value of the underlying asset.

[3] The literature related to the risk-return trade-off on the stock market is rather extensive. Ang et al. (2006) and Dennis et al. (2006) are just two examples for studies examining the relationship between changes in volatility and the cross-section of stock returns. Both works decompose volatility into its two components and find robust evidence for a negative effect of systematic volatility and show mixed results for the influence of idiosyncratic volatility.

[4] The return vega is the first derivative of the expected option rate of return with respect to the volatility of the underlying.

this so-called drift effect is that more volatile stocks might be associated with higher expected prices and, thereby, higher expected option returns. The numerical results further elaborate on how direction and magnitude of the net effect resulting from those two opposing effects depend on the underlying asset beta, option moneyness and maturity. For example, for call options with a time-to-maturity of more than one year, a volatility above 30 percent and a moneyness level above 106 percent, the return vega turns positive since the SVOL effect is strong enough to offset the negative IVOL effect. Hu and Jacobs (2020) analytically show in the BSM framework, that the return vega is negative for call options and positive for put options. Their predictions are empirically supported by US market data for index and equity options over a sample period from January 1996 to July 2013. The authors alternatively consider the stochastic volatility model by Heston (1993), where the sign of the return vega cannot be derived analytically. However, numerical calculations for various parametrizations still show an inverse (direct) relation between call (put) option returns and volatility.

Also recently, a new stream of empirical literature focuses on the components of underlying volatility, i.e., SVOL and IVOL, to measure the influence of volatility on option rates of return. Cao and Han (2013) find an alternative explanation for the inverse relationship between equity option rates of return and IVOL of the underlying. They use a similar data set to that of Hu and Jacobs (2020). However, they focus on delta-hedged short-term at-the-money call and put options. Thereby, the authors ensure that their empirical results are not driven by any stock characteristics other than its IVOL. Additionally, they empirically confirm that dealers charge a higher premium for options on stocks with high IVOL. This extra compensation increases option prices and thereby lowers option returns. This explains the inverse relationship that is equivalent to a negative return vega. The work of Aretz et al. (2023) also supports the finding that expected option rates of return are not unambiguously related to their underlying asset's volatility. They theoretically examine this relation by taking the partial derivative of the instantaneous expected rate of return with respect to the volatility of the underlying and then corroborate their findings empirically with the help of double-sorted portfolios and regression analysis applied to single-stock American-style call option data from January 1996 to August 2014. When splitting total volatility into its two components, they conclude that higher IVOL reduces (raises) the expected return of call (put) options and that the effect of higher SVOL can be positive or negative for both call and put options. In addition, they find that the strike price influences the strengths of these two effects.

As the existing empirical evidence regarding the sensitivity of equity option rates of return to changes in SVOL and IVOL is not extensive and rather inconclusive, the goal of our paper is to expand the results of previous works. Firstly, our sample data consists of multiple data sets and contains the data for both US and EU option markets (mostly American-style options). The sample period is between January 2011 and March 2021, the sample size is between 10 and 70 million single observations per data set. Our work complements previous ones with more recent, bigger scaled samples and analysis conducted for both option markets, i.e., the US and the EU, and option types, i.e., call and put options. We further contribute to the existing literature by decomposing total volatility into its two components via the Fama-French-Carhart four-factor (FFC) model and via an exponential GARCH (EGARCH) model.[5] While the initial estimates (FFC model) of IVOL range from approximately 29 percent to 33 percent, the alternative estimation (EGARCH model) presents a slightly higher average, between 30 percent to 45 percent.

In our main regressions, we follow the Fama-MacBeth-Campbell (FMC) method so that the cross-sectional and time-series dimensions of the returns are considered separately.[6] The FMC method is a popular statistical procedure in finance research that involves a two-step regression analysis. The first step represents a cross-sectional regression for each time period that generates a set of estimated

[5] See Carhart (1997) and Nelson (1991).
[6] See Campbell et al. (1997), pp. 215-217.

coefficients for each factor and results in a time-series of estimated factor premia. The second step takes the average of these estimated coefficients across time and tests if these average coefficients are statistically different from zero. The FMC procedure helps to estimate and draw inferences about the risk premia of the factors, which may not be constant over time. However, the standard model is adjusted to account for varying moneyness levels, nonlinearities and liquidity controls. After estimating SVOL and IVOL for every underlying stock, we run cross-sectional regressions of option rates of return on SVOL, IVOL and moneyness (M) for each point in time (first step). Subsequently (second step), we run time series regressions of option rates of return on the coefficients found in the risk step, i.e., risk premia. Therefore, the first step determines each option's exposure to risk components SVOL and IVOL, i.e., risk sensitivities, and the second step determines how much an investor can earn for the exposure to these risk sensitivities. In both steps, we control for moneyness. With respect to IVOL and at-the-money (ATM) options, the first step results presented in the following are in accordance with previous findings where IVOL betas are negative for call options[7] and positive for put options in both the US and the EU markets. The influence of moneyness levels is stronger compared to previous studies,[8] as IVOL sensitivities for call options are more negative for in-the-money (ITM) options and turn positive for out-of-the-money (OTM) options with a moneyness below 82 percent to 91 percent. Conversely, IVOL sensitivities for put options are more positive for OTM options and turn negative for ITM options with a moneyness below 51 percent to 68 percent, respectively.

We clarify some contradictory findings in the literature and show in the first step results that the sign of the SVOL sensitivity does not only depend on moneyness but also varies across the US and the EU option markets. While the negative effect of SVOL for ATM call options intensifies for ITM options on the EU market and turns positive for OTM options with a moneyness below 85 percent, it behaves the opposite way on the US market where it intensifies for OTM options and only turns positive for ITM options with a moneyness above 130 percent. Put option sensitivities mirror the results for call options so that they are positive for ATM options, increasing (decreasing) with moneyness on the EU (US) market, turning negative for ITM (OTM) options with a moneyness below 95 (above 116) percent. Overall, the second step results support the explanatory power of the first step sensitivities. Our regressions show a positive SVOL premium and mixed results for the IVOL premium, which is negative when the regression is applied to single options and positive when applied to portfolios grouped by moneyness and IVOL. We conduct robustness tests of our empirical results with respect to liquidity controls, alternative volatility estimates (FFC versus EGARCH) and more restrictive data cleaning requirements.

The rest of our paper is structured as follows: While section 2 revisits the economic theory behind option rates of return and their sensitivity to the volatility of the underlying, section 3 is devoted to the empirical analysis of our data set. We describe the call and put option samples from the EU and US market in section 3.1, section 3.2 explains the construction of the chosen econometric model, and section 3.3 evaluates the empirical results. Robustness tests follow in section 4 before the paper concludes in section 5.

2 Theory on expected option rates of return

In the BSM model, the underlying stock price S follows a geometric Brownian motion with drift rate μ and constant volatility σ. In this model, the price of a call(put) $C(P)$ option can be computed as:

$$\begin{aligned} C &= S \cdot \mathrm{N}(d_1) - K \cdot e^{-r \cdot T} \cdot \mathrm{N}(d_2) \\ P &= K \cdot e^{-r \cdot T} \cdot \mathrm{N}(-d_2) - S \cdot \mathrm{N}(-d_1) \end{aligned} \tag{2.1}$$

[7] See Aretz et al. (2023), p. 304.
[8] See Aretz et al. (2023), p. 309.

where $d_1 = \frac{\ln\left(\frac{S}{K}\right)+\left(r+\frac{1}{2}\cdot\sigma^2\right)T}{\sigma\cdot\sqrt{T}}$ and $d_2 = d_1 - \sigma\cdot\sqrt{T}$, K denotes the option strike price, T denotes the time-to-maturity, r is the risk-free rate and N(.) denotes the standard normal cumulative distribution function. Hu and Jacobs (2020) compute the expected option rate of return by considering the expected option pay-off under the physical probability:[9]

$$\begin{aligned} \mathrm{E}(R_C) &= \frac{\mathrm{E}(C_T)}{C} = \frac{e^{\mu\cdot T}\left[S\cdot\mathrm{N}(d_1^*) - K\cdot e^{-\mu\cdot T}\cdot\mathrm{N}(d_2^*)\right]}{S\cdot\mathrm{N}(d_1) - K\cdot e^{-r\cdot T}\mathrm{N}(d_2)} \\ \mathrm{E}(R_P) &= \frac{\mathrm{E}(P_T)}{P} = \frac{e^{\mu\cdot T}\left[K\cdot e^{-\mu\cdot T}\cdot\mathrm{N}(-d_2^*) - S\cdot\mathrm{N}(-d_1^*)\right]}{K\cdot e^{-r\cdot T}\cdot\mathrm{N}(-d_2) - S\cdot\mathrm{N}(-d_1)} \end{aligned} \tag{2.2}$$

where $d_1^* = \frac{\ln\left(\frac{S}{K}\right)+\left(\mu+\frac{1}{2}\cdot\sigma^2\right)T}{\sigma\cdot\sqrt{T}}$ and $d_2^* = d_1^* - \sigma\cdot\sqrt{T}$.

The sensitivity of the option price to changes in the volatility of the underlying is represented by the price vega $\mathcal{V}^{\text{price}}$ and reads as:

$$\mathcal{V}^{\text{price}} = \frac{\partial C}{\partial\sigma} = \frac{\partial P}{\partial\sigma} = S\cdot\mathrm{n}(d_1)\cdot\sqrt{T} > 0 \tag{2.3}$$

where n(.) denotes the standard normal density function. Here, $\mathcal{V}^{\text{price}}$ is positive for any call or put option. However, the derivation of the option rate of return with respect to volatility is more complex. Hu and Jacobs (2020) derive the return vega $\mathcal{V}^{\text{return}}$ as follows, thereby implicitly only considering idiosyncratic risk of the underlying:[10]

$$\begin{aligned} \mathcal{V}^{\text{return}}_{\text{C}} &= \frac{\partial\mathrm{E}(R_C)}{\partial\sigma} = \frac{e^{\mu\cdot T}\cdot S\cdot\sqrt{T}\cdot\mathrm{EX}}{[C]^2} < 0\,\text{with}\,\mathrm{EX} = \mathrm{n}(d_1^*)\cdot C - \mathrm{n}(d_1)\cdot\mathrm{E}(C_T)\cdot e^{-\mu\cdot T} < 0 \\ \mathcal{V}^{\text{return}}_{\text{P}} &= \frac{\partial\mathrm{E}(R_P)}{\partial\sigma} = \frac{e^{\mu\cdot T}\cdot S\cdot\sqrt{T}\cdot B}{[P]^2} > 0\,\text{with}\,B = \mathrm{n}(-d_1^*)\cdot P - \mathrm{n}(-d_1)\cdot\mathrm{E}(P_T)\cdot e^{-\mu\cdot T} > 0 \end{aligned} \tag{2.4}$$

Chaudhury (2017) generalizes these results by considering systematic and idiosyncratic risk of the underlying. By defining the drift rate as $\mu = r + \lambda\cdot\sigma$ where λ is the (positive) systematic risk premium, he shows:

$$\begin{aligned} \mathcal{V}^{\text{return}}_{\text{C}} &= \frac{\partial\mathrm{E}(R_C)}{\partial\sigma} = \frac{X_C\cdot e^{r\cdot T}}{[\mathrm{E}^{Q}(C_T)]^2}\,\text{with}\,X_C = \underbrace{e^{r\cdot T+\mu\cdot T}\cdot S\cdot\sqrt{T}}_{>0}\cdot\Big[\underbrace{EX}_{<0} + \underbrace{C\cdot\mathrm{N}(d_1^*)\cdot\lambda\cdot\sqrt{T}}_{>0}\Big] \\ \mathcal{V}^{\text{return}}_{\text{P}} &= \frac{\partial\mathrm{E}(R_P)}{\partial\sigma} = \frac{X_P\cdot e^{r\cdot T}}{[\mathrm{E}^{Q}(P_T)]^2}\,\text{with}\,X_P = \underbrace{e^{r\cdot T+\mu\cdot T}\cdot S\cdot\sqrt{T}}_{>0}\cdot\Big[\underbrace{B}_{>0} - \underbrace{P\cdot\mathrm{N}(-d_1^*)\cdot\lambda\cdot\sqrt{T}}_{>0}\Big] \end{aligned} \tag{2.5}$$

where $\mathrm{E}^{Q}(C_T) = C\cdot e^{r\cdot T}$ and $\mathrm{E}^{Q}(P_T) = P\cdot e^{r\cdot T}$. The signs of X_C and X_P determine the signs of $\mathcal{V}^{\text{return}}_{\text{C}}$ and $\mathcal{V}^{\text{return}}_{\text{P}}$, respectively.[11] The author relates the terms X_C and X_P to the terms EX and B from Hu and Jacobs (2020), for which the signs are known. Hence, the signs of X_C and X_P depend on the relative size of the terms $C\cdot\mathrm{N}(d_1^*)\cdot\lambda\cdot\sqrt{T}$ and $P\cdot\mathrm{N}(-d_1^*)\cdot\lambda\cdot\sqrt{T}$, which describe the drift effect. Only if the drift effect is small, i.e., $|EX| > C\cdot\mathrm{N}(d_1^*)\cdot\lambda\cdot\sqrt{T}$ and $|B| > P\cdot\mathrm{N}(-d_1^*)\cdot\lambda\cdot\sqrt{T}$, $\mathcal{V}^{\text{return}}_{\text{C}}$ and $\mathcal{V}^{\text{return}}_{\text{P}}$ keep their respective negative and positive sign as in equation 2.4. This suggests that the volatility component determines the effect on option rates of return.[12]

Aretz et al. (2023) emphasize the ambiguous nature of the option return vega. They assume a two-period, continuous-pay-off stochastic discount factor model with a log-normally distributed future pay-off of the underlying and of the future realization of the stochastic discount factor. By deriving the

[9] See Hu and Jacobs (2020), p. 1029.
[10] See Hu and Jacobs (2020), p. 1030.
[11] See Chaudhury (2017), pp. 1-2.
[12] See Chaudhury (2017), p. 4.

return vega in this framework, the authors show that the expected return of a European call option unambiguously increases with the strike price and decreases with the drift rate and IVOL. However, the sign of the return vega can only be determined for certain moneyness levels. It is positive for ATM and ITM call options, but remains unclear for OTM options. This result can be explained by two effects. Firstly, there is an omega effect. It describes how expected option returns are affected by the option elasticity, called the option omega. Aretz et al. (2023) show that the omega effect is always negative for changes in SVOL and IVOL. Secondly, there is the underlying asset effect. This effect influences expected option rates of return via the expected rate of return of the underlying. Whether the effect is positive or negative depends on the sign of the derivative of the underlying asset's expected rate of return with respect to the respective volatility component. It is positive for SVOL, however, it is nearly zero for IVOL. Hence, the total effect, which is the sum of omega effect and underlying asset effect, is negative for IVOL and depends on the trade-off between the two oppositely-signed effects for SVOL.[13]

3 Empirical analysis

3.1 Data

Option data is obtained from IVolatility.com. The sample period is from January 2011 to March 2021. Data for the Fama-French factors and the risk-free rate of return are obtained from Kenneth French's website for the corresponding time period. Each individual option in the data set is uniquely identified by the company name of its underlying stock, its strike price and its expiration date. Time-to-maturity, calculated in business days, is the difference between expiration and observation date. The closing stock price of the underlying S is used to compute the daily stock return as $r_t = \frac{S_t}{S_{t-1}} - 1$. We apply the following filters to increase the data quality. Only options with positive bid and ask prices as well as positive trading volume and open interest are kept in the sample. We consider only options that have not reached their expiration date yet. We remove options that have a higher bid price than ask price from our analysis. Later in the analysis, we further exclude observations that show abnormally high returns (above 300 percent per day). Additionally, we leave out observations that lead to low sample sizes for a regression (less than 30 observations per single regression). The original data set contains data for the EU and US market separately, abbreviated by EU_* and US_*, respectively. The data for European-style equity options is too small to obtain a decent sample size. Therefore, we only report results for American-style options.

The option rate of return $R_{i,t}$ for option i at time t is calculated as follows:

$$R_{i,t} = \frac{P_{i,t}}{P_{i,t-1}} - 1 \tag{3.1}$$

where the option price $P_{i,t}$ is the average of bid and ask prices. Moneyness M is defined as the ratio of the underlying stock's closing price S and the option's strike price K at the starting point of the corresponding time series. For moneyness levels $1.025 \geq M \geq 0.975$, we refer to ATM options, call options with $M > 1.025$ represent ITM options and with $M < 0.975$, they represent OTM options. The opposite holds for put options.

Descriptive statistics for the analysed samples are depicted in table 3.1. In accordance with previous studies, the mean daily returns of American-style call options are positive, although their lower quartiles are negative. When converted to monthly returns, our samples show values at the level of 15.8 percent to 18.2 percent and are, thereby, at a comparable level to those found by Hu and Jacobs (2020) and Aretz et al. (2023) with 11.1 percent and 14.6 percent, respectively. The mean daily returns of American-

[13] See Aretz et al. (2023), p. 2.

Table 3.1: Descriptive statistics of option samples

	Daily Return	Moneyness	Maturity	Volume	Open Interest
EU Market, American Calls (EU_AC, n = 9 891 360)					
Mean	0.0069	1.6617	125	115	2504
Std Deviation	0.2375	6.395 29	182	729	7985
25 %-Quartile	−0.0858	0.8867	26.0000	4.0000	69.0000
50 %-Quartile	−0.0044	0.9676	64.0000	15.0000	328.0000
75 %-Quartile	0.0668	1.0415	159.0000	50.0000	1689.0000
EU Market, American Puts (EU_AP, n = 10 842 793)					
Mean	−0.0010	1.3064	117	110	2631
Std Deviation	0.2171	3.0266	166	762	7834
25 %-Quartile	−0.0791	0.9456	25.0000	4.0000	67.0000
50 %-Quartile	−0.0087	1.0316	60.0000	12.0000	322.0000
75 %-Quartile	0.0506	1.1347	149.0000	50.0000	1761.0000
US Market, American Calls (US_AC, n = 70 843 968)					
Mean	0.0080	1.1226	85	144	1792
Std Deviation	0.2965	8.8411	114	181	9151
25 %-Quartile	−0.1080	0.8870	14.0000	3.0000	60.0000
50 %-Quartile	−0.0054	0.9723	36.0000	12.0000	251.0000
75 %-Quartile	0.0801	1.0422	109.0000	51.0000	1039.0000
US Market, American Puts (US_AP, n = 55 239 132)					
Mean	−0.0105	1.1637	75	107	1558
Std Deviation	0.3034	4.5291	105	831	7188
25 %-Quartile	−0.1264	0.9782	13.0000	3.0000	55.0000
50 %-Quartile	−0.0203	1.0415	30.0000	11.0000	219.0000
75 %-Quartile	0.0580	1.1470	95.0000	44.0000	910.0000

This table reports descriptive statistics for all sub samples with their sample size n. Daily return is defined by equation 3.1, moneyness is the ratio S/K, maturity is the time-to-maturity in business days, volume is the daily trading volume as the number of options traded, and open interest as the number of currently active options, i.e., traded but not yet closed by an offsetting trade or an exercise.

style put options in our sample are negative. Both American call and put option samples show average moneyness levels of above 1.025, corresponding to ITM call and OTM put options. Further, the samples cover a wide range of different options with respect to maturities, trading volume and open interest.

On average, data for the EU market shows longer time-to-maturities, slightly lower trading volumes and higher open interest than the larger sample for the US market. With 71 million observations for call options and 55 million observations for put options, the US samples size is five to seven times higher than the EU samples with 10 million call and 11 million put observations.

3.2 Model construction

As a preparatory work in our analysis, we apply the FFC approach in time series analyses of daily stock returns r to estimate SVOL_i and IVOL_i for each option's underlying i:

$$r_{i,t} = \alpha_i^{FFC} + \beta_i^{mkt} \cdot (r_{mkt,t} - r_{f,t}) + \beta_i^{smb} \cdot r_{smb,t} + \beta_i^{hml} \cdot r_{hml,t} + \beta_i^{mom} \cdot r_{mom,t} + \varepsilon_{i,t} \tag{3.2}$$

where $r_{mkt,t} - r_{f,t}$ denotes the market excess return, $r_{smb,t}$ is the size factor, $r_{hml,t}$ is the value factor and $r_{mom,t}$ is the monthly momentum factor. We use the factor returns for the US and EU markets, correspondingly. IVOL_i is estimated as the annualized standard deviation of the residuals $\varepsilon_{i,t}$ and SVOL_i as the annualized standard deviation of the fitted values $r_{i,t} - \varepsilon_{i,t}$.

Alternatively, we estimate IVOL_i by implementing the EGARCH model to capture the time-varying nature of volatility. Here, IVOL_i equals the one-period-ahead predicted idiosyncratic volatility based on:

$$\begin{aligned} &\varepsilon_{i,t} \sim \mathcal{N}(0,\ \sigma_{i,t}^2) \\ &\ln \sigma_{i,t}^2 = \alpha_i^{EGARCH} + \sum_{l=1}^{p} b_{i,l} \cdot \ln \sigma_{i,t-l}^2 + \sum_{k=1}^{q} c_{i,k} \cdot \left(\theta_i \cdot \frac{\varepsilon_{i,t-k}}{\sigma_{i,t-k}} + \gamma_i \cdot \left(\left| \frac{\varepsilon_{i,t-k}}{\sigma_{i,t-k}} \right| - \sqrt{2/\pi} \right) \right) \end{aligned} \tag{3.3}$$

To account for differences among the underlying stocks, an individual EGARCH model is estimated for nine combinations of the parameters p and q in equation 3.3, whereby p and q can each take the values

1, 2 or 3. Subsequently, the (p, q)-combination with the lowest Akaike Information Criteria (AIC) is selected to estimate the expected IVOL of each individual stock i. This approach is popular in the literature related to stock return analyses.[14] Based on the EGARCH residuals, SVOL_i and IVOL_i are again estimated as the annualized standard deviation of the residuals and of the fitted values, respectively.

Our goal is to examine the explanatory power of option risk sensitivities. For this, we apply the FMC procedure. As the first step of our analysis, we analyse the sensitivity of option rates of return R with respect to SVOL and IVOL, accounting for the moneyness level M. Here, we employ the following cross-sectional regressions for each t:[15]

$$R_{j_i,t} = \alpha_t^{CS} + \beta_t^{SVOL} \cdot \text{SVOL}_i + \beta_t^{IVOL} \cdot \text{IVOL}_i + \beta_t^{M} \cdot M_{j_i,t} + \eta_{j_i,t} \tag{3.4}$$

where $R_{j_i,t}$ is the rate of return of option j written on the underlying stock i at point in time t and $\eta_{j_i,t}$ is the corresponding residual. The idea is to identify the time effect of risk sensitivities on option rates of return. Both SVOL and IVOL measure individual risks of the underlying, however, are constant over time. Therefore, we estimate time varying option risk sensitivities with respect to SVOL and IVOL in a cross-sectional analysis. To control for nonlinearities, we expand this regression by adding interaction and squared terms to the right-hand-side of equation 3.4. Thus, the regressions are carried out in three configurations, which represent base configurations in our analysis:

(i) *pure*, as shown in equation 3.4

(ii) *interacted*, by adding regressors $\text{SVOL}_i \cdot M_{j_i,t}$ and $\text{IVOL}_i \cdot M_{j_i,t}$

$$\begin{aligned} R_{j_i,t} = {} & \alpha_t^{CS} + \beta_t^{SVOL} \cdot \text{SVOL}_i + \beta_t^{IVOL} \cdot \text{IVOL}_i + \beta_t^{M} \cdot M_{j_i,t} \\ & + \beta_t^{M \cdot SVOL} \cdot M_{j_i,t} \cdot \text{SVOL}_i + \beta_t^{M \cdot IVOL} \cdot M_{j_i,t} \cdot \text{IVOL}_i + \eta_{j_i,t} \end{aligned} \tag{3.5}$$

(iii) *squared*, by further adding the regressors $\text{SVOL}_i \cdot M_{j_i,t}^2$, $\text{IVOL}_i \cdot M_{j_i,t}^2$ and $M_{j_i,t}^2$

$$\begin{aligned} R_{j_i,t} = {} & \alpha_t^{CS} + \beta_t^{SVOL} \cdot \text{SVOL}_i + \beta_t^{IVOL} \cdot \text{IVOL}_i + \beta_t^{M} \cdot M_{j_i,t} \\ & + \beta_t^{M \cdot SVOL} \cdot M_{j_i,t} \cdot \text{SVOL}_i + \beta_t^{M \cdot IVOL} \cdot M_{j_i,t} \cdot \text{IVOL}_i + \beta_t^{M^2} \cdot M_{j_i,t}^2 \\ & + \beta_t^{M^2 \cdot SVOL} \cdot M_{j_i,t}^2 \cdot \text{SVOL}_i + \beta_t^{M^2 \cdot IVOL} \cdot M_{j_i,t}^2 \cdot \text{IVOL}_i + \eta_{j_i,t} \end{aligned} \tag{3.6}$$

We mitigate possible heteroscedasticity and autocorrelation in the error terms of our regression model by applying the Newey–West adjusted standard errors method. To examine the assumption of normality in our regression residuals, the Jarque-Bera (JB) statistic is utilized. The null-hypothesis could not be rejected, therefore, the time-series average over all t provides feasible estimates of the beta coefficients.

The second step in our analysis is to determine the explanatory power of risk sensitivities from equation 3.4. For this, we run time-series regressions for each individual option j. In the pure configuration these regressions read as follows (analogue equations are applied to interacted and squared configurations):

$$R_{j,t} = \gamma_j^{TS} + \gamma_j^{SVOL} \cdot \hat{\beta}_t^{SVOL} + \gamma_j^{IVOL} \cdot \hat{\beta}_t^{IVOL} + \gamma_j^{M} \cdot \hat{\beta}_t^{M} + \zeta_{j,t} \tag{3.7}$$

where the first step coefficients $\hat{\beta}$ reflect the influence of SVOL, IVOL and M on option rates of return at a particular point in time t. The second step coefficients $\hat{\gamma}$ from equation 3.7 explain the relation

[14] See, e.g., Fu (2009), Guo et al. (2014) and Bergbrant and Kassa (2021)

[15] The regressors in equations 3.2 and 3.4 differ (stock rates of returns versus option rates of return). Our samples contain observations for about 2600 days (for the EU and US markets T is equal to 2621 and 2571 days, respectively), this amounts to around 2600 cross-sectional regressions. Examples for the application of the FMC regressions in the analysis of stock returns can be found, e.g., in Ang et al. (2009), Malagon et al. (2015) and Bergbrant and Kassa (2021).

between risk sensitivities and individual option rates of return over time. Therefore, these coefficients can be interpreted as risk premia.

Table 3.2: Descriptive statistics of option portfolios

		EU_AC	EU_AP	US_AC	US_AP
Total Observations		9,891,360	10,842,793	70,843,968	55,239,132
Number of Portfolios		45	45	50	50
Average Observations per Portfolio		219,808	240,951	1,416,879	1,104,783
Moneyness Bins (number of observations)	$M < 0.9$	2,769,313	1,989,210	19,582,866	6,483,475
	$M < 0.975$	2,471,841	1,393,700	16,596,931	6,795,082
	ATM	1,799,567	1,781,746	13,807,712	10,797,467
	$M > 1.025$	1,213,009	2,280,453	9,524,748	12,705,452
	$M > 1.1$	1,637,630	3,397,684	11,331,711	18,457,656
IVOL Bins	Lower Bound	0.0736	0.0860	0.0450	0.0915
	Upper Bound	0.8876	0.9195	0.9972	0.9936
	Bin Size	0.0814	0.0834	0.0952	0.0902

The table reports descriptive statistics for portfolios created by sorting the option data into five moneyness and ten IVOL bins. The boundaries for the moneyness bins are chosen around one ATM group with $0.975 < M < 1.025$ and for the IVOL bins by dividing the range of the minimum and maximum values (lower bound and upper bound) into ten equally spaced intervals.

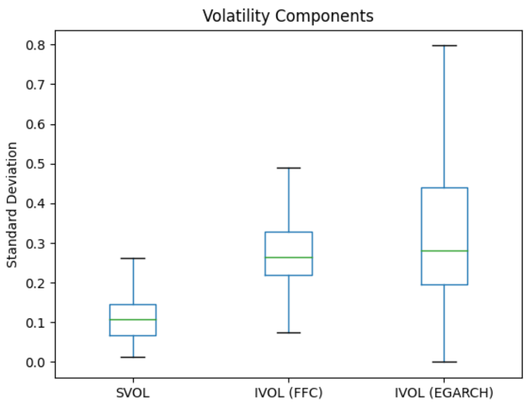
A drawback of FMC procedure is known as the errors-in-variables bias. To avoid this, we apply equation 3.7 to portfolios rather than single assets. For this, the data is sorted into five moneyness groups and ten IVOL groups so that there are up to 50 possible portfolios. The portfolios are equally weighted and the results of portfolio formation are described in table 3.2. All four samples contain a wide range of moneyness and volatility levels. The US data fills all 50 portfolios and the EU data not less than 45 portfolios with only the third highest volatility bin being empty. A much higher number of observations is centred in the OTM bins rather than in ITM bins.

3.3 Empirical results

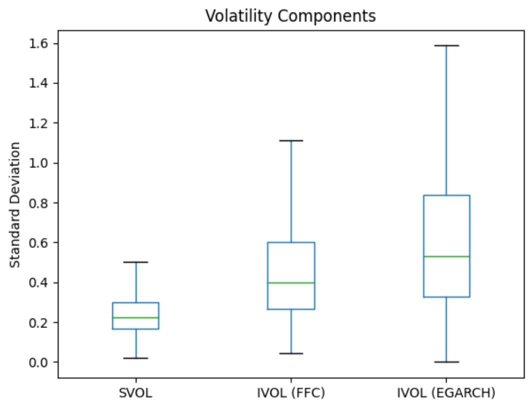
Figure 3.1 visualizes the estimated volatility components SVOL and IVOL according to equation 3.2 (FFC) and the alternative estimation of expected IVOL according to equation 3.3 (EGARCH). Based on equation 3.2 for the EU market, samples show an annualized mean SVOL of around 15 percent and an annualized mean IVOL of around 29 percent. For the US market, the estimates are slightly higher with 23 percent and 33 percent, respectively. In general, the boxplots for the US market show a higher dispersion than those for the EU market. Our results for call options on the US market are in line with Aretz et al. (2023). Their mean estimates for SVOL of around 32 percent and for IVOL of around 43 percent are somewhat higher but also more dispersed with standard deviations of 21 percent and 26 percent, respectively. Based on equation 3.3 the estimates for expected IVOL show a mean value of around 30 percent for the EU market and 45 percent for the US market. Thus, the EGARCH model gives higher estimates with a higher degree of dispersion.

The results for the first step in our analysis can be found in table 3.3. The various regression configurations show adjusted coefficients of determination of 2.9 percent to 4.1 percent for the EU data and 2.2 percent to 2.7 percent for the US data. The pure configuration explains a consistently lower proportion of the variation in option rates of return than the squared configuration. When examining different configurations, we note the contrasting behaviour of the linear coefficients for SVOL and IVOL in the pure versus the interacted and squared configurations. According to the top panel of table 3.3 (results for call options), the linear coefficients for SVOL and IVOL (β^{SVOL} and β^{IVOL}, respectively) in the pure configuration are negative for both markets, significant (except for the IVOL coefficient for the US market) and higher for the EU market. For the interacted and squared configurations the linear coefficients for SVOL and IVOL are positive (except for the SVOL coefficient for the US market) and significant (except for the IVOL coefficient in the squared configuration for the EU market). This

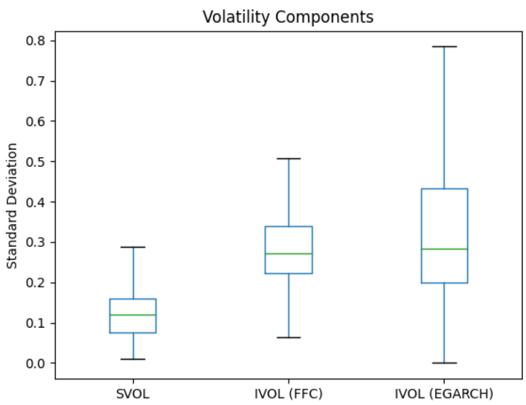
Figure 3.1: Volatility components estimates.



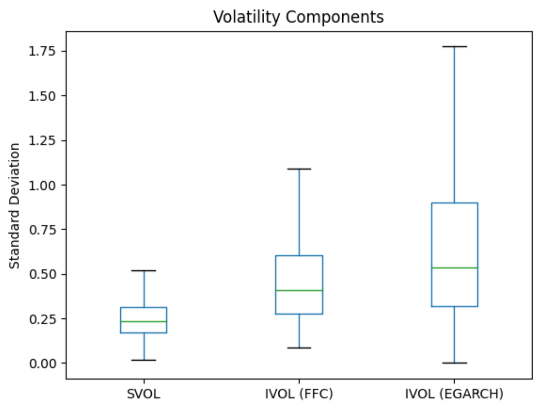
(a) EU_AC



(b) US_AC



(c) EU_AP



(d) US_AP

Table 3.3: Cross-sectional regressions - First step

	EU_AC			US_AC		
Configuration	pure	interacted	squared	pure	interacted	squared
Intercept	0.0031	-0.0673***	-0.1509***	0.0058***	-0.0155***	-0.0414***
	(0.0025)	(0.0044)	(0.0255)	(0.0060)	(0.0105)	(0.0151)
$SVOL$	-0.0246**	0.1692***	0.2223*	-0.0140*	-0.0454***	-0.0673***
	(0.0133)	(0.0227)	(0.1672)	(0.0282)	(0.0427)	(0.0592)
$IVOL$	-0.0109*	0.0489***	0.1232	-0.0057	0.0423***	0.0795***
	(0.0067)	(0.0153)	(0.1289)	(0.0133)	(0.0186)	(0.0248)
M	0.0083***	0.0801***	0.1895***	0.0032***	0.0248***	0.0546***
	(0.0008)	(0.0040)	(0.0526)	(0.0009)	(0.0082)	(0.0144)
$M \cdot SVOL$		-0.1985***	-0.2199		0.0314***	0.0590***
		(0.0184)	(0.3285)		(0.0269)	(0.0514)
$M \cdot IVOL$		-0.0593***	-0.1548		-0.0481***	-0.0926***
		(0.0152)	(0.2602)		(0.0110)	(0.0200)
M^2			-0.0231			-0.0031***
			(0.0268)			(0.0011)
$M^2 \cdot SVOL$			-0.0426			-0.0061***
			(0.1616)			(0.0045)
$M^2 \cdot IVOL$			0.0219			-0.0061***
			(0.1301)			(0.0016)
$adjR^2$	0.0308	0.0351	0.0414	0.0224	0.0240	0.0261

	EU_AP			US_AP		
Configuration	pure	interacted	squared	pure	interacted	squared
Intercept	-0.0121***	0.0538***	0.1504***	-0.0198***	0.0020	0.0204***
	(0.0025)	(0.0046)	(0.0087)	(0.0028)	(0.0038)	(0.0045)
$SVOL$	0.0114	-0.1502***	-0.4265***	0.0019	0.0342***	0.0809***
	(0.0111)	(0.0157)	(0.0686)	(0.0091)	(0.0106)	(0.0127)
$IVOL$	0.0383***	-0.0293***	-0.0732**	0.0275***	-0.0227***	-0.0537***
	(0.0063)	(0.0103)	(0.0334)	(0.0049)	(0.0068)	(0.0077)
M	-0.0072***	-0.0685***	-0.2229***	-0.0033***	-0.0235***	-0.0491***
	(0.0006)	(0.0028)	(0.0153)	(0.0002)	(0.0014)	(0.0025)
$M \cdot SVOL$		0.1580***	0.6240***		-0.0279***	-0.0790***
		(0.0122)	(0.1290)		(0.0027)	(0.0063)
$M \cdot IVOL$		0.0572***	0.1333**		0.0446***	0.0893***
		(0.0066)	(0.0689)		(0.0026)	(0.0044)
M^2			0.0588***			0.0073***
			(0.0072)			(0.0005)
$M^2 \cdot SVOL$			-0.1854***			0.0083***
			(0.0595)			(0.0006)
$M^2 \cdot IVOL$			-0.0360			-0.0137***
			(0.0354)			(0.0009)
$adjR^2$	0.0289	0.0337	0.0408	0.0222	0.0245	0.0268

The table reports results for the first step in our analysis (equation 3.4). Volatility components are estimated with the FFC model. The top panel refers to call options on the EU and US market. The bottom panel shows the results for put options. Standard errors are reported in parentheses. Statistical significance at the 1 percent, 5 percent, 10 percent levels are denoted by ***, **, *, respectively.

suggests that the relationship between these volatility measures and option rates of return depends on other factors (moneyness) and their form (linear versus squared). In interaction with moneyness M, $\beta^{M \cdot SVOL}$ is significantly negative for the EU market and significantly positive for the US market; $\beta^{M \cdot IVOL}$ is negative and highly significant for both markets. In nonlinear interaction with moneyness M^2, $\beta^{M^2 \cdot SVOL}$ is negative for both markets, however, only significant for the US market; $\beta^{M^2 \cdot IVOL}$ is positive for the EU market and negative for the US market, being again only significant for the US market. Hence, an increase in SVOL leads to a decrease in call option rates of return at decreasing scale that is conditional on moneyness. The same holds for the IVOL effect.

These results are in line with the theoretical proof by Aretz et al. (2023) that the influence of the underlying risk components on option rates of return depends on moneyness. We note that the influence of SVOL on option rates of return is different between the EU and the US markets. For the EU market, the linear influence is positive, turns negative with interaction with moneyness and gets less negative for deep ITM options, however, being only significant in its linear term. In contrast, for the US market, SVOL negatively influences call option rates of return at a decreasing scale (only $\beta^{M \cdot SVOL}$ is positive), all coefficients are highly significant. The different influence of SVOL on option rates of return on the EU and the US markets can possibly be explained by structural differences of these markets. For example, capital requirements, risk management practices and disclosure requirements are different, which could influence the behaviour of options traders and, hence, the influence of SVOL on options returns. Moreover, macro-economic conditions, such as interest rates, inflation, and GDP growth, differ between the EU and US, and these differences can also affect systematic volatility. The linear coefficients for moneyness M are positive and highly significant, lower for the US market and the highest for the squared configuration. This suggests that the deeper in the money a call option is, the higher is its rate of return. We note that this effect is less pronounced in the US market compared to the EU market, what again could be attributed to the aforementioned structural differences between the two markets. The nonlinear influence of moneyness M^2 is negative for both markets, higher for the EU market and significant only for the US market. Therefore, an increase in moneyness leads to an increase in call option rates of return, but on a decreasing scale so that the effect becomes weaker for ITM call options.

The bottom panel of table 3.3 (results for put options) shows corresponding findings for put options. Here, the linear coefficients for SVOL and IVOL in the pure configuration are positive for both markets, where only the IVOL coefficients are significant. We note an intriguing flip-flop pattern in the SVOL coefficients and again the influence on put option rates of return is different for the EU and the US market. For the US market, the linear SVOL coefficient remains positive in both interacted and squared configurations, however, turns negative in interaction with moneyness M and then again changes to positive in the nonlinear interaction with moneyness M^2. For the EU market, this relation is mirrored, so that the linear SVOL coefficient is negative, becomes positive in interaction with moneyness M and changes to negative in nonlinear interaction with moneyness M^2. All coefficients are highly significant. The linear IVOL coefficients are positive in the pure configuration, however, become negative in both interacted and squared configurations for both markets. In interaction with moneyness M, the coefficient $\beta^{M \cdot IVOL}$ is positive and highly significant for both markets in both interacted and squared configurations, however, turns negative in the nonlinear interaction with moneyness M^2 for both markets, but remains significant only for the US market. For put options, linear moneyness coefficients are negative and highly significant, in absolute terms lower for the US market and the highest for the squared configuration. There is a positive and significant nonlinear influence of moneyness M^2 indicating that the decreasing effect on put option rates of return appears to be weaker for higher moneyness levels, i.e., OTM put options. Hence, IVOL shows a negative effect on rates of return for ATM put options which becomes more negative for higher moneyness levels and turns positive for sufficiently OTM options. This implies a diminishing sensitivity of put option rates of return to changes in moneyness as they become deeper

OTM options.

To further investigate the influence of SVOL and IVOL on option rates of return, we analyse volatility slopes. We define volatility slopes as the partial derivatives of R with respect to IVOL and SVOL, respectively, based on equation 3.6 (squared configuration):

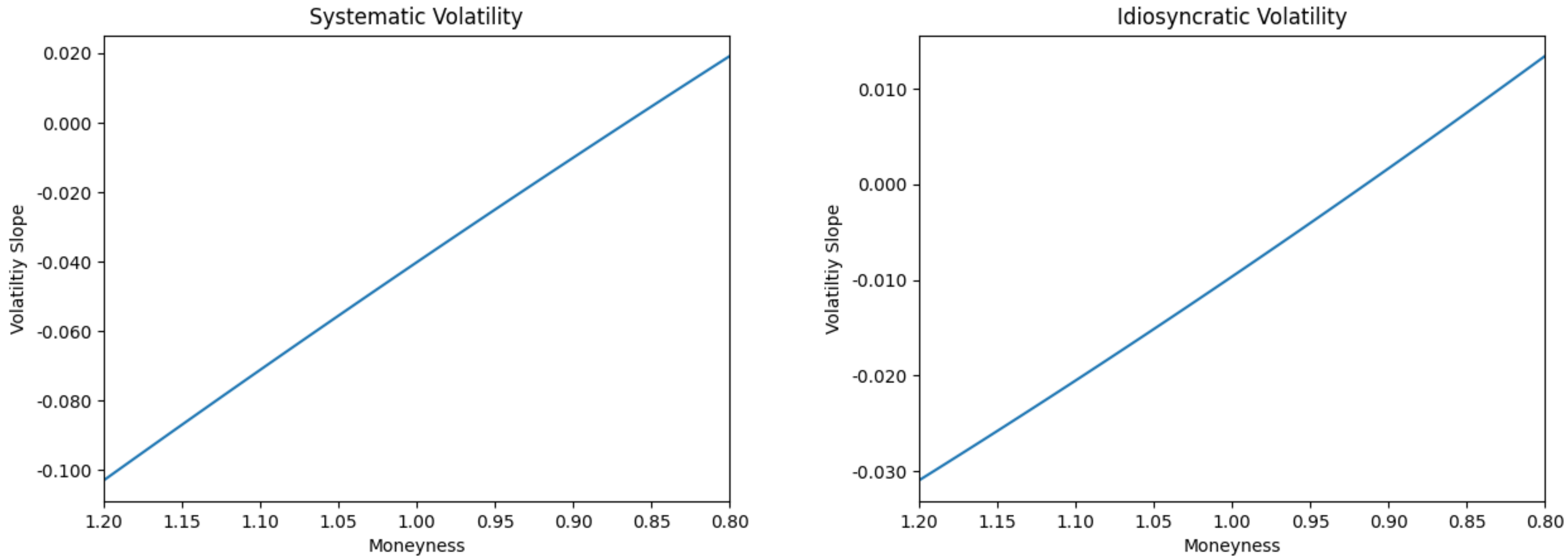
$$\begin{aligned}\frac{\partial R}{\partial\, SVOL} &= \beta^{SVOL} + \beta^{M\cdot SVOL}\cdot M + \beta^{M^2\cdot SVOL}\cdot M^2 \\ \frac{\partial R}{\partial\, IVOL} &= \beta^{IVOL} + \beta^{M\cdot IVOL}\cdot M + \beta^{M^2\cdot IVOL}\cdot M^2\end{aligned} \tag{3.8}$$

Figure 3.2 (call options) and figure 3.3 (put options) visualize volatility slopes for our samples. The left hand sides of figure 3.2 depict systematic volatility slopes for the EU market (upper graph) and the US market (lower graph). We note there is a distinct difference between the EU and the US markets. For the EU market, the systematic volatility slope shows a negative effect on ATM call option rates of return, which becomes more negative with higher moneyness and positive for OTM options with moneyness below 0.85. For the US market, the systematic volatility slope also shows a negative effect on ATM call option rates of return. However, the slope increases (for the EU market the slope decreases) with moneyness. This suggests that the US market is more sensitive to changes in underlying asset prices and its deviation from the strike price. In the depicted range, the slope is negative, but it becomes positive for ITM calls with $M > 1.3$ (not displayed in figure 3.2), since the interaction term $M \cdot$SVOL is positive. In addition, the range of the systematic volatility slope is smaller for the US market than for the EU market. The right hand side graphs of figure 3.2 depict idiosyncratic volatility slopes. For both markets, the slope is mostly negative, decreasing with moneyness and positive only for OTM options, where signs switch at moneyness levels between 0.82 (interacted configuration) and 0.91 (squared configuration). The idiosyncratic volatility slopes being mostly negative in both markets reflect that individual company risk effects options rates of return in a similar way in these markets.

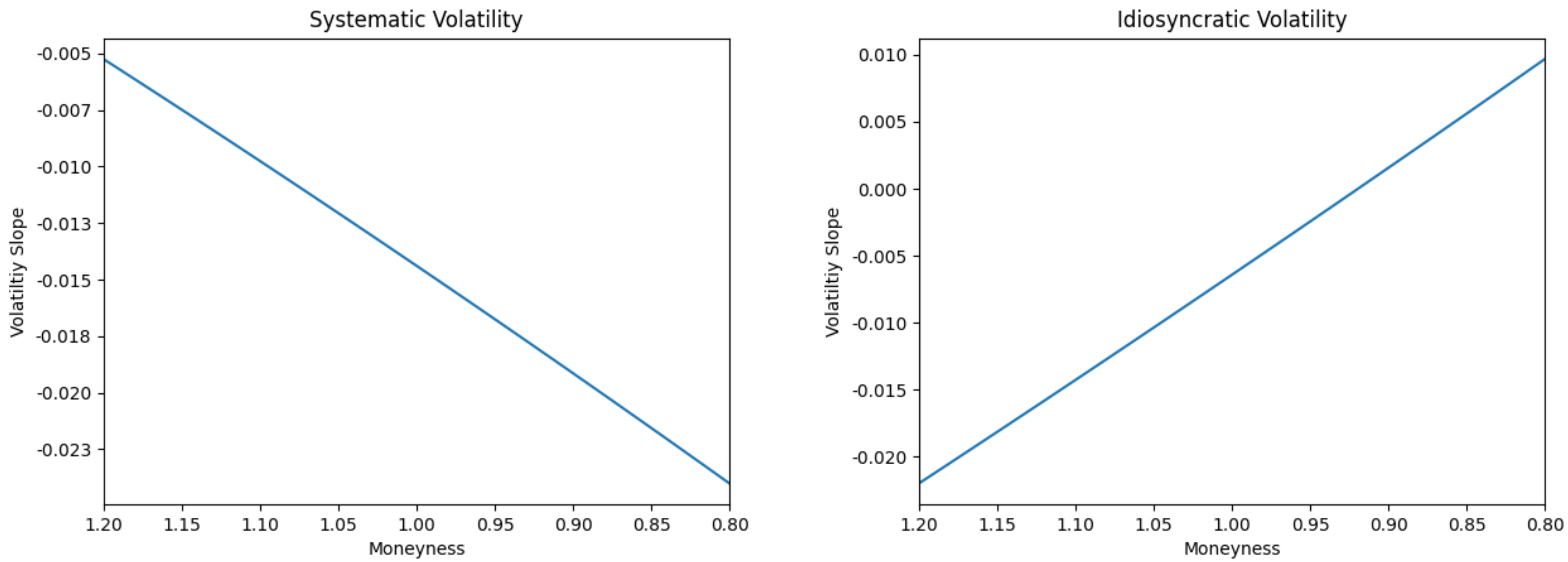
Figure 3.3 displays the corresponding results for put options. In summary, they mirror the call option results but with opposite signs. Again, the influence of moneyness shows different directions of the systematic volatility slope for the EU and the US markets. For the EU market (upper left hand side graph of figure 3.3), the systematic volatility slope is positive for OTM and ATM put options. It increases with moneyness (positive interaction term $M \cdot$ SVOL) and turns negative for ITM put options with moneyness below 0.95. However, for the US market (lower left hand side graph of figure 3.3), the systematic volatility slope shows a different pattern; it decreases with moneyness (negative interaction term $M \cdot$ SVOL) and becomes negative for OTM options with moneyness above 1.2. This highlights a significant divergence in the influence of moneyness on systematic volatility and differences in downside risk perception (since put options provide a hedge against downside risk) between the two markets . The right hand side graphs of figure 3.3 show the corresponding idiosyncratic volatility slopes for the EU and the US market. Both slopes are positive for ATM put options and increasing with moneyness. From table 3.3, the interacted and squared configurations show negative coefficients for IVOL, positive in interaction with moneyness M and then negative again in interaction with nonlinear moneyness M^2. Hence, the positive influence of IVOL on put option rates of return becomes positive with increasing moneyness but at a decreasing scale. It turns negative only for ITM put options with M below 0.51 (interacted configuration) and 0.68 (squared configuration), respectively (not displayed in figure 3.3). The range of idiosyncratic volatility slopes for put options is larger than for call options. Our findings related to the behaviour of systematic and idiosyncratic volatility on the EU and the US market underscore the risk asymmetry in markets and, therefore, the need to account for market differences and the role of moneyness in volatility analysis.

At this point, we contrast our results to the findings of previous studies. The negative SVOL and

Figure 3.2: Volatility Slopes Conditional on Moneyness (call options).

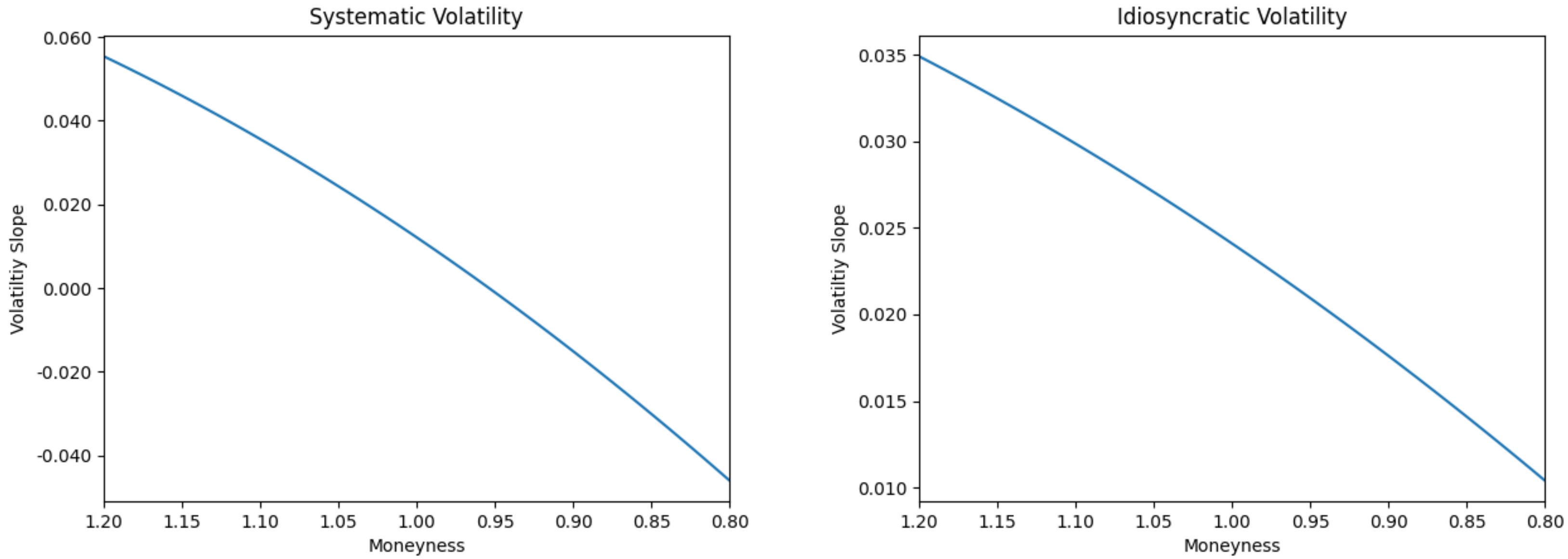


Call options – EU market

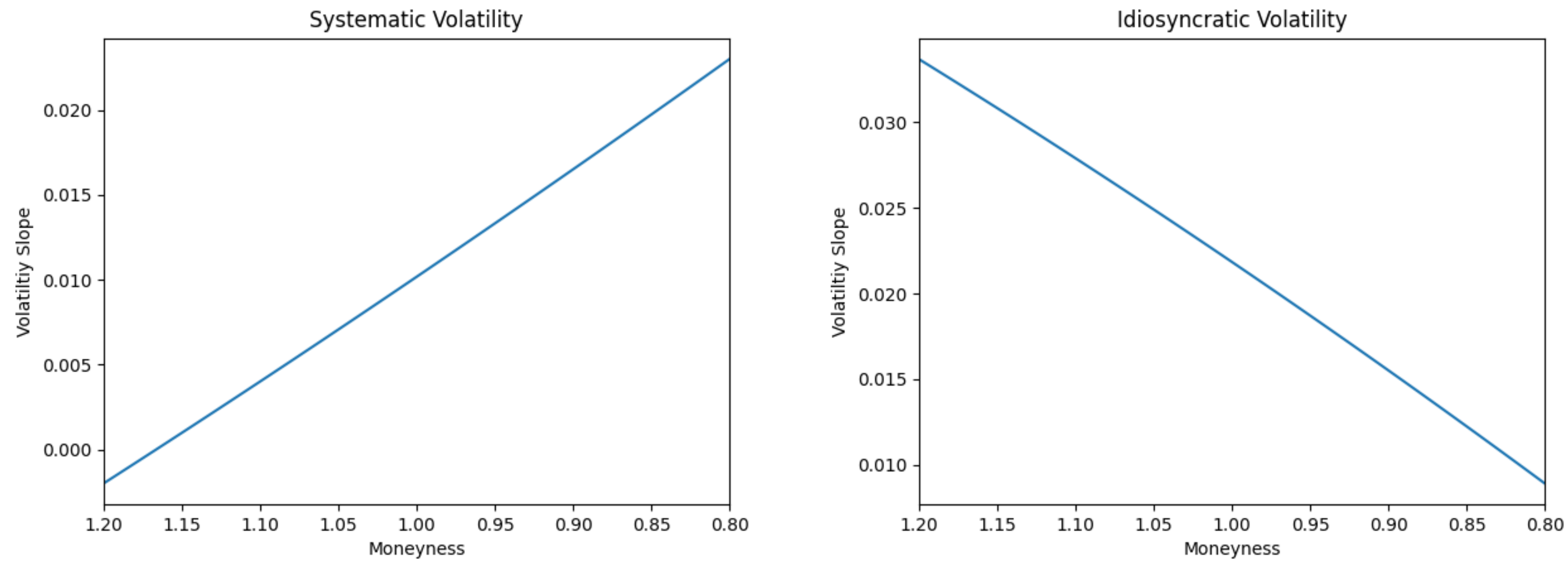


Call options – US market

Figure 3.3: Volatility Slopes Conditional on Moneyness (put options).



Put options – EU market



Put options – US market

IVOL betas for call options as well as the positive ones for put options in the pure configurations are in line with the findings of Hu and Jacobs (2020). The volatility coefficient for call options in their sample amounts to -0.389 and compares to a value of -0.446 in our sample. For put options, the volatility coefficients are even closer with 0.590 and 0.584, respectively. Our study extends their work by breaking down volatility components, focusing on daily instead of monthly returns, and considering a broader range of option types across both the EU and the US market. Our finding regarding SVOL and IVOL are also partially in line with the results of Aretz et al. (2023) – at least for call options on the US market as they do not consider put options in their analysis. Their coefficients for the interacted terms $M \cdot$ SVOL and $M \cdot$ IVOL are always positive, so that volatility slopes are increasing with moneyness. However in our analysis, the coefficient of $M \cdot$ IVOL is negative, leading to an idiosyncratic volatility slope that decreases with moneyness. In particular, Aretz et al. (2023) find a negative effect of SVOL on US call option rates of return for OTM and ATM options and a positive effect only for sufficiently ITM options. We observe the same negative effect of SVOL for ATM options and, at least for the US market, for OTM options as well. We find a positive effect for ITM options (with moneyness above 1.3) only for the US market, while there is no such evidence for the EU market. Related to the influence of IVOL on call option rates of return, we confirm their results regarding the negative effect for ATM and sufficiently ITM options. However, the positive effect for OTM call options in our sample is not observed by other authors. In summary, our findings corroborate and extend previous research, thereby enriching the understanding of the option rates of return dynamics, volatility, and moneyness across different markets.

The results of the second step in our analysis (time-series regressions according to equation 3.7) is presented in table 3.4. Compared to the first step cross-sectional regressions, the higher adjusted coefficients of determination (between 33.4 percent to 49.6 percent for call options and 44.9 percent to 68.3 percent for put options) and high levels of F-statistics prove a high goodness-of-fit of our model, in particular for the US data. While the focus of this part of our empirical analysis lays on the coefficients of $\hat{\beta}^{SVOL}$ and $\hat{\beta}^{IVOL}$, we note that most coefficients for moneyness beta $\hat{\beta}^{M}$ are not significant for the EU market but significantly negative for the US market. Further, the interaction and squared terms are also highly significant for the US data while we observe a mixed picture for the EU data, where mainly terms related to SVOL are significant.

The results for both call and put options suggest a significantly positive risk premium for the market sensitivity towards SVOL. The results for the market sensitivity towards IVOL oppose those observed for SVOL and show a significant negative risk premium. The magnitude of this effect varies for the different samples, ranging between -0.04 for call options in the EU market and -0.20 for put options in the US market. The observed negative risk premium for IVOL may initially appear a rather counter intuitive finding. However, it can be understood from an insurance or hedging perspective. In this sense, it might be beneficial for an investor to accept a negative risk premium to hold the option in order to compensate for alternative risk and, thereby, reduce the risk of his portfolio. However, based on the JB-statistic with consistently high values and low p-values, the null hypothesis of normally distributed regression residuals is rejected. Non-normal residuals might indicate an inadequate model and as described in section 3.2, this may arise due to a possible errors-in-variables bias and is mitigated by the means of portfolio formation.

The results of the regression implemented for portfolios rather than single assets are presented in table 3.5. In contrast to the regressions run for single assets, the JB-statistics show lower values and higher p-values, in particular, for the EU market. The null hypothesis of normally distributed errors can not be rejected at the five percent significance level, except possibly for the pure configuration for US put options. Further, the F-statistics and their p-values indicate an overall significance of the applied model. The sample for call options on the EU market shows low adjusted coefficients of determination between 12.5 percent to 48.6 percent compared to put samples that reach 60 percent to 90 percent.

Table 3.4: Time-series regressions - Second step

	EU_AC			US_AC		
Configuration	pure	interacted	squared	pure	interacted	squared
Intercept	0.0054***	0.0065***	0.0017	0.0098***	0.0144***	0.0201***
	(0.0015)	(0.0022)	(0.0028)	(0.0022)	(0.0023)	(0.0023)
β^{SVOL}	0.0590***	0.0563***	0.0558***	0.0553***	0.0540***	0.0515***
	(0.0041)	(0.0043)	(0.0042)	(0.0058)	(0.0064)	(0.0068)
β^{IVOL}	-0.0407***	-0.0414***	-0.0432***	-0.1294***	-0.1389***	-0.1366***
	(0.0084)	(0.0079)	(0.0075)	(0.0123)	(0.0149)	(0.0124)
β^{M}	0.0798	-0.0258	0.0537*	-1.5982***	-3.3075***	-2.8500***
	(0.0591)	(0.0712)	(0.0323)	(0.5855)	(0.4276)	(0.2935)
$\beta^{M \cdot SVOL}$		0.0473***	0.0636***		-0.7407***	-0.6303***
		(0.0173)	(0.0081)		(0.1168)	(0.0784)
$\beta^{M \cdot IVOL}$		-0.0416*	-0.0223		-2.1608***	-1.8152***
		(0.0253)	(0.0149)		(0.2830)	(0.1920)
β^{M^2}			0.0143			-46.0118***
			(0.0632)			(6.3884)
$\beta^{M^2 \cdot SVOL}$			0.0568***			-12.3610***
			(0.0143)			(1.7830)
$\beta^{M^2 \cdot IVOL}$			-0.0296			-28.9879***
			(0.0257)			(4.2297)
$adj R^2$	0.3344	0.3381	0.3821	0.3952	0.4464	0.4959
F-statistic	200.97	143.40	113.72	209.52	164.05	169.76
p-value	0.00	0.00	0.00	0.00	0.00	0.00
JB-statistic	217.0180	171.5434	175.9686	99.1569	221.0127	133.1247
p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

	EU_AP			US_AP		
Configuration	pure	interacted	squared	pure	interacted	squared
Intercept	-0.0011	-0.0113***	-0.0064	-0.0177***	-0.0237***	-0.0239***
	(0.0022)	(0.0031)	(0.0040)	(0.0037)	(0.0034)	(0.0033)
β^{SVOL}	0.0532***	0.0524***	0.0549***	0.0347***	0.0489***	0.0549***
	(0.0047)	(0.0044)	(0.0042)	(0.0085)	(0.0098)	(0.0096)
β^{IVOL}	-0.1147***	-0.0898***	-0.0725***	-0.2447***	-0.2039***	-0.1804***
	(0.0105)	(0.0114)	(0.0126)	(0.0240)	(0.0244)	(0.0247)
β^{M}	0.2957***	0.0606	-0.0372	-3.0032***	-3.6506***	-3.5755***
	(0.0934)	(0.0737)	(0.0750)	(0.6065)	(0.4613)	(0.3615)
$\beta^{M \cdot SVOL}$		0.0957***	0.0758***		-0.7412***	-0.7993***
		(0.0148)	(0.0144)		(0.1242)	(0.1093)
$\beta^{M \cdot IVOL}$		-0.0238	-0.0548**		-2.3192***	-2.2695***
		(0.0267)	(0.0230)		(0.3258)	(0.2764)
β^{M^2}			-0.3590*			-54.1206***
			(0.1854)			(7.4574)
$\beta^{M^2 \cdot SVOL}$			0.0732**			-14.9796***
			(0.0331)			(2.2032)
$\beta^{M^2 \cdot IVOL}$			-0.1089*			-34.7541***
			(0.0559)			(5.0004)
$adj R^2$	0.4492	0.4939	0.5514	0.5322	0.6210	0.6832
F-statistic	187.24	184.00	151.03	263.64	335.79	280.05
p-value	0.00	0.00	0.00	0.00	0.00	0.00
JB-statistic	847.8958	1640.2716	3554.9860	5359.5675	1545.8430	2606.7931
p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

The table reports the results for the time-series regressions according to equation 3.7. The top panel refers to call options and the bottom panel refers to put options. In addition to $\hat{\gamma}$, the respective Newey-West adjusted standard errors are reported in parentheses. Statistical significance at the 1 percent, 5 percent, 10 percent level is denoted by ***, **, *. In addition to the R^2 value, the goodness-of-fit of the applied model can be judged by the F-statistic and the JB-statistic with the corresponding p-values.

Table 3.5: Portfolio time-series regressions - Second step

	EU_AC			US_AC		
Configuration	pure	interacted	squared	pure	interacted	squared
Intercept	0.0282	0.0266***	0.0595***	0.0709***	0.0361	0.0520
	(0.0169)	(0.0059)	(0.0123)	(0.0142)	(0.0306)	(0.0591)
β^{SVOL}	0.2381**	0.4609***	0.0896	2.3506***	2.7243***	2.4543***
	(0.1042)	(0.0630)	(0.0907)	(0.2746)	(0.3065)	(0.3489)
β^{IVOL}	0.5935***	0.3465	0.9810***	1.4295***	1.7129***	1.2438*
	(0.1493)	(0.2992)	(0.3273)	(0.5104)	(0.5205)	(0.6965)
β^{M}	-0.4702	3.5780**	-4.7256***	-10.2363***	-22.3687***	-30.9904***
	(0.5664)	(1.7156)	(1.5059)	(1.8466)	(3.9924)	(8.6246)
$\beta^{M \cdot SVOL}$		1.5382***	-0.7143		-3.5933***	-7.7324**
		(0.5566)	(0.4612)		(0.4139)	(3.2635)
$\beta^{M \cdot IVOL}$		1.6277***	-1.2832***		-13.9218***	-19.6370**
		(0.4880)	(0.3898)		(2.2244)	(7.6809)
β^{M^2}			-23.8167***			-518.6952**
			(6.0712)			(208.3030)
$\beta^{M^2 \cdot SVOL}$			-4.5606***			-149.8041**
			(1.5429)			(63.2507)
$\beta^{M^2 \cdot IVOL}$			-9.5533***			-325.6015**
			(2.1262)			(145.1200)
R^2	0.1250	0.2584	0.4862	0.6762	0.7510	0.8188
F-statistic	8.08	41.70	58.11	57.08	73.94	236.00
p-value	0.00	0.00	0.00	0.00	0.00	0.00
JB-statistic	0.6514	0.5610	0.2113	0.3179	3.0622	2.8368
p-value	0.7220	0.7554	0.8998	0.8530	0.2163	0.2421

	EU_AP			US_AP		
Configuration	pure	interacted	squared	pure	interacted	squared
Intercept	-0.1054***	-0.0546***	-0.1225***	-0.0772***	-0.1197***	-0.2331***
	(0.0250)	(0.0139)	(0.0137)	(0.0175)	(0.0130)	(0.0316)
β^{SVOL}	0.8972**	0.4901***	0.8214***	2.0084***	1.6967***	1.4696***
	(0.3508)	(0.0939)	(0.1386)	(0.2407)	(0.3456)	(0.3772)
β^{IVOL}	2.4180***	0.5029	1.1365**	-0.0905	-0.1262	0.2692
	(0.4969)	(0.5544)	(0.5043)	(0.4114)	(0.5135)	(0.4502)
β^{M}	-4.0401***	-0.2119	-4.0776***	-11.2948***	-13.1497	-12.5397*
	(1.2955)	(0.2108)	(1.1447)	(3.1175)	(7.8571)	(7.3237)
$\beta^{M \cdot SVOL}$		0.7700***	0.7993*		-0.8557	-1.2712
		(0.0605)	(0.4005)		(2.8684)	(2.2551)
$\beta^{M \cdot IVOL}$		0.2092	-0.1758		-7.2386	-5.0245
		(0.5212)	(0.9478)		(6.5856)	(4.9400)
β^{M^2}			-13.8008**			29.0629
			(5.0764)			(144.8184)
$\beta^{M^2 \cdot SVOL}$			0.5949			20.0618
			(1.2644)			(39.6543)
$\beta^{M^2 \cdot IVOL}$			-2.5097			42.3813
			(2.5360)			(94.5817)
R^2	0.6424	0.8668	0.9219	0.8164	0.8341	0.8855
F-statistic	14.19	1305.02	5990.37	54.61	143.77	292.32
p-value	0.00	0.00	0.00	0.00	0.00	0.00
JB-statistic	1.9768	0.9488	1.6686	5.1084	2.4328	1.0004
p-value	0.3722	0.6223	0.4342	0.0778	0.2963	0.6064

The table reports the results for the time-series regressions applied to portfolios according to equation 3.7. The top panel refers to call options and the bottom panel refers to put options. In addition to $\hat{\gamma}$, the respective Newey-West adjusted standard errors are reported in parentheses. Statistical significance at the 1 percent, 5 percent, 10 percent level is denoted by ***, **, *. In addition to the R^2 value, the goodness-of-fit of the applied model is represented by the F-statistic and the JB-statistic as well as the corresponding p-values.

Again, both call and put options show a positive (except for the squared configuration for EU call options) highly significant SVOL premium. Contrary to our previous results, we also observe a positive and highly significant IVOL premium for most samples, except for US put options. However, some exceptions to these patterns do occur. For instance, the IVOL premium for put options is not significant in the interacted configurations for the EU market and in all configurations for the US market. The moneyness coefficient tends to be negative with varying significance levels. In sum, our results suggest a clearly positive SVOL premium and show mixed results for the IVOL premium, which is negative when the regression is applied to single assets and positive when applied to portfolios.

4 Robustness Tests

In this part we analyse the robustness of the results presented in section 3.3. We consider robustness with respect to (i) adding control variables, (ii) using alternative volatility estimates (iii) implementing more restrictive data cleaning requirements. The empirical results for these modifications to the base configurations according to equations 3.4, 3.5 and 3.6 can be found in the appendix.

Modification (i) expands equation 3.4 by additionally including option trading volume and open interest as regressors.[16] For the first step regressions, both call and put option samples show an improved goodness-of-fit with higher adjusted coefficients of determination than in the base configurations and the same signs and magnitude for moneyness betas. Table A.1 shows that SVOL and IVOL coefficients remain unchanged for call option rates of return, except for a positive sign with nonlinear interaction with moneyness $\beta^{M^2 \cdot SVOL}$ for the US market. Coefficients are statistically significant throughout all configurations. Moreover, table A.1 shows robust SVOL and IVOL coefficients for put options. The magnitude of all coefficients for call and put options for both markets are very similar to those reported in table 3.3. To sum up, the inclusion of volume and open interest neither change the main messages outlined in section 3.3 nor provide additional information, so our results are robust to including these control variables.

The results of the second step regressions implemented for single assets are displayed in table A.2. For call options, the results are similar to those reported in section 3.3 for the US market, expect of all intercepts being negative. For call options on the EU market, the moneyness pemium γ^{M} in the interacted configuration and the IVOL premium in interaction with nonlinear moneyness $\gamma^{M^2 \cdot IVOL}$ in the squared configuration are positive, however, remain insignificant. For put options on the US market, only the linear SVOL premium in the pure configuration changed to a negative one but is insignificant compared to table 3.3 where is it positive and significant. For put options on the EU market, $\gamma^{M^2 \cdot IVOL}$ in the squared configuration changed the sign to negative but is insignificant compared to positive and significant in table 3.3; the moneyness premium in the pure configuration remains its sing but becomes insignificant. All coefficients are slightly lower in absolute terms except of γ^{M^2}, $\gamma^{M^2 \cdot SVOL}$ and $\gamma^{M^2 \cdot IVOL}$ M^2 in the squared configuration for the US market, these coefficients become notably lower.

Table A.3 shows a robustness test when including controls into the portfolio setting. Here, for call options on the EU market, the moneyness premium γ^{M} in the pure configuration becomes positive but stays insignificant. On the US market, SVOL and IVOL premia are also negative in all configurations and highly significant. For put options on the EU market, the SVOL premium is negative (insignificant) (in the interacted configuration), coefficients $\gamma^{M \cdot SVOL}$ and $\gamma^{M \cdot IVOL}$ are negative and significant, however, the coefficient $\gamma^{M \cdot IVOL}$ becomes positive in the squared configuration, although being insignificant. For the US market, the SVOL premium is negative in all configurations, being significant only in the interacted configuration, in the interaction with both linear and nonlinear moneyness, it keeps the sign

[16]Liquidity controls are often used for robustness purposes in the analysis of both stock and option rates of return. See, e.g., Malagon et al. (2018) or Aretz et al. (2023).

but becomes highly significant. In the squared configuration, the IVOL premium becomes negative and the moneyness premium becomes positive. In general, all coefficients for US put options become highly significant.

Modification (ii) uses EGARCH estimates according to equation 3.3 instead of FFC estimates for idiosyncratic volatility. Modified regression configurations show lower adjusted coefficients of determination for both call and put options for both markets, compared to the base configuration. For call options, all linear SVOL coefficients are robust to EGARCH estimates for both markets, except for the SVOL coefficient in the pure configuration for the US market, which becomes insignificant. For the EU market, the coefficient $\beta^{M^2 \cdot SVOL}$ in the squared configuration becomes significantly positive. Linear EGARCH IVOL coefficients for call options are rather of lower magnitude than in the base configuration, however, still almost all highly significant. The coefficient $\beta^{M^2 \cdot IVOL}$ in the squared configuration changes to negative for the EU market and to significantly positive for the US market. For put options on the EU market, linear SVOL coefficients remain unchanged in general, only the coefficient in the pure configuration becomes highly significant. For put options on the US market, linear SVOL coefficients in the pure and interacted configuration are negative, being only significant in the pure configuration. The linear EGARCH IVOL coefficients for put options are also lower in magnitude than in the base configuration and are almost all highly significant as well. All other coefficients remain their sign and significance level, expect of the $\beta^{M \times SVOL}$ coefficient for the EU market which becomes insignificant. Signs and magnitude for moneyness betas remain unchanged.

The robustness of the second step results for the single-asset setting is reported in table B.2. As in the base configurations, there is a significantly positive SVOL premium and a significantly negative IVOL premium, both at slightly higher magnitude in absolute terms. Again, the findings (reported in table B.3) differ when applying regressions to portfolios. For call options, the results show positive and significant SVOL and IVOL premia for both markets. In interaction with linear moneyness M, SVOL premium is negative (positive) in the interacted configuration for the EU (US) market, and positive for both markets, but only significant on the US market. In interaction with nonlinear moneyness M^2, SVOL and IVOL premia are positive for both markets, however highly significant only for the US market. In contrast to the base configuration, this premium is negative. For put options, the SVOL premium matches our previous results and is positive for both markets, expect for the squared configuration for the EU market. The SVOL premium in interaction with nonlinear moneyness becomes significantly negative for the EU market. Compared to the base configuration, the IVOL premium becomes significantly negative for the EU market and it becomes significantly positive in the squared configuration for the US market. For the EU market, the IVOL premium in interaction with moneyness becomes significantly negative. For the US market, all coefficients in the squared configuration are positive and become highly significant.

Modification (iii) repeats the same analysis as in the base configuration but on slightly different data that is subject to a more restrictive data cleaning process. For this, each single observation is checked for major outliers and dropped out if one of the variables deviates from its respective mean by more than three standard deviations. As in modification (i), both call and put option samples show an improved goodness-of-fit with higher coefficients of determination than in the base configuration as well as the same signs and magnitude of moneyness betas for the first step regressions. The results in table C.1 show SVOL and IVOL coefficients behaving equally robust as in modifications (i) and (ii), both risk sensitivities being of higher magnitude in absolute terms. The main results of the base configuration become clearer: For example, the effect of SVOL on call options in the US market only turns positive for $M > 2$, whereas the switching point in base configurations has already been at $M = 1.3$. For put options, the SVOL coefficient shows the same sign but at smaller magnitude on the EU market. Once again, deviations appear for the US market with a negative SVOL coefficient for the pure configuration and it turns negative at lower moneyness levels (0.71 and 0.92 instead of 1.16 and 1.21, respectively, for the other two configurations). The results for put options show that IVOL coefficients are positive for all moneyness levels on the US market. For the EU market, the results are in accordance with our previous ones, but there are deviations for the interacted configuration with the IVOL coefficient being positive and decreasing with moneyness. Table C.2 confirms the robustness of the second step regression results for both call and put options when treated as single assets. The coefficients for the portfolio setting in table C.3 exhibit the same deviations from base configurations as for the EGARCH estimates in modification (ii).

To sum up the robustness of our analysis, we confirm the consistency of a positive SVOL premium across multiple configurations and the negative IVOL premium in the single-asset setting (significant only for the EU market). The interaction terms with moneyness (both linear and nonlinear) in the portfolio setting show mixed results what indicates that these relationships are complex and nonlinear. The observed differences in the findings between the EU and the US market again confirm the differences on both markets.

5 Conclusion

Our paper provides an in-depth empirical study of the relationship between equity option rates of return and volatility of the underlying over time. We utilize large-scale datasets covering call and put options on the EU and US markets from 2011 to 2021, with each sample containing up to 70 million observations. The analysis lays the primary goal to determine the time effect of risk sensitivities on option rates of return. Theory predicts a negative effect of volatility on call option rates of return and a positive effect on put option rates of return as long as only idiosyncratic volatility (IVOL) is considered. However, when simultaneously considering systematic volatility (SVOL) and IVOL, the total volatility effect depends on further option characteristics such as moneyness or maturity and its sign is not unambiguously negative. Our data indicate that daily option rates of return are sufficiently close to a normal distribution and show averages at around 15.78 percent to 18.21 percent per month for call options and −0.02 percent to −0.21 percent per month for put options. We apply the Fama-French-Carhart (FFC) model to the respective underlying stock rates of return and split total volatility into its two components. This results in an average SVOL of 15 percent and IVOL of 29 percent on the EU and an average SVOL of 23 percent and IVOL of 33 percent on the US market. The alternatively implemented EGARCH model shows average IVOL estimates of 30 percent and 45 percent, on the EU and the US market, respectively.

We employ the Fama-McBeth-Campbell (FMC) procedure to identify the sensitivity of option rates of return to idiosyncratic and systematic volatility, accounting for various moneyness levels and nonlinearities. In the first step of our analysis, one cross-sectional regression is run for each of the approximately 2600 days in the sample to obtain time series estimates for volatility and moneyness betas, i.e., the exposure of option rates of return to volatility and moneyness risks. For call (put) options, there is statistically significant evidence for a positive (negative) but decreasing (increasing) effect of moneyness on option rates of return. The SVOL and IVOL coefficients are considered with respect to different moneyness levels and, for ATM options, they are unambiguously negative for call options and positive for put options. Further, for call options, the IVOL coefficient is decreasing with moneyness and it is even more negative for ITM options. It only gets positive for sufficiently OTM options with moneyness below 91 percent. On the EU market, the SVOL coefficients for call options show the same inverse relationship with moneyness (switching signs at the moneyness of 85 percent). The coefficients are increasing with a moneyness on the US market so that they are negative for OTM options and switch to positive for ITM options with moneyness above 130 percent. For put options, the signs of the SVOL and IVOL coefficients consistently behave in the exact opposite way to those observed for call options, only the tipping points in terms of moneyness between positive and negative coefficients are slightly different.

These findings suggest potential differences in market-specific dynamics. Overall, the first step results confirm the general trends observed in previous studies. A combined total volatility coefficient with respect to monthly returns of ATM options in the US market of -0.446 for call options and 0.584 for put options is consistent with the results of Hu and Jacobs (2020). Additionally, when comparing the effects on call options with those of Aretz et al. (2023), we confirm a negative IVOL effect for ATM and ITM options on both markets. On the US market, there is a negative SVOL effect for ATM and OTM options and a positive one for ITM options. However, we also find a positive IVOL effect on OTM calls in both markets, a negative SVOL effect on ITM calls and a positive one for OTM call options on the EU market.

The second step regression is conducted as a time-series analysis using the risk sensitivities as explanatory variables in order to determine their explanatory power and estimate their corresponding risk premia. For both call and put options, the SVOL risk premium is positive and highly significant. There is also statistically significant evidence for a negative IVOL risk premium, however, the validity of these findings might be debatable since the regression residuals fail the JB test for normality. This may arise due to an errors-in-variables bias and in order to address this issue, we implement an alternative regression where we sort the data into 50 equally-weighted portfolios. In this setting, the null hypothesis is not rejected and the model is globally significant. Also here, the data suggests a positive and highly significant SVOL risk premium – conversely though, the IVOL risk premium is now also significantly positive.

Our findings are robust, several robustness tests confirm the main message of our findings. Including liquidity controls or applying more restrictive data cleaning requirements improve the predictive power of the regression models. However, the use of alternative EGARCH estimates slightly weakens their performance. Some deviations were observed in a few configurations for the US market, the effect of SVOL on put option rates of return is negative and the effect of IVOL on call option rates of return already switches from negative to positive at higher moneyness levels. The second step regressions in the single-asset setting are robust with respect to all applied modifications. Some robustness configurations in the portfolio setting show deviations for the IVOL risk premium where it is negative compared to the base configuration.

Appendix: Further empirical results

A Including liquidity controls

The empirical results presented in this section are generated with the same approach as those in Table 3.3, Table 3.4 and Table 3.5. However, the base configuration is expanded by additionally including option trading volume and open interest as liquidity controls.

Table A.1: Cross-sectional regressions – First step

	EU_AC			US_AC		
Configuration	pure	interacted	squared	pure	interacted	squared
Intercept	0.0022	-0.0691***	-0.1555***	0.0055***	-0.0158***	-0.0418***
	(0.0025)	(0.0045)	(0.0232)	(0.0021)	(0.0025)	(0.0029)
SVOL	-0.0265**	0.1624***	0.1981	-0.0155*	-0.0470***	-0.0693***
	(0.0132)	(0.0227)	(0.1628)	(0.0098)	(0.0106)	(0.0113)
IVOL	-0.0093*	0.0552***	0.1458	-0.0055	0.0427***	0.0799***
	(0.0066)	(0.0157)	(0.1200)	(0.0045)	(0.0053)	(0.0059)
M	0.0085***	0.0811***	0.1958***	0.0032***	0.0249***	0.0546***
	(0.0008)	(0.0041)	(0.0475)	(0.0002)	(0.0010)	(0.0018)
$M \cdot SVOL$		-0.1942***	-0.1810		0.0316***	0.0595***
		(0.0184)	(0.3198)		(0.0026)	(0.0049)
$M \cdot IVOL$		-0.0638***	-0.1924		-0.0482***	-0.0928***
		(0.0158)	(0.2409)		(0.0018)	(0.0032)
M^2			-0.0257			-0.0031***
			(0.0240)			(0.0002)
$M^2 \cdot SVOL$			-0.0602			-0.0061***
			(0.1575)			(0.0008)
$M^2 \cdot IVOL$			0.0393			0.0067***
			(0.1196)			(0.0004)
Volume	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Open Interest	-0.0000***	-0.0000***	-0.0000**	-0.0000***	-0.0000***	-0.0000***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
R^2	0.0354	0.0396	0.0459	0.0265	0.0281	0.0301
	EU_AP			**US_AP**		
Configuration	pure	interacted	squared	pure	interacted	squared
Intercept	-0.0131***	0.0526***	0.1515***	-0.0200***	0.0019	0.0203***
	(0.0025)	(0.0046)	(0.0085)	(0.0028)	(0.0038)	(0.0045)
SVOL	0.0054	-0.1551***	-0.3899***	-0.0002	0.0321***	0.0797***
	(0.0111)	(0.0158)	(0.0568)	(0.0091)	(0.0105)	(0.0126)
IVOL	0.0424***	-0.0250***	-0.0954***	0.0285***	-0.0219***	-0.0532***
	(0.0062)	(0.0100)	(0.0218)	(0.0049)	(0.0067)	(0.0077)
M	-0.0072***	-0.0684***	-0.2281***	-0.0033***	-0.0237***	-0.0494***
	(0.0006)	(0.0028)	(0.0142)	(0.0002)	(0.0014)	(0.0025)
$M \cdot SVOL$		0.1572***	0.5405***		-0.0279***	-0.0800***
		(0.0123)	(0.1036)		(0.0027)	(0.0062)
$M \cdot IVOL$		0.0571***	0.1886***		0.0448***	0.0899***
		(0.0064)	(0.0386)		(0.0025)	(0.0044)
M^2			0.0616***			0.0073***
			(0.0062)			(0.0005)
$M^2 \cdot SVOL$			-0.1448***			0.0083***
			(0.0463)			(0.0006)
$M^2 \cdot IVOL$			-0.0643***			-0.0138***
			(0.0176)			(0.0009)
Volume	0.0000	0.0000	0.0000	0.0000***	0.0000***	0.0000***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Open Interest	0.0000	0.0000	0.0000**	0.0000***	0.0000***	0.0000***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
R^2	0.0330	0.0378	0.0448	0.0269	0.0291	0.0314

The table reports results for the first step regression applied to the model described by equation 3.4. The coefficients are derived by regressing daily option returns R on risk factors $SVOL$, $IVOL$ and M (and additional combinations in interacted and squared configurations) as well as on control variables volume and open interest for each individual time step t and then taking the time-series average of the single cross-sectional estimates for $\bar{\beta}$. The top panel refers to call options and the bottom panel to put options. In addition to $\bar{\beta}$, the respective standard errors are reported in parentheses. Statistical significance is judged according to the global t-statistic and the 1 percent, 5 percent, 10 percent levels are denoted by ***, **, *. The goodness-of-fit of the applied model is judged by the average R^2 value.

Table A.2: Time-series regressions – Second step

	EU_AC			US_AC		
Configuration	pure	interacted	squared	pure	interacted	squared
Intercept	-0.0035	-0.0021	-0.0023	-0.0142***	-0.0109***	-0.0063***
	(0.0024)	(0.0025)	(0.0025)	(0.0013)	(0.0013)	(0.0015)
$SVOL$	0.0464***	0.0437***	0.0457***	0.0213***	0.0217***	0.0235***
	(0.0049)	(0.0049)	(0.0044)	(0.0037)	(0.0043)	(0.0045)
$IVOL$	-0.0326***	-0.0352***	-0.0368***	-0.0983***	-0.0996***	-0.0959***
	(0.0083)	(0.0073)	(0.0071)	(0.0063)	(0.0062)	(0.0066)
M	0.1247	0.0452	0.0768**	-1.1047***	-1.5276***	-1.2939***
	(0.0891)	(0.0523)	(0.0308)	(0.1984)	(0.2593)	(0.2162)
$M \cdot SVOL$		0.0520***	0.0709***		-0.3495***	-0.2713***
		(0.0132)	(0.0091)		(0.0573)	(0.0552)
$M \cdot IVOL$		-0.0067	-0.0018		-1.0117***	-0.8269***
		(0.0186)	(0.0158)		(0.1606)	(0.1431)
M^2			0.0596			-20.4259***
			(0.0578)			(4.4503)
$M^2 \cdot SVOL$			0.0826***			-5.3682***
			(0.0151)			(1.2496)
$M^2 \cdot IVOL$			0.0057			-12.7361***
			(0.0264)			(2.9474)
Volume	834.6633***	818.6842***	801.3255***	1662.7945***	1644.6688***	1604.2971***
	(189.2596)	(184.5453)	(115.6767)	(83.5769)	(84.3323)	(84.9871)
Open Interest	-14133.5494***	-14974.1553***	-11745.4954***	-24186.5176***	-22674.6436***	-21271.7219***
	(1796.8008)	(2024.4968)	(1998.5205)	(1628.3966)	(1549.2069)	(1495.90)
R^2	0.4640	0.4684	0.4930	0.7095	0.7163	0.7291
F-statistic	149.62	133.49	97.40	331.92	270.48	230.74
p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
JB-statistic	2702.6373	1953.8342	635.3690	-0.0037	-0.0037	-0.0037
p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

	EU_AP			US_AP		
Configuration	pure	interacted	squared	pure	interacted	squared
Intercept	-0.0010	-0.0103***	-0.0048	-0.0107***	-0.0136***	-0.0146***
	(0.0023)	(0.0031)	(0.0037)	(0.0025)	(0.0024)	(0.0026)
$SVOL$	0.0498***	0.0491***	0.0397***	-0.0006	0.0123**	0.0194***
	(0.0051)	(0.0047)	(0.0050)	(0.0046)	(0.0058)	(0.0060)
$IVOL$	-0.1108***	-0.0889***	-0.0629***	-0.1598***	-0.1467***	-0.1447***
	(0.0109)	(0.0112)	(0.0100)	(0.0107)	(0.0123)	(0.0144)
M	0.1909	0.0644	-0.0709	-0.4037	-1.1180***	-1.3898***
	(0.1167)	(0.0749)	(0.0646)	(0.3580)	(0.2422)	(0.1899)
$M \cdot SVOL$		0.0914***	0.0463***		-0.1719***	-0.2880***
		(0.0152)	(0.0124)		(0.0660)	(0.0532)
$M \cdot IVOL$		-0.0204	-0.0614***		-0.7805***	-0.9734***
		(0.0273)	(0.0193)		(0.1684)	(0.1431)
M^2			-0.5487***			-19.0452***
			(0.1480)			(3.6792)
$M^2 \cdot SVOL$			-0.0009			-5.1388***
			(0.0261)			(1.0897)
$M^2 \cdot IVOL$			-0.1941***			-12.336***
			(0.0455)			(2.4531)
Volume	170.8344	183.7440	611.8111***	1573.1215***	1526.8481***	1457.2021***
	(119.3369)	(112.0621)	(50.6129)	(86.6915)	(86.6578)	(93.6908)
Open Interest	-4931.5398*	-4204.4843	-18280.8327***	-31599.4297***	-27452.9441***	-24610.9401***
	(2814.1692)	(2850.6427)	(2146.2212)	(2701.2896)	(2108.3679)	(2006.5701)
R^2	0.4849	0.5292	0.6490	0.8125	0.8259	0.8304
F-statistic	121.33	174.74	214.71	349.42	327.80	283.04
p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
JB-statistic	2307.8816	3200.7233	2504.5540	3663.2430	2074.9652	2350.4605
p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

The table reports results for the second step regression according to equation 3.7. The coefficients are derived by regressing average daily option returns $\bar{R}$ on first step betas $\hat{\beta}^{SVOL}$, $\hat{\beta}^{IVOL}$ and $\hat{\beta}^{M}$ (and additional combinations in the interacted and squared configurations) as well as $\hat{\beta}^{\text{Volume}}$ and $\hat{\beta}_t^{\text{Open Interest}}$ in one global time-series regression. The top panel refers to call options and the bottom panel to put options. In addition to $\hat{\gamma}$, the respective Newey-West adjusted standard errors are reported in parentheses. Statistical significance at the 1 percent, 5 percent, 10 percent level is denoted by ***, **, *. In addition to the R^2 value, the goodness-of-fit of the applied model is judged by the F-statistic and the JB-statistic as well as the corresponding p-values.

Table A.3: Portfolio regressions – Second step

	EU_AC			US_AC		
	pure	interacted	squared	pure	interacted	squared
Intercept	-0.0334	-0.0166	0.0605**	-0.2240***	-0.4638***	-0.3574***
	(0.0209)	(0.0251)	(0.0269)	(0.0684)	(0.1143)	(0.1211)
SVOL	0.0203	0.1138	0.1147	-1.5106***	-1.4154***	-1.0684**
	(0.0490)	(0.1524)	(0.2149)	(0.3732)	(0.4854)	(0.4650)
IVOL	0.4166***	0.2406**	1.1015***	-0.7754**	-0.4769*	-1.6757***
	(0.0912)	(0.1150)	(0.3190)	(0.3284)	(0.2747)	(0.5013)
M	0.6622	3.1193**	-3.2396**	-28.7445***	-21.7675***	-38.0022***
	(0.7699)	(1.4221)	(1.5145)	(4.2222)	(2.3385)	(6.9901)
$M \cdot SVOL$		1.1139**	-0.3162		-11.9017***	-14.8813***
		(0.4911)	(0.5594)		(1.6042)	(2.6606)
$M \cdot IVOL$		1.6014***	-0.5403		-18.6088***	-30.3760***
		(0.4072)	(0.4149)		(1.8987)	(5.8873)
M^2			-17.8807***			-727.1410***
			(5.8552)			(190.5812)
$M^2 \cdot SVOL$			-3.0277*			-212.0742***
			(1.6463)			(53.0659)
$M^2 \cdot IVOL$			-6.9493***			-485.5693***
			(1.9316)			(130.8696)
Volume	2029.3460	5405.0539	-3771.3124	9248.5520	34169.5503***	5160.8048
	(4353.7000)	(5575.1706)	(5745.8268)	(9476.3142)	(12064.3365)	(11433.2746)
Open Interest	-257132.8511***	-208119.8072***	-199589.6434***	-594110.7481***	-417690.7682***	-663861.1664***
	(44445.7148)	(46060.4359)	(45573.3071)	(100463.0732)	(60129.0049)	(127537.1081)
R^2	0.3143	0.3997	0.5264	0.8752	0.9027	0.9052
F-statistic	42.58	43.90	59.69	28.11	57.60	132.25
p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
JB-statistic	3.1171	11.3297	0.4570	2.5963	2.1608	2.7708
p-value	0.2104	0.0035	0.7957	0.2730	0.3395	0.2502
	EU_AP			US_AP		
	pure	interacted	squared	pure	interacted	squared
Intercept	-0.1347***	-0.0276***	-0.0989***	-0.0938***	-0.0989***	-0.0149
	(0.0182)	(0.0092)	(0.0223)	(0.0114)	(0.0225)	(0.0722)
SVOL	0.0498	-0.0455	0.4991***	-0.0341	-1.0963***	-0.3066
	(0.1881)	(0.1001)	(0.1824)	(0.5404)	(0.2390)	(0.2729)
IVOL	1.9392***	0.5802	1.1177*	-0.7167*	-1.9019***	-0.6239*
	(0.5031)	(0.4301)	(0.5621)	(0.3897)	(0.3428)	(0.3335)
M	-1.6452*	-2.5117***	-2.7869***	-18.2073***	-43.1702***	59.7306***
	(0.9001)	(0.5665)	(0.6101)	(1.7833)	(15.2666)	(14.4130)
$M \cdot SVOL$		-0.1035*	0.7007*		-14.7683***	14.2962***
		(0.0610)	(0.3700)		(4.7912)	(3.1936)
$M \cdot IVOL$		-0.6503**	0.1427		-31.9381***	38.0148***
		(0.2709)	(0.8501)		(11.3563)	(8.6328)
M^2			-6.9620*			1411.8989***
			(3.5690)			(239.0898)
$M^2 \cdot SVOL$			1.3650			401.4489***
			(1.1158)			(65.4884)
$M^2 \cdot IVOL$			-0.3930			937.3408***
			(2.1850)			(154.3318)
Volume	24707.5495***	-7381.4228*	-887.6768	11646.7695**	26988.1066***	1797.5691
	(3300.2800)	(4110.1515)	(2557.6364)	(4905.1425)	(7652.5190)	(8528.0512)
Open Interest	-204768.4279***	-428239.9832***	-317632.4010***	-75156.6005	34697.4750	-635365.2707***
	(74794.6658)	(54023.8182)	(51137.1172)	(64885.9595)	(105229.9821)	(177718.2698)
R^2	0.7844	0.9100	0.9356	0.8489	0.8813	0.9308
F-statistic	63.32	1863.79	84.57	160.22	290.31	760.11
p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
JB-statistic	2.9232	1.0217	1.6530	1.4429	14.0556	1.5004
p-value	0.2319	0.6000	0.4376	0.4861	0.0009	0.4723

The table reports results for the second step regression according to equation 3.7. The coefficients are derived by regressing equally-weighted portfolio returns R on first step portfolio betas $\hat{\beta}^{SVOL}$, $\hat{\beta}^{IVOL}$ and $\hat{\beta}^{M}$ (and additional combinations in the interacted and squared configurations) as well as $\hat{\beta}^{\text{Volume}}$ and $\hat{\beta}^{\text{Open Interest}}$. The top panel refers to call options and the bottom panel to put options. In addition to $\hat{\gamma}$, the respective Newey-West adjusted standard errors are reported in parentheses. Statistical significance at the 1 percent, 5 percent, 10 percent level is denoted by ***, **, *. In addition to the R^2 value, the goodness-of-fit of the applied model is judged by the F-statistic and the JB-statistic as well as the corresponding p-values.

B Alternative volatility estimates

The empirical results presented in this section are generated with the same approach as those in Table 3.3, Table 3.4 and Table 3.5. However, the baseline model is modified by using volatility estimates based on the EGARCH instead of the FFC model.

Table B.1: Cross-sectional regressions – First step

	EU_AC			US_AC		
Configuration	pure	interacted	squared	pure	interacted	squared
Intercept	0.0020	-0.0626***	-0.1503***	0.0051***	-0.0152***	-0.0435***
	(0.0021)	(0.0038)	(0.0268)	(0.0020)	(0.0023)	(0.0028)
SVOL	-0.0306***	0.1743***	0.4128***	-0.0087	-0.0414***	-0.0660***
	(0.0126)	(0.0192)	(0.0690)	(0.0099)	(0.0107)	(0.0117)
IVOL	-0.0032	0.0447***	0.0492	-0.0052**	0.0287***	0.0629***
	(0.0036)	(0.0078)	(0.0697)	(0.0031)	(0.0035)	(0.0041)
M	0.0082***	0.0741***	0.1932***	0.0033***	0.0240***	0.0560***
	(0.0008)	(0.0033)	(0.0562)	(0.0002)	(0.0009)	(0.0017)
$M \cdot SVOL$		-0.2037***	-0.5704***		0.0324***	0.0638***
		(0.0148)	(0.1403)		(0.0027)	(0.0055)
$M \cdot IVOL$		-0.0505***	-0.0288		-0.0341***	-0.0740***
		(0.0074)	(0.1458)		(0.0012)	(0.0024)
M^2			-0.0286			-0.0028***
			(0.0292)			(0.0002)
$M^2 \cdot SVOL$			0.1155*			-0.0070***
			(0.0743)			(0.0009)
$M^2 \cdot SVOL$			-0.0248			0.0048***
			(0.0757)			(0.0003)
R^2	0.0281	0.0323	0.0384	0.0180	0.0197	0.0217
	EU_AP			US_AP		
Configuration	pure	interacted	squared	pure	interacted	squared
Intercept	-0.0073***	0.0440***	0.1297***	-0.0172***	0.0041	0.0226***
	(0.0020)	(0.0037)	(0.0090)	(0.0027)	(0.0036)	(0.0044)
SVOL	0.0347***	-0.1310***	-0.3787***	-0.0217***	-0.0110	0.0116
	(0.0101)	(0.0164)	(0.0669)	(0.0093)	(0.0105)	(0.0126)
IVOL	0.0087***	-0.0118*	-0.0221	0.0257***	-0.0036	-0.0197***
	(0.0028)	(0.0073)	(0.0307)	(0.0032)	(0.0042)	(0.0051)
M	-0.0071***	-0.0553***	-0.1865***	-0.0033***	-0.0232***	-0.0465***
	(0.0006)	(0.0024)	(0.0155)	(0.0002)	(0.0014)	(0.0024)
$M \cdot SVOL$		0.1537***	0.5243***		-0.0075***	-0.0307***
		(0.0126)	(0.1249)		(0.0029)	(0.0061)
$M \cdot IVOL$		0.0192***	0.0476		0.0261***	0.0477***
		(0.0060)	(0.0506)		(0.0015)	(0.0028)
M^2			0.0462***			0.0052***
			(0.0069)			(0.0003)
$M^2 \cdot SVOL$			-0.1223**			0.0031***
			(0.0585)			(0.0008)
$M^2 \cdot IVOL$			-0.0189			-0.0058***
			(0.0209)			(0.0004)
R^2	0.0250	0.0297	0.0365	0.0174	0.0194	0.0216

The table reports results for the first step regression applied to the model described by equation 3.4 and using volatility components estimated with an EGARCH model. The coefficients are derived by regressing daily option returns R on risk factors $SVOL$, $IVOL$ and M (and additional combinations in the interacted and squared configurations) for each individual time step t and then taking the time-series average of the single cross-sectional estimates for $\hat{\beta}$. The top panel refers to call options and the bottom panel to put options. In addition to $\bar{\beta}$, the respective standard errors are reported in parentheses. Statistical significance is judged according to the global t-statistic and the 1 percent, 5 percent, 10 percent levels are denoted by ***, **, *. The goodness-of-fit of the applied model ise judged by the average R^2 value.

Table B.2: Time-series regressions – Second step

	EU_AC			US_AC		
Configuration	pure	interacted	squared	pure	interacted	squared
Intercept	0.0062***	0.0077***	0.0012	0.0096***	0.0117***	0.0189***
	(0.0016)	(0.0021)	(0.0028)	(0.0023)	(0.0025)	(0.0027)
$SVOL$	0.0586***	0.0578***	0.0573***	0.0670***	0.0665***	0.0653***
	(0.0037)	(0.0037)	(0.0036)	(0.0059)	(0.0062)	(0.0066)
$IVOL$	-0.0538***	-0.0505***	-0.0648***	-0.1484***	-0.1524***	-0.1437***
	(0.0141)	(0.0156)	(0.0126)	(0.0181)	(0.0229)	(0.0204)
M	0.0578	-0.0497	0.0954***	-1.5997***	-2.2955***	-1.8131***
	(0.0507)	(0.0849)	(0.0341)	(0.5332)	(0.3088)	(0.1554)
$M \cdot SVOL$		0.0476**	0.0708***		-0.4456***	-0.3207***
		(0.0185)	(0.0071)		(0.0700)	(0.0459)
$M \cdot IVOL$		-0.0584	-0.0187		-2.0398***	-1.5168***
		(0.0439)	(0.0200)		(0.2534)	(0.1516)
M^2			0.1337*			-22.2877***
			(0.0794)			(3.7115)
$M^2 \cdot SVOL$			0.0760***			-5.6353***
			(0.0127)			(1.0533)
$M^2 \cdot IVOL$			0.0077			-19.3724***
			(0.0357)			(3.6385)
R^2	0.2588	0.2597	0.2921	0.3942	0.4203	0.4653
F-statistic	116.60	74.12	49.68	197.12	151.01	143.83
p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
JB-statistic	108.5094	161.5634	138.9543	94.5744	299.5511	116.0610
p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	EU_AP			US_AP		
Configuration	pure	interacted	squared	pure	interacted	squared
Intercept	-0.0059**	-0.0185***	-0.0107**	-0.0163***	-0.0224***	-0.0250***
	(0.0027)	(0.0033)	(0.0046)	(0.0038)	(0.0034)	(0.0034)
$SVOL$	0.0540***	0.0555***	0.0498***	0.0510***	0.0673***	0.0761***
	(0.0046)	(0.0042)	(0.0046)	(0.0084)	(0.0097)	(0.0094)
$IVOL$	-0.1533***	-0.1161***	-0.1071***	-0.3112***	-0.2271***	-0.1933***
	(0.0224)	(0.0209)	(0.0213)	(0.0386)	(0.0434)	(0.0361)
M	0.2263	-0.1259	-0.0492	-3.3064***	-1.7388***	-1.7137***
	(0.1791)	(0.1074)	(0.1055)	(0.5415)	(0.4807)	(0.2039)
$M \cdot SVOL$		0.0819***	0.0624***		-0.2206	-0.2394***
		(0.0214)	(0.0197)		(0.1383)	(0.0602)
$M \cdot IVOL$		-0.1113**	-0.0306		-1.3069***	-1.3292***
		(0.0503)	(0.0470)		(0.4925)	(0.2314)
M^2			-0.2613			-21.6441***
			(0.2894)			(4.2967)
$M^2 \cdot SVOL$			0.0597			-5.4841***
			(0.0497)			(1.2364)
$M^2 \cdot IVOL$			0.0422			-19.2035 ***
			(0.1173)			(4.3580)
R^2	0.2249	0.3173	0.3684	0.5343	0.5785	0.6376
F-statistic	85.78	99.47	64.36	274.94	151.76	268.73
p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
JB-statistic	1244.4931	2259.4430	3252.3616	4689.9031	1821.1360	3134.9067
p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

The table reports results for the second step regression according to equation 3.7. The coefficients are derived by regressing average daily option returns $\bar{R}$ on first step betas $\hat{\beta}^{SVOL}$, $\hat{\beta}^{IVOL}$ and $\hat{\beta}^{M}$ (and additional combinations in the interacted and squared configurations) in one global time-series regression. The top panel refers to call options and the bottom panel to put options. In addition to $\hat{\gamma}$, the respective Newey-West adjusted standard errors are reported in parentheses. Statistical significance at the 1 percent, 5 percent, 10 percent level is denoted by ***, **, *. In addition to the R^2 value, the goodness-of-fit of the applied model is judged by the F-statistic and the JB-statistic as well as the corresponding p-values.

Table B.3: Portfolio regressions – Second step

	EU_AC			US_AC		
Configuration	pure	interacted	squared	pure	interacted	squared
Intercept	0.0080	0.0115	0.0387***	0.0250	0.2586***	0.0563
	(0.0118)	(0.0129)	(0.0080)	(0.0203)	(0.0556)	(0.0770)
$SVOL$	0.0820*	0.1050***	0.1824**	1.2391***	1.1849***	1.9332***
	(0.0410)	(0.0380)	(0.0732)	(0.3135)	(0.1546)	(0.5410)
$IVOL$	0.3068	0.3795	1.5882***	0.2913	2.0471***	1.3367***
	(0.4559)	(0.3184)	(0.3014)	(0.3323)	(0.4591)	(0.3784)
M	0.7573	-0.4772	-0.8704	-2.9072	-23.6406***	-0.4334
	(0.4835)	(1.2171)	(0.5388)	(2.8682)	(6.4211)	(1.7525)
$M \cdot SVOL$		-0.0479	0.1175		1.1307	1.1797**
		(0.3081)	(0.0926)		(1.4650)	(0.5638)
$M \cdot IVOL$		0.2155	1.3223***		-8.3601*	5.4629**
		(0.6468)	(0.3189)		(4.8465)	(2.1249)
M^2			-1.9016			235.2962**
			(1.2210)			(97.5196)
$M^2 \cdot SVOL$			0.1588			71.4137**
			(0.2055)			(27.2092)
$M^2 \cdot IVOL$			1.4283**			311.0648***
			(0.6383)			(97.2006)
R^2	0.0992	0.1015	0.3410	0.3223	0.5464	0.7074
F-statistic	13.96	4.32	814.38	12.12	43.12	182.02
p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
JB-statistic	1.5190	1.3758	0.0043	61.4686	2.3322	0.9712
p-value	0.4679	0.5026	0.9979	0.0000	0.3116	0.6153
	EU_AP			**US_AP**		
Configuration	pure	interacted	squared	pure	interacted	squared
Intercept	-0.0363***	-0.1021***	0.0079	0.0039	-0.0589**	-0.2364***
	(0.0102)	(0.0248)	(0.0086)	(0.0183)	(0.0246)	(0.0280)
$SVOL$	0.5618***	0.3387*	-0.2320***	1.4772***	1.1367***	2.1617***
	(0.1724)	(0.1774)	(0.0653)	(0.2345)	(0.2160)	(0.3101)
$IVOL$	-1.7830**	-1.7892**	-0.6750***	-1.0302	-1.1258*	1.8480***
	(0.8305)	(0.8186)	(0.1327)	(0.7213)	(0.6378)	(0.6559)
M	-3.1720***	-2.1985***	0.2112	-6.3547***	-11.1852***	1.7132
	(0.8389)	(0.3007)	(0.9678)	(1.5706)	(4.1399)	(1.7601)
$M \cdot SVOL$		0.4519	-0.4610***		-0.8871	6.1655***
		(0.2673)	(0.1640)		(1.2054)	(0.8179)
$M \cdot IVOL$		-2.6025***	-0.6798*		-9.4324*	10.6481***
		(0.5988)	(0.3695)		(4.8743)	(2.1409)
M^2			-1.1153			348.7821***
			(4.1037)			(69.5549)
$M^2 \cdot SVOL$			-1.6132**			124.7138***
			(0.7670)			(22.8270)
$M^2 \cdot IVOL$			-2.0856			388.0172***
			(1.8315)			(75.2387)
R^2	0.6370	0.7624	0.8911	0.7202	0.7496	0.8509
F-statistic	7.91	91.75	541.20	27.16	55.31	196.16
p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
JB-statistic	7.8030	4.5369	0.0920	1.0802	1.0469	1.0100
p-value	0.0202	0.1035	0.9551	0.5827	0.5925	0.6035

The table reports results for the second step regression according to equation 3.7. The coefficients shown here are derived by regressing equally-weighted portfolio returns R on first step portfolio betas $\hat{\beta}^{SVOL}$, $\hat{\beta}^{IVOL}$ and $\hat{\beta}^{M}$ (and additional combinations in the interacted and squared configurations). The top panel refers to call options and the bottom panel to Put options. In addition to $\hat{\gamma}$, the respective Newey-West adjusted standard errors are reported in parentheses. Statistical significance at the 1 percent, 5 percent, 10 percent level is denoted by ***, **, *. In addition to the R^2 value, the goodness-of-fit of the applied model is judged by the F-statistic and the JB-statistic as well as the corresponding p-values.

C More restrictive data cleaning

The empirical results presented in this section are generated with the same approach as those in Table 3.3, Table 3.4 and Table 3.5. However, the baseline model is applied to a slightly different data set which has been adjusted for major outliers in the main variables.

Table C.1: Cross-sectional regressions – First step

	EU_AC			US_AC		
Configuration	pure	interacted	squared	pure	interacted	squared
Intercept	-0.0149***	-0.1300***	-0.2123***	-0.0130***	-0.0558***	-0.0914***
	(0.0022)	(0.0039)	(0.0134)	(0.0019)	(0.0025)	(0.0031)
$SVOL$	-0.0221**	0.1361***	0.2788***	-0.0247***	-0.0547***	-0.0703***
	(0.0115)	(0.0182)	(0.0573)	(0.0085)	(0.0098)	(0.0112)
$IVOL$	-0.0151***	0.1747***	0.2473***	-0.0107***	0.0750***	0.1171***
	(0.0059)	(0.0109)	(0.0514)	(0.0041)	(0.0053)	(0.0059)
M	0.0134***	0.1318***	0.2535***	0.0075***	0.0511***	0.0960***
	(0.0007)	(0.0033)	(0.0263)	(0.0002)	(0.0013)	(0.0022)
$M \cdot SVOL$		-0.1672***	-0.3731***		0.0268***	0.0432***
		(0.0132)	(0.1178)		(0.0026)	(0.0056)
$M \cdot IVOL$		-0.1924***	-0.3067***		-0.0841***	-0.1389***
		(0.0092)	(0.0995)		(0.0024)	(0.0036)
M^2			-0.0376***			-0.0077***
			(0.0128)			(0.0003)
$M^2 \cdot SVOL$			0.0555			-0.0035***
			(0.0629)			(0.0008)
$M^2 \cdot IVOL$			0.0433			0.0120***
			(0.0486)			(0.0005)
R^2	0.0398	0.0373	0.0534	0.0280	0.0309	0.0340
	EU_AP			**US_AP**		
Configuration	pure	interacted	squared	pure	interacted	squared
Intercept	-0.0087***	0.0275***	0.1344***	-0.0275***	-0.0239***	-0.0031
	(0.0022)	(0.0040)	(0.0083)	(0.0025)	(0.0036)	(0.0042)
$SVOL$	0.0098	-0.1848***	-0.2184***	-0.0163**	0.0302***	0.1105***
	(0.0096)	(0.0169)	(0.0690)	(0.0079)	(0.0105)	(0.0132)
$IVOL$	0.0378***	0.0582***	-0.1028***	0.0342***	0.0039	-0.0084
	(0.0054)	(0.0127)	(0.0359)	(0.0045)	(0.0066)	(0.0077)
M	-0.0206***	-0.0538***	-0.2361***	-0.0113***	-0.0149***	-0.0548***
	(0.0007)	(0.002)6	(0.0150)	(0.0005)	(0.0016)	(0.0032)
$M \cdot SVOL$		0.1862***	0.2597**		-0.0422***	-0.1444***
		(0.0123)	(0.1312)		(0.0039)	(0.0098)
$M \cdot IVOL$		-0.0255***	0.2562***		0.0278***	0.0746***
		(0.0096)	(0.0716)		(0.0026)	(0.0055)
M^2			0.0758***			0.0185***
			(0.0069)			(0.0008)
$M^2 \cdot SVOL$			-0.0369			0.0254***
			(0.0614)			(0.0018)
$M^2 \cdot IVOL$			-0.1235***			-0.0325***
			(0.0361)			(0.0014)
R^2	0.0377	0.0435	0.0518	0.0277	0.0299	0.0332

The table reports results for the first step regression applied to the model described by equation 3.4. The coefficients shown here are derived by regressing daily option returns R on risk factors $SVOL$, $IVOL$ and M (and additional combinations in the interacted and squared configurations) for each individual time step t and then taking the time-series average of the single cross-sectional estimates for $\hat{\beta}$. The top panel refers to call options and the bottom panel to put options. In addition to $\bar{\beta}$, the respective standard errors are reported in parentheses. Statistical significance is judged according to the global t-statistic and the 1 percent, 5 percent, 10 percent levels are denoted by ***, **, *. The goodness-of-fit of the applied model is judged by the average R^2 value.

Table C.2: Time-series regressions – Second step

Configuration	EU_AC pure	EU_AC interacted	EU_AC squared	US_AC pure	US_AC interacted	US_AC squared
Intercept	0.0050***	0.0100***	0.0047	0.0125***	0.0213***	0.0277***
	(0.0016)	(0.0028)	(0.0031)	(0.0023)	(0.0031)	(0.0027)
$SVOL$	0.0708***	0.0683***	0.0643***	0.0731***	0.0790***	0.0763***
	(0.0046)	(0.0048)	(0.0048)	(0.0062)	(0.0072)	(0.0067)
$IVOL$	-0.0541***	-0.0523***	-0.0447***	-0.1288***	-0.1304***	-0.1284***
	(0.0085)	(0.0087)	(0.0085)	(0.0132)	(0.0159)	(0.0148)
M	0.0600	-0.0531	0.1034***	-1.0074***	-1.5643***	-1.8963***
	(0.0602)	(0.0808)	(0.0310)	(0.3470)	(0.2092)	(0.1991)
$M \cdot SVOL$		0.0593***	0.0876***		-0.2176***	-0.3428***
		(0.0199)	(0.0083)		(0.0511)	(0.0535)
$M \cdot IVOL$		-0.0616*	0.0143		-0.9886***	-1.1536***
		(0.0354)	(0.0149)		(0.1297)	(0.1386)
M^2			0.0459			-22.3135***
			(0.0685)			(3.5070)
$M^2 \cdot SVOL$			0.0873***			-5.5287***
			(0.0156)			(0.9671)
$M^2 \cdot IVOL$			0.0272			-13.1938***
			(0.0270)			(2.2950)
R^2	0.3773	0.3822	0.4533	0.4022	0.4519	0.5086
F-statistic	228.26	174.76	127.87	212.16	202.64	213.06
p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
JB-statistic	266.8918	513.6195	365.5130	172.4250	413.2394	206.1739
p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Configuration	EU_AP pure	EU_AP interacted	EU_AP squared	US_AP pure	US_AP interacted	US_AP squared
Intercept	0.0025	0.0020	0.0145**	-0.0201***	-0.0203***	-0.0067
	(0.0032)	(0.0054)	(0.0060)	(0.0041)	(0.0036)	(0.0042)
$SVOL$	0.0608***	0.0548***	0.0572***	0.0534***	0.1002***	0.0924***
	(0.0047)	(0.0043)	(0.0048)	(0.0087)	(0.0106)	(0.0095)
$IVOL$	-0.1367***	-0.1091***	-0.0714***	-0.2173***	-0.1605***	-0.1025***
	(0.0110)	(0.0111)	(0.0113)	(0.0263)	(0.0274)	(0.0261)
M	0.2394***	0.2573**	0.2156**	-1.2279***	-1.5549***	-1.0664***
	(0.0794)	(0.1083)	(0.1043)	(0.2262)	(0.1709)	(0.1256)
$M \cdot SVOL$		0.1180***	0.1065***		-0.0894*	-0.0381
		(0.0174)	(0.0161)		(0.0485)	(0.0375)
$M \cdot IVOL$		0.0252	0.0283		-0.8476***	-0.4073***
		(0.0346)	(0.0269)		(0.1282)	(0.0624)
M^2			0.1651			-4.9285***
			(0.2401)			(0.8010)
$M^2 \cdot SVOL$			0.1327***			-0.6548***
			(0.0357)			(0.1789)
$M^2 \cdot IVOL$			0.0642			-1.7145***
			(0.0673)			(0.4363)
R^2	0.4472	0.4892	0.5646	0.4667	0.5514	0.5858
F-statistic	239.10	189.53	179.51	243.76	208.72	141.06
p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
JB-statistic	1891.7001	2161.8398	3420.3981	3579.2927	2684.8383	3653.2630
p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

The table reports results for the second step regression according to equation 3.7. The coefficients shown here are derived by regressing average daily option returns $\bar{R}$ on first step betas $\hat{\beta}^{SVOL}$, $\hat{\beta}^{IVOL}$ and $\hat{\beta}^{M}$ (and additional combinations in the interacted and squared configurations) in one global time-series regression. The top panel refers to call options and the bottom panel to put options. In addition to $\hat{\gamma}$, the respective Newey-West adjusted standard errors are reported in parentheses. Statistical significance at the 1 percent, 5 percent, 10 percent level is denoted by ***, **, *. In addition to the R^2 value, the goodness-of-fit of the applied model is judged by the F-statistic and the JB-statistic as well as the corresponding p-values.

Table C.3: Portfolio regressions – Second step

	EU_AC			US_AC		
Configuration	pure	interacted	squared	pure	interacted	squared
Intercept	0.0179	-0.0048	0.0125	0.1185***	0.0055	0.2211***
	(0.0141)	(0.0141)	(0.0220)	(0.0116)	(0.0503)	(0.0324)
$SVOL$	0.2602**	0.5539***	0.4262***	2.8043***	3.1469***	2.0918***
	(0.1081)	(0.0885)	(0.0769)	(0.3241)	(0.3412)	(0.2421)
$IVOL$	-0.0162	-0.5532**	-0.6580***	1.7697***	1.5566**	-0.6060
	(0.1378)	(0.2234)	(0.1332)	(0.5485)	(0.6007)	(0.6272)
M	-0.2945	1.9849	0.0653	-4.7331***	-11.1106***	-91.930***
	(0.3757)	(1.2830)	(0.9201)	(0.6156)	(1.6249)	(18.458)
$M \cdot SVOL$		1.2501***	0.9279***		-2.1822	-19.524***
		(0.2548)	(0.2728)		(1.4135)	(4.6866)
$M \cdot IVOL$		0.1231	-0.8145*		-7.7836***	-59.148***
		(0.7753)	(0.4448)		(2.1562)	(12.678)
M^2			-6.4203**			-1471.6***
			(2.9439)			(310.61)
$M^2 \cdot SVOL$			0.2761			-383.55***
			(0.6854)			(83.911)
$M^2 \cdot IVOL$			-3.7188**			-942.44***
			(1.3775)			(203.31)
R^2	0.0704	0.4252	0.6050	0.7479	0.7893	0.8704
F-statistic	2.58	46.19	188.12	51.60	53.11	50.34
p-value	0.0700	0.0000	0.0000	0.0000	0.0000	0.0000
JB-statistic	0.3377	4.2215	8.6763	1.4877	2.0084	1.6857
p-value	0.8447	0.1211	0.0131	0.4753	0.3663	0.4305

	EU_AP			US_AP		
Configuration	pure	interacted	squared	pure	interacted	squared
Intercept	0.0807***	-0.0086	-0.0167	-0.0772***	-0.1189***	-0.2536***
	(0.0120)	(0.0519)	(0.0958)	(0.0191)	(0.0352)	(0.0421)
$SVOL$	1.0743***	1.0938***	0.8649**	1.5889***	1.6365***	0.8400**
	(0.1790)	(0.1583)	(0.3822)	(0.2092)	(0.4802)	(0.3591)
$IVOL$	-2.8107***	-2.3272***	-0.8095*	-0.7522	-0.1570	-0.6829
	(0.4433)	(0.3209)	(0.4023)	(0.6318)	(0.9834)	(0.9054)
M	0.1364	-0.5731	-0.9694	-7.4071***	-7.8278***	-14.975***
	(0.4420)	(0.8645)	(2.0217)	(1.6049)	(1.3927)	(2.5247)
$M \cdot SVOL$		1.1489***	0.7965*		0.2881	-3.1690***
		(0.2192)	(0.4276)		(0.6013)	(0.7656)
$M \cdot IVOL$		-3.0167***	-1.4144***		-3.008	-6.5585***
		(0.4590)	(0.4504)		(2.3424)	(2.1826)
M^2			-2.4838			-58.368***
			(5.9311)			(15.726)
$M^2 \cdot SVOL$			0.4256			-12.872**
			(0.5008)			(4.9703)
$M^2 \cdot IVOL$			-1.9781			-22.0306**
			(1.3381)			(10.637)
R^2	0.7296	0.7461	0.8022	0.7788	0.7923	0.8196
F-statistic	35.31	28.30	74.20	35.23	56.80	114.91
p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
JB-statistic	3.4373	1.3528	0.2080	0.2335	0.2711	2.4358
p-value	0.1793	0.5084	0.9012	0.8898	0.8732	0.2959

The table reports results for the second step regression according to equation 3.7. The coefficients shown here are derived by regressing equally-weighted portfolio returns R on first step portfolio betas $\hat{\beta}^{SVOL}$, $\hat{\beta}^{IVOL}$ and $\hat{\beta}^{M}$ (and additional combinations in the interacted and squared configurations). The top panel refers to call options and the bottom panel to put options. In addition to $\hat{\gamma}$, the respective Newey-West adjusted standard errors are reported in parentheses. Statistical significance at the 1 percent, 5 percent, 10 percent level is denoted by ***, **, *. In addition to the R^2 value, the goodness-of-fit of the applied model is judged by the F-statistic and the JB-statistic as well as the corresponding p-values.

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