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The Pricing of Volatility and Jump Risks in the Cross-Section of Index Option Returns

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Abstract

Existing studies relate the puzzling low average returns on out-of-the-money (OTM) index call and put options to nonstandard preferences. We argue the low option returns are primarily due to the pricing of market volatility risk. When volatility risk is priced, expected option returns match the realized average option returns. Moreover, consistent with its theoretical effect on expected option returns, the volatility risk premium is positively related to future index option returns and this relationship is stronger for OTM options and at-the-money straddles. Finally, we find the jump risk premium contributes to some portion of OTM put option returns.

I. Introduction

One of the most enduring puzzles of the asset pricing literature is that out-of-the-money (OTM) index put options are associated with large negative average returns (e.g., Jackwerth (2000), Santa-Clara and Saretto (2009), and Bondarenko (2014)). While an index put option is a negative beta asset and thus is expected to have a negative rate of return, the magnitudes in the data seem too large to be consistent with standard models (Chambers, Foy, Liebner, and Lu (2014)). On the other hand, Bakshi, Madan, and Panayotov (2010) document that the average returns of OTM index call options are also negative and declining with the strike price. This stylized fact is somewhat less known, but is perhaps even more puzzling because it

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contradicts the prediction from standard theories that expected call option returns should be positive and increase with the strike price (Coval and Shumway (2001)).[1]

Previous research relates these large negative OTM call and put option returns to models featuring nonstandard preferences. For instance, Polkovnichenko and Zhao (2013) consider a rank-dependent utility model with a particular probability weighting function to explain the data. Baele, Driessen, Ebert, Londono, and Spalt (2019) show that a model with cumulative prospect theory preferences is able to generate the otherwise puzzling index option return patterns. The low returns on OTM call and put options can also be explained with theories of skewness/lottery preferences and leverage constraints (Brunnermeier, Gollier, and Parker (2007), Mitton and Vorkink (2007), Barberis and Huang (2008), and Frazzini and Pedersen (2012)). OTM options are often associated with substantial skewness and embedded leverage, which make them particularly attractive for investors who have skewness preferences or face leverage constraints. Demand pressure will drive up prices and consequently lead to low returns in equilibrium (Gârleanu, Pedersen, and Poteshman (2009)).

This article investigates whether the low returns on OTM index options can be consistent with the pricing of market volatility and jump risks. Options are sensitive to changes in volatility and price jumps, therefore their expected returns should critically depend on investor's attitudes toward volatility and jump risks. To study how the pricing of volatility and jump risks affects the cross-section of index option returns, we follow Broadie, Chernov, and Johannes (2009) and compare historical realized option returns with the expected returns implied from option pricing models. Figure 1 summarizes our results. First, we find that the large negative OTM option returns cannot be explained by models involving the equity risk premium alone, which include the classical Black–Scholes–Merton (BSM) model as well as the stochastic volatility and jump models (SV and SVJ) in which volatility and jump risks are not priced. However, when market volatility risk is priced (SV+), the implied expected option returns match the average returns of call and put options across all strikes. Consistent with the data, the pricing of volatility risk implies not only a steep relationship between expected put returns and the strike price with OTM puts earning large negative rates of return, but also an overall decreasing relation between expected call returns and the strike price with OTM calls earning negative expected returns. Additionally, we show that the presence of a volatility risk premium (VRP) is consistent with the average returns of different option portfolios. Finally, we find that the pricing of jump risk (SVJ+) implies that OTM puts have large negative expected returns with magnitudes very close to the data, but the jump risk premium also implies the expected call return is an increasing function of the strike price and OTM calls should earn large positive expected returns, which is contrary to the data. Our results are robust to different parameterizations of stochastic volatility and jumps.

Option pricing theory not only predicts that the pricing of volatility risk results in lower expected option returns, but also predicts that the effect of the VRP varies across moneyness with OTM options and at-the-money (ATM) straddles being more sensitive to changes in the VRP. Confirming these predictions, we find that the

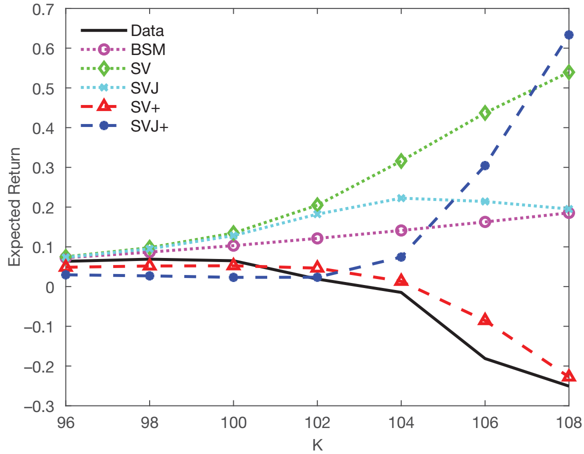
[1] Related, Constantinides and Jackwerth (2009) and Constantinides, Czerwonko, Jackwerth, and Perrakis (2011) document widespread violations of stochastic dominance in OTM index and index futures options.

FIGURE 1

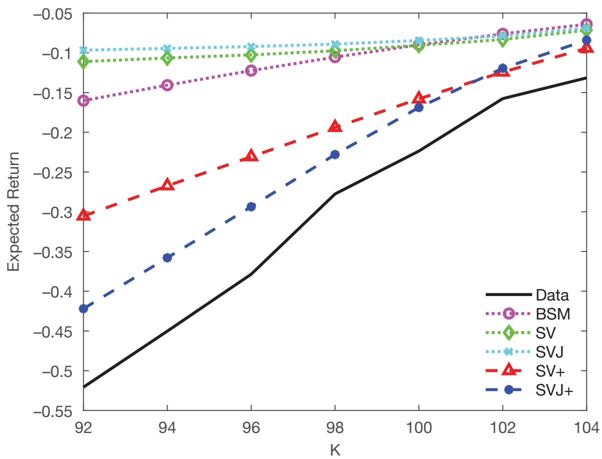
Moneyness and Expected Option Returns

Figure 1 plots expected option returns as a function of the strike price for the three option pricing models with only an equity risk premium (BSM, SV, and SVJ), the SV+ model in which volatility risk is priced, and the SVJ+ model in which jump risk is priced but volatility risk is not. Graph A is for call options and Graph B is for put options. Expected option returns are computed analytically based on parameters reported in Table 2. The realized average option returns are also included (Data).

Graph A. Expected Call Option Returns



Graph B. Expected Put Option Returns



VRP is positively related to future index option returns: A more negative VRP in a given month is associated with low option returns in the subsequent month. Moreover, this relationship is indeed stronger for OTM options and ATM straddles. Our findings cannot be explained by the underlying return predictability by the VRP (Bollerslev, Tauchen, and Zhou (2009)), and are robust to different empirical implementations and controlling for other variables. Finally, we find that the jump risk premium is significantly related to future OTM index put returns, but its relationship with call option and straddle returns is insignificant.

Taken together, our results suggest that the low returns on OTM index options are primarily due to the pricing of market volatility risk, although the jump risk premium also accounts for some portion of OTM put option returns. The rest of the article is organized as follows: Section II discusses related literature. Section III compares expected option returns implied from option pricing models to historical S&P 500 option returns, with a particular focus on the effect of volatility and jump risk premiums. Section IV studies the time-series relationship between the volatility and jump risk premiums and future index option returns. Section V contains robustness results, and Section VI concludes the article.

II. Related Literature

Our article is most closely related to Broadie et al. (2009) and Chambers et al. (2014), which compare historical returns of put options and a number of option portfolios with those implied from option pricing models, finding that index option returns can be explained by a jump risk premium.[2] We extend their analysis to include index call options. Studying index calls is important because any theory put forward to explain the low returns on OTM puts should also fit OTM call returns. Moreover, OTM calls, which are claims on the upside, are critical for disentangling the VRP from the jump risk premium as these two risk premiums have drastically different implications on expected OTM call returns. In contrast, separately identifying the volatility and jump risk premiums using only put returns can be challenging. We confirm the results of Broadie et al. (2009) and Chambers et al. (2014) that the jump risk premium fits OTM put returns well, but we also show that the jump risk premium fails to match OTM call returns. In contrast, the VRP is able to match the low returns on OTM calls and OTM puts simultaneously. Bakshi et al. (2010) relate the low OTM option returns to a U-shaped pricing kernel that arises in a model featuring short-selling and heterogeneity in investors' beliefs about return outcomes. In their model, there are two types of risk averse investors: long equity investors and short equity investors. Just as long investors can hedge their positions by purchasing OTM puts, short investors can hedge their positions by purchasing OTM calls. In both cases, the demand for protection results in negative expected returns for OTM call and put options. Our analysis suggests that investor heterogeneity and the U-shaped pricing kernel need not be necessary and the low returns on OTM options are consistent with the pricing of market volatility risk.[3] Driessen, Maenhout, and Vilkov (2009) investigate the differential pricing of options on the S&P 100 index and its component stocks, and find strong evidence of a large correlation risk premium. While their focus is not on the low returns on OTM index options, they report that OTM calls have larger correlation betas than ITM (in-the-money) calls. Since correlation is negatively priced, exposure to the correlation risk may explain the low returns on OTM calls. Our findings are thus consistent with

[2]The two papers have different conclusions about whether index put returns are consistent with standard option pricing models in which volatility and jump risks are not priced. Our analysis confirms the results in Chambers et al. (2014) that the hypothesis of no additional risk premiums can be rejected in general.

[3]We also compare the confidence intervals on OTM call returns implied from the pricing of volatility risk and the U-shaped pricing kernel. While both suggest that the confidence interval is large for call returns and becomes increasingly wider for calls that are further out-of-the-money, the pricing of volatility risk implies that the confidence interval widens symmetrically which is consistent with the data.

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Driessen et al. (2009) in the sense that the pricing of aggregate volatility risk is driven by the pricing of correlation risk.[4]

The bulk of the index option literature focuses on the behavior of *option prices.* For example, Bates (1991) finds that OTM puts became unusually expensive during the year preceding the 1987 market crash, but the prices were back to normal levels during the 2 months immediately preceding the crash. It is also well-known that since the 1987 market crash implied volatilities from OTM puts have been consistently higher than their ATM counterparts (Rubinstein (1994)). This stylized fact is often referred to as the implied volatility skew or volatility smirk, and contradicts the prediction of the BSM model that the implied volatility is constant across strikes. The presence of a pronounced volatility skew has inspired many subsequent studies. For example, there is an extensive literature that demonstrates stochastic volatility and jumps are needed in order to fit rich option price dynamics, although the empirical evidence is somewhat mixed regarding the relative importance of these additional factors as well as their pricing. For important contributions, see Bakshi, Cao, and Chen (1997), Bates (2000), Chernov and Ghysels (2000), Pan (2002), Jones (2003), Eraker (2004), Broadie, Chernov, and Johannes (2007), and Andersen, Fusari, and Todorov (2015). Our article differs from this literature in that we examine *option returns* rather than *option prices.* Understanding option returns is also important because option returns contain additional information not spanned by option prices. For example, the low returns on OTM calls and OTM puts suggest that both are problematic, whereas one might wrongly conclude that only OTM puts are problematic by observing the volatility skew only. We show that a simple stochastic volatility model in which volatility risk is priced describes the average option returns reasonably well.

There is a large body of literature on the pricing of volatility and jump risks in financial markets. The pricing of aggregate volatility and jump risks in the cross-section of stock returns has been examined extensively. See, among others, Ang, Hodrick, Xing, and Zhang (2006), Adrian and Rosenberg (2008), and Cremers, Halling, and Weinbaum (2015). Our article is more closely related to studies that focus on the pricing of volatility and jump risks in options market. Index options market, where stochastic volatility and jump risks play a prominent role, contains rich economic information about the pricing of these risk factors. For example, Coval and Shumway (2001) report that zero-beta ATM straddles produce large losses and they interpret it as evidence that systematic stochastic volatility is priced in option returns. Bakshi and Kapadia (2003) find that delta-hedged option portfolios have negative average returns, which implies a negative VRP. Our results are consistent with the findings of Coval and Shumway (2001) and Bakshi and Kapadia (2003) that the VRP is negative in the index options market. The key difference between the above studies and this article is that their emphasis is on using option portfolios to infer the existence and sign of the VRP, while this article

[4]Related, Jones (2006), Cao and Huang (2007), and Constantinides, Jackwerth, and Savov (2013) use factor models to gain a better understanding of index option returns. Israelov and Kelly (2017) propose a method for constructing the conditional distribution for index option returns. Driessen and Maenhout (2007) and Faias and Santa-Clara (2017) analyze index option returns from a portfolio allocation perspective. Chaudhuri and Schroder (2015) develop model-free tests of stochastic discount factor monotonicity based on option returns.

aims to quantify the impact of the VRP on the cross-section of *unhedged* index option returns. We also characterize the effect of the jump risk premium on expected option returns.

III. The Volatility Risk Premium, the Jump Risk Premium, and Expected Option Returns

In this section, we begin by examining historical returns of S&P 500 index options across a wide range of strikes, as well as the returns of a number of option portfolios. We then evaluate realized average option returns relative to what would have been obtained in option pricing models. We investigate whether index option returns are consistent with the pricing of volatility and jump risks.

A. Historical S&P 500 Index Option Returns

Following the existing literature, we construct time-series of monthly holding-to-maturity returns for S&P 500 index options with a maturity of 1 month and fixed moneyness ranging from 0.96 to 1.08 for calls and 0.92 to 1.04 for puts, with an increment of 2%. Moneyness is defined as the strike price over the underlying index: K/S. We do not investigate options that are beyond 8% OTM or 4% ITM in light of potential data issues (e.g., low price, low trading volume, or missing observations). We also compute returns on a number of option portfolios, including ATM straddles (ATMS), put spreads (PSPs), crash-neutral spreads (CNS), call spreads (CSPs), and strangles (STRN). ATMS involves the simultaneous purchase of a call option and a put option with $K/S = 1$. PSP consists of a short position in a 6% OTM put and a long position in an ATM put. CNS consists of a long position in an ATM straddle and a short position in a 6% OTM put. CSP combines a long position in an ATM call with a short position in a 6% OTM call. Finally, STRN involves the simultaneous purchase of a 6% OTM call and a 6% OTM put. When computing option returns, we use the mid-point of bid–ask quotes as a proxy for option price, and we calculate option payoff at maturity based on the index settlement values. The sample period for our analysis is from Mar. 1998 to Aug. 2015.[5] The Supplementary Material provides additional details about the data.

Table 1 reports the average monthly returns for the cross-section of index call and put options with different strikes, as well as the average returns for different option portfolios. Confirming the finding of Bakshi et al. (2010), Panel A of Table 1 shows that over our sample period the average call option returns tend to decline with the strike price, with OTM calls earning negative returns. Specifically, the average return for ATM calls is 6.5% per month, and it drops monotonically to –25.05% for 8% OTM calls. The call option return pattern is puzzling because Coval and Shumway (2001) show that under general conditions the expected call option return is an increasing function of the strike price and OTM calls should have positive returns.

[5]Our sample starts in Mar. 1998 because the settlement values (SET) for SPX options required to compute holding-to-maturity returns are only available from Apr. 1998.

TABLE 1

Average Monthly Returns of S&P 500 Index Options

Table 1 reports the average monthly returns of S&P 500 call and put options with different moneyness (defined as the strike price over the index: K/S), as well as the average monthly returns of several option portfolios. For option portfolios, we consider an at-the-money straddle (ATMS) that consists of a long position in an ATM call and a long position in an ATM put, a put spread (PSP) that consists of a short position in a 6% OTM put and a long position in an ATM put, a crash-neutral spread (CNS) that consists of a long position in an ATM straddle and a short position in a 6% OTM put, a call spread (CSP) that consists of a long position in an ATM call and a short position in a 6% OTM call, and a strangle (STRN) that consists of a long position in a 6% OTM call and a long position in a 6% OTM put. Returns are reported in percentage per month. The sample period is Mar. 1998 to Aug. 2015.

Panel A. Call Option

K/S	0.96	0.98	1.00	1.02	1.04	1.06	1.08
Ret	6.36	6.89	6.50	1.89	−1.47	−18.12	−25.05

Panel B. Put Option

K/S	0.92	0.94	0.96	0.98	1.00	1.02	1.04
Ret	−52.07	−45.02	−37.86	−27.76	−22.36	−15.76	−13.15

Panel C. Option Portfolio

	ATMS	PSP	CNS	CSP	STRN
Ret	−8.47	−18.54	−3.93	13.56	−38.64

Panel B of Table 1 presents the well-documented stylized fact that index put options, especially OTM puts, have large negative average returns. For example, over our sample period, buying a 6% OTM put and an 8% OTM put would, on average, lose 45.02% and 52.07% per month, respectively. It is of course not surprising that put options have negative average returns as they are negative beta assets. However, as shown in the next section, the magnitudes of OTM put returns are too large to be explained by standard option pricing models (e.g., the BSM model).

Panel C of Table 1 reports the average returns for option portfolios. Consistent with Coval and Shumway (2001), we find that ATM straddles on average lose 8.47% per month over our sample period. Also, notice that the average return for CSPs is 13.56% per month. CSPs earn high returns because both the long position in ATM calls and the short position in 6% OTM calls generate positive returns as shown in Panel A of Table 1. Finally, the strangle has an average return of −38.64% per month. The strangle earns a large negative average return because the underlying OTM call and OTM put are both associated with negative returns.

In summary, confirming existing studies, we show that OTM calls and puts are both associated with low average returns. In the next section, we evaluate these option returns in the context of option pricing models. We also examine if the models can fit option portfolio returns. This is important because, as demonstrated in Broadie et al. (2009), option portfolios are more informative than individual option returns and therefore provide more powerful tests.

B. Analytical Framework for Expected Option Returns

Statistical inference on option returns is in general difficult because option returns are highly nonnormal, which makes the standard linear models inappropriate. To overcome these statistical difficulties, we apply the methodology developed by Broadie et al. (2009). In particular, we compare the average returns in the data with expected option returns implied by various option pricing models estimated over the same period.[6] We also simulate each model to form a finite sample distribution for testing statistical significance.

We consider a standard affine jump-diffusion framework with mean-reverting stochastic volatility and jumps in stock price (Bates (1996)), which nests the BSM model (Black and Scholes (1973), Merton (1973)), the Heston stochastic volatility model (Heston (1993)), and the Merton jump diffusion model (Merton (1976)) as special cases. The general model says the index level (S_t) and its spot variance (V_t) have the following dynamics under the physical measure ($\mathbb{P}$):

$$dS_t = (\mu + r - d)S_t dt + S_t\sqrt{V_t}dW_1 + \left(e^Z - 1\right)S_t dN_t - \lambda\overline{\mu}S_t dt,$$
$$dV_t = \kappa(\theta - V_t)dt + \sigma\sqrt{V_t}dW_2,$$

where μ is the equity risk premium, r is the risk-free rate, d is the dividend yield, N_t is a $\mathbb{P}$-measure Poisson process with a constant intensity λ, $Z \sim N\left(\mu_z, \sigma_z^2\right)$ are the jumps in price which can take both positive and negative values, $\overline{\mu}$ is the mean jump size with $\overline{\mu} = \exp\left(\mu_z + \frac{1}{2}\sigma_z^2\right) - 1$, θ is the long-run mean of variance, κ is the rate of mean reversion, σ is the volatility of volatility, and W_1 and W_2 are two correlated Brownian motions with $\mathbb{E}[dW_1 dW_2] = \rho dt$. The dynamics under the risk-neutral measure ($\mathbb{Q}$) are given by

$$dS_t = (r - d)S_t + S_t\sqrt{V_t}dW_1^{\mathbb{Q}} + \left(e^{Z^{\mathbb{Q}}} - 1\right)S_t dN_t^{\mathbb{Q}} - \lambda^{\mathbb{Q}}\overline{\mu}^{\mathbb{Q}}S_t dt,$$
$$dV_t = [\kappa(\theta - V_t) - \eta V_t]dt + \sigma\sqrt{V_t}dW_2^{\mathbb{Q}},$$

where η is the price of volatility risk, $N_t^{\mathbb{Q}} \sim \text{Poisson}\,(\lambda^{\mathbb{Q}}t)$, $Z^{\mathbb{Q}} \sim N\left(\mu_z^{\mathbb{Q}}, \left(\sigma_z^{\mathbb{Q}}\right)^2\right)$, and $\overline{\mu}^{\mathbb{Q}} = \exp\left(\mu_z^{\mathbb{Q}} + \frac{1}{2}\left(\sigma_z^{\mathbb{Q}}\right)^2\right) - 1$. Throughout the article, risk-neutral quantities will be denoted with $\mathbb{Q}$ and all other quantities are taken under the physical measure. Note that there are three types of risk premiums in this model: the equity risk premium (μ), the VRP (ηV_t), and the jump risk premium (price jump has different distributions under $\mathbb{P}$ and $\mathbb{Q}$ probability measures).

Expected option returns can be computed analytically within the above framework.[7] This analytical tractability is particularly useful as we can quantify the impact of different risk premiums on expected option returns. We first compute expected call and put option returns as well as expected returns on option portfolios using models with only an equity risk premium, including the BSM model (BSM), a Heston model in which volatility risk is not priced (SV), and a stochastic volatility jump model in which neither volatility risk nor jump risk is priced (SVJ). As we will see, models involving equity risk premium alone are not able to fit index

[6]Realized option returns are highly dependent on the sample, and therefore it is necessary to estimate a model over the same period for which a model is asked to explain option returns.

[7]The intuition is that since physical dynamics are also affine, expected option payoffs and consequently expected returns can be computed analytically. For models with stochastic volatility and jumps, the conditional expected option return is a function of spot variance which has a gamma distribution. We take a numerical integration over gamma distribution to obtain unconditional expected option returns.

option return data. In light of these results, we further investigate if option pricing models with additional volatility and jump risk premiums can lead to a better fit. In particular, we also examine a stochastic volatility model in which volatility risk is priced (SV+), but otherwise identical to the SV model. To study the effect of the jump risk premium, we extend the SVJ model to incorporate a risk premium for jump risk (SVJ+). Note that in the SVJ+ model, volatility risk is not priced. By setting the VRP to 0 ($\eta = 0$), we can isolate the effect of the jump risk premium. In total, we calculate expected option returns for five different option pricing models: Three with the equity risk premium only (BSM, SV, and SVJ), one with the additional VRP (SV+), and one with the additional jump risk premium (SVJ+).

Following Broadie et al. (2009) and Chambers et al. (2014), we also simulate each model to form a finite sample distribution of average option returns, from which we test the null hypothesis that the expected returns implied from various models equal the realized average option returns in the data. Specifically, for each model, we simulate 25,000 sample paths of the index, with each path having 210 months (the length of our empirical sample). For each sample path, we compute one set of average option returns using simulated data. The p-values are then calculated as the percentile of the realized average option returns in the 25,000 simulated average options returns. If the percentile is higher than 0.5, we report the p-value as 1 minus the percentile.

We estimate model parameters in two steps as in Broadie et al. (2009). First, we calibrate the equity risk premium, the risk-free rate, and the dividend yield based on those realized over our sample period and we use particle filtering to estimate the remaining $\mathbb{P}$-measure parameters from the time-series of daily index returns. The Supplementary Material describes the details of our particle filtering estimation. Second, we obtain estimates of the volatility and jump risk premiums by observing that in a standard power utility framework (see, e.g., Naik and Lee (1990), Bakshi and Kapadia (2003), Broadie et al. (2009), and Christoffersen, Heston, and Jacobs (2013)), the risk adjustment for volatility risk is given by

$$\eta V_t = \text{cov}\left(\gamma \frac{dS_t}{S_t}, dV_t\right) \Rightarrow \eta = \gamma\sigma\rho \tag{1}$$

and the risk adjustment for price jump risk is given by

$$\begin{aligned} \lambda^{\mathbb{Q}} &= \lambda \exp\left(-\mu_z\gamma + \frac{1}{2}\gamma^2\sigma_z^2\right), \\ \mu_Z^{\mathbb{Q}} &= \mu_z - \gamma\sigma_z^2, \end{aligned} \tag{2}$$

where γ is relative risk aversion of the agent.[8] For our benchmark analysis, we follow Broadie et al. (2009) and assume a risk aversion of 10.

Table 2 reports (annualized) parameter values that we use for computing expected option returns and simulations. Our parameter estimates are within the

[8]If one ignores the equilibrium restrictions and allows the variance of jump size to take different values under the physical and risk-neutral measures, expected option returns become even more complicated and can exhibit different patterns. See Branger, Hansis, and Schlag (2010) for a related discussion.

reasonable range reported in the literature. For the BSM model, the constant volatility parameter is set equal to the square root of the long run mean of stock variance (θ) in the SV model ($\sigma_{\text{BSM}} = 19.05\%$). For the SV+ model, given a risk aversion of 10 and a negative ρ, equation (1) indicates that the VRP parameter η must be negative and is equal to -4.347. Our calibration of the SV+ model implies the expected 1-month volatilities under $\mathbb{P}$ and $\mathbb{Q}$ measures are 19.1% and 20.7% (annualized), yielding a VRP ($\mathbb{P} - \mathbb{Q}$) of –1.6%. Pan (2002) finds that the magnitudes of the VRP needed to reconcile time-series and option-based spot volatility measures imply explosive risk-neutral volatility dynamics ($\kappa + \eta < 0$). In contrast, our calibration does not lead to explosive volatility process under $\mathbb{Q}$ because the mean reversion parameter we estimate is large relative to the VRP parameter ($\kappa + \eta > 0$). This could be due to our sample period. For the SVJ+ model, consistent with the notion that investors fear large adverse price jumps, the risk corrections in equation (2) indicate that price jumps occur more frequently and more severely under the risk-neutral measure. Our estimates imply about 1.50 jumps per year on average ($\lambda^{\mathbb{Q}} = 1.4969$) and a mean jump size of –6.67% ($\mu_z^{\mathbb{Q}} = -0.0667$) under $\mathbb{Q}$ probability measure, and about 0.97 jumps per year on average ($\lambda = 0.9658$) with a mean jump size of –2.09% ($\mu_z = -0.0209$) under $\mathbb{P}$ probability measure. We perform an extensive sensitivity analysis with respect to model parameters in Section V.A.

TABLE 2

Parameters

Table 2 reports parameter values for the five option pricing models we use to compute expected option returns: the Black–Scholes–Merton model (BSM), a stochastic volatility model in which volatility risk is not priced (SV), a stochastic volatility jump model in which neither volatility nor jump risk is priced (SVJ), a stochastic volatility model in which volatility risk is priced (SV+), and a stochastic volatility jump model in which jump risk is priced but volatility risk is not (SVJ+). The equity risk premium (μ), risk-free rate (r), and dividend yield (d) are calibrated to match those observed in our sample. For the BSM model, the constant volatility parameter (σ_{BSM}) is equal to the square root of the long-run variance (θ) in the SV model. We use particle filtering to estimate the remaining $\mathbb{P}$-measure parameters for each model and report standard errors of those estimates in the parentheses. The VRP (η) and $\mathbb{Q}$-measure jump parameters ($\lambda^{\mathbb{Q}}$ and $\mu_z^{\mathbb{Q}}$) are obtained according to equations (1) and (2) with a risk aversion of 10. All parameters are reported in annual terms.

	BSM	SV	SVJ	SV+	SVJ+
μ	0.0506	0.0506	0.0506	0.0506	0.0506
r	0.0201	0.0201	0.0201	0.0201	0.0201
d	0.0174	0.0174	0.0174	0.0174	0.0174
σ_{BSM}	0.1905				
κ		6.4130	5.9859	6.4130	5.9859
		(0.923)	(0.909)	(0.923)	(0.909)
θ		0.0363	0.0358	0.0363	0.0358
		(0.004)	(0.004)	(0.004)	(0.004)
σ		0.5472	0.5423	0.5472	0.5423
		(0.033)	(0.035)	(0.033)	(0.035)
ρ		–0.7944	–0.8015	–0.7944	–0.8015
		(0.026)	(0.028)	(0.026)	(0.028)
λ			0.9658		0.9658
			(0.114)		(0.114)
μ_z			–0.0209		–0.0209
			(0.007)		(0.007)
σ_z			0.0677		0.0677
			(0.009)		(0.009)
η		0.0000	0.0000	–4.3470	0.0000
$\lambda^{\mathbb{Q}}$			0.9658		1.4969
$\mu_z^{\mathbb{Q}}$			–0.0209		–0.0667

C. The Effects of the Volatility and Jump Risk Premiums

Before presenting our findings, we discuss the role of various risk premiums in determining expected option returns. Taking a call option as an example, the expected gross return is given by

$$\mathbb{E}(C) = \frac{\mathbb{E}^{\mathbb{P}}[\max(S-K,0)]}{e^{-rT}\mathbb{E}^{\mathbb{Q}}[\max(S-K,0)]}, \tag{3}$$

where the denominator is the price of the option and the numerator is the expected option payoff. Equation (3) suggests that the expected option return is determined by the gap between the $\mathbb{P}$ and $\mathbb{Q}$ probability measures, which arises due to the presence of various risk premiums. If there were no risk premium (e.g., the $\mathbb{P}$ and $\mathbb{Q}$ probability measures are identical), the expected option return would be equal to the risk-free rate.

In models involving the equity risk premium alone (BSM, SV, and SVJ), a call option is a leveraged long position in the underlying asset. As such, the expected return of an index call option exceeds the expected return of the underlying index and OTM calls should have positive expected returns, which is contrary to the data. On the other hand, these models imply that expected index put returns are negative because puts represent leveraged short positions in the underlying. However, Section III.D shows the expected put returns implied from these models are in general too small to be consistent with the data.

The pricing of volatility and jump risks leads to more interesting patterns of expected option returns. First, notice that the volatility and jump risk premiums do not affect expected option payoff, but they affect expected option returns by inducing changes in the risk-neutral index return distribution under which option prices are determined. In other words, considering the expected call return in equation (3), the volatility and jump risk premiums affect the denominator of this expression but not the numerator.

Specifically, the pricing of volatility risk lowers the expected returns of OTM calls and OTM puts. Increasing the VRP, namely a more negative η, adds probability mass to both tails of the risk-neutral distribution (e.g., a higher risk-neutral volatility) and therefore increases the prices of OTM calls and OTM puts. As the numerator of the expected return expression is not affected, this means that expected returns of OTM calls and OTM puts decrease. The next section shows that consistent with the data, the SV+ model in which volatility risk is priced produces large negative expected returns for both OTM calls and OTM puts.

On the other hand, the jump risk premium has different implications for OTM option returns. The pricing of jump risk implies a larger jump intensity ($\lambda^{\mathbb{Q}} > \lambda^{\mathbb{P}}$) and a more negative mean jump size ($\mu_z^{\mathbb{Q}} < \mu_z^{\mathbb{P}}$) under the risk-neutral measure, and these two elements have different impacts on the risk-neutral distribution. A more negative mean jump size primarily adds left skewness, resulting in a more negatively skewed risk-neutral distribution. This, in turn, increases the prices of OTM puts and decreases the prices of OTM calls. In contrast, a larger jump intensity fattens both tails, which increases the prices of both OTM calls and OTM puts. For OTM puts, both effects lead to a higher valuation and thus expected put option returns are much more negative in the presence of a jump risk premium. On the other hand, for OTM calls, the two effects offset each other and the overall impact is somewhat ambiguous. Below we show that under plausible parameterizations, the presence of the jump risk premium results in positive expected returns for OTM calls.

D. Results

Tables 3–5 report the results of comparing realized option returns with the expected option returns implied from the five option pricing models discussed in Section III.B. Realized historical option returns are taken from Table 1, denoted by "Data." Expected option returns computed analytically are labeled as "$\mathbb{E}^{P}$." We also report the average simulated option returns, denoted by "Simulation." Not surprisingly, these two measures of expected returns are very close to each other.

Table 3 shows that option pricing models involving the equity risk premium only (BSM, SV, and SVJ) have difficulties in fitting index option returns. First of all, Panel B of Table 3 suggests that these models in general can be rejected by OTM put option returns, although not for all moneyness levels, confirming the results of Chambers et al. (2014). For example, a 4% OTM put has an average return of –37.86% in the data, which is much larger than the expected returns implied from the three models: –12.24% (BSM), –10.20% (SV), and –9.16% (SVJ).[9] The return differences are also statistically significant at 10% with a p-value of 0.04, 0.08, and 0.07, respectively. A p-value of 0.04 for the BSM model means that only 4% of the 25,000 simulated average put returns from the BSM model are less than the –37.86% realized return. Panel A of Table 3 shows that models involving the equity risk premium only are also inconsistent with index call option returns. Specifically, these models predict an overall increasing relationship between expected call option returns and the strike price with OTM calls earning large positive returns, which is contrary to the data. Interestingly, despite the large return difference between data and the models, p-values indicate that only the BSM model can be rejected (based on 6% and 8% OTM calls). This is because OTM call returns have very large standard deviations, which makes a model difficult to reject even if the model is wrong. Broadie et al. (2009) demonstrate that the statistical uncertainty is substantial for put returns. Our analysis further suggests that the statistical uncertainty is even greater for call returns. Panel C of Table 3 reports the results based on option portfolio returns. The BSM, SV, and SVJ models are all rejected by straddle and strangle returns.

Table 4 compares realized option returns with the expected option returns implied from the SV+ model in which volatility risk is priced. When a VRP is incorporated, expected option returns match the average returns of call and put options across all strikes as well as the average returns of option portfolios. In particular, consistent with the data, the pricing of volatility risk implies that

[9]Expected put option returns in the SV and SVJ models are actually less negative than those in the BSM model, despite the fact that the two models are able to generate a volatility skew. In other words, the volatility skew per se does not imply large negative returns unless the skew is driven by risk premiums (e.g., volatility and jump risks are priced).

TABLE 3

Expected Option Returns: BSM, SV, and SVJ Models

Table 3 compares realized average index option returns in Table 1 with expected option returns implied from models involving the equity risk premium only (BSM, SV, and SVJ). "$\mathbb{E}^p$" represents expected option returns computed analytically using parameters from Table 2. We also simulate 25,000 sample paths of the index from which we report the average simulated option returns (denoted by "Simulation") and *p*-values. The *p*-values are calculated based on the percentile of realized option returns relative to the 25,000 simulated options returns. Sample paths are simulated based on the same parameters used for computing expected option returns. Returns are reported in percentage per month.

Panel A. Call Option

	K/S	0.96	0.98	1.00	1.02	1.04	1.06	1.08
Data		6.36	6.89	6.50	1.89	−1.47	−18.12	−25.05
BSM	$\mathbb{E}^p$	7.25	8.67	10.30	12.13	14.12	16.27	18.54
	Simulation	7.18	8.58	10.19	12.00	14.01	16.18	18.53
	p-value	(0.45)	(0.42)	(0.37)	(0.23)	(0.19)	(0.07)	(0.08)
SV	$\mathbb{E}^p$	7.51	9.78	13.46	20.06	31.11	43.26	53.63
	Simulation	7.52	9.81	13.53	20.22	31.64	44.39	52.50
	p-value	(0.42)	(0.35)	(0.24)	(0.10)	(0.11)	(0.16)	(0.38)
SVJ	$\mathbb{E}^p$	7.32	9.45	12.80	18.10	22.14	21.35	19.62
	Simulation	7.28	9.41	12.78	18.15	22.36	21.61	19.76
	p-value	(0.44)	(0.37)	(0.27)	(0.14)	(0.20)	(0.22)	(0.33)

Panel B. Put Option

	K/S	0.92	0.94	0.96	0.98	1.00	1.02	1.04
Data		−52.07	−45.02	−37.86	−27.76	−22.36	−15.76	−13.15
BSM	$\mathbb{E}^p$	−16.01	−14.07	−12.24	−10.54	−8.99	−7.61	−6.40
	Simulation	−15.92	−13.99	−12.19	−10.49	−8.94	−7.56	−6.35
	p-value	(0.10)	(0.05)	(0.04)	(0.06)	(0.06)	(0.12)	(0.12)
SV	$\mathbb{E}^p$	−11.08	−10.67	−10.20	−9.66	−9.02	−8.20	−7.08
	Simulation	−11.34	−10.76	−10.23	−9.67	−9.02	−8.20	−7.09
	p-value	(0.13)	(0.09)	(0.08)	(0.11)	(0.12)	(0.20)	(0.19)
SVJ	$\mathbb{E}^p$	−9.65	−9.41	−9.16	−8.85	−8.44	−7.84	−6.88
	Simulation	−9.53	−9.29	−9.06	−8.76	−8.37	−7.78	−6.83
	p-value	(0.09)	(0.07)	(0.07)	(0.10)	(0.11)	(0.19)	(0.19)

Panel C. Option Portfolio

	Portfolio	ATMS	PSP	CNS	CSP	STRN
Data		−8.47	−18.54	−3.93	13.56	−38.64
BSM	$\mathbb{E}^p$	0.71	−8.03	1.97	8.88	2.65
	Simulation	0.67	−7.99	1.93	8.77	2.69
	p-value	(0.03)	(0.09)	(0.11)	(0.29)	(0.00)
SV	$\mathbb{E}^p$	2.30	−8.56	3.70	12.11	−2.01
	Simulation	2.33	−8.56	3.73	12.16	−2.25
	p-value	(0.02)	(0.16)	(0.05)	(0.44)	(0.00)
SVJ	$\mathbb{E}^p$	2.24	−8.08	3.74	11.59	−0.54
	Simulation	2.27	−8.02	3.74	11.58	−0.44
	p-value	(0.03)	(0.14)	(0.06)	(0.41)	(0.00)

the expected call option return tends to decrease with the strike price, especially over the OTM range. For example, the expected return drops monotonically from 5.14% per month for ATM calls to –22.54% for 8% OTM calls. This result sharply contrasts with other models in which the expected call option return is an increasing function of the strike price. On the put option side, we find that expected put returns are more negative in the presence of the VRP, which again is consistent with the data. Finally, Panel C of Table 4 shows that the pricing of volatility risk is also consistent with option portfolio returns. The *p*-values suggest that in all cases realized historical average option returns are not statistically significantly different

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TABLE 4

Expected Option Returns: SV+ Model

Table 4 compares realized average index option returns in Table 1 with expected option returns implied from the SV+ model in which volatility risk is priced. "$\mathbb{E}^p$" represents expected option returns computed analytically using parameters reported in Table 2. We also simulate 25,000 sample paths of the index from which we report the average simulated option returns (denoted by "Simulation") and p-values. The p-values are calculated based on the percentile of realized option returns relative to the 25,000 simulated options returns. Sample paths are simulated based on the same parameters used for computing expected option returns. Returns are reported in percentage per month.

Panel A. Call Option

K/S	0.96	0.98	1.00	1.02	1.04	1.06	1.08
Data	6.36	6.89	6.50	1.89	−1.47	−18.12	−25.05
$\mathbb{E}^p$	4.82	5.10	5.14	4.50	1.12	−8.53	−22.54
Simulation	4.90	5.24	5.38	4.94	1.78	−7.99	−21.34
p-value	(0.40)	(0.40)	(0.44)	(0.41)	(0.48)	(0.50)	(0.30)

Panel B. Put Option

K/S	0.92	0.94	0.96	0.98	1.00	1.02	1.04
Data	−52.07	−45.02	−37.86	−27.76	−22.36	−15.76	−13.15
$\mathbb{E}^p$	−30.43	−26.69	−22.96	−19.29	−15.74	−12.39	−9.40
Simulation	−30.54	−26.77	−23.03	−19.33	−15.76	−12.42	−9.42
p-value	(0.22)	(0.19)	(0.18)	(0.26)	(0.26)	(0.34)	(0.28)

Panel C. Option Portfolio

Portfolio	ATMS	PSP	CNS	CSP	STRN
Data	−8.47	−18.54	−3.93	13.56	−38.64
$\mathbb{E}^p$	−5.24	−12.33	−2.52	6.74	−22.43
Simulation	−5.13	−12.37	−2.41	6.94	−22.60
p-value	(0.24)	(0.25)	(0.36)	(0.20)	(0.20)

TABLE 5

Expected Option Returns: SVJ+ Model

Table 5 compares realized average index option returns in Table 1 with expected option returns implied from the SVJ+ model in which jump risk is priced, but volatility risk is not. "$\mathbb{E}^p$" represents expected option returns computed analytically using parameters reported in Table 2. We also simulate 25,000 sample paths of the index from which we report the average simulated option returns (denoted by "Simulation") and p-values. The p-values are calculated based on the percentile of realized option returns relative to the 25,000 simulated options returns. Sample paths are simulated based on the same parameters used for computing expected option returns. Returns are reported in percentage per month.

Panel A. Call Option

K/S	0.96	0.98	1.00	1.02	1.04	1.06	1.08
Data	6.36	6.89	6.50	1.89	−1.47	−18.12	−25.05
$\mathbb{E}^p$	2.96	2.70	2.32	2.34	7.31	29.39	64.09
Simulation	3.01	2.74	2.35	2.39	7.63	29.65	64.05
p-value	(0.26)	(0.26)	(0.30)	(0.50)	(0.40)	(0.25)	(0.29)

Panel B. Put Option

K/S	0.92	0.94	0.96	0.98	1.00	1.02	1.04
Data	−52.07	−45.02	−37.86	−27.76	−22.36	−15.76	−13.15
$\mathbb{E}^p$	−41.93	−35.61	−29.10	−22.71	−16.85	−11.95	−8.38
Simulation	−42.22	−35.93	−29.40	−22.98	−17.05	−12.09	−8.46
p-value	(0.32)	(0.31)	(0.29)	(0.35)	(0.30)	(0.33)	(0.24)

Panel C. Option Portfolio

Portfolio	ATMS	PSP	CNS	CSP	STRN
Data	−8.47	−18.54	−3.93	13.56	−38.64
$\mathbb{E}^p$	−7.21	−9.30	−2.45	1.46	−25.35
Simulation	−7.30	−9.47	−2.50	1.49	−25.44
p-value	(0.41)	(0.16)	(0.38)	(0.04)	(0.20)

from those generated by the SV+ model. Note that our calibration of the SV+ model, which is based on a risk version of 10, implies a monthly VRP of –1.6%. This is close to but somewhat smaller (in magnitude) than the realized VRP over our sample period, which is –2%. We can match the realized VRP by setting risk aversion to 13 and Section V.A shows that this does not affect the conclusion.

Table 5 compares realized option returns with the expected option returns implied from the SVJ+ model in which jump risk is priced but volatility risk is not. Confirming the findings of Broadie et al. (2009) and Chambers et al. (2014), Panel B of Table 5 shows that the pricing of jump risk implies put options have large negative expected returns, which is consistent with the data. While the jump risk premium matches put returns very well, it fails to explain index call option returns. Specifically, Panel A of Table 5 shows that when jump risk is priced, there is an increasing relation between expected call option returns and the strike price with OTM calls earning large positive returns, which is contrary to the data. Because OTM call returns in the SVJ+ model are associated with even larger variation, the model cannot be rejected despite the fact that it generates a wrong return pattern. However, portfolio-based evidence in Panel C of Table 5 shows that the SVJ+ model is rejected by CSP returns. The average monthly return of CSPs is 13.56% in the data, significantly higher than the model-implied return of 1.46%. Specifically, the 13.56% realized average return is greater than 96% of the 25,000 simulated average returns from SVJ+ model, yielding a *p*-value of 0.04.

Comparing Tables 4 and 5 shows that the volatility and jump risk premiums generate similar expected returns for the strangle (−22.43% vs. −25.35%), but the underlying mechanisms are different. In the presence of a volatility risk premium, the underlying OTM call and OTM put both have large negative expected returns and hence the strangle also has a negative expected return. In contrast, the jump risk premium implies that the OTM call has a large positive expected return and the OTM put has a large negative expected return. However, because the OTM put is more expensive than the OTM call and therefore contributes more to the expected return of the strangle, a strangle is similar to an OTM put option in the presence of the jump risk premium and earns a negative expected return.

Figure 1 summarizes our findings by plotting expected option returns in Tables 3–5 against the strike price. For comparison, we also include realized average returns, denoted by "Data." Graph A shows that the volatility and jump risk premiums have drastically different implications on expected call option returns. The jump risk premium implies that expected returns of OTM call options are positive and increasing with the strike price, similar to models with the equity risk premium only. In contrast, the volatility risk premium predicts a decreasing relationship between expected call returns and the strike price, with OTM calls earning large negative expected returns. Graph B shows that all models have qualitatively similar predictions for puts: Expected put option returns should be negative and increasing with the strike price, with the jump risk premium yielding the most negative estimates, followed by the volatility risk premium.

Our analysis shows that a simple stochastic volatility model in which volatility risk is priced describes the average option returns reasonably well. This result is somewhat surprising because we know the stochastic volatility model is not rich enough and additional factors are required to capture the behavior of option prices.

Our results are nevertheless consistent with the findings of Cochrane and Piazzesi (2005) for the bond market that although multiple factors are needed to describe empirical patterns in bond prices, a single factor summarizes nearly all information about risk premium/returns. Johnson (2017) also reports similar results in the VIX market.

E. The Effect of the Volatility Risk Premium: Further Investigation

In this section, we analyze how expected option returns vary with respect to changes in the volatility risk premium. Based on the parameter values reported in Table 2, Figure 2 plots expected returns on call options, put options, and straddles in the SV+ model as a function of risk aversion γ for different moneyness. A higher γ implies a larger volatility risk premium (more negative) as shown in equation (1).

Figure 2 shows that a more negative volatility risk premium lowers expected option returns and this effect varies significantly across moneyness. Graphs A and B indicate that the relation between the volatility risk premium and the expected option return is much stronger for OTM calls and OTM puts with the steepest slope. As options move toward the in-the-money direction, the slope flattens out as expected option returns become less sensitive to the changes in the volatility risk premium. Specifically, our analysis suggests that a 1% decrease (in absolute term) in the volatility risk premium results in 32.37%, 5.19%, and 0.97% drop (in absolute term) in the expected return for 6% OTM call, ATM call, and 6% ITM call, yielding a slope of 32.37, 5.19, and 0.97, respectively.[10] On the put side, a 1% drop in the volatility risk premium is associated with 10.01%, 4.19%, and 0.73% drop in the expected return for 6% OTM put, ATM put, and 6% ITM put, respectively. Graph C shows that straddles have their own unique pattern. ATM straddle returns are more sensitive to changes in the volatility risk premium as compared to their ITM and OTM counterparts. Our estimates imply that the expected return will drop by 1.74%, 4.71%, and 1.35% for straddles with $K/S = 0.94$, 1.00, and 1.06, respectively, given a 1% decrease in the volatility risk premium. We test the differential impact of the volatility risk premium on expected option returns in Section IV.

Figure 2 also helps understand why the volatility risk premium fits index option returns well. As discussed, a negative volatility risk premium increases option value, which then leads to a lower expected return. Moreover, this effect is disproportionately stronger for OTM options. As a result, the pricing of volatility risk is able to generate not only a steeper relation between expected put option returns and the strike price, with OTM put options earning large negative returns, but also a decreasing relation between expected call option returns and the strike price, with OTM calls having negative expected returns.

IV. Time-Series Analysis

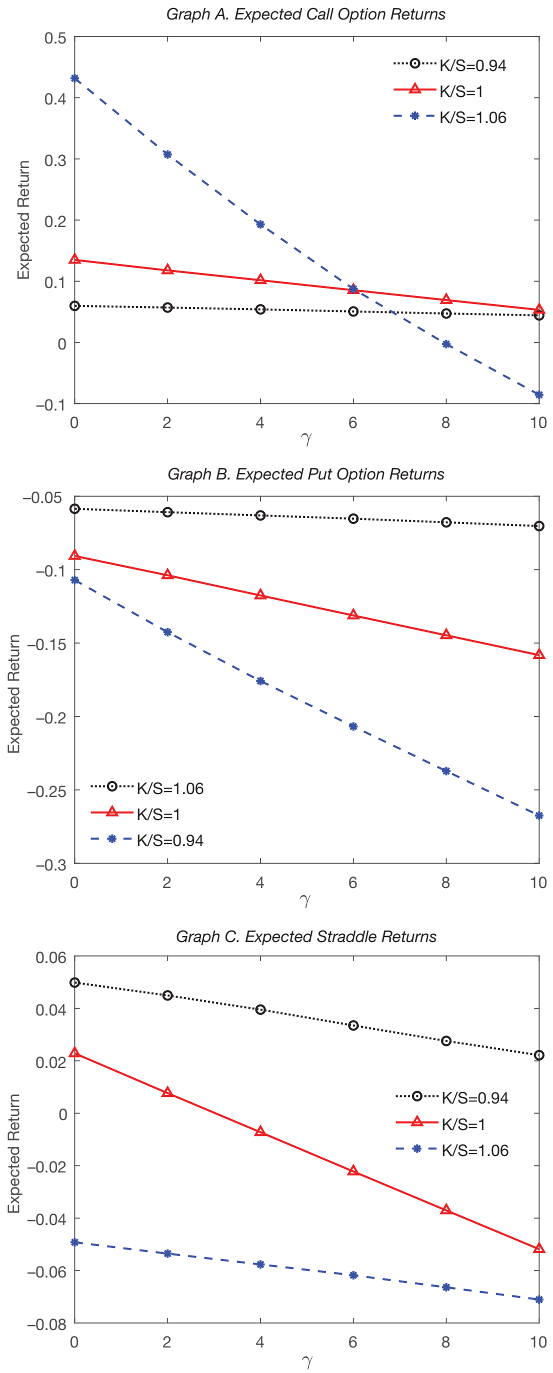
Section III.E shows that the presence of a negative volatility risk premium decreases expected option returns. Moreover, the effect of the volatility risk

[10] Taking the 6% OTM call as an example, Figure 2 shows that as γ increases from 0 to 10 (namely the volatility risk premium changes from 0 to −0.016), the expected return of the 6% OTM call drops from 43.26% to −8.53%, yielding a slope of $(0.4326 - (-0.0853))/(0 - (-0.016)) = 32.37$.

FIGURE 2

The Volatility Risk Premium and Expected Option Returns

Figure 2 plots expected option returns against risk aversion coefficient (γ) in the SV+ model: Graph A for calls, Graph B for puts, and Graph C for straddles. A higher γ corresponds to a more negative volatility risk premium. The remaining parameters required for computing expected returns are based on Table 2.



premium is stronger for OTM options and ATM straddles. We formally test these predictions by investigating the time-series relationship between the volatility risk premium and future index option returns. We also examine how the jump risk premium is related to future option returns.

A. The Volatility Risk Premium and Future Option Returns

To test the differential impact of the volatility risk premium on expected option returns, we estimate the following time-series predictive regressions at monthly frequency:

$$(4)\qquad \text{OPTION\_RET}^i_{t,t+1} = \alpha^i + \beta^i \text{VRP}_t + \epsilon, i \in \{\text{call}, \text{put}, \text{straddle}\},$$

where the dependent variable $\text{OPTION\_RET}_{t,t+1}$ is the returns from holding call options, put options and straddles from month t to month $t+1$. The analysis in Section III.E suggests that options with different moneyness have different sensitivities with respect to the volatility risk premium and therefore we estimate the above regressions separately for different moneyness groups. In particular, for call options, we consider the following three groups: $0.96 \le K/S < 1.00$, $1.00 \le K/S < 1.04$, and $1.04 \le K/S < 1.08$. For put options, we consider $0.92 \le K/S < 0.96$, $0.96 \le K/S < 1.00$, and $1.00 \le K/S < 1.04$. Again we do not investigate options that are beyond 8% OTM or 4% ITM in light of potential data issues. For straddles, we consider the following three moneyness groups: $0.94 \le K/S < 0.98$, $0.98 \le K/S < 1.02$, and $1.02 \le K/S < 1.06$.

Following the definition of the equity risk premium, we define the volatility risk premium as the difference between physical and risk-neutral expectations of future realized volatility:

$$\text{VRP}_t = \mathbb{E}_t(\text{RV}_{t,t+1}) - \mathbb{E}_t^{\mathbb{Q}}(\text{RV}_{t,t+1}).$$

The volatility risk premium is constructed each month on the option selection date and will be used to forecast option returns over the following month. For the baseline results, we follow Bollerslev et al. (2009) and measure the volatility risk premium as the difference between realized volatility and the VIX index:

$$\text{VRP}_t = \text{RV}_{t-1,t} - \text{VIX}_t,$$

where realized volatility is computed based on 5-min log returns on S&P 500 futures over the past 30 days (see, e.g., Andersen, Bollerslev, Diebold, and Ebens (2001), Barndorff-Nielsen and Shephard (2002)). The VIX index is published by the Chicago Board Options Exchange (CBOE), and it tracks 30-day risk-neutral expectation of future realized volatility. Consistent with the findings in Carr and Wu (2009) and Todorov (2010), Figure A1 in the Supplementary Material shows that the volatility risk premium, like volatility itself, is also time varying. In the robustness analysis, we show that our empirical results are robust to the measurement of the volatility risk premium.

Panel A of Table 6 reports regression results for index call options. For calls that are between 4% and 8% OTM, the volatility risk premium is positively related

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to future returns with a statistically significant coefficient. The t-statistic is 2.11 and the adjusted R^2 of the regression is 0.99%. Throughout the article, t-statistics are computed using Newey–West standard errors with four lags (Newey and West (1987), (1994)). Interestingly, this relationship between the volatility risk premium and call returns weakens as call options move toward the in-the-money direction. The slope coefficient, t-stat, and R^2 all decrease monotonically.

Panel B of Table 6 shows that there is a positive relationship between the volatility risk premium and future index put option returns. Similar to calls, this relation becomes increasingly weak as put options move toward the in-the-money direction, judging by the slope coefficient, statistical significance, and R^2. For example, for put options that are between 4% OTM and 8% OTM, the slope coefficient is estimated to be 8.37 with a Newey–West t-statistic of 2.21 and an adjusted R^2 of 2.04%. In contrast, for put options that are between ATM and 4% ITM, the slope coefficient is only 2.70 and is not statistically significant.

TABLE 6

The Volatility Risk Premium and Future Option Returns

Table 6 reports results of the following monthly predictive regression:

$$\text{OPTION\_RET}^i_{t,t+1} = \alpha^i + \beta^i \text{VRP}_t + \epsilon, i \in \{\text{call}, \text{put}, \text{straddle}\},$$

where OPTION_RET is monthly holding-to-maturity returns on call options (Panel A), put options (Panel B), and straddles (Panel C). Each month VRP_t is computed as the difference between realized volatility and the VIX. Realized volatility is constructed based on 5-min log returns on S&P 500 futures over the past 30 calendar days. We run predictive regressions for different moneyness groups as indicated by different columns. Newey–West t-statistics with 4 lags are reported in the parentheses. The p-values, reported in square brackets, are calculated based on the percentile of empirical slope coefficients in the finite sample distribution of 25,000 simulated slopes from the SV+ model. The sample period is Mar. 1998 to Aug. 2015.

Panel A. Call Option

	$0.96 \le K/S < 1.00$	$1.00 \le K/S < 1.04$	$1.04 \le K/S < 1.08$
INTERCEPT	0.11	0.27	1.28
	(1.66)	(1.57)	(1.50)
VRP	−0.06	4.35	24.44
	(−0.04)	(1.70)	(2.11)
	[0.47]	[0.45]	[0.50]
Adj. R^2	−0.06%	0.37%	0.99%

Panel B. Put Option

	$0.92 \le K/S < 0.96$	$0.96 \le K/S < 1.00$	$1.00 \le K/S < 1.04$
INTERCEPT	−0.23	−0.12	−0.09
	(−1.21)	(−0.83)	(−0.72)
VRP	8.37	4.38	2.70
	(2.21)	(1.53)	(1.21)
	[0.46]	[0.49]	[0.50]
Adj. R^2	2.04%	0.64%	0.55%

Panel C. Straddle

	$0.94 \le K/S < 0.98$	$0.98 \le K/S < 1.02$	$1.02 \le K/S < 1.06$
INTERCEPT	0.08	0.04	−0.04
	(1.91)	(0.83)	(−0.50)
VRP	1.47	2.63	2.39
	(1.84)	(2.83)	(1.76)
	[0.45]	[0.43]	[0.48]
Adj. R^2	0.87%	1.59%	1.41%

Panel C of Table 6 shows that the volatility risk premium also exhibits a positive relation with future straddle returns, but with a different pattern. In particular, the relationship between the volatility risk premium and future returns is stronger for ATM straddles. As straddles move away from the money, this relation is only marginally significant.

In summary, we find that the volatility risk premium is positively related to future index option returns: A more negative volatility risk premium in a given month is associated with lower option returns in the subsequent month. This positive relationship is consistent with the theoretical prediction that a negative volatility risk premium leads to lower expected option returns. We also find that the relationship between the volatility risk premium and future option returns is stronger for OTM calls, OTM puts, and ATM straddles. This pattern is consistent with the differential impact of the volatility risk premium on expected option returns discussed in Section III.E. Following the general approach we take in the paper, we also test whether the empirical relationship between the volatility risk premium and future option returns is consistent with what is implied by the SV+ model. Specifically, we use the simulated data from the SV+ model to estimate the same predictive regression in (4) and store the slope coefficient of the VRP. We repeat this exercise 25,000 times to form a finite sample distribution of the slope, from which we calculate p-values. As before, p-value is calculated as min[L, 1-L], where L denotes the percentile of the realized slope in the 25,000 simulated slopes. Table 6 shows that p-values, reported in square brackets, are large and in the range of 0.4 to 0.5, which suggests that the realized slope of the VRP is not statistically different from what is implied by the model. Lastly, the Supplementary Material shows that the positive relationship between the volatility risk premium and future option returns is also economically significant and can be translated into large economic gains.

Bollerslev et al. (2009), among others, document that the volatility risk premium predicts future index returns at short horizons. Therefore, a natural interpretation of our finding is that it is merely a manifestation of the underlying index return predictability afforded by the volatility risk premium. While this explanation appears plausible, it can be ruled out based on the fact that the volatility risk premium forecasts future option returns with the same sign: A more negative volatility risk premium this month is associated with lower option returns in the subsequent month. If option return predictability were caused by stock return predictability, then one would observe opposite signs for calls and puts because the expected call (put) option return increases (decreases) with the expected stock return. Instead, we argue that the economic source of option return predictability is due to the time-varying volatility risk premium embedded in index options, because both the sign and pattern of index option return predictability are consistent with the theoretical impact of the volatility risk premium on expected option returns.

B. The Jump Risk Premium and Future Option Returns

This section investigates how the jump risk premium is related to future option returns. The presence of a jump risk premium will lead to a steeper slope of the implied volatility curve, and therefore we use the difference in average implied volatilities (IVOL) between OTM and ATM put options as a proxy for the jump risk premium[11]:

$$\text{JUMP}_t = \text{IVOL}_{\text{OTM},t} - \text{IVOL}_{\text{ATM},t}, \tag{5}$$

where OTM and ATM refer to put options with $0.90 \leq K/S \leq 0.94$ and $0.98 \leq K/S \leq 1.02$, respectively.

The predictive regression results for the jump risk premium are included in the Supplementary Material. We find that the jump risk premium significantly predicts future OTM put option returns: A larger jump risk premium in a given month is associated with lower OTM put returns in the subsequent month. However, the jump risk premium does not contain predictive information about future call and straddle returns.

V. Robustness

This section includes several robustness checks. We study how different parameterizations might affect expected option returns. We also investigate the robustness of the empirical relationship between the volatility risk premium and future option returns to a number of implementation choices. Lastly, we assess the impact of bid–ask spreads on computing option returns.

A. Parameters

Our main analysis shows that the presence of the volatility risk premium implies that both OTM calls and OTM puts have large negative expected returns. On the other hand, the jump risk premium implies that OTM puts earn large negative expected returns, whereas OTM calls are associated with large positive expected returns. In this section, we assess how these conclusions might be affected by different parameterizations with respect to both physical measure parameters and the risk premia.

Table 7 recalculates expected option returns in the SV+ model by increasing/decreasing each $\mathbb{P}$-measure stochastic volatility parameter by 3 standard errors, which covers a wide range of parameter values. We keep the volatility risk premium parameter (η) unchanged when computing expected option returns. The results suggest that alternative parameterizations of the stochastic volatility process under the physical measure generate different expected option returns, but the overall return patterns are similar to those obtained with our baseline parameterization. For example, it is well-known that the mean reverting parameter κ is notoriously difficult to pin down precisely and different estimates can have dramatically different implications on the term structure of volatilities, but its impact on expected option returns turns out to be quite consistent: Decreasing or increasing κ by 3 standard errors produces similar expected return patterns.

[11]This proxy is likely to be noisy because it also captures the asymmetric distribution (physical) of index returns, which may be generated from the leverage effect and the presence of negative jumps.

TABLE 7

Sensitivity Analysis: Stochastic Volatility Parameters

Table 7 reports expected option returns for the SV+ model by increasing (+) and decreasing (–) each stochastic volatility parameter under the physical measure by 3 standard errors. Expected option returns based on our baseline parameterization are also included for comparison. Returns are in percentage per month.

Panel A. Call Option

K/S	0.96	0.98	1	1.02	1.04	1.06	1.08
Baseline	4.82	5.10	5.14	4.50	1.12	−8.53	−22.54
$\kappa+$	4.77	4.92	4.70	3.73	1.11	−4.98	−15.61
$\kappa-$	5.13	5.94	7.38	9.59	−0.02	−16.30	−32.27
$\theta+$	3.83	3.63	3.00	1.55	−1.47	−7.43	−16.89
$\theta-$	6.39	7.84	10.26	14.27	6.05	−14.24	−34.46
$\sigma+$	4.96	5.52	6.20	6.80	2.67	−9.90	−25.05
$\sigma-$	4.72	4.78	4.37	3.03	−0.36	−7.83	−19.70
$\rho+$	4.96	5.28	5.32	4.50	0.67	−8.12	−19.92
$\rho-$	4.77	5.08	5.24	5.07	2.64	−9.28	−27.65

Panel B. Put Option

K/S	0.92	0.94	0.96	0.98	1	1.02	1.04
Baseline	−30.43	−26.69	−22.96	−19.29	−15.74	−12.39	−9.40
$\kappa+$	−29.54	−25.79	−22.08	−18.47	−15.04	−11.88	−9.12
$\kappa-$	−31.82	−28.13	−24.41	−20.70	−17.04	−13.41	−9.75
$\theta+$	−28.24	−24.69	−21.20	−17.84	−14.65	−11.71	−9.13
$\theta-$	−33.90	−29.97	−25.97	−21.93	−17.90	−13.85	−9.83
$\sigma+$	−29.22	−25.83	−22.44	−19.07	−15.76	−12.55	−9.48
$\sigma-$	−31.85	−27.68	−23.56	−19.55	−15.77	−12.31	−9.34
$\rho+$	−31.24	−27.35	−23.47	−19.65	−15.96	−12.48	−9.40
$\rho-$	−29.83	−26.21	−22.60	−19.06	−15.62	−12.36	−9.41

Panel C. Option Portfolio

	ATMS	PSP	CNS	CSP	STRN
Baseline	−5.24	−12.33	−2.52	6.74	−22.43
$\kappa+$	−5.11	−11.64	−2.40	6.16	−19.99
$\kappa-$	−4.73	−13.78	−2.12	9.07	−25.28
$\theta+$	−5.78	−10.74	−2.83	5.17	−19.18
$\theta-$	−3.70	−15.33	−1.43	11.12	−27.62
$\sigma+$	−4.71	−12.46	−1.98	7.67	−22.51
$\sigma-$	−5.64	−12.27	−2.94	6.13	−21.89
$\rho+$	−5.25	−12.63	−2.61	6.98	−22.31
$\rho-$	−5.13	−12.18	−2.37	6.75	−22.53

Table 8 reports the effect of the volatility risk premium on expected option returns in the SV+ model by changing the risk aversion parameter from 0 to 20. For $\mathbb{P}$-measure parameters, we continue to use our baseline estimates reported in Table 2. Table 8 shows that risk aversion (and therefore the volatility risk premium) has a much larger effect on expected option returns, especially for OTM options. When risk aversion is equal to 0 (e.g., volatility risk is not priced), the SV+ model collapses to the SV model and expected call and put returns both increase with the strike price. As risk aversion increases, namely the volatility risk premium becomes more negative, expected option returns decrease. Note that the low returns on OTM index options can be eventually matched by considering a large risk aversion, it is therefore important to examine the plausibility of the estimated volatility risk premium magnitude. As discussed in Section III.B, our baseline parameterization considers a risk aversion of 10 and the implied volatility risk premium is economically reasonable.

The Supplementary Material includes the corresponding results for the SVJ+ model and shows that our conclusion about the effects of the jump risk premium on expected option returns is robust to different parameterizations.

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TABLE 8
Sensitivity Analysis: Risk Aversion

Table 8 reports expected option returns for the SV+ model using different values of risk aversion (γ) ranging from 0 to 20. The remaining parameters are based on Table 2. Returns are in percentage per month.

Panel A. Call Option

$\gamma/(K/S)$	0.96	0.98	1.00	1.02	1.04	1.06	1.08
0	7.51	9.78	13.46	20.06	31.11	43.26	53.63
2	6.99	8.86	11.76	16.66	24.06	30.17	32.46
4	6.55	8.08	10.36	14.03	18.66	19.58	15.45
6	5.98	7.09	8.60	10.75	12.36	8.94	0.35
8	5.49	6.24	7.11	8.00	7.06	−0.14	−12.30
10	4.82	5.10	5.14	4.50	1.12	−8.53	−22.54
12	4.25	4.15	3.54	1.75	−3.73	−15.87	−31.44
14	3.80	3.38	2.18	−0.72	−8.24	−22.77	−39.74
16	3.01	2.14	0.22	−3.85	−12.88	−28.33	−45.40
18	2.40	1.15	−1.40	−6.53	−17.08	−33.73	−51.12
20	1.87	0.25	−2.90	−9.04	−21.06	−38.81	−56.33

Panel B. Put Option

$\gamma/(K/S)$	0.92	0.94	0.96	0.98	1.00	1.02	1.04
0	−11.08	−10.67	−10.20	−9.66	−9.02	−8.20	−7.08
2	−15.34	−14.12	−12.88	−11.63	−10.35	−9.00	−7.52
4	−19.58	−17.61	−15.66	−13.73	−11.83	−9.93	−8.02
6	−23.37	−20.74	−18.15	−15.60	−13.12	−10.72	−8.45
8	−27.16	−23.93	−20.73	−17.58	−14.52	−11.62	−8.94
10	−30.43	−26.69	−22.96	−19.29	−15.74	−12.39	−9.40
12	−33.77	−29.55	−25.32	−21.14	−17.09	−13.28	−9.90
14	−37.16	−32.49	−27.78	−23.09	−18.51	−14.20	−10.42
16	−39.85	−34.85	−29.77	−24.69	−19.73	−15.05	−10.97
18	−42.71	−37.39	−31.94	−26.45	−21.05	−15.96	−11.52
20	−45.56	−39.94	−34.14	−28.24	−22.41	−16.88	−12.06

Panel C. Option Portfolio

γ/Portfolio	ATMS	PSP	CNS	CSP	STRN
0	2.30	−8.56	3.70	12.11	−2.01
2	0.78	−9.30	2.45	10.97	−6.45
4	−0.66	−10.22	1.25	10.14	−10.68
6	−2.19	−10.91	0.00	8.97	−14.80
8	−3.64	−11.76	−1.21	8.05	−18.67
10	−5.24	−12.33	−2.52	6.74	−22.43
12	−6.71	−13.09	−3.74	5.78	−26.01
14	−8.10	−14.01	−4.92	4.96	−29.45
16	−9.70	−14.53	−6.22	3.80	−32.70
18	−11.17	−15.27	−7.46	2.84	−35.82
20	−12.60	−16.10	−8.66	1.95	−38.77

B. The Measurement of the Volatility Risk Premium

In the main analysis, we measure the volatility risk premium as the difference between realized volatility and the VIX. In other words, we assume that volatility follows a random walk and lagged realized volatility is an unbiased estimate of expected volatility. To ensure our empirical results are not driven by this assumption, we also estimate expected physical volatility using the heterogeneous autoregressive model (the HAR model) proposed by Corsi (2009). In particular, we obtain conditional forecasts of future volatility by projecting realized volatility onto lagged realized volatilities computed over difference frequencies:

$$\log \mathrm{RV}_{t,t+1} = \delta_0 + \delta_1 \log \mathrm{RV}_{t-1,t} + \delta_2 \log \mathrm{RV}_t^W + \delta_3 \log \mathrm{RV}_t^D + \epsilon,$$

where $\text{RV}_{t-1,t}$ is realized volatility over the past month, and RV_t^W and RV_t^D denote realized volatilities over the past week and day, respectively. Because realized volatilities are approximately log-normally distributed (Andersen, Bollerslev, Diebold, and Labys (2003)), it is more appropriate to forecast the logarithmic of realized volatilities with linear models. The log specification also ensures that volatility forecasts always remain positive. We estimate the above model based on the full sample and take the fitted values as expectations of future realized volatility:

$$\mathbb{E}_t(\text{RV}_{t,t+1}) = \exp\left(\delta_0 + \delta_1 \log \text{RV}_{t-1,t} + \delta_2 \log \text{RV}_t^W + \delta_3 \log \text{RV}_t^D + \frac{1}{2}\sigma_\epsilon^2\right).$$

Finally, we compute the difference between $\mathbb{E}_t(\text{RV}_{t,t+1})$ and the VIX to obtain the volatility risk premium estimates.

The results for this new measure of the volatility risk premium are contained in the Supplementary Material. Consistent with our benchmark findings, the volatility risk premium is positively related to future option returns, and this relationship is stronger for OTM options and ATM straddles. The Supplementary Material also shows that the positive relationship between the volatility risk premium and option returns is robust to controlling for other variables and persists to other holding periods.

C. The Effect of Bid–Ask Spreads

The average option returns reported in Table 1 are based on the assumption that options are transacted at the mid-point of the bid–ask spread; in other words, the effective spread is 0. The bid–ask spreads are large in option markets and spreads can also vary sharply depending on moneyness. To assess if the index option return patterns documented in Table 1 are robust to the effect of transaction costs, we also compute option returns by using different ratios of effective spreads to quoted spreads. In particular, we consider trading options at an effective spread equal to 25%, 50%, and 100% of the quoted spread. Note that when the effective spread is equal to 100% of the quoted spread, options are bought at the ask price and sold at the bid price.[12]

The results are contained in the Supplementary Material. We find that a larger effective spread, not surprisingly, lowers option returns and this impact is more pronounced for OTM calls and option portfolios. More importantly, the results confirm that the index option return patterns documented in Table 1 are robust to alternative measurements of option returns. Regardless of the assumption on the effective spread, the average call option returns tend to decrease with the strike price with OTM calls earning large negative average returns, while the average put option returns increase with the strike price, and OTM puts are associated with large negative average returns.

[12]Muravyev and Pearson (2020) show that effective spreads are much lower than conventional estimates because option prices are predictable at high frequency and traders can exploit this in timing their executions.

VI. Conclusion

OTM S&P 500 index call and put options are both associated with large negative average returns. Existing studies relate the low returns on OTM index options to behavioral factors or nonstandard preferences. We argue that the low returns on OTM options are primarily due to the pricing of market volatility risk. When volatility risk is priced, expected option returns are consistent with realized historical index option returns across all strikes as well as the returns of a number of option portfolios. Further corroborating the volatility risk premium hypothesis, we document that the volatility risk premium is positively related to future option returns, and this relationship is stronger for OTM options and ATM straddles. These findings are consistent with the differential effect of the volatility risk premium on expected option returns. Overall, our results suggest that the pricing of volatility risk has a first-order effect on the cross-section of index option returns. On the jump risk premium side, we find that the pricing of jump risk is also important and some portion of OTM put option returns are related to the jump risk premium.

This article can be extended in several ways. First, in our theoretical analysis, we assume there is only one factor that drives time-varying stochastic volatility. In the data, volatility dynamics are much more complex and our analysis can be extended to take this into account. Second, we have focused on the 1-month maturity and unconditional average returns, and extensions to investigating the term structure and conditional risk premium would be useful. Third, we consider option pricing models as a benchmark, and it may prove interesting to study index option returns against a structural framework with economic fundamentals (e.g., consumption). We plan to address these in future research.

Supplementary Material

To view supplementary material for this article, please visit http://doi.org/10.1017/S0022109022000333.

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