A margin requirement based return calculation for portfolios of short option positions

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Abstract

Purpose – Short option positions carry significant risk of losses well in excess of 100 per cent of the initial option price. Margin requirements associated with such positions are therefore considerable. The purpose of this paper is to develop a methodology for calculating margin requirement-based option portfolio returns that realistically represent the returns realized by investors, and to demonstrate the effects of this methodology on analyses of option returns.

Design/methodology/approach – A methodology is developed for calculating margin requirement-based short option portfolio returns.

Findings – Accounting for margin requirements reduces the returns of simple short option strategies by up to 92 per cent compared to the price return. In long/short portfolio analyses, use of margin requirement returns necessitates additional methodological adjustments to ensure that unwanted volatility risk is properly hedged.

Originality/value – The result is a portfolio return that more accurately represents the return realized by investors, and increased power to detect cross-sectional patterns in option returns.

Keywords Margin requirements, Options market, Share options, Returns, Short option returns, Volatility risk premium

Paper type Research paper

1. Introduction

Short option positions carry significant risk of losses well in excess of 100 percent of the initial price of the option. This risk requires investors with short option positions to hold a cash reserve (margin requirement) sufficient to cover potential losses. The commonly used price return calculation is therefore not reflective of the return an investor realizes on short option positions. Short positions in options may also be hedged with other option positions or a position in the underlying security, significantly decreasing the potential losses. The objectives of this paper are to develop a methodology for calculating margin requirement-based option portfolio returns that

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realistically represent the returns realized by investors, and to demonstrate the effects
of this methodology on analyses of option returns.

The results indicate that accounting for margin requirements reduces the returns
associated with simple short option strategies such as selling calls, puts, and straddles
by up to 92 percent. A simple estimate of the price of volatility risk is 61 percent lower
using margin rather than price-based returns. In long/short portfolio analyses, margin
requirement-based returns must be accompanied by volatility hedging, which
necessitates allocating a different amount of capital to the long and short portfolios.
The end result is a portfolio that produces returns that are more reflective of returns
realized by investors, and a test with more power to detect cross-sectional option return
patterns. The main implication of the results is that to truly understand the risks and
rewards of short option based investment strategies, it is necessary to account for the
margin requirement associated with the short margin position. Failure to do so may
result in substantially inflated estimates of the rewards associated with investment
strategies that incorporate short option positions.

Issues concerning calculation and analysis of option returns are not new to the
literature Broadie et al. (2009) propose comparing historical option returns to returns
generated by option pricing models Cao and Han (2009) use the stock price as the
denominator for calculating daily delta-hedged option returns. Their methodology is
based on Merton (1973), who finds that option prices are homogeneous of degree one in
the stock price Santa-Clara and Saretto (2009) demonstrate that daily Chicago
Mercantile Exchange (CME) and Chicago Board Options Exchange (CBOE) margin
requirements have a significant impact on the returns of investors short selling S&P
500 index options.

The CME and the CBOE, the two primary options exchanges, each have their own
methods for determining margin requirements on short option positions. The CME
uses a system known as CME SPAN, which:

\[ \ldots \] evaluates overall portfolio risk by calculating the worst possible loss that a portfolio of
derivative and physical instruments might reasonably incur over a specified time period
(typically one trading day)[1].

The CBOE margin requirements for individual short index (equity) option positions
are 100 percent of the market price of the option plus 15 percent (20 percent) of the price
of the underlying security, less the amount that the option is out-of-the-money[2].
Both systems are daily margin requirements designed with the goal of protecting
against the worst case one day loss on a portfolio. Investors also face margin
requirements from their broker-dealers (BD). While each BD has its own system for
determining margin requirements, these requirements will be at least as stringent as
those imposed by the exchanges.

Despite numerous papers on the topic and the transparency of the option exchange
margin requirements, a consensus has yet to be reached on a methodology for
calculating returns on buy and hold (or more appropriately sell and hold) option
portfolios. Such a methodology is necessary to understand the true risks taken and
rewards earned by investors implementing short options based investment strategies.

The daily nature of exchange imposed margin requirements make them
inappropriate for analyzing buy and hold portfolio returns because margin calls are
quite frequent[3]. BD margin requirements form a lower bound on the amount of cash the
investor must supply, but may fall well short of the amount the investor needs to hold
the positions to expiration[4]. To correctly calculate the returns realized by an investor
with short option positions, one must have knowledge of the amount of cash held in
reserve by the investor, either in her own accounts or in the form of a margin requirement
posted to the exchange or broker-dealer, to cover potential required payouts. The sum
of the amounts held in reserve in the investor’s own accounts or in margin accounts
with a BD or exchange will hereafter be referred to as the margin requirement. The
margin requirement-based return calculation developed in this paper focuses on
generating a reasonable estimate of this amount for a representative option seller.

The return calculation is based on a margin requirement sufficient to cover any
“reasonably probable” loss the portfolio may realize at expiration. While the actual
return realized by any specific investor depends not only on the initial amount held in
reserve by that investor, but also on her choice of action when losses exceed the
amount held in reserve, the purpose of this paper is not to replicate the returns realized
by any specific investor. Instead, the goal is to develop a simple methodology capable
of calculating a return similar to that realized by a representative investor
implementing a short option based investment strategy. Though developed in a very
general setting, the methodology is designed for use on portfolios held for relatively
short periods of time, for example one month[5]. Given the prevalence of one-month
studies, the methodology represents a significant improvement over previously used
methods (primarily the price return).

The remainder of this paper is organized as follows. Section 2 presents reasons for,
and issues associated with, the margin requirement for short option positions. Section 3
presents the model for calculating the margin requirement of an option portfolio.
Section 4 calibrates the margin requirement model. Section 5 demonstrates the effect of
margin requirements on the distribution of returns for common short option positions.
Section 6 explains methodological and empirical ramifications of the margin
requirement-based return in long/short portfolio return analyses. Section 7 concludes.

2. Why a margin requirement?
Take the hypothetical situation of a non-dividend paying stock with spot price of $50
and risk-neutral volatility of 0.5. Assume, for simplicity, a risk-free rate of 0. The Black
and Scholes (1973) price for a call option with strike $55 and time to expiration one year
is $8.05. To purchase this option, an investor must supply the $8.05, and the worst case
loss is the $8.05 investment. Now, imagine an investor who shorts this option. A two
standard deviation up move in the stock over the next year makes the stock price at
expiration $50 \times 10^{2 \times 0.5} = $135.91. The option is exercised, and the investor must buy
shares at the market price, deliver them for $55, realizing a loss of $80.91 per share.
Accounting for the $8.05 sale price of the option, the loss is $72.86. To cover such
potential losses, the investor must hold at least this amount in reserve, either in her
own accounts or in the form of margin requirements on deposit with a BD or exchange.

The simple price return for this short position is \((-72.86/8.05) = -905.14%\).
However, for a reasonable investor who held enough in reserve to cover an up move
of two-standard deviations or less ($72.86), the realized return is
\((Profit/Margin) = (-72.86/(72.86)) = -100\%[6].\) For a long position in the same
option however, the only cash required is the $8.05 used to purchase the option, thus
the return on the long position is 905.14 percent. The concept of having a short return
that is not equal to the negative of the long return seems unnatural at first, but hopefully this example is sufficient to convince the reader that in the case of short option positions, calculating returns as described above provides a more realistic assessment of the actual returns realized by an investor.

Imagine now that the investor sells the $55 strike call and buys a $60 strike call for $6.55, realizing a net cash inflow of $1.50 from the trades. A two standard deviation up move results in a $72.86 loss on the short call position, and a profit of $135.91 - $60 - $6.55 = $69.36 on the long call position. The total payout and loss at expiration are $5.00 and $72.86 - $69.36 = $3.50, respectively. This worst case scenario for the combined portfolio will result from any expiration stock price greater than $60 (the strike of the long call). For such a portfolio the investor would adjust the margin requirement accordingly, most likely to $3.50. This $3.50 plus the $1.50 received from the initial trades cover the investor in the worst case scenario, a required payout of $5.00.

The situation becomes more complicated as more option positions or positions in the underlying security are added to the portfolio. To correctly calculate returns of such portfolios requires estimating the margin requirement for such portfolios, and using the margin requirement (not the price) as a basis for return calculations. The next section formally develops such a return calculation.

3. Return calculation methodology
In this section, I present a general framework for calculating returns for portfolios comprised of option positions and a position in the underlying security, where all the options have the same underlying security and expiration. All positions are to be held until option expiration, at which time the portfolio is liquidated. The methodology is intended to replicate the returns that an actual investor would realize when trading any general stock option portfolio that meets these criteria.

As is the case with any return calculation, the numerator is determined by the profit or loss realized by the investor. The difference between the methodology presented here and the standard price return methodology is that here I determine the amount of cash held in reserve (margin requirement) by a reasonable investor to cover potential payouts from short option positions. The margin requirement is designed to cover any loss that may be realized by the portfolio. In many cases, for example the case of a portfolio consisting of only a short call position, the maximum loss on the portfolio is infinite. As an infinitely large margin requirement is not reasonable, I use the term “reasonably probable” to describe the situations that the margin requirement must cover. Section 4 is devoted to calibration of the parameters that determine what is “reasonably probable”.

3.1 Definitions
Before presenting the methodology for calculating returns, a few definitions are necessary. Let \( t_0 \) be the date on which the portfolio is formed, \( t_1 \) be the expiration date of the options in the portfolio, and \( t \) be the time, in years, between \( t_0 \) and \( t_1 \) (\( t = t_1 - t_0 \))[7]. Let \( n \) be the number of options held in the portfolio, \( P_i \) be the position held in the \( i \)th option, \( K_i \) be the strike of the \( i \)th option, \( S_{i0} \) be the price of the \( i \)th option on date \( t_0 \), and \( C_i \) be an indicator with value 1 for a call option and 0 for a put option, where \( i \in \{1, 2, ..., n\} \). Let \( P_S \) be the position in the underlying security and let \( S_0 \) be the price of the underlying security on day \( t_0 \). Let \( V \) represent the annualized volatility of the underlying security (how the volatility is determined will be discussed in
Section 4), and \( r \) represent the risk-free rate of return for a deposit made on date \( t_0 \) and withdrawn on date \( t_1 \). Finally, let \( PVDivas \) be the present value, on date \( t_0 \), of all dividends paid on the underlying stock that have an ex-date between \( t_0 \) (exclusive) and \( t_1 \) (inclusive)[8]. If the underlying security is an index, let \( y \) be the dividend yield of the index. It is assumed that either \( y \) or \( PVDivas \), or both, is equal to 0.

The payoff function for the portfolios defined in the previous section can be written as:

\[
S^p_t(S_t) = P_S e^{rt} (S_t + PVDivas \times e^{rt}) + \sum_{i=1}^{n} P_i S^i_t(S_t)
\]

where \( S_t \) is the price of the stock at expiration, and \( S^i_t(S_t) \) is the payoff of the \( i \)th option in the portfolio if the stock price at expiration is \( S_t \)[9]. Specifically, \( S^i_t(S_t) = \max(0, S_t - K_i) \) if \( C_i = 1 \) and \( S^i_t(S_t) = \max(0, K_i - S_t) \) if \( C_i = 0 \). We can define the price of the portfolio on date \( t_0 \) as:

\[
S^p_0 = P_S S_0 + \sum_{i=1}^{n} P_i S^i_0.
\]

An important feature of the payoff function of the portfolio is that it is linear for expiration stock prices below the lowest strike price, between each successive strike price, and above the highest strike price. The importance of this is that the minimum payoff for the portfolio must come at an expiration stock price that is either equal to one of the strikes, below the lowest strike, or above the highest strike. Thus, in evaluating the minimum “reasonably probable” payoff for the portfolio, only payoffs for the lowest and highest “reasonably probable” expiration stock prices, and the strikes of the options in the portfolio, need to be evaluated.

### 3.2 What is reasonably probable?

I calculate the lowest (highest) “reasonably probable” expiration price for the stock, denoted \( S^d_t \) (\( S^u_t \)), to be the price associated with a \( SD_d \) (\( SD_u \)) standard deviation down (up) move in the stock. Thus, the lowest and highest “reasonably probable” stock prices at option expiration are \( S^d_t = (S_0 - PVDivas)e^{(r-y) t - \frac{1}{2} SD_d^2 t}} \) and \( S^u_t = (S_0 - PVDivas)e^{(r-y) t + \frac{1}{2} SD_u^2 t}} \). As the preponderance of evidence regarding the distribution of stock returns, including evidence to be presented later in this paper, indicates that stock returns exhibit negative skewness and thus do not follow a log-normal distribution, I allow the parameters \( SD_u \) and \( SD_d \) take on different values.

### 3.3 Cash-flow assumptions

The final items that need to be addressed before presenting the methodology are the assumptions behind the return calculation. First, all positions are assumed to be financed. If the portfolio has a positive price at inception, the investor borrows the money at the risk-free rate. If the portfolio has a negative price, resulting in a positive cash flow, that cash earns the risk-free rate until the options expire. Thus, in addition to the difference between the payoff and the initial price of the portfolio, the investor will have to pay \( S^p_0 (e^{rt} - 1) \) in interest[10].

Second, the investor sets aside enough cash to cover any “reasonably probable” loss at expiration. This amount, which I call the margin requirement and denote with margin, earns the risk-free rate until expiration. Thus, when calculating the returns,
the investor will earn an additional $\text{MARGIN}(e^{rt} - 1)$. With the details of the assumed cash-flows in order, I proceed to the development of the model.

3.4 Return calculation

The first part of calculating any return is to calculate the profit or loss ($\text{PnL}$) realized by the investor. In the case of the option portfolios of the type discussed in this paper, there are three components of the $\text{PnL}$. First, there is the difference between the payoff of the portfolio and the initial price of the portfolio ($S^P_t(S_t) - S^P_0$), the second is the loss from interest paid to finance the position ($-S^P_0(e^{rt} - 1)$), and the third is interest received on the margin requirement ($\text{MARGIN}(e^{rt} - 1)$). Thus, the total $\text{PnL}$ from the portfolio can be defined as:

$$\text{PnL}(S_t) = S^P_t(S_t) - S^P_0 - S^P_0(e^{rt} - 1) + \text{MARGIN}(e^{rt} - 1),$$

or equivalently:

$$\text{PnL}(S_t) = S^P_t(S_t) - S^P_0 e^{rt} + \text{MARGIN}(e^{rt} - 1). \quad (3)$$

The denominator of the return calculation will be the margin requirement. A few things are worth remembering here. First, the purpose of the margin requirement is to cover any “reasonably probable” losses. As the margin requirement will earn interest, the amount of margin is the “present value” of the absolute value of the worst case “reasonably probable” loss on the positions. Second, as discussed above, in evaluating the worst case “reasonably probable” loss, one must only evaluate the payoff function at stock prices equal to the lowest and highest “reasonably probable” prices, as well as the strikes of the options in the portfolio ($S_t \in \{S^d_t, S^n_t, K_i; 1 \leq i \leq n\}$). Thus, I define the margin requirement as:

$$\text{MARGIN} = \min_{S_t \in \{S^d_t, S^n_t, K_i; 1 \leq i \leq n\}} |S^P_t(S_t) - S^P_0 e^{rt}| e^{-rt}. \quad (4)$$

With the margin requirement for the option portfolio defined, I calculate the return on the option portfolio to be:

$$R = \frac{\text{PnL}(S_t)}{\text{MARGIN}} = \frac{S^P_t(S_t) - S^P_0 e^{rt} + \text{MARGIN}(e^{rt} - 1)}{\text{MARGIN}}.$$

Rearranging gives a form that looks very much like the traditional return calculation, except with margin in the denominator instead of the price:

$$R = \frac{S^P_t(S_t) - S^P_0 e^{rt}}{\text{MARGIN}} + e^{rt} - 1 \quad (5)$$

Removing the $e^{rt} - 1$ from the end of the return formula gives the excess return. If the margin requirement is equal to the initial price of the portfolio, as is the case for most portfolios with long positions only, then this return calculation is the standard price-based return calculation[11].

This completes the presentation of the margin-based return calculation methodology for option portfolios. In the next section, I turn my attention to calibrating the values of $SD_u$ and $SD_d$, and determining how to find an appropriate value for $V$. A return calculation
4. Calibration of model parameters
Implementation of the margin-based option portfolio return calculation requires calibration of parameters $V$, $SD_u$, and $SD_d$. The goal in fitting these parameters is to find values such that in all “reasonably probable” scenarios, the stock price at expiration is between

$$S_t^d = (S_0 - PVDivs)e^{(r-y)t-SD_dV\sqrt{t}}$$

and

$$S_t^u = (S_0 - PVDivs)e^{(r-y)t+SD_dV\sqrt{t}}.$$

The parameter $V$ is defined as the annualized volatility of log stock returns over the holding period. The natural place to look for a forward looking measure of volatility is the options market. Therefore, I take $V$ to be the average implied volatility of the at-the-money (ATM) call and put contracts with the same expiration as the options in the portfolio [12]. The ATM call (put) is taken to be the contract with delta closest to 0.5 ($-0.5$) [13].

To calibrate the parameters $SD_u$ and $SD_d$, I analyze the distribution of the standardized log excess returns in the cross-section of stocks. I define the standardized log excess return for a stock to be:

$$R_{Std} = \frac{\ln(S_t/(S_0 - PVDivs)e^{rt})}{V\sqrt{t}}.$$  (6)

Each month from February 1996 through December 2010, the standardized returns for the past one, two, three, and six months are calculated for all stocks using stock and option data from the OptionMetrics database [14]. For entry into the sample, I require that a valid stock return be available in the OptionMetrics database for all days during the holding period. I also require that the absolute deltas of the options used to calculate $V$ be between 0.4 and 0.6. The holding periods begin on the second trading day following each monthly expiration, and end when the options expire. $V$ is calculated at the beginning of the holding period.

I calculate monthly cross-sectional means, as well as selected percentiles of the monthly cross-sectional distributions of $R_{Std}$ for each holding period. Table I presents the time-series average of monthly cross-sectional percentiles (row mean CS Pctls), along with the time-series distribution of the cross-sectional mean (TS of means) $R_{Std}$. A more complete presentation of the time-series and cross-sectional distribution of $R_{Std}$ is available in the internet Appendix.

The average cross-sectional percentiles cover the case of an undiversified investor who takes a position in only one stock each month. Here, I consider the “reasonably probable” outcomes to be the middle 98 percent of the distribution in the average month. Thus, for an investor who will realize large losses when the underlying stock is down (up), I look at the first (99th) percentile of $R_{Std}$ in the average month (mean Cs Pctls). The average first percentile one, two, three, and six month standardized returns are $-2.43$, $-2.48$, $-2.49$, and $-2.73$. To cover all of these scenarios, $SD_d$ must be set to at least 2.73. A similar analysis of the 99th percentile produces $R_{Std}$ values of 2.00, 1.92, 1.89, and 1.93. $SD_u$ must therefore be at least 2.00.

I also examine the time-series of cross-sectional means to determine “reasonably probable” outcomes for a diversified investor who takes a similar short option position in all stocks each month (diversified). For this investor, I examine the minimum (maximum) of the time-series of cross-sectional mean $R_{Std}$ (TS of means) to find appropriate values of $SD_d$ and $SD_u$. The minimum mean $R_{Std}$ for one, two, three, and six month holding period are $-2.32$, $-2.94$, $-2.99$, and $-2.76$, respectively. Thus, $SD_d$ must be set to at least 2.99. The maxima are 0.86, 0.95, 0.92, and 0.93, thus the value of 2.00 for $SD_u$ found in the previous paragraph still holds.
<table>
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<th>Months</th>
<th>Mean CS Pctls</th>
<th>Mean</th>
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<th>1%</th>
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<th>3%</th>
<th>4%</th>
<th>5%</th>
<th>25%</th>
<th>50%</th>
<th>75%</th>
<th>95%</th>
<th>96%</th>
<th>97%</th>
<th>98%</th>
<th>99%</th>
<th>Max.</th>
</tr>
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<td>1</td>
<td>Mean CS Pctls</td>
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<td>-1.98</td>
<td>-1.74</td>
<td>-1.58</td>
<td>-1.45</td>
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<tr>
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<td>-2.02</td>
<td>-1.84</td>
<td>-1.70</td>
<td>-0.65</td>
<td>-0.05</td>
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<td>1.33</td>
<td>1.42</td>
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<td>1.69</td>
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<tr>
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<td>-2.07</td>
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<td>-1.58</td>
<td>-1.48</td>
<td>-1.41</td>
<td>-0.30</td>
<td>-0.02</td>
<td>0.26</td>
<td>0.69</td>
<td>0.72</td>
<td>0.79</td>
<td>0.81</td>
<td>0.84</td>
<td>0.93</td>
</tr>
</tbody>
</table>

Notes: The table presents selected percentiles of the distribution of standardized excess returns for $k \in 1, 2, 3, 6$ month holding periods; the standardized excess return is defined as $R_{std} = \frac{\ln(S_t/S_0) - PVDivs}{\sqrt{T/V}}$, where $S_0$ and $S_t$ are the stock prices at the beginning and end of the holding period, $PVDivs$ is the present value, at the beginning of the period, of all dividends paid on the stock during the holding period, $r$ is the risk-free rate, $t$ is the length in years of the holding period, and $V$ is the implied volatility of the stock at the beginning of the holding period, calculated as the average of the ATM call and put implied volatilities of the $k$ month options; the holding periods begin at the close of the second trading day following each monthly expiration and end on the expiration $k$ months in the future; each month, the mean and selected percentiles of the cross-sectional distribution of $k$ month standardized excess returns are calculated; the rows labeled mean CS Pctls in the tables presents the time series average of the monthly cross-sectional mean (column mean) and selected percentiles of standardized excess returns; the rows labeled TS of means present the time-series distribution of monthly cross-sectional means of standardized excess returns; the column labeled months indicates the length of the holding period; the sample covers holding periods ending in February, March, April, and July 1996 through October of 2010 for the one, two, three, and six month holding periods.
5. Distribution of option returns

5.1 Stock options

In this section, I compare the margin-based returns of short positions in common option portfolios to the standard price returns. Each month, for each stock, I calculate the price and margin-based return of a short position in a one month ATM call, out-of-the-money (OTM) call, ATM put, OTM put, and ATM straddle. The ATM (OTM) positions are found by taking the contract with absolute delta closest to 0.5 (0.2) at the beginning of the holding period. The straddle position is created by taking the call option with delta closest to 0.5 and the put option with the same strike. The holding period starts at the close of the second trading day following each monthly expiration and ends on the next monthly expiration, when the options expire. For entry into the sample, I require that the options used to calculate \( V \) have absolute deltas between 0.4 and 0.6, that return data for the underlying stock be available for all days during the holding period, and that the delta of the actual option shorted be within 0.1 of the targeted delta (either 0.5 or 0.2). For the straddle positions, I require that the absolute delta of both options be between 0.4 and 0.6.

Panel A of Table II presents the time-series average of selected percentiles of the cross-sectional distribution of monthly price and margin-based returns for each type of short option position[15]. The results indicate that in the average month more than 5 percent of positions in all strategies have price-based returns less than \(-100\) percent. Using the margin-based return, less than 1 percent (2 percent) of puts and OTM calls (ATM calls and straddles) realize losses in excess of 100 percent of the margin requirement. More importantly, the column labeled mean presents the average monthly excess return of the equal weighted portfolio with a short option position on all stocks. The results indicate that the magnitude of the average monthly margin-based returns are dramatically lower than the price-based returns for all strategies. Margin-based returns are between 54 and 91 percent lower than price-based returns for these common option positions.

The time-series distributions of monthly cross-sectional mean returns are presented in Panel B of Table II. The results show that for each of the single option based strategies, more than 5 percent of months have price-based losses in excess of 100 percent. The margin-based loss, however, never exceeds the margin requirement. It appears as if margin requirement serves its intended purpose, as losses in excess of the margin requirement are mitigated.
<table>
<thead>
<tr>
<th>Position</th>
<th>OTM</th>
<th>Return</th>
<th>Mean</th>
<th>Reduction%</th>
<th>Min.</th>
<th>1%</th>
<th>2%</th>
<th>3%</th>
<th>4%</th>
<th>5%</th>
<th>25%</th>
<th>50%</th>
<th>75%</th>
<th>95%</th>
<th>96%</th>
<th>97%</th>
<th>98%</th>
<th>99%</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short call ATM</td>
<td>Price</td>
<td>-5.5</td>
<td>-1,054</td>
<td>-529</td>
<td>-428</td>
<td>-369</td>
<td>-328</td>
<td>-296</td>
<td>-264</td>
<td>-233</td>
<td>-209</td>
<td>-181</td>
<td>-160</td>
<td>-141</td>
<td>-122</td>
<td>-103</td>
<td>-87</td>
<td>-75</td>
<td>-66</td>
</tr>
<tr>
<td>OTM</td>
<td>Margin</td>
<td>1.0</td>
<td>77.4</td>
<td>-350</td>
<td>-96</td>
<td>-70</td>
<td>-55</td>
<td>-45</td>
<td>-37</td>
<td>-30</td>
<td>-25</td>
<td>-20</td>
<td>-17</td>
<td>-15</td>
<td>-13</td>
<td>-12</td>
<td>-11</td>
<td>-10</td>
<td>-9</td>
</tr>
<tr>
<td>Short straddle</td>
<td>Margin</td>
<td>1.6</td>
<td>90.7</td>
<td>-175</td>
<td>-71</td>
<td>-49</td>
<td>-38</td>
<td>-30</td>
<td>-25</td>
<td>-20</td>
<td>-17</td>
<td>-15</td>
<td>-13</td>
<td>-12</td>
<td>-11</td>
<td>-10</td>
<td>-9</td>
<td>-8</td>
<td>-7</td>
</tr>
</tbody>
</table>

**Panel A: time-series average of cross-sectional excess return distribution**

**Panel B: time-series distribution of monthly cross-sectional mean excess return**

**Notes:** The table shows the selected statistics from the distribution of short one month ATM and OTM call and put, and ATM straddle price and margin-based excess returns; each month, on the second trading day following the monthly expiration, the ATM (OTM) call and put for each are stock defined to be the one month options with delta closest to 0.5 and -0.5. 0.2 and -0.2, respectively; the straddle is comprised of the ATM call and the put with the same strike; the mean, as well as selected percentiles of the cross-sectional distribution of the price and margin-based returns are calculated each month; Panel A presents the time-series means of the monthly cross-sectional means and percentiles; Panel B presents the time-series distribution of monthly cross-sectional means; the column labeled Reduction% presents the percentage reduction in average cross-sectional mean excess return achieved by using the margin return as compared to the price return; the sample covers holding periods ending from February 1996 through October 2010; all values are in percent.
5.2 Index options
Here I investigate the impact of the margin requirement on index option returns. Several authors have found that the returns associated with selling puts or selling straddles on an index are very large. Coval and Shumway (2001) show that calls (puts) are expected to have positive (negative) returns for underliers with positive correlation to the market, and find that S&P index options returns, while exhibiting these characteristics, underperform their expectations. They interpret this result as evidence of a negative price of volatility risk[16]. Bondarenko (2003) finds very large negative returns associated with selling ATM and OTM S&P 500 index puts, and concludes that the returns are too large in magnitude to be associated with any reasonable investor preferences.

Table III presents the time-series distribution of monthly returns associated with selling ATM and OTM calls and puts, and ATM straddles for the S&P 500 and Nasdaq 100 indices[17]. The positions are constructed in exactly the same manner as the stock option positions.

The results indicate that margin requirements reduce the magnitude of short index option returns by 59-92 percent. The percentage of months that realize losses in excess of 100 percent, and the size of losses in these months is also substantially decreased. Consistent with results of previous studies, selling S&P and Nasdaq puts produces very large price-based returns. When margin requirements are introduced, the returns associated with selling ATM (OTM) S&P puts are only 3.20 percent (3.40 percent) per month, compared to returns of 18.83 percent (44.02 percent) using the price-based measure. The results for short Nasdaq put positions are similar[18].

Finally, the results demonstrate that price-based returns may exaggerate estimates of the gains realized by shorting index straddles. S&P straddle returns are frequently used as estimates of the price of volatility risk. The results indicate that accounting for margin requirements may reduce straddle return-based estimates of the price of volatility risk by as much as 61 percent.

5.3 Summary of effects of margin requirements
In summary, the margin requirement-based return calculation performs as designed. Diversified short option portfolios (index option portfolio) never (rarely) realize losses in excess of 100 percent of the margin requirement. The margin requirement-based returns associated with such strategies are more reflective of the returns realized by investors than the price-based returns. In the next section, I turn my attention the effects of margin requirements on long/short option portfolio return analyses.

6. Effect of margin on long/short portfolio analysis
Several recent studies have analyzed the cross-section of option returns. Most notably, Goyal and Saretto (2009) (GS hereafter) use a long/short portfolio analysis to detect a positive cross-sectional relation between $HV - IV$ (historical minus implied volatility) and price-based ATM straddle returns[19]. In this section, I replicate the GS results, and demonstrate that using margin-based returns results in a lower, more realistic, high-low (10-1) portfolio return, while maintaining the level of statistical significance. En-route, I develop additional methodological modifications, necessitated by the use of margin-based returns, to the standard portfolio analysis.
| Position | ATM/OTM | Index | Return | Mean     | Reduction% | Min. 1% | 2% | 3% | 4% | 5% | 25% | 50% | 75% | 95% | 96% | 97% | 98% | 99% | Max. |
|----------|---------|-------|--------|----------|------------|---------|----|----|----|----|-----|-----|-----|-----|-----|-----|-----|-----|
| Short    | ATM     | S&P   | Price  | 1.32     | -367       | -310    | -292| -265| -260| -257| -80  | 61  | 100 | 100 | 100 | 100 | 100 | 100 |
|          | Margin  |       |        | 0.28     | 78.7       | -83     | -70 | -64 | -61 | -59 | -55  | -18 | 13  | 22  | 24  | 24  | 25  | 25  |
| Nasdaq   | Price   |       | -12.88 | -615     | -401       | -360    | -350| -329| -322| -302| -105 | 76  | 100 | 100 | 100 | 100 | 100 | 100 |
| OTM      | S&P     | Price  | 12.84  | -1,050   | -873       | -637    | -618| -570| -522| -500| 100  | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Nasdaq   | Price   |       | -14.19 | -1,813   | -999       | -809    | -735| -705| -647| -622| 100  | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
|          | Margin  |       | -1.11  | -134     | -75        | -66     | -62 | -60 | -53 | -50 | 6    | 7   | 8   | 8   | 8   | 8   | 8   | 8   |
| Short    | ATM     | S&P   | Price  | 18.83    | -639       | -565    | -463| -347| -282| -21  | 100  | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
|          | Margin  |       | 3.20   | 83.0     | -106      | -94     | -89 | -64 | -50 | -47  | -3   | 15  | 17  | 19  | 19  | 19  | 19  | 19  |
| Nasdaq   | Price   |       | 20.95  | -630     | -528      | -345    | -281| -274| -266| -9   | 100  | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| OTM      | S&P     | Price  | 44.02  | -1,244   | -1,121    | -900    | -566| -361| -314| -282| 100  | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Nasdaq   | Price   |       | 36.70  | 92.3     | -109     | -91     | -73 | -51 | -29 | -26  | 7    | 8   | 8   | 8   | 8   | 8   | 8   | 8   |
|          | Margin  |       | 3.40   | 90.7     | -111     | -89     | -50 | -37 | -35 | -32  | 7    | 8   | 8   | 8   | 8   | 8   | 8   | 8   |
| Nasdaq   | Price   |       | 4.64   | 102      | -200     | -244    | -188| -133| -115| -111| -37  | 16  | 61  | 92  | 95  | 97  | 98  | 99  |
|          | Margin  |       | 1.88   | 59.5     | -110     | -102    | -80 | -59 | -49 | -47  | 14   | 7   | 25  | 38  | 39  | 40  | 41  | 43  |

Notes: The table presents the time-series distribution of short one month ATM and OTM call and put, and ATM straddle price and margin-based excess returns for S&P 500 (S&P) and Nasdaq 100 (Nasdaq) index options; each month, on the second trading day following the monthly expiration, the ATM (OTM) call and put for each index are defined to be the one month options with delta closest to 0.5 and 20.5 (0.2 and 20.2), respectively; the straddle is comprised of the ATM call and the put with the same strike; the table presents the mean and selected percentiles of the time-series distribution of monthly price and margin-based excess returns; the column labeled Reduction% presents the percentage reduction in average cross-sectional mean excess return achieved by using the margin return as compared to the price return; the sample covers holding periods ending from February 1996 through October 2010; all values are in percent.
6.1 Replication of Goyal-Saretto results

I begin by replicating the results of GS. Each month, on the first trading day after option expiration, \( HV - IV \) is calculated. \( HV \) is the one-year historical stock volatility, calculated as \( HV = \sigma_{R,Daily} \sqrt{252} \), where \( \sigma_{R,Daily} \) is the standard deviation of daily log returns over the past year[20]. \( IV \) is calculated using one month options in exactly the same way as \( V \) in the margin requirement calculation. For a stock/month pair to gain entry into the sample, I require that return data be available for all trading days during the \( HV \) calculation period, and that the absolute deltas of the options used to calculate \( IV \) be between 0.4 and 0.6.

On the second trading day following expiration, I form decile portfolios of one-month straddles sorted on \( HV - IV \). The portfolios are held for one month, until the options expire. For a stock/month observation to enter the sample, I require that stock return data for all days during the portfolio holding period be available in OptionMetrics.

The results, presented in Table IV Panel A, are very similar to those of GS Table III. The first decile portfolio realizes an average monthly loss of 13.09 percent (GS find loss of 12.8 percent), and the tenth decile portfolio gains 5.52 percent per month (GS find gain of 9.9 percent). The cross-sectional difference in returns is a very statistically significant 18.61 percent (\( t \)-statistic is 8.38). The table shows that the results are not driven by any of the market, size, book-to-market, or momentum factors of Fama and French (1993) or Carhart (1997)[21]. Panel A demonstrates that the sample I am working with exhibits the same cross-sectional pattern of straddle returns as the sample used by GS.

Panel B shows the margin-based returns of decile portfolios of short straddle positions sorted into deciles of \( HV - IV \). As the positions analyzed in Panel B are short straddle positions, the difference between the tenth decile and first decile returns takes a negative sign. Notice that due to margin requirements diluting the returns, the magnitude of the return difference between the tenth and first decile portfolios has decreased significantly to 8.67 percent a month, but the statistical significance of the difference, measured by the magnitude of the \( t \)-statistic, has changed very little.

6.2 Long/short straddle portfolio returns

Neither Panel A nor Panel B of Table IV represent the returns realized by a tradable investment strategy. The results in Table IV simply represent cross-sectional differences in the returns from long (Panel A) and short (Panel B) straddle positions[22].

An investor who longs straddles on certain stocks and shorts straddles on other stocks will be required to supply margin equal to the sum of the margin requirements on the long and short straddle positions[23]. For an investor who commits equal margin to long (short) straddles for the tenth (first) decile of \( HV - IV \), the realized return is therefore half of the tenth decile long return (tenth decile from Table IV, Panel A), plus half the first decile short return (first decile from Table IV, Panel B). The returns of this portfolio are shown in Table V Panel A[24]. The results demonstrate that the returns realized by an investor implementing this strategy are much lower than indicated in Table IV, and the \( t \)-statistics have dropped considerably. The drop in returns is an expected outcome of using margin requirements. The drop in \( t \)-statistics comes from increased risk due to unequal position sizes on the long and short sides of the portfolio. The next section discusses how to remedy this issue.
### Table IV.

Relation between $HV - IV$ and straddle returns

<table>
<thead>
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<th>10</th>
<th>10-1</th>
<th>10-1 $t$-stat.</th>
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</thead>
<tbody>
<tr>
<td><strong>Panel A: $HV - IV$ decile long straddle portfolio excess returns</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excess ret</td>
<td>-13.09</td>
<td>-9.72</td>
<td>-7.55</td>
<td>-5.10</td>
<td>-3.02</td>
<td>-2.30</td>
<td>-2.03</td>
<td>-0.18</td>
<td>1.08</td>
<td>5.52</td>
<td>18.61</td>
<td>8.38</td>
</tr>
<tr>
<td>CAPM</td>
<td>-12.47</td>
<td>-8.85</td>
<td>-6.69</td>
<td>-4.12</td>
<td>-1.89</td>
<td>-1.29</td>
<td>-1.05</td>
<td>0.78</td>
<td>2.14</td>
<td>6.51</td>
<td>18.98</td>
<td>8.87</td>
</tr>
<tr>
<td>FF3</td>
<td>-11.98</td>
<td>-8.44</td>
<td>-6.10</td>
<td>-3.63</td>
<td>-1.31</td>
<td>-0.60</td>
<td>-0.37</td>
<td>1.57</td>
<td>2.69</td>
<td>7.21</td>
<td>19.18</td>
<td>8.36</td>
</tr>
<tr>
<td>FFC4</td>
<td>-11.88</td>
<td>-8.50</td>
<td>-6.15</td>
<td>-3.63</td>
<td>-1.29</td>
<td>-0.80</td>
<td>-0.49</td>
<td>1.66</td>
<td>2.52</td>
<td>7.02</td>
<td>18.89</td>
<td>8.70</td>
</tr>
</tbody>
</table>

<table>
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<tr>
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<th>10-1</th>
<th>10-1 $t$-stat.</th>
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</thead>
<tbody>
<tr>
<td><strong>Panel B: $HV - IV$ decile short straddle portfolio excess returns</strong></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Excess ret</td>
<td>6.16</td>
<td>4.48</td>
<td>3.38</td>
<td>2.26</td>
<td>1.41</td>
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<td>0.93</td>
<td>0.12</td>
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<tr>
<td>CAPM</td>
<td>5.86</td>
<td>4.07</td>
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<td>1.81</td>
<td>0.89</td>
<td>0.63</td>
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<td>-0.97</td>
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<tr>
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<td>2.70</td>
<td>1.59</td>
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<td>-1.12</td>
<td>-3.17</td>
<td>-8.76</td>
<td>-8.59</td>
</tr>
</tbody>
</table>

**Notes:** Goyal and Saretto (2009) demonstrate a positive relation between $HV - IV$ and straddle returns; Panel A presents a replication of the main result of Goyal and Saretto (2009); each month, portfolios of straddle positions are formed by sorting stocks into deciles of historical volatility minus implied volatility ($HV - IV$); $HV$ is the realized volatility over the past one year; $IV$ is the average of the ATM call and ATM put implied volatilities; the signal, $HV - IV$, is calculated on the first trading day after each monthly expiration; on the second trading day, portfolios of ATM straddles are formed based on the deciles of $HV - IV$; Panel A presents the decile portfolio excess returns for long ATM straddle positions, thus replicating the main result of Goyal and Saretto (2009); Panel B presents the portfolio excess returns for short ATM straddle positions using the margin requirement-based returns; the row labeled Excess Ret presents the excess returns for each of the decile portfolios; the rows labeled CAPM, FF3, and FFC4 present the alphas from the capital asset pricing model (Sharpe, 1964; Lintner, 1965), Fama and French three-factor model (Fama and French, 1993; Carhart, 1997) risk models; the column labeled 10-1 presents the difference in returns or alphas between the tenth and first decile portfolios; the column labeled 10-1 $t$-stat presents the $t$-statistic testing the null hypothesis that the average return or alpha of the 10-1 portfolio is equal to 0; all $t$-statistics are calculated using the Newey and West (1987) adjustment with six lags; the sample covers holding periods ending from February 1996 through October 2010; all excess returns and are in percent.
6.2.1 Vega hedged long/short straddle portfolio returns. Allocating equal margin to the long and short sides of the portfolio results in much smaller position sizes for the short side, and as a result a substantial long aggregate volatility exposure. Not only is this inconsistent with how a long/short investor would likely construct her portfolio, but it fails to isolate the targeted cross-sectional effect, in this case the relation between \( HV - IV \) and straddle returns. To alleviate this issue, an investor would allocate the portfolios such that there is equal \( \text{vega} \) exposure on the long and short sides. To generate the returns of the volatility hedged portfolio, at the beginning of each holding period, I calculate the total \( \text{vega} \) exposure for the long and short portfolios as the sum of the option \( \text{vegas} \) times the size of the option positions. The amount of margin committed to the long and short sides of the portfolio is then inversely related to the side’s total \( \text{vega} \) exposure.

Table V, Panel B shows the average returns for a long/short portfolio with equal \( \text{vega} \) exposure on both sides of the portfolio, along with the average percentage of total margin required by each side. As the long and short returns from Panel A are roughly the same,
it is not surprising that the re-weighting does not substantially change the average return. What does change is the risk of the long/short portfolio. Each of the $t$-statistics increase by more than 2.4. The standard deviation of the monthly returns decreases from 13.45 percent per month for the equal margin portfolio to 7.39 percent per month for vega neutral portfolio. The increased $t$-statistic and lower standard deviation is evidence that removing undesired cross-sectional variation in portfolio returns gives the portfolio analysis more power to detect the cross-sectional pattern being studied.

To test whether the increase in performance is statistically significant, I standardize the returns by dividing each monthly portfolio return by the standard deviation of the monthly portfolio returns. I then perform a $t$-test to compare the average standardized returns of the two investment strategies. The test produces a $t$-statistic of 3.23, strong evidence that the risk-reward profile of the vega-hedged investment strategy is superior to that of the equal margin portfolio.

6.3 Summary of long/short portfolio results
There are two main conclusions to be drawn from this section. First, when analyzing option returns in the cross-section, the high-low (in this case decile 10 – decile 1) return does not represent the return of an investable portfolio, as it fails to account for the margin requirement associated with short option positions. Second, when creating long/short option portfolios, allocating equal margin to the long and short portfolios may fail to isolate the targeted cross-sectional effect, as the portfolio may be exposed to aggregate volatility risk. The long/short portfolio should be constructed such that it is neutral to volatility (or other) risk. Doing so requires different margin commitments on each side of the portfolio.

7. Conclusion
Margin requirements have a large effect on the returns realized by an investor who is short options. In this paper, I develop and calibrate a model for calculating the margin requirement on portfolios containing short option positions. The results indicate that a margin requirement equal to the worst case portfolio loss for expiration stock prices between three standard deviations below and two standard deviations above the stock price at portfolio inception provides a realistic assessment of the returns realized by investors.

Empirically, I demonstrate that there is a very substantial difference between the price and margin-based returns for several common option strategies. Returns on standard short option positions can be reduced by as much as 91 percent when accounting for margin requirements. Furthermore, margin requirements reduce a straddle return-based estimate of the price of volatility risk by 61 percent.

In long/short portfolio analyses of option returns, generating realistic return estimates while effectively isolating the targeted cross-sectional effect requires allocating margin to the long and short portfolios in quantities such that unwanted risk exposure is hedged. When studying the cross-section of volatility portfolios, such as straddles, it is optimal to allocate margin such that there is an equal amount of volatility exposure on each side of the portfolio. Doing so removes exposure to aggregate volatility changes, resulting in increased power to detect the targeted pattern in option returns.
Notes

1. Quote taken from the CME web site. The worst possible loss is taken to be the margin-requirement. For more details on the calculation of the worst possible loss and CME margin requirements, see the CME web site: www.cmegroup.com

2. For calls (puts) that are far out-of-the-money, the minimum margin requirement is the market value of the option plus 10 percent of the value of the underlying security (10 percent of the strike). For combination positions such as short straddles, the margin-requirement is the maximum of the margin requirements for each of the two individual options. For more details on CBOE margin requirements, visit the CBOE web site: www.cboe.com

3. When a margin call occurs, the investor must produce enough cash to satisfy the call, or the position will be liquidated. This means that the investor must have been holding some cash in reserve to satisfy potential margin calls. It is unreasonable to assume that a margin call can be covered by profits from some other trading strategy implemented by the investor, as margin calls that cannot be met by investors tend to happen at the worst possible times (Santa-Clara and Saretto, 2009).

4. Broker-dealer margin requirements also vary substantially across brokers and clients.

5. Taking a margin-requirement equal to the worst case “reasonably probable” loss at expiration on a long term option portfolio will result in a very large margin requirement, creating a calculated return that may be smaller in magnitude than that realized by an investor.

6. It is important to note that the margin requirement does not include the initial proceeds from the sale. It is assumed that the initial proceeds are also available to cover potential required payouts. It is irrelevant to the investor whether the margin requirement is held in her own accounts or in a margin account with a broker-dealer or an exchange.

7. To be precise, $t_1$ is the last trading day before the option expiration. Option expiration dates fall on Saturdays, thus in most cases $t_1$ is the Friday before expiration.

8. See the Appendix for the details of the calculation of $PVDivs$ and $r$.

9. The term $PVDivs \times e^{rt}$ assumes that dividends are invested at the risk free rate from the payment date until expiration. The risk free rate at which the dividends are invested is determined by the theoretical forward rate calculated at the time of portfolio inception. Equivalently, the dividends are considered to be sold at time $t_0$ for their present value ($PVDivs$), with the proceeds invested in the risk free asset.

10. The payment is negative if the initial price of the portfolio, $S_0^C$, is negative (assuming a positive risk-free rate).

11. A portfolio comprised of only long positions of well in the money options may not have a reasonable probability of having a 0 payoff. Likewise, a portfolio with a long position in a call with strike $K$ and a long position in a put with a strike higher than $K$ would have a 0 probability of a payoff of 0. Such portfolios, however, are of little interest to researchers and of little practical use to investors.

12. All analyses performed in the calibration of the parameters $SD_d$ and $SD_u$ have also been done using one, two, three, six, and 12 month historical volatility as the value for $V$. The results are qualitatively similar.

13. The strike of the ATM call and ATM put contracts may not be the same.

14. Due to data availability, for two, three, and six month standardized returns, the analysis starts in March, April, and July 1996, respectively.

15. A more complete presentation of the time-series and cross-sectional distribution of option position returns is available in the internet Appendix. Results for two, three, and six month returns are also available.
16. The price of volatility risk, also referred to as the volatility risk premium, is the expected excess return of a portfolio subjected to one unit of volatility risk and no other risks. A negative volatility risk premium means that the expected excess return of such a volatility portfolio is negative.

17. Results for the two, three, and six month index option strategies are presented in the internet Appendix.

18. Contrary to the theoretical and empirical results of Coval and Shumway (2001), short positions in ATM S&P calls produce a positive average monthly price (margin) based return of 1.32 percent (0.63 percent). This departure from theory is due to the sample period. Unreported results from the subperiod 1996 through 2006 show negative returns. The market turmoil of 2007-2009 has a large impact on the full-sample results in Table III, as selling calls during this later period produced very high returns.

19. In another such study, Cao and Han (2009) find a negative cross-sectional relation between volatility and covered call returns.

20. In calculating HV, stock data from OptionMetrics is augmented by stock data from the Center for Research in Security Prices (CRSP) for dates prior to January 1996, as OptionMetrics does not provide data prior to this time. CRSP PERMNOs are matched to OptionMetrics Security IDs using CUSIPs.

21. Daily risk factor data is taken from Kenneth French’s online data library. As the holding periods for the option positions do not correspond to calendar months, monthly risk factor returns for the holding periods are calculated from the daily risk factor return data.

22. For long straddle positions, the price return and the margin based return are exactly the same, as the maximum loss is the initial price of the straddle.

23. One may argue that the long and short positions should have an offsetting effect on the amount of margin required, as one side will tend to profit when the other side loses. Conversations with industry practitioners indicate that for standard clients, broker-dealers are unlikely to reduce the margin requirement, but for large and preferred clients, the reduction can be substantial.

24. Because of this halving, the magnitude of returns presented in Table IV cannot be directly compared to those in Table V.

25. As straddle positions are primarily volatility positions, the risk to be hedged is volatility exposure. There are examples where it would be appropriate to allocate portfolios to hedge some other risk. For example, Bali and Murray (2012) form delta and vega hedged skewness positions on each stock. In this scenario, to isolate the cross-sectional skewness effect, the authors would want to allocate equal skewness exposure to the long and short portfolios. This would require an option pricing model that, unlike the Black and Scholes (1973) model and the Cox et al. (1979) model used by OptionMetrics, accounts for skewness.

References
Appendix. Calculation of risk free rate and present value of dividends

The present value of dividends ($PVDivs$) on date $t_0$ for an option expiring on date $t_1$ is calculated to be the sum of the present values of all dividends paid on the underlying stock with ex-dates between date $t_0$ (exclusive) and $t_1$ (inclusive). Specifically, let $Div_{e, t}$ be a dividend paid on the underlying stock with ex-date $e$ and pay-date $t$, where $t_0 < e \leq t_1$, and let $r_\tau$ be the risk-free rate of return on a deposit made on date $t_0$ to be withdrawn on date $t_\tau$, and $t_\tau$ be the time, in years, between dates $t_0$ and $t$, then we have:

$$PVDivs = \sum_{t_0 < e \leq t_1} e^{-r_\tau t_\tau} Div_{e, t}$$ (A1)

OptionMetrics provides zero-rate data for each date $t_0$ and a series of maturities. $r_\tau$, for any specific value of $t_0$ and $t_\tau$, is found by applying a cubic spline to the zero-rate data for date $t_0$ and finding the interpolated zero-rate for maturity $t_\tau$.

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