The Term Structure of Systematic and Idiosyncratic Risk*

Fabian Hollstein[†], Marcel Prokopczuk[†,‡], and Chardin Wese Simen[‡]

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Abstract

We study the term structure of variance (total risk), systematic and idiosyncratic risk. Consistent with the expectations hypothesis, we find that, for the entire market, the slope of the term structure of variance is mainly informative about the path of future variance. Thus, there is little indication of a time-varying term premium. Turning the focus to individual stocks, we cannot reject the expectations hypothesis for the systematic variance, but we strongly reject it for idiosyncratic variance. Our results are robust to jumps and potential statistical biases.

JEL classification: G12, G11, G17

Keywords: Options, term structure, expectations hypothesis, model-free option implied variance, implied correlation, systematic risk, beta, idiosyncratic variance

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†School of Economics and Management, Leibniz University Hannover, Koenigsworther Platz 1, 30167 Hannover, Germany.

‡ICMA Centre, Henley Business School, University of Reading, Reading, RG6 6BA, UK.

I Introduction

Recent studies document the predictive power of the term structure of option-related variables. For example, Vasquez (2016) and Koijen et al. (2017) document that the spread between option prices of different maturities predicts future option returns. At the same time, security exchanges are increasingly disseminating information about the term structure of option implied volatility and correlation. For instance, the Chicago Board Options Exchange (CBOE) now publishes information not only about the popular 1-month VIX but also about the 3-month VIX and the option implied correlation of various maturities. The academic and professional interest in the term structure of option-related variables raises several questions: What does the term structure of option prices tell us about future developments? Are there differences in the term structures of market and stock option prices? In particular, does the term structure encode information about the future path of the variable of interest or does it instead reflect variations in a possible term premium?

Understanding whether there is a time-varying term premium is important in many situations. For asset managers, knowledge about the term premium is essential for strategies that take positions in the long-term variance and roll over short positions in the short-term variance. If the term premium varies over time in a predictable fashion, investors could exploit this. On the other hand, it is important to know whether it is cheaper to hedge against variance increases by buying a long-term variance swap contract or rolling over short-term variance swaps. Similar considerations hold for correlation trading strategies. Understanding the differences in the term structures of systematic and idiosyncratic variance can help for asset managers decide how to hedge individual stock variance. Answers to the above questions are also important for risk managers who need an estimate of future variance. To the extent that there is a time-varying premium in the term structure of variance, the implied forward variance will be a noisy proxy for the expected future implied variance. Thus, a risk manager would need to purge the implied forward variance from the time-varying term premium.

This paper analyzes the term structures of model-free option implied variance, systematic and idiosyncratic stock variance, as well as option implied correlation.[1] We formally derive testable predictions of the expectations hypothesis for each of these term structures. The expectations hypothesis essentially states that the spread between the current long-term estimate of these risk measures and the current short-term estimate of risk is mainly informative about future developments in short-term risk. Our derivation points to a relationship between the term structure of equity index options prices and that of the option prices on the underlying equities.

We use a large options dataset to empirically test the expectations hypothesis for each term structure. Our results suggest that the expectations hypothesis generally cannot be rejected for the term structures of option implied variance of the market as well as for systematic stock variance. Thus, there is little indication of a time-varying term premium associated with these variables. As a consequence, the slope of each term structure is informative about investors' expectations of future short-term (systematic) variance. As opposed to that, we typically detect a negative term premium in the term structure of option implied idiosyncratic variance. For option implied correlation, the results are indecisive. We typically cannot formally reject the expectations hypothesis, but the coefficient estimates are far from those predicted. These results are robust to the presence of jumps in the underlying price process, as well as potential statistical biases in our tests. We thus conclude that overall the expectations hypothesis provides a good description of the term structure of market option prices, but not to the extent that they account for idiosyncratic variance.

[1]Note that systematic risk, and hence idiosyncratic variance, is not entirely model-free since it partly depends on a parametric model for beta.

Our work extends the literature on the term structure of variance and volatility.[2] Campa & Chang (1995) and Della Corte et al. (2011) study the term structure of foreign exchange variance and volatility, respectively. Mixon (2007) and Johnson (2016) extend these studies to the term structure of equity index implied variance. Our work is most strongly related to a study by Heynen et al. (1994), who focus on the term structure of the index and individual equity option implied volatility. Taken together, the above studies reach conflicting conclusions. These range from a rejection of (an implication of) the expectations hypothesis (Della Corte et al., 2011 and Johnson, 2016) to mixed results (Mixon, 2007) and not being able to reject the expectations hypothesis for the term structure of variance (Heynen et al., 1994 and Campa & Chang, 1995). Our study is different in several important aspects. First, unlike Heynen et al. (1994), Campa & Chang (1995), and Mixon (2007), we study the model-free option implied variance, which makes our results immune to potential misspecification of a specific option pricing model used. That is, we avoid performing a joint test of correct option pricing model specification and the expectations hypothesis. Second, we extend the work of Mixon (2007) and Johnson (2016), who focus on the market index only. Because our derivation points to the link between the option implied variance of the index and the individual equities, we study the term structure of the option implied variance of individual equities. Third, and most importantly, motivated by partly differential results on the market and individual stocks, we decompose the term structure of option implied variance into parts related to systematic and idiosyncratic variance.

Our paper is also related to Feunou et al. (2013) who show that principal components from the option implied variance term structure have predictive power for bond and equity returns. Our results indicate that factors capturing the slope of the term structure on the market level are related to expectations about the future variance and may help rationalize

[2] Ait-Sahalia et al. (2015) extend the work of Egloff et al. (2010), modelling the term structure of variance swaps in a continuous time setup. Further papers that model the term structure of variance swap rates include Andries et al. (2015), Amengual & Xiu (2015), Dew-Becker et al. (2015), and Filipović et al. (2016).

these findings.

We also add to the literature on the term structure of option implied correlation. Faria & Kosowski (2016) study the term structure of option implied correlation. However, they make no attempt to test the expectations hypothesis. Moreover, to the best of our knowledge, we are the first to study the term structures of systematic and idiosyncratic variance.

Our study carries implications for asset pricing and risk management in general, and the design of trading strategies in particular. From an asset pricing standpoint, our findings imply, though do not directly test, that the cross-sectional strategies of Vasquez (2016) and Koijen et al. (2017) mainly sort on the expected path of the future short-term option implied volatility, rather than a related term premium. Thus, our results suggest that these studies capture a risk premium associated with cross-sectional differences in expectations about future short-term risk. Furthermore, our finding that the implied (systematic) variance term structure mainly reflects expectations about future short-term variance can be used for risk management purposes. Finally, the results presented in this study reveal that a trading strategy that buys the long-term option implied variance and sells the future short-term option implied variances is not profitable on average at the market level but yields substantial negative returns when applied for individual stocks.

The remainder of this paper is organized as follows. In Section II, we introduce the data and the methodology for the estimation of the option implied quantities. In Sections III and VI, we derive the theoretical relationship between option prices of different maturities and present our empirical results for variance and correlation, respectively. In Sections IV and V, we study the term structure of option implied systematic and idiosyncratic variance, respectively. We conduct additional analyses and test the robustness of our results in Section VII. Section VIII concludes.

II Data and Methodology

A Data

We obtain monthly options data for all stocks in the S&P 500 and the corresponding index from IvyDB OptionMetrics for the sample period between January 1996 and August 2015.[3] We use the Volatility Surface that directly provides implied volatilities over standardized times to maturity for certain levels of delta.[4,5] We select out-of-the-money options, namely puts with deltas larger than -0.5 and calls with deltas smaller than 0.5, using constant maturities of 1, 3, 6, 9, and 12 months for our analysis. Data on the interest rate come from the IvyDB zero coupon yield curve file.[6] Additionally, we obtain daily return data for the S&P 500 index and its constituents from the Center for Research in Security Prices (CRSP).

When testing the expectations hypothesis for individual stocks, we require at least 50 monthly observations to include the firm in the sample.[7]

B Variance, Correlation, and Beta Estimation

We follow the approach developed by Britten-Jones & Neuberger (2000) and Jiang & Tian (2005) to compute the (annualized) model-free option implied variance:

$$\sigma^2_{j,t,T} = \frac{2e^{r_t(T-t)}}{T-t}\int_0^\infty \frac{M_t(T,K)}{K^2}dK. \tag{1}$$

[3] The starting date of our study aligns with the start of the OptionMetrics database in 1996, while options data were only available up to August 2015 when we started this study, determining the end point of our sample period.

[4] IvyDB uses a kernel smoothing algorithm that generates standardized options only *"if there exists enough option price data on that date to accurately interpolate the required values"*. For more details we refer the interested reader to the IvyDB technical document.

[5] The results are qualitatively similar when directly using "real" options instead of the Volatility Surface.

[6] IvyDB derives the zero coupon yield from the London Interbank Offered Rates (LIBOR) and settlement prices of Chicago Mercantile Exchange Eurodollar futures.

[7] Overall, we are able to include 658 of the constituents of the S&P 500, which vary over time due to index additions and deletions.

$\sigma^2_{j,t,T}$ is the (annualized) option implied variance of asset j for the period starting at time t and ending at time T. Note that the option implied variance is available at time t. r_t is the risk-free rate and $T-t$ is the time to maturity of the option, denominated as the fraction of one year. $M_t(T,K)$ is the price of the out-of-the-money option (put or call) with strike K and time to maturity $T-t$ at time t.

For the empirical implementation, we follow Chang et al. (2012). First, we compute ex-dividend stock prices. Second, we interpolate implied volatilities on a grid of 1,000 moneyness levels ($\frac{K}{S}$, strike-to-spot), equally spaced between 0.3% and 300%, for any given stock and trading day. For implied volatilities outside the range of available strike prices, we extrapolate using the nearest neighbor method (as in Jiang & Tian, 2005 and Chang et al., 2012).[8] Using the interpolated volatilities, we compute Black & Scholes (1973) option prices for calls if $\frac{K}{S} > 1$ and puts if $\frac{K}{S} < 1$. Third, we use these prices to numerically compute the above integral using a trapezoidal rule (Dennis & Mayhew, 2002).

For the computation of the option implied correlation, we follow Driessen et al. (2009), computing the average pairwise correlation among all N stocks in an index:

$$\rho_{t,T} = \frac{\sigma^2_{M,t,T} - \sum_{j=1}^{N} \omega^2_{j,t}\sigma^2_{j,t,T}}{\sum_{j,l\neq j} \omega_{j,t}\omega_{l,t}\sigma_{j,t,T}\sigma_{l,t,T}}. \tag{2}$$

$\sigma^2_{M,t,T}$ is the (annualized) option implied variance of the market index and $\omega_{j,t}$ denotes the weight of asset j in the market index at time t.

To obtain forward-looking estimates of beta, we use the methodology proposed by Buss & Vilkov (2012). Hollstein & Prokopczuk (2016) show that the Buss & Vilkov (2012) estimator predicts future realized beta better than, e.g., the simple historical approach. The approach essentially consists in mapping historical correlations, obtained from a 12-month time-series of daily returns, to risk-neutral correlations ($\rho_{jl,t,T}$) and combining these estimates with the

[8] The OptionMetrics Volatiltiy Surface contains calls with deltas down to 0.20 and puts with deltas ranging up to -0.20.

model-free option implied volatilities.[9] A forward-looking estimate for beta of security j is given by:

$$\beta^{\mathrm{BV}}_{j,t,T} = \frac{\sigma_{j,t,T}\sum_{l=1}^{N}\omega_{l,t}\sigma_{l,t,T}\rho_{jl,t,T}}{\sigma^2_{M,t,T}}, \tag{3}$$

where all variables are as previously defined. The implied volatilities needed for the approach are obtained as the square-root of the option implied variance extracted from options with time to expiration matching the forecast horizon.

III The Term Structure of Option Implied Variance

A Derivation of the Term Structure Relation

Let X_t denote the price of an asset at time t. Under no arbitrage, the price should be a semi-martingale. Under the assumption that the price is an Itô semi-martingale and there are jumps of finite variation in the price process, the price dynamics can be expressed as (e.g., Bollerslev & Todorov, 2011):

$$\frac{dX_t}{X_t} = \alpha_t dt + v_t dW_t + \int_{\mathbb{R}} \left(e^x - 1\right)\tilde{\mu}^{\mathbb{P}}\left(dt, dx\right). \tag{4}$$

α_t is the drift and v_t is the instantaneous volatility process. W_t is a standard Brownian motion. $\tilde{\mu}^{\mathbb{P}}\left(dt, dx\right) = \mu(dt, dx) - \nu^{\mathbb{P}}_t(dx)dt$ is the compensated jump measure, where $\mu(dt, dx)$ is a counting measure for the jumps and $\nu^{\mathbb{P}}_t(dx)dt$ denotes the compensator of the jumps. The time-t expectation of the quadratic variation of the log price process, $\mathbb{E}_t(QV_{j,t,t+km})$,

[9] The authors use (i) the identity that the implied variance of the market index has to be the same as the implied variance of the value-weighted portfolio of all index constituents and (ii) a technical condition that maps physical correlations ($\rho^{\mathbb{P}}_{jl,t,T}$) into risk-neutral correlations, namely $\rho_{jl,t,T} = \rho^{\mathbb{P}}_{jl,t,T} - \alpha_{t,T}(1 - \rho^{\mathbb{P}}_{jl,t,T})$. Combining these two relations and solving for $\alpha_{t,T}$, the authors recover the implied correlation matrix of a stock index. For further details, we refer the interested reader to the original article.

then solves

$$\mathbb{E}_t\left(QV_{j,t,t+km}\right) = \int_t^{t+km} v_{j,\tau}^2 \mathrm{d}\tau + \int_t^{t+km}\int_{\mathbb{R}} x^2 \mu\left(d\tau, dx\right). \tag{5}$$

$\mathbb{E}_t(QV_{j,t,t+km})$ denotes the time-t expectation of the variance of stock j over k periods, each of length m (expressed in months), following time t. $v_{j,\tau}^2$ is the instantaneous variance at time τ. Without loss of generality, in the following we set $t = 0$. For discrete time steps, we have

$$\frac{1}{k}\sum_{i=0}^{k-1} \mathbb{E}_0\left(QV_{j,im,(i+1)m}\right) = \mathbb{E}_0\left(QV_{j,0,km}\right). \tag{6}$$

Equation (6) reveals that the long-term implied variance is equal to the mean of time-0 expectations of future short-term implied variances.[10] Note that this equation holds under both the physical and the risk-neutral probability measures. Under the expectations hypothesis, $\mathbb{E}_0(QV_{j,im,(i+1)m})$ is an unbiased predictor of $\mathbb{E}_{im}(QV_{j,im,(i+1)m})$. Hence, we can test the expectations hypothesis by substituting $\mathbb{E}_0(QV_{j,im,(i+1)m})$ with $\mathbb{E}_{im}(QV_{j,im,(i+1)m}) = \sigma_{j,im,(i+1)m}^2$.

Intuitively, Equation (6) implies that an upward-sloping term structure reveals that the market expects the future short-term implied variance to rise and vice versa. Notice also that Equation (6) implies a constant and zero term premium if the expectations hypothesis holds, where the term premium is defined as the return to the strategy that takes a long position in the long-term implied variance and rolls over short positions in the short-term implied variance (see also Section III.C).

Since the level of variance may have a unit root or follow a near-unit-root process, we follow Campa & Chang (1995) and subtract the short-term option implied variance on both sides of Equation (6). Hence, we test the expectations hypothesis in the term structure of option implied variance by estimating the following regression model:

$$\frac{1}{k}\sum_{i=0}^{k-1}\left(\sigma_{j,im,(i+1)m}^2 - \sigma_{j,0,m}^2\right) = a_j + b_j\left(\sigma_{j,0,km}^2 - \sigma_{j,0,m}^2\right) + \nu_{j,km}, \tag{7}$$

[10] Note that the term $\frac{1}{k}$ in Equation (6) reflects the fact that all variances are annualized.

where a_j and b_j are the regression intercept and slope, respectively. All other variables are as previously defined. For example, when testing the expectations hypothesis comparing a 12-month variance contract with 12 successive 1-month contracts, we set $k = 12$ and $m = 1$ in Equation (7).[11]

The regression equation above provides several insights. First, the regression slope b_j is economically interesting since it reveals the share of variation in the slope of the term structure that relates to future changes in the short-term option implied variance. The remainder $(1 - b_j)$ captures that share of the variation in the slope of the term structure that is related to the variation in the term premium. Notice that if the term premium is zero (constant), as predicted by the expectations hypothesis, we expect $(1 - b_j) = 0$.

Second, Equation (7) presents two formally testable versions of the expectations hypothesis. The pure version of the expectations hypothesis predicts a zero term premium. We can formally test the pure expectations hypothesis with the joint null hypothesis $a_j = 0$ and $b_j = 1$. The general version of the expectations hypothesis instead allows for a non-zero but constant term premium (Cargill, 1975), i.e., the null hypothesis only states $b_j = 1$. We test the two hypotheses using a Wald test (for the joint hypothesis) and a t-test (for the simple hypothesis). For all tests at the market level we use Newey & West (1987) corrected standard errors with lag length equal to k times m, with m expressed in months.

Finally, to gain power for the tests on the market level, we also perform a joint Wald test across all maturity specifications of both the pure and general expectations hypotheses. Since the residuals are not independent across maturity specifications, we simulate the critical values with a block-bootstrap that also preserves the dependence across maturity

[11] Different from, e.g., Campbell & Shiller (1991), Bekaert & Hodrick (2001), and Della Corte et al. (2008) we do not use a vector autoregressive (VAR) approach for the expectations hypothesis tests. As noted by Della Corte et al. (2008), in order to set up a VAR for the short-term and long-term variances, one has to make additional assumptions on their data-generating processes (dgp). This implies that the VAR approach is a joint test of the expectations hypothesis and model specification of the dgp. In light of this and the evidence on explosive paths by Downing & Oliner (2007), we choose not to follow the VAR approach.

specifications. We sample the residuals with replacement in blocks of 12 observations using blocks that begin at the same time across each maturity specification. Afterwards, we create an artificial time-series of the same length as the original one for the expectations hypothesis test, imposing the joint restrictions implied by the pure expectations hypothesis and compute both test statistics. We repeat this step 1,000 times, thus obtaining the distribution of the two test statistics.

For tests on individual stocks, we estimate Equation (7) jointly for all stocks in a panel regression. To perform the inference, we follow the advice of Petersen (2009) and use the two-way clustering approach of Cameron et al. (2011).[12] We cluster the residuals by both calendar time and firm observations.

B Empirical Results

Table 1 presents summary statistics on option implied variance and correlation for different maturities. In Panel A, we present summary statistics on the market option implied variance. We find that the term structure is relatively flat on average and increases only marginally with time to maturity. Since variance is positive by definition, this preliminary evidence indicates that the average variance term premium is likely small. The 1-month option implied variance is far more volatile than the 12-month option implied variance with standard deviations of 0.041 and 0.027, respectively. The fact that short-term variance has a higher standard deviation, to some extent, indicates that shocks to variance might be mainly transitory.[13] The first-order autocorrelation is higher for longer maturities and both skewness and kurtosis decrease with maturity.

Figure 1 shows the evolution of 1-month and 12-month option implied variance of the

[12]If the resulting coefficient covariance matrix is not positive semi-definit, we follow the approach of Higham (1988).

[13]A similar pattern across maturities holds for the term structure of interest rates, where shocks cannot easily be considered transitory. It is thus also possible that there is simply more noise short-term options prices. However, we find further support for our conclusion, e.g., studying Figure 1.

S&P 500 over time.[14] There is a large peak during the financial crisis for both maturities. We find that the slope of the term structure, defined as the 12-month minus the 1-month option implied variance is frequently positive during calm periods, when estimates for the option implied variance are small. However, the term structure becomes inverted during bad economic times, e.g., during recessions, highlighted by the shaded areas. Taken together, these patterns further strengthen the view that variance shocks are mainly transitory and point towards the presence of mean-reversion in risk-neutral expectations about future variance.

Panel A of Table 2 reports the results of the test of the expectations hypothesis for the market. We present the results for different pairs of long and short horizons. Several findings are worth noting. First, the slope estimates are generally close to the value of 1 predicted by the expectations hypothesis. For instance, we obtain a slope estimate of 1.042 that is not significantly different from 1 when analyzing 12 months as the long horizon vs. the 12 consecutive 1-month short horizons. The magnitude of the slope coefficient indicates that the term structure slope is almost exclusively informative about future short-term changes in the option implied variance. Similar results emerge for other combinations of maturities. Second, the intercept is generally of small economic magnitude and not significantly different from 0. Third, we formally test the joint restriction implied by the pure expectations hypothesis, i.e., $a = 0$ and $b = 1$. As the p-value associated with the Wald test shows, we cannot reject this null hypothesis. Finally, we also cannot reject the expectations hypothesis based on a joint test across all maturity specifications. We thus conclude that the pure expectations hypothesis provides a good description of the term structure of the market option implied variance.[15]

Turning the focus on individual stocks, Panel B of Table 1 presents some key statistics.

[14]To enhance the exposition, we plot the longest and the shortest time to maturity only. The variances of intermediate maturities are generally in between those of the 1-month and 12-month maturities.

[15]In a recent related study, Johnson (2016) tests an implication of the expectations hypothesis and rejects it. In Section VII.A, we discuss the relation of his results to ours.

We obtain the numbers in the table by first averaging over time and then across stocks. We first note that the average level of option implied variance is substantially higher compared to that of the market. This indicates that a substantial fraction of the option implied variance of the stocks consists of idiosyncratic variance. Furthermore, we find that, on average across stocks, the term structure of the stock option implied variance is downward-sloping with an average 1-month variance of 0.166 and an average 12-month variance of 0.145. A similar relation results when value-weighting the stocks. This clear pattern in the option implied variance across maturities delivers some indication of a negative term premium. The remaining patterns regarding standard deviations, persistence, skewness, and kurtosis across maturities are similar to those of the market index.

Panel B of Table 2 presents our tests of the expectations hypothesis for individual stocks.[16] These deliver an interesting pattern. For the 12 months vs. 1 month maturity specification, we find a statistically significant positive intercept coefficient of 0.012 and a slope coefficient of 0.909 that is not significantly different from one. The Wald test rejects the pure expectations hypothesis in the term structure of individual stock variance but not the general expectations hypothesis. For long overall horizons, we obtain similar results. We are typically able to reject the pure but not the general expectations hypothesis. On the other hand, for short horizons of especially 6 and 3 months, we can strongly reject both the general and the pure expectation hypothesis.

Taken together, although we are not able to reject the expectations hypothesis for the market option-implied variance, Panels A and B of Table 2 indicate that there is in general a decreasing pattern in the slope estimates of the term structure of option implied variance with respect to the time to maturity. To our knowledge, this pattern has not been documented in the previous literature, presenting a new stylized fact in options markets.

[16]Note that for our main results, we restrict both the intercept and slope coefficients to be the same across all stocks. We relax this assumption in Section VII.C.

A natural question to ask is: does the expectations hypothesis work for some stocks and not others? If so, one possibility is that the firms for which the expectations hypothesis is rejected are small firms with illiquid options. Indeed, when testing the expectations hypothesis separately for each stock, we find that it can only be rejected for part of the stocks while we cannot reject for others. Stocks for which we reject the expectations hypothesis are typically small firms relative to the average firm in our sample, have low options trading volumes, and have high average variances. We present these results in Table 3. For example, for the 12 months vs. 1 month maturity specification, the average 1-month and 12-month option implied variances are 0.19 and 0.16 for stocks for which we reject the pure expectations hypothesis and 0.16 and 0.14 for stocks for which we cannot reject the pure expectations hypothesis, respectively. Furthermore, the average weight in the market index for stocks for which we reject the pure expectations hypothesis is 0.13% while that for the remaining stocks is 0.22% on average. Finally, the average daily options volume is 4,412 for stocks for which we reject and 6,117 for the stocks for which we cannot reject the pure expectations hypothesis.

One possible interpretation of these results could be that in the term structure of option prices expectations evolve more consistently for large firms and firms with more liquid options. On the other hand, given that the expectations hypothesis cannot be rejected for the market option-implied variance, it could be that the expectations hypothesis holds for systematic but not for idiosyncratic risk. Thus, the firms for which we are able to reject the expectations hypothesis might simply carry more idiosyncratic risk. In the following sections, we therefore test the expectations hypothesis separately for the systematic and idiosyncratic parts of the variance.

C Variance Term Premia

We also examine the return on a strategy that takes a long position in the long-term option implied variance and rolls over short positions in the short-term option implied variance.[17] We compute these returns as

$$\frac{\sigma^2_{j,0,km} - \frac{1}{k}\sum_{i=0}^{k-1}\sigma^2_{j,im,(i+1)m}}{\sigma^2_{j,0,km}}, \tag{8}$$

where all variables are as previously defined. The results of Section III indicate that the variance term premia should be close to zero on average.

We present the results on the variance term premia in Table 4. For example, buying the 12-month option implied variance and rolling over 12 1-month contracts yields an average annualized return of 1.1%. However, this point estimate is not significantly different from zero. Neither do we obtain a significant average return for any of the other maturity specifications. Hence, on average, there seems to be no variance term premium on the market level.

For the variance term premia of the individual stocks, presented in Panel B of Table 4, the picture looks quite differently. On average across all stocks, the variance term premia are economically and statistically clearly significantly negative. For example when buying a 12-month variance swap contract and rolling over 12 consecutive 1-month contracts, one realizes an average return of −17%.

[17]Note that, in practice, this payoff can be achieved by buying a long-term variance swap and shorting consecutive short-term variance swaps. The payoffs of the floating leg on the long and short positions offset one another.

IV The Term Structure of Systematic Risk

A Derivation of the Term Structure Relation

Bringing together the results of the option implied variance of the market and the individual stocks, in this section we study the term structure of systematic risk. We find that we cannot reject the expectations hypothesis for the market variance but in part for the variance of individual stocks. A potential explanation for these findings is a differential pattern in the evolution of option implied systematic and idiosyncratic risk. Thus, in this and Section (V), we decompose the variance term structure into its systematic and idiosyncratic components.

While the terms "systematic risk" and "beta" are often used interchangeably, in the following we use the term "systematic risk" to denote the systematic part of the total variance ($\beta^2_{j,t,T}\sigma^2_{M,t,T}$) while beta relates to the standard definition, i.e., the expected covariance of an asset's excess return with that of the market over the expected variance of the market excess return. During our sample period, on average, systematic risk accounts for roughly 40% of the total variance of individual stocks.[18] Leading theoretical models predict that the exposure to systematic risk is priced.[19] Hence, it might be that the expectations hypothesis holds only for systematic risk, while investors pay less attention to the term structure of idiosyncratic risk.

We assume that asset returns are generated by a single index model of the form

$$r_{j,t,T} = \alpha_{j,t,T} + \beta_{j,t,T} r_{M,t,T} + \epsilon_{j,t,T}, \tag{9}$$

where $r_{j,t,T}$ and $r_{M,t,T}$ denote the excess returns of stock j and the market for the period t

[18] For example, for the 1-month horizon, the firm-level average total variance is 0.166 and the average systematic variance ($\beta^2_{j,t,T}\sigma^2_{M,t,T}$) amounts to 0.064, which corresponds to a share of 38.7%. For the 12-month horizon, the average option implied variance is 0.145. The systematic part, on average amounts to 0.063, which means that it accounts for 43.2% of the total variance.

[19] Although, recent empirical evidence partly suggests otherwise (e.g., Ang et al., 2006; Herskovic et al., 2016; and Schürhoff & Ziegler, 2016), which is why we also examine idiosyncratic risk in the next section.

until T, respectively. $\epsilon_{j,t,T}$ is the idiosyncratic return component.

In Section A1 of the appendix, we derive the term structure equation systematic risk under the return generating process of Equation (9) and obtain the following result:

$$\frac{1}{k}\sum_{i=0}^{k-1}\left[\mathbb{E}_0\left(\beta_{j,im,(i+1)m}\right)^2\mathbb{E}_0\left(\sigma^2_{M,im,(i+1)m}\right)\right]+\Delta_{\beta\sigma}+\Delta_{\beta r}+\Delta_{\epsilon}=\mathbb{E}_0\left(\beta_{j,0,km}\right)^2\mathbb{E}_0\left(\sigma^2_{M,0,km}\right). \tag{10}$$

$\Delta_{\beta\sigma}$, $\Delta_{\beta r}$, and Δ_{ϵ} are defined in Section A1 of the appendix.

For testing the expectations hypothesis, we proceed analogously to the case of the option implied variance and subtract the short-term estimate for systematic risk on both sides of Equation (10), and set up a regression similar to that of Equation (7). While it is hard to directly set up a trading strategy on beta, an investment strategy on the systematic risk of a firm is realizable much easier. An investor simply needs to compute the forward-looking beta of a stock and trade β^2 shares in the variance of the market index.

B Empirical Results

Table 5 shows the results of expectations hypothesis tests in the term structure of systematic risk for individual stocks.[20] As was the case for the total variance of individual stocks, we detect an intercept coefficient that is positive and significantly different from zero in many cases. We are thus able to reject the pure expectations hypothesis which states that both the intercept should be zero and the slope coefficient should be equal to one at least marginally for all maturity specifications but one. However, the slope coefficients for all horizons are typically close to one, and we are not able to reject the general expectations hypothesis for individual stocks' systematic risk for any of the maturity specifications. Thus, given that we are able to reject the general expectations hypothesis for the total variance of individual

[20]Note that the results of this section are not entirely model-free since the option implied beta of Buss & Vilkov (2012) depends on a parametric model.

stocks especially for short horizons, but not for systematic risk, it appears worthwhile to have another look at the term structure of idiosyncratic variance.

V The Term Structure of Idiosyncratic Variance

A Derivation of the Term Structure Relation

In the previous sections, we find that the the term structure of option implied variance is downward-sloping on average while the term structure of the market option implied variance is rather flat. Furthermore, we cannot reject the general expectations hypothesis for systematic risk while the expectations hypothesis does not overall obtain similar support in the term structure of total stock variance. These stylized facts may be indicative of a downward-sloping term structure of option implied idiosyncratic variance. Thus, in this section, we study the term structure of idiosyncratic variance. We obtain the idiosyncratic variance for all stocks and maturities by solving Equation (A1) of the appendix for the idiosyncratic variance $\mathbb{E}_0\left(\sigma^2_{\epsilon,t,T}\right)$.[21] We then test the expectations hypothesis for idiosyncratic variance as

$$\frac{1}{k}\sum_{i=0}^{k-1}\left(\sigma^2_{\epsilon,j,im,(i+1)m}-\sigma^2_{\epsilon,j,0,m}\right)=a_j+b_j\left(\sigma^2_{\epsilon,j,0,km}-\sigma^2_{\epsilon,j,0,m}\right)+\nu_{j,km}, \tag{11}$$

where $\sigma^2_{\epsilon,j,im,(i+1)m}$ denotes the estimate for the option implied idiosyncratic variance.[22] All other variables are as previously defined.

[21]As described in Section A1, we proxy the expected squared market return by the market variance and obtain estimates for the variance of beta and the covariance of beta with the market variance using the full sample estimate.

[22]Note that the decomposition of the total stock variance term structure into a systematic and an idiosyncratic part is not entirely exhaustive. We neglect the parts $\Delta_{\beta\sigma}$ and $\Delta_{\beta r}$ of Equation (10) that are difficult to interpret.

B Empirical Results

We find that the slope coefficients for the expectations hypothesis tests on systematic risk are typically larger than those for the expectations hypothesis tests on the total stock variance. Thus, given these patterns and the finding that the option implied variance term structure of individual stocks is typically downward-sloping, we expect the slope coefficients to be below 1.

We present the results of the expectations hypothesis tests in the term structure of idiosyncratic variance in Table 6. Consistent with our previous results, and as expected, we find that the slope coefficient is clearly below 1 for all maturity combinations. For example, for the 12 months vs. 1 month maturity specification, the slope coefficient is 0.737. For other maturity specifications, the slope coefficients are typically even lower. We are able to strongly reject both the general and the pure expectations hypothesis for all maturity combinations.

Thus, overall we find that the expectations hypothesis cannot be rejected for the market as well as the systematic risk of individual stocks. However, we can strongly reject the expectations hypothesis for idiosyncratic variance.

C Idiosyncratic Variance Term Premia

In the recent years, there has been an extensive literature that studies strategies on idiosyncratic volatility (e.g., Ang et al., 2006, 2009; Fu, 2009; Bekaert et al., 2012). Typically, the authors find that stocks with high past idiosyncratic volatility underperform those stocks with low past idiosyncratic volatility. As opposed to that, in this section, we examine the average term premia on idiosyncratic variance. Instead of sorting the stocks on their past idiosyncratic variance, the strategy considered here takes a long position in the long-term option implied idiosyncratic variance and rolls over short positions in the short-term option implied idiosyncratic variance of the same stock. We compute these returns as

$$\frac{\sigma^2_{\epsilon,j,0,km} - \frac{1}{k}\sum_{i=0}^{k-1}\sigma^2_{\epsilon,j,im,(i+1)m}}{\sigma^2_{\epsilon,j,0,km}}. \tag{12}$$

All variables are as previously defined.

We present the results in Table 7. Consistent with the results of the previous subsection, we find that the average idiosyncratic variance term premia are typically negative and significantly different from zero. Hence, buying a long-term position in idiosyncratic stock variance is typically cheaper than rolling over short-term positions. Thus, there is a negative term premium in the term structure of option implied idiosyncratic variance. Compared to the average total variance term premia for individual stocks, the idiosyncratic variance term premia are even clearly larger in magnitude. Thus, it seems that it is mostly the idiosyncratic part of the stock variance that drives the negative average payoffs.

VI The Term Structure of Option Implied Correlation

A Derivation of the Term Structure Relation

In order to link the evidence on the term structure of the option implied variance of the market and the individual stocks, we study the term structure of option implied correlation. Using the fact that the index is a value-weighted portfolio of its constituents, Equation (6) implies:

$$\begin{aligned}\frac{1}{k}\sum_{i=0}^{k-1}\mathbb{E}_0\left(\sum_{j=1}^{N}\omega^2_{j,im}QV_{j,im,(i+1)m} + \sum_{j,l\neq j}\omega_{j,im}\omega_{l,im}\sqrt{QV}_{j,im,(i+1)m}\sqrt{QV}_{l,im,(i+1)m}\rho_{im,(i+1)m}\right)\\ =\mathbb{E}_0\left(\sum_{j=1}^{N}\omega^2_{j,0}QV_{j,0,km} + \sum_{j,l\neq j}\omega_{j,0}\omega_{l,0}\sqrt{QV}_{j,0,km}\sqrt{QV}_{l,0,km}\rho_{0,km}\right).\end{aligned} \tag{13}$$

N is the number of stocks in the index and $\omega_{j,im}$ is the market capitalization weight of stock j in the index at time im. $\rho_{im,(i+1)m}$ denotes the average correlation of all stocks in the index between times im and $(i+1)m$, following the definition of Driessen et al. (2009). In Section A2 of the appendix, we show that Equation (13) implies the following relation between the long-term and short-term expectations about the future option implied correlation:

$$\frac{1}{k}\sum_{i=0}^{k-1}\left(\mathbb{E}_0\left(\rho_{im,(i+1)m}\right)\frac{\mathbb{E}_0\left(q_{im,(i+1)m}\right)}{\mathbb{E}_0\left(q_{0,km}\right)}\right)+\Delta_{QV}+\Delta_{pq}=\mathbb{E}_0\left(\rho_{0,km}\right). \tag{14}$$

Equation (14) provides several interesting insights. First, it shows that the long-term correlation is informative about (i) the (weighted) expectation about future short-term correlations, (ii) the spread between the average long-term and rolled short-term implied variance of individual equities (Δ_{QV}), and (iii) the spread between the long-term and rolled short-term covariances of the option implied correlation with the weighted cross-sum of option implied volatilities (Δ_{pq}). The expression makes it clear that, contrary to what one might intuitively expect, changes in the term structure of the implied correlations need not be linked to the future path of the implied correlation.

Notice, however, that if the expectations hypothesis holds for individual equities, the second part on the left hand side of Equation (14) is relatively small.[23] Since Section III.B shows that in some instances we can reject the expectations hypothesis while in others we cannot, it remains an empirical question whether the long-term implied correlation mainly reflects information about the weighted future short-term implied correlation.

We formally test the expectations hypothesis in the term structure of the option implied correlation by running the regression:

$$\frac{1}{k}\sum_{i=0}^{k-1}\left(\rho_{im,(i+1)m}\frac{q^*_{im,(i+1)m}}{q^*_{0,km}}-\rho_{0,m}\right)+\hat{\Delta}_{QV}+\hat{\Delta}_{pq}=a+b\left(\rho_{0,km}-\rho_{0,m}\right)+\nu_{km}. \tag{15}$$

[23]Note that the weights are also potentially time-varying. Thus, changes in long-term implied correlation could also be linked to changes in the index weights.

with $q^*_{t,T} = \sum_{j,l\neq j} \omega_{j,t}\omega_{l,t} \left(\sigma_{j,t,T}\sigma_{l,t,T} + Cov_t\left(\sigma_{j,t,T}, \sigma_{l,t,T}\right)\right)$. $\hat{\Delta}_{QV}$ and $\hat{\Delta}_{pq}$ are defined in Section A2 of the appendix.

B Empirical Results

To begin with, Panel C of Table 1 presents summary statistics on the option implied correlation for different maturities. We find that, on average, the term structure of the option implied correlation slopes upward. The average over a 1-month horizon amounts to 0.418, which rises monotonically to 0.490 for the 12-month horizon. Hence, it seems that participants in the options market expect (i) the correlations to rise in the long run and/or (ii) a negative term premium. As is the case for option implied variance, we find the long-horizon option implied correlation estimates to be more persistent and less volatile, but only slightly less skewed and the kurtosis is close to 3 for all maturities.

Figure 2 presents the time series of option implied correlation for maturities of 1 and 12 months. We find that the term structure is in general upward-sloping; however, consistent with recent evidence in Faria & Kosowski (2016), we also find that the term structure of implied correlation flattens during times of economic distress.

Table 8 presents the results for expectations hypothesis tests.[24] Again, we test both the pure expectations hypothesis, which predicts $a_j = 0$ and $b_j = 1$ and the general expectations hypothesis, that only requires $b_j = 1$. For the 12 months vs. 1 month horizon, we obtain a slope estimate of 0.626 and an intercept estimate of 0.035. We cannot reject the null of the pure expectations hypothesis. For the remaining horizons, we find that the slope estimates are also generally below 1, with values between 0.47 and 0.70. For all horizons, we can neither reject the pure nor the general expectations hypothesis. However, one should notice

[24] One may wonder about the effect of the multiplicative term $\frac{q^*_{im,(i+1)m}}{q^*_{0,km}}$ in Equation (15). For example, the average of the 1-month q^* is 0.115, while that of the 12-month q^* is 0.107. The average of fraction when using the q^* observed at the same time only is 1.04. Hence, on average, the short-term option implied correlation is multiplied by a factor slightly above 1.

that the standard errors are relatively large. Thus, our failure to reject might also be driven by a lack of power in the statistical test. To further address the potential lack-of-power issue, we also run a joint test across all maturity specifications. The test shows that we can neither reject the pure nor the general expectations hypothesis in the term structure of option implied correlation.

VII Additional Analyses

A Forward Unbiasedness

Equation (7) is not the only implication of the expectations hypothesis. The forward-unbiasedness hypothesis, that can also be derived as an implication of Equation (6), states that current forward rates of implied variance should predict future spot rates of implied variance as (Johnson, 2016):[25]

$$\sigma^2_{j,m,km} - \sigma^2_{j,0,m} = a_j + b_j \left(f^2_{j,0,m,km} - \sigma^2_{j,0,m} \right) + \nu_{j,km}. \tag{16}$$

The forward variance implied by the term structure is obtained as $f^2_{j,0,m,km} = \sigma^2_{j,0,km} + \frac{1}{k-1}\left(\sigma^2_{j,0,km} - \sigma^2_{j,0,m}\right)$. As before, the pure expectations hypothesis predicts $a_j = 0$ and $b_j = 1$, while the general expectations hypothesis only states $b_j = 1$. To thoroughly assess its validity, in this section, we also examine the forward unbiasedness implication of the expectations hypothesis.

We present the results in Table 9.[26,27] In Panel A, we present the results for the option implied variance of the market. Overall, the results for the forward unbiasedness formulation

[25] We make use of the expectations hypothesis to substitute $\mathbb{E}_n(QV_{j,n,km}) = \sigma^2_{j,n,km}$ for $\mathbb{E}_0(QV_{j,n,km})$.

[26] Note that we only present the results for option implied variance and not correlation, systematic risk, and idiosyncratic variance. In principle, a forward formulation can also be derived for these term structures. However, in the derivations, the forward correlation and beta contain information that becomes known after t only. Hence, with an unobservable forward rate, the forward unbiasedness hypothesis is not testable.

[27] Note that for this analysis, we additionally use the 2-month option-implied variance contract.

of the expectations hypothesis are qualitatively similar to those in Section III. For most of the maturity specifications, we cannot reject the expectations hypothesis. The expectations hypothesis receives the strongest empirical support for long forward horizons of 9 and 6 months. On the other hand, the slope coefficients for the shortest forward horizons is lower. For the 3 months vs. 1 month horizon (2 months forward horizon), we even reject the expectations hypothesis in its pure form at 5% and the general form at 10%. For all other horizons as well as with the joint test, we cannot reject the expectations hypothesis.

Using the aforementioned setup, Johnson (2016) rejects the expectations hypothesis for the market index. There are two core differences between our approach and that of Johnson (2016). First, the author uses daily observations, which induces a substantial amount of overlap, likely introducing an overlapping-observations bias in the analysis. We use monthly observations, which substantially reduces the overlap and makes a bias less likely. On the other hand, moving from daily to monthly observations reduces the sample size and most likely also the statistical power of the test. However, our sample period covers almost 20 years and thus involves 236 monthly observations. Additionally, we address this issue with our joint test that pooles observations across maturities. Hence, it is unlikely that our expectations hypothesis tests lack power. Second, Johnson (2016) concentrates on short horizons. While our results of the expectations hypothesis tests are also weaker for short horizons, these results are ultimately consistent with Johnson (2016).

In Panel B of Table 9, we present the results for the forward unbiasedness hypothesis for individual stocks. We can reject both the pure and the general forward unbiasedness hypothesis at least weakly for every horizon. Since we find that we cannot reject the expectations hypothesis for the systematic part of the total stock variance, but strongly reject the expectations hypothesis for the idiosyncratic part, it seems that the forward unbiasedness test loads more strongly on the idiosyncratic part of the stock variance than the test in Section III.B.

Panel C of Table 9 presents the results for the forward unbiasedness hypothesis for option implied idiosyncratic variance. Consistent with our previous results, we find that we can strongly reject both the pure and the general expectations for every maturity specification.

B The Role of Jumps

Du & Kapadia (2013) show that the Britten-Jones & Neuberger (2000) approach is not robust to the presence of jumps in the underlying price process. Hence, jumps in the price processes might affect the results of our expectations hypothesis tests. To account for this, we repeat our main tests using the option implied variance following Bakshi et al. (2003), which Du & Kapadia (2013) show to be empirically robust to jumps. The alternative option implied variance can be computed as:

$$\begin{aligned}
\text{QUAD} &= \int_S^{\infty} \frac{2\left(1-\ln\left[\frac{K}{S}\right]\right)}{K^2} C(T,K)dK \\
&+ \int_0^S \frac{2\left(1+\ln\left[\frac{S}{K}\right]\right)}{K^2} P(T,K)dK, \\
\text{CUBIC} &= \int_S^{\infty} \frac{6\ln\left[\frac{K}{S}\right]-3\left(\ln\left[\frac{K}{S}\right]\right)^2}{K^2} C(T,K)dK \\
&+ \int_0^S \frac{6\ln\left[\frac{S}{K}\right]+3\left(\ln\left[\frac{S}{K}\right]\right)^2}{K^2} P(T,K)dK, \\
\text{QUART} &= \int_S^{\infty} \frac{12\left(\ln\left[\frac{K}{S}\right]\right)^2-4\left(\ln\left[\frac{K}{S}\right]\right)^3}{K^2} C(T,K)dK \\
&+ \int_0^S \frac{12\left(\ln\left[\frac{S}{K}\right]\right)^2+4\left(\ln\left[\frac{S}{K}\right]\right)^3}{K^2} P(T,K)dK.
\end{aligned} \tag{17--19}$$

$$\mu_{j,t,T} = e^{r_t(T-t)} - 1 - \frac{e^{r_t(T-t)}}{2}\text{QUAD} - \frac{e^{r_t(T-t)}}{6}\text{CUBIC} - \frac{e^{r_t(T-t)}}{24}\text{QUART}, \tag{20}$$

$$\sigma^2_{j,t,T} = e^{r_t(T-t)}\text{QUAD} - \mu^2_{j,t,T}, \tag{21}$$

where all variables are as previously defined. We implement the variance computation along the lines outlined in Section II.B.

We present the results for the expectations hypothesis tests using the jump-robust option implied variance in Tables 10–13. In Table 10, we present the results for option implied variance. For the market, these are qualitatively similar as before. For individual stocks, presented in Panel B of Table 10, with the jump-robust variance estimates we are able to reject the general expectations hypothesis also for long horizons. Thus, once we account for jumps, the expectations hypothesis receives only little empirical support anymore in the term structure of individual stock option implied variance.

For systematic and idiosyncratic risk, presented in Tables 11 and 12, we obtain largely similar results as before. In the case of systematic risk, we can reject the pure expectations hypothesis, but we are typically not able to reject the genera expectations hypothesis. For idiosyncratic variance, we are able to reject both the general and pure versions of the expectations hypothesis in each case.

Table 13 presents the results for option implied correlation. With the jump-robust option implied variance, the slope coefficients of the expectations hypothesis regression are even further from one than with the standard measure. For all but two maturity specifications we are able to marginally reject the general expectations hypothesis. Thus, overall the expectations hypothesis also receives only little support in the term structure of option implied correlation.

C Firm-Specific Intercept Coefficients

Note that estimating just one intercept coefficient in a panel regression essentially restricts the intercept coefficient for all stocks to be the same. However, in reality, some stocks might have positive average term premia while others have zero or negative average term premia.

In this section, we test the robustness of our main results to this restriction. To do so, we set up a panel regression with firm-fixed intercept coefficients. The Wald test then tests the joint hypothesis that the slope coefficient is equal to one and all intercept coefficients are equal to zero.

We present these results in Tables A1–A3. Overall, these results are largely similar as those without allowing for firm-specific intercepts. We find that in all term structures only part of the stocks have intercept coefficients that are significantly different from zero. However, in every instance, the joint Wald test yields a strongly significant rejection of that the "expanded" pure expectations hypothesis, which states that it holds jointly for all stocks.

D Finite Sample Bias

We account for possible finite sample bias in the expectations hypothesis tests, as discussed in the literature, e.g., by Bekaert et al. (1997). We address this issue in two steps. First, we study the bias in coefficient estimates. Subsequently, we use a bootstrap approach to infer critical values for the test statistics, avoiding reliance on asymptotic results that may not be valid in finite samples.

To correct the bias in coefficient estimates, we first estimate the regression model of Equation (7). We use the parameter estimates and the time series of residuals to conduct a block-bootstrap of the dependent variable, sampling with replacement from the residuals to create the same number of observations as in the initial regression model.[28] We run the expectations hypothesis regression of Equation (7) on the simulated data. We repeat this procedure 1,000 times. In a final step, we obtain the finite sample bias as the difference between the original coefficient estimate and the average of coefficients across the 1,000

[28]We follow Hall et al. (1995) using a block length of $n^{\frac{1}{3}}$, where n is the total sample size. We use overlapping blocks (Lahiri, 1999).

simulations.[29]

Second, using the bias-corrected coefficients, we obtain the series of residuals and examine the finite sample properties of the t- and Wald tests. We sample the residuals with replacement and obtain the time series of the dependent variable under the null hypothesis of $a = 0$ and $b = 1$. We run the regression of Equation (7) and save the values of the test statistics. Again, we repeat this step 1,000 times, thus obtaining the distribution for each of the test statistics. Finally, from the percentiles of the simulated distribution of the test statistics, we obtain the p-values for our expectations hypothesis tests.

We present the empirical results in Table A4 of the Online Appendix.[30] The results suggest that our main conclusions are robust to potential finite sample bias. The bias in coefficient estimates is negligible throughout. For example, for the option implied variance of the market, the maximum (absolute) bias in the slope coefficient is -0.24 percentage points, which is far too low to overturn our results on the expectations hypothesis. Turning the focus to finite sample distributions of the test statistics, we also find that the results with the simulated critical values are qualitatively similar to those relying on asymptotic critical values for the test statistics. Hence, it is very unlikely that our main results are significantly affected by finite sample distortions.

E Errors-In-Variables

Finally, we examine the robustness of our results to potential errors-in-variables concerns. To do that, we follow the instrument variable approach of Christensen & Prabhala (1998). First, we regress the right-hand-side variables on their observation one period before.

[29] Efron & Tibshirani (1986) and Kosowski et al. (2006) show that, typically, the bootstrap results are not sensitive for repetitions larger than 500–1,000. Therefore, we choose 1,000 simulations to limit the computational effort.

[30] To limit the number of tables, we only report the results for option implied variance. The results on systematic risk and idiosyncratic variance for Sections VII.D and VII.E are qualitatively similar. These results are available upon request.

Subsequently, we replace the right-hand-side variables with their fitted values and run the expectations hypothesis regressions. In the presence of measurement errors in the independent variable, there is a downward attenuation bias in the slope coefficient. Hence, we expect the regression slopes to rise once we use the instrumental variables.

We present the results in Table A5 of the Online Appendix. Consistent with our expectation, we find that the slope coefficients rise in general. Our conclusions, however, remain unchanged.

VIII Conclusion

This study analyzes the relationship between option prices of different maturities. Using model-free option implied estimates for variance, we find evidence in support of the expectations hypothesis for the S&P 500. Hence, the term structure slope is mainly informative about future changes in the option implied variance. Second, we test the expectations hypothesis in the term structure of the model-free option implied variance of individual stocks. We find that the expectations hypothesis results are mixed, although in many instances we reject both the pure and the general expectations hypothesis.

Motivated by the differential results for the market and individual stocks, we further decompose the variance term structure, separately studying systematic and idiosyncratic risk. We obtain differential results. Consistent with the results for the market, we cannot reject the general expectations hypothesis for systematic risk while we strongly reject the expectations hypothesis for idiosyncratic risk. Thus, our results suggest that systematic risk evolves consistently over time while there are large and time-varying negative term premia for idiosyncratic risk. Buying long-term market or systematic risk contracts on average yields similar results as rolling over short-term contracts, while for idiosyncratic variance contracts rolling over short-term contracts is considerably more expensive.

Finally, for option implied correlation, the expectations hypothesis gains limited support. We are not able to consistently reject the expectations hypothesis, but the point estimates of our regressions are relatively far from those predicted.

Technical Appendix: Derivations

A1 Systematic Risk and Beta

It is straightforward to show that the return generating process of Equation (9) implies:[31]

$$\begin{aligned}\mathbb{E}_0\left(Var_{t,T}(\alpha_j+\beta_j r_M+\epsilon_j)\right) =&\mathbb{E}_0\left(\beta_{j,t,T}\right)^2\mathbb{E}_0\left(\sigma^2_{M,t,T}\right)+Var_0(\beta_{j,t,T})\mathbb{E}_0\left(\sigma^2_{M,t,T}\right)\\&+Cov_0\left(\beta^2_{j,t,T},r^2_{M,t,T}\right)+\mathbb{E}_0\left(\sigma^2_{\epsilon,t,T}\right).\end{aligned} \tag{A1}$$

$\mathbb{E}_{t,T}(\cdot)$, $Var_{t,T}(\cdot)$, and $Cov_{t,T}(\cdot)$ are the conditional time-t expectations, variance, and covariance operators for the period t until T, respectively. To empirically implement the expectations hypothesis test, we proxy the expected squared market return by the market variance. Finally, we obtain estimates for the time-t variance of beta and covariance of beta with the market variance using the full sample estimate.

Inserting the relation of Equation (A1) into Equation (6), we get

$$\begin{aligned}&\frac{1}{k}\sum_{i=0}^{k-1}\Big[\mathbb{E}_0\left(\beta_{j,im,(i+1)m}\right)^2\mathbb{E}_0\left(\sigma^2_{M,im,(i+1)m}\right)+Var_0(\beta_{j,im,(i+1)m})\mathbb{E}_0\left(\sigma^2_{M,im,(i+1)m}\right)\\&\quad+Cov_0(\beta^2_{j,im,(i+1)m},r^2_{M,im,(i+1)m})+\mathbb{E}_0\left(\sigma^2_{\epsilon,im,(i+1)m}\right)\Big]=\mathbb{E}_0\left(\beta_{j,0,km}\right)^2\mathbb{E}_0\left(\sigma^2_{M,0,km}\right)\\&\quad+Var_0(\beta_{j,0,km})\mathbb{E}_0\left(\sigma^2_{M,0,km}\right)+Cov_0(\beta^2_{j,0,km},r^2_{M,0,km})+\mathbb{E}_0\left(\sigma^2_{\epsilon,0,km}\right).\end{aligned} \tag{A2}$$

[31] We assume continuous time, that $\alpha_{j,t,T}$ is constant for each period, and that $\epsilon_{j,t,T}$ is independent of $\beta_{j,t,T}r_{M,t,T}$. Using $\mathbb{E}_0\left(Var_{t,T}(\alpha_j+\beta_j r_M+\epsilon_j)\right) = \mathbb{E}_0\left(Var_{t,T}(\beta_j r_M+\epsilon_j)\right) = \mathbb{E}_0\left(\mathbb{E}_{t,T}((\beta_j r_M+\epsilon_j)^2)-\mathbb{E}_{t,T}((\beta_j r_M+\epsilon_j))^2\right)$ and accounting for the fact that the squared expectation part is negligible for a continuous time process, one can easily derive Equation (A1).

Collecting terms on the left hand side of the equality sign, we obtain:

$$\begin{aligned}\frac{1}{k}\sum_{i=0}^{k-1}&\left[\mathbb{E}_0\left(\beta_{j,im,(i+1)m}\right)^2\mathbb{E}_0\left(\sigma^2_{M,im,(i+1)m}\right)\right]-Var_0(\beta_{j,0,km})\mathbb{E}_0\left(\sigma^2_{M,0,km}\right)\\&+\frac{1}{k}\sum_{i=0}^{k-1}\left[Var_0(\beta_{j,im,(i+1)m})\mathbb{E}_0\left(\sigma^2_{M,im,(i+1)m}\right)\right]-Cov_0(\beta^2_{j,0,km},r^2_{M,0,km})\\&+\frac{1}{k}\sum_{i=0}^{k-1}\left[Cov_0(\beta^2_{j,im,(i+1)m},r^2_{M,im,(i+1)m})\right]-\mathbb{E}_0\left(\sigma^2_{\epsilon,0,km}\right)\\&+\frac{1}{k}\sum_{i=0}^{k-1}\left[\mathbb{E}_0\left(\sigma^2_{\epsilon,im,(i+1)m}\right)\right]=\mathbb{E}_0\left(\beta_{j,0,km}\right)^2\mathbb{E}_0\left(\sigma^2_{M,0,km}\right).\end{aligned}\tag{A3}$$

Defining $\Delta_{\beta\sigma}=\frac{1}{k}\sum_{i=0}^{k-1}\left[Var_0(\beta_{j,im,(i+1)m})\mathbb{E}_0\left(\sigma^2_{M,im,(i+1)m}\right)\right]-Var_0(\beta_{j,0,km})\mathbb{E}_0\left(\sigma^2_{M,0,km}\right)$, $\Delta_{\beta r}=\frac{1}{k}\sum_{i=0}^{k-1}\left[Cov_0(\beta^2_{j,im,(i+1)m},r^2_{M,im,(i+1)m})\right]-Cov_0(\beta^2_{j,0,km},r^2_{M,0,km})$, and $\Delta_\epsilon=\frac{1}{k}\sum_{i=0}^{k-1}\left[\mathbb{E}_0\left(\sigma^2_{\epsilon,im,(i+1)m}\right)\right]-\mathbb{E}_0\left(\sigma^2_{\epsilon,0,km}\right)$, we obtain:

$$\frac{1}{k}\sum_{i=0}^{k-1}\left[\mathbb{E}_0\left(\beta_{j,im,(i+1)m}\right)^2\mathbb{E}_0\left(\sigma^2_{M,im,(i+1)m}\right)\right]+\Delta_{\beta\sigma}+\Delta_{\beta r}+\Delta_\epsilon=\mathbb{E}_0\left(\beta_{j,0,km}\right)^2\mathbb{E}_0\left(\sigma^2_{M,0,km}\right).\tag{A4}$$

A2 Option Implied Correlation

Re-arranging Equation (13), we obtain:

$$\begin{aligned}\frac{1}{k}\sum_{i=0}^{k-1}&\left(\mathbb{E}_0\left(\rho_{im,(i+1)m}\right)\frac{\mathbb{E}_0\left(q_{im,(i+1)m}\right)}{\mathbb{E}_0\left(q_{0,km}\right)}\right)\\&-\frac{\mathbb{E}_0\left(\sum_{j=1}^N\omega^2_{j,0}QV_{j,0,km}\right)-\frac{1}{k}\sum_{i=0}^{k-1}\left(\mathbb{E}_0\left(\sum_{j=1}^N\omega^2_{j,im}QV_{j,im,(i+1)m}\right)\right)}{\mathbb{E}_0\left(q_{0,km}\right)}\\&-\frac{Cov_0\left(\rho_{0,km},q_{0,km}\right)-\frac{1}{k}\sum_{i=0}^{k-1}\left(Cov_0\left(\rho_{im,(i+1)m},q_{im,(i+1)m}\right)\right)}{\mathbb{E}_0\left(q_{0,km}\right)}=\mathbb{E}_0\left(\rho_{0,km}\right),\end{aligned}\tag{A5}$$

with $q_{t,T}=\sum_{j,l\neq j}\omega_{j,t}\omega_{l,t}\sqrt{QV}_{j,t,T}\sqrt{QV}_{l,t,T}$ and $\mathbb{E}_0\left(q_{t,T}\right)=\sum_{j,l\neq j}\mathbb{E}_0\left(\omega_{j,t}\right)\mathbb{E}_0\left(\omega_{l,t}\right)\left(\mathbb{E}_0\left(\sqrt{QV}_{j,t,T}\right)\mathbb{E}_0\left(\sqrt{QV}_{l,t,T}\right)+Cov_0\left(\sqrt{QV}_{j,t,T},\sqrt{QV}_{l,t,T}\right)\right)$.[32] Defining $\Delta_{QV}=-\frac{\mathbb{E}_0\left(\sum_{j=1}^N\omega^2_{j,0}QV_{j,0,km}\right)-\frac{1}{k}\sum_{i=0}^{k-1}\left(\mathbb{E}_0\left(\sum_{j=1}^N\omega^2_{j,im}QV_{j,im,(i+1)m}\right)\right)}{\mathbb{E}_0\left(q_{0,km}\right)}$

[32] We assume that the weights are independent of the quadratic variations.

and $\Delta_{pq} = -\frac{Cov_0\left(\rho_{0,km}, q_{0,km}\right) - \frac{1}{k}\sum_{i=0}^{k-1}\left(Cov_0\left(\rho_{im,(i+1)m}, q_{im,(i+1)m}\right)\right)}{\mathbb{E}_0\left(q_{0,km}\right)}$, Equation A5 reads:

$$\frac{1}{k}\sum_{i=0}^{k-1}\left(\mathbb{E}_0\left(\rho_{im,(i+1)m}\right)\frac{\mathbb{E}_0\left(q_{im,(i+1)m}\right)}{\mathbb{E}_0\left(q_{0,km}\right)}\right) + \Delta_{QV} + \Delta_{pq} = \mathbb{E}_0\left(\rho_{0,km}\right). \tag{A6}$$

We formally test the expectations hypothesis in the term structure of the option implied correlation by running the regression:

$$\begin{aligned} &\frac{1}{k}\sum_{i=0}^{k-1}\left(\rho_{im,(i+1)m}\frac{q^*_{im,(i+1)m}}{q^*_{0,km}} - \rho_{0,m}\right) + \frac{\frac{1}{k}\sum_{i=0}^{k-1}\left(\sum_{j=1}^{N}\omega^2_{j,im}\sigma^2_{j,im,(i+1)m}\right) - \sum_{j=1}^{N}\omega^2_{j,0}\sigma^2_{j,0,km}}{q^*_{0,km}} \\ &\quad + \frac{\frac{1}{k}\sum_{i=0}^{k-1}\left(Cov_{im}(\rho_{im,(i+1)m}, q^*_{im,(i+1)m})\right) - Cov_0\left(\rho_{0,km}, q^*_{0,km}\right)}{q^*_{0,km}} \\ &\quad = a + b\left(\rho_{0,km} - \rho_{0,m}\right) + \nu_{km}, \end{aligned} \tag{A7}$$

with $q^*_{t,T} = \sum_{j,l\neq j}\omega_{j,t}\omega_{l,t}\left(\sigma_{j,t,T}\sigma_{l,t,T} + Cov_t\left(\sigma_{j,t,T}, \sigma_{l,t,T}\right)\right)$.

Defining $\hat{\Delta}_{QV} = \frac{\frac{1}{k}\sum_{i=0}^{k-1}\left(\sum_{j=1}^{N}\omega^2_{j,im}\sigma^2_{j,im,(i+1)m}\right) - \sum_{j=1}^{N}\omega^2_{j,0}\sigma^2_{j,0,km}}{q^*_{0,km}}$ and $\hat{\Delta}_{pq} = \frac{\frac{1}{k}\sum_{i=0}^{k-1}\left(Cov_{im}(\rho_{im,(i+1)m}, q^*_{im,(i+1)m})\right) - Cov_0\left(\rho_{0,km}, q^*_{0,km}\right)}{q^*_{0,km}}$, we obtain the equation presented in the main text:

$$\frac{1}{k}\sum_{i=0}^{k-1}\left(\rho_{im,(i+1)m}\frac{q^*_{im,(i+1)m}}{q^*_{0,km}} - \rho_{0,m}\right) + \hat{\Delta}_{QV} + \hat{\Delta}_{pq} = a + b\left(\rho_{0,km} - \rho_{0,m}\right) + \nu_{km}. \tag{A8}$$

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Figure 1: The Term Structure of Option Implied Variance

This figure plots the 12-month option implied variance (*solid, blue*), the 1-month option implied variance (*dashed, orange*), and the 12-month minus 1-month term structure slope (*dash-dotted, turquoise*). The sample spans 1996 until 2015. The shaded areas indicate business cycle contractions as identified by the NBER.

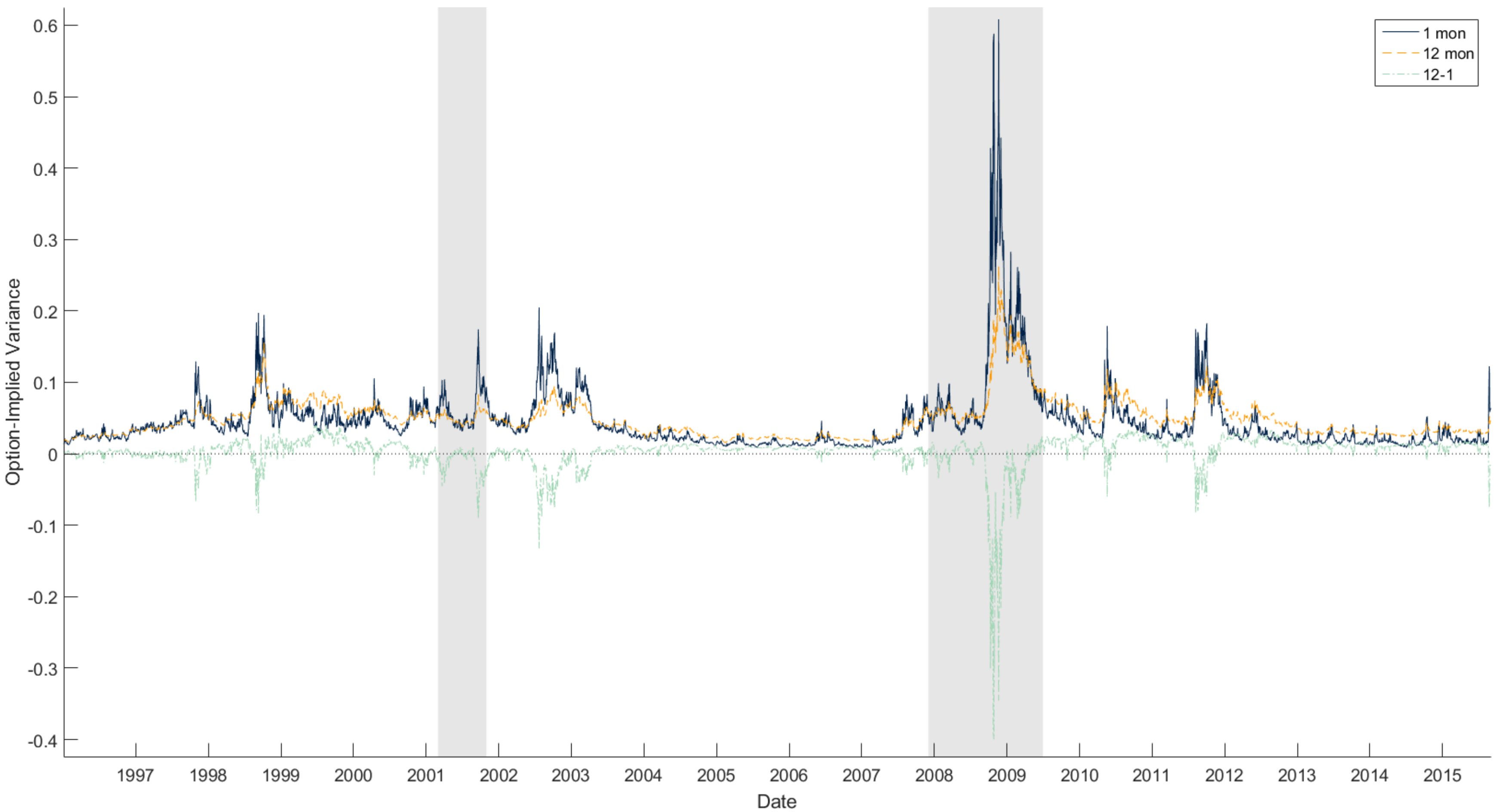

Figure 2: The Term Structure of Option Implied Correlation

This figure plots the 12-month option implied correlation (*dashed, blue*), the 1-month option implied correlation (*dashed, orange*), and the 12-month minus 1-month term structure slope (*dash-dotted, turquoise*). The sample spans 1996 until 2015. The shaded areas indicate business cycle contractions as identified by the NBER.

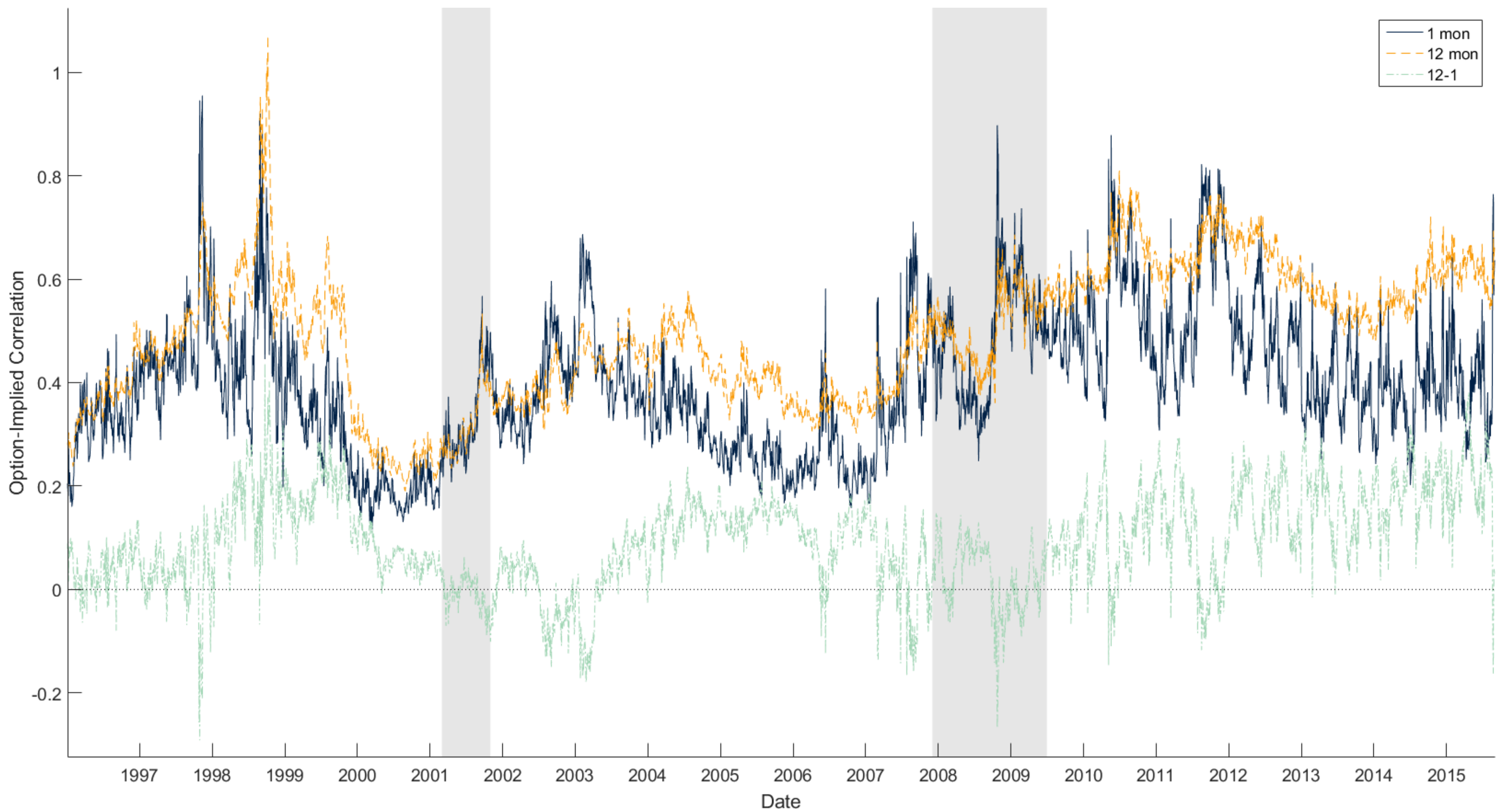

Table 1: Summary Statistics

This table presents summary statistics on the (annualized) option implied variance of the market (Panel A) and individual stocks (Panel B) of different maturities, as well as summary statistics on the option implied correlation (Panel C). We report the results for maturities of 1, 3, 6, 9, and 12 months. $Mean$ and $Median$ are the overall average and median of the estimates over the entire sample period. *Std.* and $AR(1)$ present further summary statistics on the (average) standard deviations and first-order autocorrelations, while $Skew$ and $Kurt$ denote the (average) skewness and kurtosis, respectively. For individual stocks, we present cross-sectional averages of the firms' time-series statistics. In case of Mean_{vw}, we present the time-series average of the value-weighted cross-sectional average.

Panel A. Market Option Implied Variance

Horizon	$Mean$	$Median$	*Std.*	$AR(1)$	$Skew$	$Kurt$
1 month	0.046	0.035	0.041	0.789	3.27	17.8
3 months	0.047	0.039	0.035	0.842	2.69	13.0
6 months	0.048	0.041	0.030	0.878	2.29	10.4
9 months	0.049	0.042	0.028	0.894	2.11	9.30
12 months	0.049	0.044	0.027	0.903	2.00	8.76

Panel B. Stock Option Implied Variance

Horizon	$Mean$	$Mean_{vw}$	$Median$	*Std.*	$AR(1)$	$Skew$	$Kurt$
1 month	0.166	0.116	0.097	0.153	0.772	2.64	13.9
3 months	0.156	0.112	0.093	0.132	0.856	2.43	12.3
6 months	0.149	0.110	0.092	0.118	0.882	2.26	11.1
9 months	0.147	0.109	0.093	0.111	0.889	2.13	10.1
12 months	0.145	0.109	0.094	0.103	0.898	2.06	9.78

Panel C. Option Implied Correlation

Horizon	$Mean$	$Median$	*Std.*	$AR(1)$	$Skew$	$Kurt$
1 month	0.418	0.403	0.138	0.744	0.49	3.05
3 months	0.447	0.449	0.128	0.814	0.32	3.73
6 months	0.476	0.480	0.123	0.886	0.03	3.06
9 months	0.487	0.500	0.123	0.912	0.01	2.86
12 months	0.490	0.493	0.120	0.915	0.03	2.85

Table 2: Expectations Hypothesis Test: Option Implied Variance

This table reports the results of the expectations hypothesis tests for the model-free option implied variance. In Panel A, we present the results for the S&P 500 market index and Panel B shows the aggregated results for the individual stocks included in the S&P 500. The regression equation is $\frac{1}{k}\sum_{i=0}^{k-1}\left(\sigma^2_{j,im,(i+1)m} - \sigma^2_{j,0,m}\right) = a_j + b_j\left(\sigma^2_{j,0,km} - \sigma^2_{j,0,m}\right) + \nu_{j,km}$. In each column, the first number denotes the long horizon (k *times* m) and the second number denotes the short horizon (m) (e.g., 12,1 means we have $km = 12$ and $m = 1$ month(s)). The pure expectations hypothesis posits that the constant a is zero and that the slope b is one while the general expectations hypothesis requires only the latter. We test the individual hypotheses with t-tests and the joint hypothesis with a Wald test. All tests employ Newey & West (1987) standard errors (*s.e.*) with km lags. We also present the results of a joint test of the expectations hypothesis along with bootstrapped p-values. In Panel B, we present the results of a panel regression using the two-way clustered standard errors of Cameron et al. (2011). *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

Panel A. Market

	12,1	**12,3**	**12,6**	**9,1**	**9,3**	**6,1**	**6,3**	**3,1**
Const.	−0.003	−0.002	−0.001	−0.003	−0.002	−0.002	−0.001	−0.001
(s.e.)	(0.004)	(0.003)	(0.002)	(0.004)	(0.003)	(0.003)	(0.002)	(0.002)
Slope	1.042	1.060	1.198	0.981	0.964	0.873	0.862	0.745
(s.e.)	(0.139)	(0.208)	(0.347)	(0.123)	(0.179)	(0.142)	(0.179)	(0.230)
adj. R^2	0.38	0.26	0.13	0.32	0.20	0.24	0.15	0.10
Wald	0.63	0.53	0.75	0.53	0.43	1.99	1.21	3.15
p-value	[0.73]	[0.77]	[0.69]	[0.77]	[0.81]	[0.37]	[0.55]	[0.21]
Joint	*Pure*	*General*						
Wald	22.1	6.23						
p-value	[0.59]	[0.54]						

Panel B. Stocks

	12,1	**12,3**	**12,6**	**9,1**	**9,3**	**6,1**	**6,3**	**3,1**
Const.	0.012***	0.006*	0.002	0.012***	0.005*	0.009**	0.003	0.005*
(s.e.)	(0.005)	(0.003)	(0.003)	(0.004)	(0.003)	(0.004)	(0.002)	(0.003)
Slope	0.909	0.890	0.751**	0.881	0.838*	0.754***	0.640***	0.620***
(s.e.)	(0.069)	(0.088)	(0.110)	(0.078)	(0.089)	(0.078)	(0.060)	(0.065)
adj. R^2	0.34	0.21	0.11	0.29	0.16	0.23	0.11	0.17
Wald	[0.02]**	[0.18]	[0.07]*	[0.02]**	[0.09]*	[0.00]***	[0.00]***	[0.00]***

Table 3: Stock Characteristics

This table reports the average stock characteristics separately for stocks for which we can reject the pure expectations hypothesis in the term structure of option implied variance and for those for which we cannot reject the pure expectations hypothesis. We present the results for different maturity combinations. In each column, the first number denotes the long horizon (k *times* m) and the second number denotes the short horizon (m) (e.g., 12,1 means we have $km = 12$ and $m = 1$ month(s)). IV_{st} and IV_{lt} denote the average option implied variance for the respective short and long horizons. Weight is the average market capitalization share of the stocks relative to the total market share of stocks in our sample and Volume is the average daily options volume of the stocks in the respective groups.

		12,1	**12,3**	**12,6**	**9,1**	**9,3**	**6,1**	**6,3**	**3,1**
rej. Stocks	IV_{st}	0.19	0.17	0.16	0.19	0.18	0.17	0.17	0.16
	IV_{lt}	0.16	0.16	0.15	0.16	0.17	0.15	0.16	0.15
	$Weight$	0.0013	0.0015	0.0013	0.0012	0.0013	0.0012	0.0011	0.0014
	$Volume$	4412	4700	3589	3780	4200	3081	3150	3399
non-rej. Stocks	IV_{st}	0.16	0.15	0.14	0.16	0.15	0.16	0.15	0.18
	IV_{lt}	0.14	0.14	0.14	0.14	0.14	0.15	0.15	0.17
	$Weight$	0.0022	0.0020	0.0020	0.0021	0.0020	0.0022	0.0021	0.0024
	$Volume$	6117	5551	5887	6164	5611	6863	6212	8069

Table 4: Variance Term Premia

This table reports the average returns to a strategy that takes a long position in the long-term option implied variance and rolls over short positions in the short-term option implied variance. In Panel A, we present the results for the S&P 500 market index and Panel B shows the aggregated results for the individual stocks included in the S&P 500. The return is $\frac{\sigma^2_{j,0,km}-\frac{1}{k}\sum_{i=0}^{k-1}\sigma^2_{j,im,(i+1)m}}{\sigma^2_{j,0,km}}$. In each column, the first number denotes the long horizon (k $times$ m) and the second number denotes the short horizon (m) (e.g., 12,1 means we have $km = 12$ and $m = 1$ month(s)). In parentheses, we present Newey & West (1987) standard errors ($s.e.$) with km lags. We also present the results of a joint test of that the returns of all maturity specifications are jointly zero along with bootstrapped p-values.In Panel B, we present the results of a panel regression on a constant using the two-way clustered standard errors of Cameron et al. (2011). *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

Panel A. Market

	12,1	**12,3**	**12,6**	**9,1**	**9,3**	**6,1**	**6,3**	**3,1**
avg. Ret.	0.011	0.001	−0.011	0.010	0.003	0.016	0.012	0.004
(s.e.)	(0.093)	(0.072)	(0.043)	(0.077)	(0.055)	(0.058)	(0.033)	(0.030)
Joint								
Wald	1.08							
p-value	[0.95]							

Panel B. Stocks

	12,1	**12,3**	**12,6**	**9,1**	**9,3**	**6,1**	**6,3**	**3,1**
avg. Ret.	-0.177^{***}	-0.099^{***}	-0.049^{***}	-0.162^{***}	-0.082^{***}	-0.138^{***}	-0.053^{***}	-0.090^{***}
(s.e.)	(0.032)	(0.024)	(0.018)	(0.028)	(0.021)	(0.023)	(0.014)	(0.015)

Table 5: Expectations Hypothesis Test: Systematic Risk

This table reports the results of the expectations hypothesis tests for systematic risk. We show the aggregated results for the individual stocks included in the S&P 500. The regression equation is $\frac{1}{k}\sum_{i=0}^{k-1}\left(\beta^2_{j,im,(i+1)m}\sigma^2_{M,im,(i+1)m} - \beta^2_{j,0,m}\sigma^2_{M,0,m}\right) + \hat{\Delta}_{\beta\sigma} + \hat{\Delta}_{\beta r} + \hat{\Delta}_{\epsilon} = a_j + b_j\left(\beta^2_{j,0,km}\sigma^2_{M,0,km} - \beta^2_{j,0,m}\sigma^2_{M,0,m}\right) + \nu_{j,km}$. In each column, the first number denotes the long horizon (k *times* m) and the second number denotes the short horizon (m) (e.g., 12,1 means we have $km = 12$ and $m = 1$ month(s)). The pure expectations hypothesis posits that the constant a is zero and that the slope b is one while the general expectations hypothesis requires only the latter. We test the individual hypotheses with t-tests and the joint hypothesis with a Wald test. All tests employ a panel regression approach using the two-way clustered standard errors of Cameron et al. (2011). *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

	12,1	**12,3**	**12,6**	**9,1**	**9,3**	**6,1**	**6,3**	**3,1**
Const.	0.012**	0.007*	0.002	0.012**	0.006*	0.011***	0.005**	0.007**
(s.e.)	(0.005)	(0.004)	(0.003)	(0.005)	(0.003)	(0.004)	(0.002)	(0.003)
Slope	1.149	1.286	0.914	1.109	1.120	0.916	0.917	0.741
(s.e.)	(0.164)	(0.228)	(0.372)	(0.164)	(0.228)	(0.171)	(0.212)	(0.237)
adj. R^2	0.20	0.13	0.03	0.18	0.09	0.13	0.06	0.07
Wald	[0.01]***	[0.02]**	[0.67]	[0.01]**	[0.08]*	[0.03]**	[0.09]*	[0.07]*

Table 6: Expectations Hypothesis Test: Idiosyncratic Variance

This table reports the results of the expectations hypothesis tests for idiosyncratic variance. We show the aggregated results for the individual stocks included in the S&P 500. The regression equation is $\frac{1}{k}\sum_{i=0}^{k-1}\left(\sigma^2_{\epsilon,j,im,(i+1)m} - \sigma^2_{\epsilon,j,0,m}\right) = a_j + b_j\left(\sigma^2_{\epsilon,j,0,km} - \sigma^2_{\epsilon,j,0,m}\right) + \nu_{j,km}$. In each column, the first number denotes the long horizon (k *times* m) and the second number denotes the short horizon (m) (e.g., 12,1 means we have $km = 12$ and $m = 1$ month(s)). The pure expectations hypothesis posits that the constant a is zero and that the slope b is one while the general expectations hypothesis requires only the latter. We test the individual hypotheses with t-tests and the joint hypothesis with a Wald test. All tests employ a panel regression approach using the two-way clustered standard errors of Cameron et al. (2011). *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

	12,1	**12,3**	**12,6**	**9,1**	**9,3**	**6,1**	**6,3**	**3,1**
Const.	0.008***	0.005**	0.002	0.008***	0.004**	0.006***	0.002**	0.004**
(s.e.)	(0.002)	(0.002)	(0.001)	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)
Slope	0.737***	0.724***	0.651***	0.696***	0.629***	0.601***	0.455***	0.548***
(s.e.)	(0.060)	(0.088)	(0.103)	(0.069)	(0.083)	(0.078)	(0.091)	(0.076)
adj. R^2	0.23	0.15	0.09	0.18	0.09	0.15	0.04	0.12
Wald	[0.00]***	[0.00]***	[0.00]***	[0.00]***	[0.00]***	[0.00]***	[0.00]***	[0.00]***

Table 7: Idiosyncratic Variance Term Premia

This table reports the average returns to a strategy that takes a long position in the long-term option implied idiosyncratic variance and rolls over short positions in the short-term option implied idiosyncratic variance. We show the aggregated results for the individual stocks included in the S&P 500. The return is $\frac{\sigma^2_{\epsilon,j,0,km} - \frac{1}{k}\sum_{i=0}^{k-1}\sigma^2_{\epsilon,j,im,(i+1)m}}{\sigma^2_{\epsilon,j,0,km}}$. In each column, the first number denotes the long horizon (k *times* m) and the second number denotes the short horizon (m) (e.g., 12,1 means we have $km = 12$ and $m = 1$ month(s)). We present the results of a panel regression on a constant using the two-way clustered standard errors of Cameron et al. (2011). *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

	12,1	**12,3**	**12,6**	**9,1**	**9,3**	**6,1**	**6,3**	**3,1**
avg. Ret.	−0.376***	−0.252***	−0.126***	−0.337*	−0.465*	−0.320***	−0.187***	−0.102
(s.e.)	(0.080)	(0.053)	(0.039)	(0.178)	(0.258)	(0.054)	(0.037)	(0.152)

Table 8: Expectations Hypothesis Test: Option Implied Correlation

This table reports the results of the expectations hypothesis tests for the option implied correlation of the stocks of the S&P 500. The regression equation is $\frac{1}{k}\sum_{i=0}^{k-1}\left(\rho_{im,(i+1)m}\frac{q^*_{im,(i+1)m}}{q^*_{0,km}} - \rho_{0,m}\right) + \hat{\Delta}_{QV} + \hat{\Delta}_{pq} = a + b\left(\rho_{0,km} - \rho_{0,m}\right) + \nu_{km}$. In each column, the first number denotes the long horizon (k *times* m) and the second number denotes the short horizon (m) (e.g., 12,1 means we have $km = 12$ and $m = 1$ month(s)). The pure expectations hypothesis posits that the constant a is zero and that the slope b is one while the general expectations hypothesis requires only the latter. We test the individual hypotheses with t-tests and the joint hypothesis with a Wald test. All tests employ Newey & West (1987) standard errors ($s.e.$) with km lags. We also present the results of a joint test of the expectations hypothesis along with bootstrapped p-values. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

	12,1	**12,3**	**12,6**	**9,1**	**9,3**	**6,1**	**6,3**	**3,1**
Const.	0.035	0.027	0.008	0.043	0.035	0.024	0.011	0.019
(s.e.)	(0.048)	(0.034)	(0.019)	(0.039)	(0.025)	(0.027)	(0.014)	(0.018)
Slope	0.626	0.504	0.704	0.631	0.470	0.689	0.673	0.499
(s.e.)	(0.292)	(0.385)	(0.571)	(0.273)	(0.369)	(0.218)	(0.349)	(0.323)
adj. R^2	0.04	0.02	0.01	0.04	0.01	0.05	0.03	0.02
Wald	1.65	1.68	0.37	2.00	2.66	2.08	1.05	2.51
p-value	[0.44]	[0.43]	[0.83]	[0.37]	[0.26]	[0.35]	[0.59]	[0.28]
Joint	*Pure*	*General*						
Wald	35.2	30.0						
p-value	[0.91]	[0.22]						

Table 9: Expectations Hypothesis Test: Forward Unbiasedness

This table reports the results of the expectations hypothesis tests for the model-free option implied variance. In Panel A, we present the results for the S&P 500 market index and Panel B shows the aggregated results for the individual stocks included in the S&P 500. The regression equation is $\sigma^2_{j,m,km} - \sigma^2_{j,0,m} = a_j + b_j \left(f^2_{j,0,m,km} - \sigma^2_{j,0,m} \right) + \nu_{j,km}$, with $f^2_{j,0,m,km} = \sigma^2_{j,0,km} + \frac{1}{k-1} \left(\sigma^2_{j,0,km} - \sigma^2_{j,0,m} \right)$. In each column, the first number denotes the long horizon (k *times* m) and the second number denotes the short horizon (m) (e.g., 12,3 means we have $km = 12$ and $m = 3$ month(s)). The pure expectations hypothesis posits that the constant a is zero and that the slope b is one while the general expectations hypothesis requires only the latter. We test the individual hypotheses with t-tests and the joint hypothesis with a Wald test. All tests employ Newey & West (1987) standard errors ($s.e.$) with km lags. We also present the results of a joint test of the expectations hypothesis along with bootstrapped p-values.In Panel B, we present the results of a panel regression on a constant using the two-way clustered standard errors of Cameron et al. (2011). *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

Panel A. Market

	12,3	**12,6**	**12,9**	**9,3**	**9,6**	**6,3**	**3,1**
Const.	−0.001	−0.003	−0.005	−0.001	−0.003	−0.002	0.000
(s.e.)	(0.002)	(0.004)	(0.006)	(0.003)	(0.005)	(0.003)	(0.002)
Slope	1.003	1.198	1.389	0.945	1.051	0.862	0.582*
(s.e.)	(0.112)	(0.347)	(0.767)	(0.135)	(0.375)	(0.179)	(0.223)
adj. R^2	0.36	0.13	0.07	0.27	0.07	0.15	0.10
Wald	0.34	0.75	0.66	0.51	0.37	1.21	9.00**
p-value	[0.85]	[0.69]	[0.72]	[0.78]	[0.83]	[0.55]	[0.01]
Joint	*Pure*	*General*					
Wald	14.8	5.49					
p-value	[0.77]	[0.67]					

Table 9: Expectations Hypothesis Test: Option Implied Variance – Forward Unbiasedness (continued)

Panel B. Stocks

	12,3	**12,6**	**12,9**	**9,3**	**9,6**	**6,3**	**3,1**
Const.	0.002	0.004	0.007	0.003	0.008	0.007	0.004
(s.e.)	(0.003)	(0.005)	(0.007)	(0.004)	(0.006)	(0.005)	(0.003)
Slope	0.787***	0.751**	0.493***	0.785***	0.768**	0.640***	0.588***
(s.e.)	(0.054)	(0.110)	(0.083)	(0.052)	(0.102)	(0.060)	(0.058)
adj. R^2	0.26	0.11	0.05	0.22	0.08	0.11	0.18
Wald	[0.00]***	[0.07]*	[0.00]***	[0.00]***	[0.05]*	[0.00]***	[0.00]***

Panel C. Idiosyncratic Variance

	12,3	**12,6**	**12,9**	**9,3**	**9,6**	**6,3**	**3,1**
Const.	0.001	0.004	0.009**	0.002	0.009***	0.005**	0.005***
(s.e.)	(0.002)	(0.003)	(0.004)	(0.002)	(0.003)	(0.002)	(0.002)
Slope	0.672***	0.647***	0.402***	0.667***	0.566***	0.466***	0.590***
(s.e.)	(0.053)	(0.101)	(0.079)	(0.059)	(0.095)	(0.086)	(0.057)
adj. R^2	0.19	0.09	0.05	0.13	0.05	0.04	0.18
Wald	[0.00]***	[0.00]***	[0.00]***	[0.00]***	[0.00]***	[0.00]***	[0.00]***

Table 10: Expectations Hypothesis Test: Option Implied Variance – The Role of Jumps

This table reports the results of the expectations hypothesis tests for the model-free option implied variance. In Panel A, we present the results for the S&P 500 market index and Panel B shows the aggregated results for the individual stocks included in the S&P 500. The regression equation is $\frac{1}{k}\sum_{i=0}^{k-1}\left(\sigma^2_{j,im,(i+1)m} - \sigma^2_{j,0,m}\right) = a_j + b_j\left(\sigma^2_{j,0,km} - \sigma^2_{j,0,m}\right) + \nu_{j,km}$. In each column, the first number denotes the long horizon (k *times* m) and the second number denotes the short horizon (m) (e.g., 12,1 means we have $km = 12$ and $m = 1$ month(s)). The pure expectations hypothesis posits that the constant a is zero and that the slope b is one while the general expectations hypothesis requires only the latter. We test the individual hypotheses with t-tests and the joint hypothesis with a Wald test. All tests employ Newey & West (1987) standard errors (*s.e.*) with km lags. We also present the results of a joint test of the expectations hypothesis along with bootstrapped p-values. In Panel B, we present the results of a panel regression on a constant using the two-way clustered standard errors of Cameron et al. (2011). *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

Panel A. Market

	12,1	**12,3**	**12,6**	**9,1**	**9,3**	**6,1**	**6,3**	**3,1**
Const.	−0.005	−0.003	−0.001	−0.004	−0.002	−0.003	−0.001	−0.001
(s.e.)	(0.005)	(0.004)	(0.002)	(0.004)	(0.003)	(0.003)	(0.002)	(0.002)
Slope	0.973	0.947	0.880	0.931	0.887	0.844	0.834	0.706
(s.e.)	(0.184)	(0.261)	(0.402)	(0.151)	(0.210)	(0.145)	(0.188)	(0.253)
adj. R^2	0.30	0.19	0.06	0.26	0.15	0.20	0.12	0.08
Wald	1.06	0.78	0.59	1.23	0.96	2.93	1.64	4.39
p-value	[0.59]	[0.68]	[0.75]	[0.54]	[0.62]	[0.23]	[0.44]	[0.11]
Joint	*Pure*	*General*						
Wald	56.5	13.8						
p-value	[0.50]	[0.42]						

Panel B. Stocks

	12,1	**12,3**	**12,6**	**9,1**	**9,3**	**6,1**	**6,3**	**3,1**
Const.	0.009*	0.005	0.002	0.009*	0.004	0.007	0.003	0.004
(s.e.)	(0.005)	(0.004)	(0.003)	(0.005)	(0.004)	(0.004)	(0.003)	(0.003)
Slope	0.872**	0.801***	0.610***	0.879*	0.737***	0.698***	0.545***	0.598***
(s.e.)	(0.054)	(0.060)	(0.074)	(0.067)	(0.086)	(0.092)	(0.095)	(0.052)
adj. R^2	0.37	0.26	0.14	0.30	0.18	0.22	0.11	0.18
Wald	[0.03]**	[0.00]***	[0.00]***	[0.06]*	[0.01]***	[0.00]***	[0.00]***	[0.00]***

Table 11: Expectations Hypothesis Test: Systematic Risk – The Role of Jumps

This table reports the results of the expectations hypothesis tests for systematic risk. We show the aggregated results for the individual stocks included in the S&P 500. The regression equation is $\frac{1}{k}\sum_{i=0}^{k-1}\left(\beta^2_{j,im,(i+1)m}\sigma^2_{M,im,(i+1)m} - \beta^2_{j,0,m}\sigma^2_{M,0,m}\right) + \hat{\Delta}_{\beta\sigma} + \hat{\Delta}_{\beta r} + \hat{\Delta}_{\epsilon} = a_j + b_j\left(\beta^2_{j,0,km}\sigma^2_{M,0,km} - \beta^2_{j,0,m}\sigma^2_{M,0,m}\right) + \nu_{j,km}$. In each column, the first number denotes the long horizon (k *times* m) and the second number denotes the short horizon (m) (e.g., 12,1 means we have $km = 12$ and $m = 1$ month(s)). The pure expectations hypothesis posits that the constant a is zero and that the slope b is one while the general expectations hypothesis requires only the latter. We test the individual hypotheses with t-tests and the joint hypothesis with a Wald test. All tests employ a panel regression approach using the two-way clustered standard errors of Cameron et al. (2011). *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

	12,1	**12,3**	**12,6**	**9,1**	**9,3**	**6,1**	**6,3**	**3,1**
Const.	0.010	0.007	0.004	0.010	0.006	0.010	0.006	0.006
(s.e.)	(0.009)	(0.007)	(0.005)	(0.009)	(0.006)	(0.008)	(0.005)	(0.006)
Slope	1.044	0.947	0.367***	1.086	1.009	0.837	0.632	0.606*
(s.e.)	(0.136)	(0.176)	(0.221)	(0.152)	(0.199)	(0.218)	(0.272)	(0.201)
adj. R^2	0.20	0.11	0.03	0.18	0.10	0.11	0.04	0.05
Wald	[0.00]***	[0.00]***	[0.00]***	[0.00]***	[0.00]***	[0.00]***	[0.00]***	[0.00]***

Table 12: Expectations Hypothesis Test: Idiosyncratic Variance – The Role of Jumps

This table reports the results of the expectations hypothesis tests for idiosyncratic variance. We show the aggregated results for the individual stocks included in the S&P 500. The regression equation is $\frac{1}{k}\sum_{i=0}^{k-1}\left(\sigma^2_{\epsilon,j,im,(i+1)m} - \sigma^2_{\epsilon,j,0,m}\right) = a_j + b_j\left(\sigma^2_{\epsilon,j,0,km} - \sigma^2_{\epsilon,j,0,m}\right) + \nu_{j,km}$. In each column, the first number denotes the long horizon (k *times* m) and the second number denotes the short horizon (m) (e.g., 12,1 means we have $km = 12$ and $m = 1$ month(s)). The pure expectations hypothesis posits that the constant a is zero and that the slope b is one while the general expectations hypothesis requires only the latter. We test the individual hypotheses with t-tests and the joint hypothesis with a Wald test. All tests employ a panel regression approach using the two-way clustered standard errors of Cameron et al. (2011). *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

	12,1	**12,3**	**12,6**	**9,1**	**9,3**	**6,1**	**6,3**	**3,1**
Const.	0.008***	0.005**	0.002	0.008***	0.005**	0.006**	0.003**	0.003*
(s.e.)	(0.003)	(0.002)	(0.002)	(0.003)	(0.002)	(0.002)	(0.001)	(0.002)
Slope	0.747***	0.710***	0.580***	0.716***	0.684***	0.583***	0.474***	0.511***
(s.e.)	(0.054)	(0.059)	(0.063)	(0.063)	(0.057)	(0.067)	(0.052)	(0.081)
adj. R^2	0.28	0.20	0.13	0.21	0.15	0.14	0.08	0.12
Wald	[0.00]***	[0.00]***	[0.00]***	[0.00]***	[0.00]***	[0.00]***	[0.00]***	[0.00]***

Table 13: Expectations Hypothesis Test: Option Implied Correlation – The Role of Jumps

This table reports the results of the expectations hypothesis tests for the option implied correlation of the stocks of the S&P 500. The regression equation is $\frac{1}{k}\sum_{i=0}^{k-1}\left(\rho_{im,(i+1)m}\frac{q^*_{im,(i+1)m}}{q^*_{0,km}} - \rho_{0,m}\right) + \hat{\Delta}_{QV} + \hat{\Delta}_{pq} = a + b\left(\rho_{0,km} - \rho_{0,m}\right) + \nu_{km}$. In each column, the first number denotes the long horizon (k *times* m) and the second number denotes the short horizon (m) (e.g., 12,1 means we have $km = 12$ and $m = 1$ month(s)). The pure expectations hypothesis posits that the constant a is zero and that the slope b is one while the general expectations hypothesis requires only the latter. We test the individual hypotheses with t-tests and the joint hypothesis with a Wald test. All tests employ Newey & West (1987) standard errors ($s.e.$) with km lags. We also present the results of a joint test of the expectations hypothesis along with bootstrapped p-values. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

	12,1	**12,3**	**12,6**	**9,1**	**9,3**	**6,1**	**6,3**	**3,1**
Const.	0.040	0.036	0.015	0.043	0.039	0.021	0.011	0.014
(s.e.)	(0.051)	(0.037)	(0.021)	(0.040)	(0.027)	(0.028)	(0.015)	(0.018)
Slope	0.425*	0.215*	0.100	0.495*	0.296*	0.603*	0.583	0.463*
(s.e.)	(0.297)	(0.401)	(0.575)	(0.276)	(0.376)	(0.223)	(0.365)	(0.307)
adj. R^2	0.02	0.00	0.00	0.03	0.00	0.04	0.02	0.01
Wald	4.08	3.87	2.49	3.34	3.78	3.23	1.34	3.84
p-value	[0.13]	[0.14]	[0.29]	[0.19]	[0.15]	[0.20]	[0.51]	[0.15]
Joint	*Pure*	*General*						
Wald	116.3	21.9						
p-value	[0.34]	[0.29]						

The Term Structure of Option Prices

Online Appendix

JEL classification: G12, G11, G17

Keywords: Options, term structure, expectations hypothesis, model-free option implied variance, implied correlation, systematic risk, beta

Table A1: Expectations Hypothesis Test: Option Implied Variance – Firm-Fixed Effects

This table reports the results of the expectations hypothesis tests for the model-free option implied variance. In Panel A, we present the results for the S&P 500 market index and Panel B shows the aggregated results for the individual stocks included in the S&P 500. The regression equation is $\frac{1}{k}\sum_{i=0}^{k-1}\left(\sigma^2_{j,im,(i+1)m}-\sigma^2_{j,0,m}\right)=a_j+b_j\left(\sigma^2_{j,0,km}-\sigma^2_{j,0,m}\right)+\nu_{j,km}$. In each column, the first number denotes the long horizon (k *times* m) and the second number denotes the short horizon (m) (e.g., 12,1 means we have $km=12$ and $m=1$ month(s)). The pure expectations hypothesis posits that the constant a is zero and that the slope b is one while the general expectations hypothesis requires only the latter. We test the individual hypotheses with t-tests and the joint hypothesis with a Wald test. All tests employ a panel regression approach, allowing for firm-specific intercept estimates and using the two-way clustered standard errors of Cameron et al. (2011). *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. [*share*] denotes the percentage share of stocks for which the intercept is significantly different from zero at the 5% level.

	12,1	**12,3**	**12,6**	**9,1**	**9,3**	**6,1**	**6,3**	**3,1**
Const.	0.014	0.007	0.002	0.014	0.006	0.011	0.004	0.006
(s.e.)	(0.008)	(0.006)	(0.005)	(0.008)	(0.005)	(0.007)	(0.004)	(0.005)
[share]	[0.52]	[0.34]	[0.19]	[0.49]	[0.27]	[0.44]	[0.18]	[0.30]
Slope	0.948	0.939	0.798*	0.917	0.883	0.783***	0.670***	0.638***
(s.e.)	(0.070)	(0.087)	(0.110)	(0.080)	(0.089)	(0.081)	(0.060)	(0.068)
adj. R^2	0.36	0.22	0.12	0.30	0.17	0.24	0.11	0.18
Wald	[0.00]***	[0.00]***	[0.00]***	[0.00]***	[0.00]***	[0.00]***	[0.00]***	[0.00]***

Table A2: Expectations Hypothesis Test: Systematic Risk – Firm-Fixed Effects

This table reports the results of the expectations hypothesis tests for systematic risk. We show the aggregated results for the individual stocks included in the S&P 500. The regression equation is $\frac{1}{k}\sum_{i=0}^{k-1}\left(\beta^2_{j,im,(i+1)m}\sigma^2_{M,im,(i+1)m} - \beta^2_{j,0,m}\sigma^2_{M,0,m}\right) + \hat{\Delta}_{\beta\sigma} + \hat{\Delta}_{\beta r} + \hat{\Delta}_{\epsilon} = a_j + b_j\left(\beta^2_{j,0,km}\sigma^2_{M,0,km} - \beta^2_{j,0,m}\sigma^2_{M,0,m}\right) + \nu_{j,km}$. In each column, the first number denotes the long horizon (k *times* m) and the second number denotes the short horizon (m) (e.g., 12,1 means we have $km = 12$ and $m = 1$ month(s)). The pure expectations hypothesis posits that the constant a is zero and that the slope b is one while the general expectations hypothesis requires only the latter. We test the individual hypotheses with t-tests and the joint hypothesis with a Wald test. All tests employ a panel regression approach, allowing for firm-specific intercept estimates and using the two-way clustered standard errors of Cameron et al. (2011). *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. [*share*] denotes the percentage share of stocks for which the intercept is significantly different from zero at the 5% level.

	12,1	**12,3**	**12,6**	**9,1**	**9,3**	**6,1**	**6,3**	**3,1**
Const.	0.014	0.007	0.003	0.013	0.007	0.013	0.006	0.008
(s.e.)	(0.008)	(0.006)	(0.005)	(0.008)	(0.006)	(0.007)	(0.004)	(0.005)
[share]	[0.48]	[0.38]	[0.24]	[0.46]	[0.31]	[0.45]	[0.31]	[0.37]
Slope	1.191	1.353	1.029	1.143	1.175	0.948	0.963	0.759
(s.e.)	(0.164)	(0.229)	(0.376)	(0.165)	(0.229)	(0.172)	(0.215)	(0.237)
adj. R^2	0.23	0.15	0.04	0.20	0.11	0.15	0.07	0.07
Wald	[0.00]***	[0.00]***	[0.00]***	[0.00]***	[0.00]***	[0.00]***	[0.00]***	[0.00]***

Table A3: Expectations Hypothesis Test: Idiosyncratic Variance – Firm-Fixed Effects

This table reports the results of the expectations hypothesis tests for idiosyncratic variance. We show the aggregated results for the individual stocks included in the S&P 500. The regression equation is $\frac{1}{k}\sum_{i=0}^{k-1}\left(\sigma^2_{\epsilon,j,im,(i+1)m} - \sigma^2_{\epsilon,j,0,m}\right) = a_j + b_j\left(\sigma^2_{\epsilon,j,0,km} - \sigma^2_{\epsilon,j,0,m}\right) + \nu_{j,km}$. In each column, the first number denotes the long horizon (k *times* m) and the second number denotes the short horizon (m) (e.g., 12,1 means we have $km = 12$ and $m = 1$ month(s)). The pure expectations hypothesis posits that the constant a is zero and that the slope b is one while the general expectations hypothesis requires only the latter. We test the individual hypotheses with t-tests and the joint hypothesis with a Wald test. All tests employ a panel regression approach, allowing for firm-specific intercept estimates and using the two-way clustered standard errors of Cameron et al. (2011). *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. [*share*] denotes the percentage share of stocks for which the intercept is significantly different from zero at the 5% level.

	12,1	**12,3**	**12,6**	**9,1**	**9,3**	**6,1**	**6,3**	**3,1**
Const.	0.010	0.006	0.002	0.009	0.005	0.008	0.003	0.005
(s.e.)	(0.005)	(0.004)	(0.003)	(0.005)	(0.003)	(0.004)	(0.003)	(0.003)
[share]	[0.54]	[0.39]	[0.21]	[0.53]	[0.33]	[0.49]	[0.23]	[0.36]
Slope	0.782***	0.768***	0.701***	0.741***	0.676***	0.641***	0.516***	0.586***
(s.e.)	(0.058)	(0.084)	(0.100)	(0.069)	(0.081)	(0.081)	(0.092)	(0.080)
adj. R^2	0.25	0.16	0.10	0.20	0.10	0.16	0.05	0.13
Wald	[0.00]***	[0.00]***	[0.00]***	[0.00]***	[0.00]***	[0.00]***	[0.00]***	[0.00]***

Table A4: Finite Sample Bias: Option Implied Variance

This table reports the results accounting for the potential finite sample bias in expectations hypothesis tests. In Panels A and B, we show the results for the bias in coefficient estimates. We obtain the bias-corrected coefficient estimates by conducting an block-bootstrap of the dependent variable. We run 1,000 repetitions and report the simulated coefficients with supplement (*sim*) and report the bias in percentage points. For individual stocks, we report the median bias as well as the 10% and 90% quantiles ($q^{0.1}$ and $q^{0.9}$). In Panels C and D, we report the results for expectations hypothesis tests with a bootstrapped distribution of the test statistics. We use the bias-corrected coefficient estimates and simulate the dependent variable under the null of $a = 0$ and $b = 1$. We repeat this step 1,000 times and obtain distributions of the t- and Wald statistics. The regression equation is $\frac{1}{k}\sum_{i=0}^{k-1}\left(\sigma^2_{j,im,(i+1)m} - \sigma^2_{j,0,m}\right) = a_j + b_j\left(\sigma^2_{j,0,km} - \sigma^2_{j,0,m}\right) + \nu_{j,km}$. In each column, the first number denotes the long horizon (k *times* m) and the second number denotes the short horizon (m) (e.g., 12,1 means we have $km = 12$ and $m = 1$ month(s)). The pure expectations hypothesis posits that the constant a is zero and that the slope b is one while the general expectations hypothesis requires only the latter. We test the individual hypotheses with t-tests and the joint hypothesis with a Wald test. We also present the results of a joint test of the expectations hypothesis along with bootstrapped p-values. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

Panel A. Coefficient Bias – Market

	12,1	**12,3**	**12,6**	**9,1**	**9,3**	**6,1**	**6,3**	**3,1**
Const.	−0.003	−0.002	−0.001	−0.003	−0.002	−0.002	−0.001	−0.001
Const. (sim)	−0.003	−0.002	−0.001	−0.003	−0.002	−0.002	−0.001	−0.001
bias (in pp)	0.003	0.003	0.001	0.005	−0.002	0.001	−0.003	0.006
Slope	1.042	1.060	1.198	0.981	0.964	0.873	0.862	0.745
Slope (sim)	1.040	1.059	1.198	0.979	0.961	0.871	0.860	0.747
bias (in pp)	0.146	0.152	−0.063	0.171	0.235	0.141	0.191	−0.236

Table A4: Finite Sample Bias: Option Implied Variance (continued)

Panel B. Coefficient Bias – Stocks

	12,1	**12,3**	**12,6**	**9,1**	**9,3**	**6,1**	**6,3**	**3,1**
Const.	0.012	0.006	0.002	0.012	0.005	0.009	0.003	0.005
Const. (sim)	0.012	0.006	0.002	0.012	0.005	0.009	0.003	0.005
bias (in pp)	−0.004	0.000	−0.004	−0.005	−0.003	−0.003	−0.005	0.003
Slope	0.909	0.890	0.751	0.881	0.838	0.754	0.640	0.620
Slope (sim)	0.909	0.890	0.750	0.881	0.839	0.754	0.640	0.621
bias (in pp)	−0.027	−0.007	0.026	−0.005	−0.011	0.015	−0.063	−0.020

Panel C. Finite Sample Distributions – Market

	12,1	**12,3**	**12,6**	**9,1**	**9,3**	**6,1**	**6,3**	**3,1**
Const.	−0.003	−0.002	−0.001	−0.003	−0.002	−0.002	−0.001	−0.001
p-value	[0.724]	[0.740]	[0.719]	[0.741]	[0.755]	[0.746]	[0.741]	[0.718]
Slope	1.042	1.060	1.198	0.981	0.964	0.873	0.862	0.745
p-value	[0.849]	[0.856]	[0.709]	[0.911]	[0.894]	[0.485]	[0.554]	[0.270]
adj. R^2	0.38	0.26	0.13	0.32	0.20	0.24	0.15	0.10
Wald	0.63	0.53	0.75	0.53	0.43	1.99	1.21	3.15
p-value	[0.91]	[0.92]	[0.88]	[0.91]	[0.93]	[0.67]	[0.75]	[0.30]
Joint	*Pure*	*General*						
Wald	22.1	6.23						
p-value	[0.59]	[0.54]						

Panel D. Finite Sample Distributions – Stocks

	12,1	**12,3**	**12,6**	**9,1**	**9,3**	**6,1**	**6,3**	**3,1**
Const.	0.012**	0.006*	0.002	0.012**	0.005*	0.009**	0.003	0.005*
p-value	[0.010]	[0.098]	[0.490]	[0.011]	[0.072]	[0.010]	[0.141]	[0.068]
Slope	0.909	0.890	0.751**	0.881	0.838*	0.754***	0.640***	0.620***
p-value	[0.213]	[0.266]	[0.048]	[0.180]	[0.094]	[0.001]	[0.001]	[0.000]
adj. R^2	0.34	0.21	0.11	0.29	0.16	0.23	0.11	0.17
Wald	7.39**	3.39	5.19	8.25**	4.88	14.4***	36.4***	35.2***
p-value	[0.04]	[0.24]	[0.12]	[0.03]	[0.11]	[0.00]	[0.00]	[0.00]

Table A5: Errors-In-Variables: Option Implied Variance

This table reports the results accounting for errors-in-variables in expectations hypothesis tests. We replace the independent variable with the fitted value of a regression on its first lag. The regression equation is $\frac{1}{k}\sum_{i=0}^{k-1}\left(\sigma^2_{j,im,(i+1)m} - \sigma^2_{j,0,m}\right) = a_j + b_j\left(\sigma^2_{M,0,km} - \sigma^2_{M,0,m}\right) + \nu_{j,km}$. In each column, the first number denotes the long horizon (k *times* m) and the second number denotes the short horizon (m) (e.g., 12,1 means we have $km = 12$ and $m = 1$ month(s)). The pure expectations hypothesis posits that the constant a is zero and that the slope b is one while the general expectations hypothesis requires only the latter. We test the individual hypotheses with t-tests and the joint hypothesis with a Wald test. All tests employ Newey & West (1987) standard errors (*s.e.*) with 4 lags. For the market and each stock, we average the coefficient estimates, standard errors, and p-values across sub-samples. We also present the results of a joint test of the expectations hypothesis along with bootstrapped p-values.In Panel B, we present the results of a panel regression on a constant using the two-way clustered standard errors of Cameron et al. (2011). *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

Panel A. Option Implied Variance – Market

	12,1	**12,3**	**12,6**	**9,1**	**9,3**	**6,1**	**6,3**	**3,1**
Const.	−0.004	−0.003	−0.002	−0.003	−0.002	−0.003	−0.001	−0.002
(s.e.)	(0.004)	(0.003)	(0.002)	(0.003)	(0.002)	(0.002)	(0.001)	(0.001)
Slope	1.284	1.209	1.576	1.266	1.152	1.216	0.933	1.564
(s.e.)	(0.270)	(0.337)	(0.579)	(0.227)	(0.261)	(0.193)	(0.220)	(0.350)
adj. R^2	0.23	0.17	0.11	0.20	0.14	0.16	0.08	0.12
Wald	1.90	0.95	1.62	2.41	0.96	2.68	0.66	4.30
p-value	[0.39]	[0.62]	[0.44]	[0.30]	[0.62]	[0.26]	[0.72]	[0.12]
Joint	*Pure*	*General*						
Wald	33.0	18.4						
p-value	[0.47]	[0.25]						

Panel B. Option Implied Variance – Stocks

	12,1	**12,3**	**12,6**	**9,1**	**9,3**	**6,1**	**6,3**	**3,1**
Const.	0.012***	0.006*	0.002	0.012***	0.005*	0.009**	0.003	0.005*
(s.e.)	(0.005)	(0.003)	(0.003)	(0.004)	(0.003)	(0.004)	(0.002)	(0.003)
Slope	0.909	0.890	0.751**	0.881	0.838*	0.754***	0.640***	0.620***
(s.e.)	(0.069)	(0.088)	(0.110)	(0.078)	(0.089)	(0.078)	(0.060)	(0.065)
adj. R^2	0.34	0.21	0.11	0.29	0.16	0.23	0.11	0.17
Wald	[0.02]**	[0.18]	[0.07]*	[0.02]**	[0.09]*	[0.00]***	[0.00]***	[0.00]***