Trading the VIX Futures Roll and Volatility Premiums with VIX Options

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This study examines the efficiency of VIX option trading strategies that exploit the VIX futures roll and the often substantial VIX futures volatility premiums from January 2007 through March 2014. The study first assesses the related issue of whether VIX options typically are overpriced by examining long VIX option delta-hedged returns and demonstrates that average losses on front contract calls and puts over 5-business day horizons either are not statistically significant or are economically small. In light of the evidence that VIX option buyers on average do not overpay at all or by much for the limited risk associated with VIX options, the study then turns to whether long VIX option positions can be used to exploit the well-documented tendencies of VIX futures to rise and fall when the VIX futures curve is in backwardation and in contango, respectively, as well as the tendency of VIX futures to build in large ex-ante volatility premiums. The results demonstrate that these defined-risk strategies are highly profitable and offer attractive risk-reward tradeoffs. Moreover, the systematic tendencies of VIX futures have far more power for predicting attractive VIX option returns than the ex-ante volatility premiums built into VIX options. The study also shows that long VIX option strategies importantly benefit from a strong tailwind that owes to the tendency of VIX option implied volatilities to rise with increases in the actual volatilities of underlying VIX futures contracts, as VIX futures move toward settlement and their volatilities rise to the typically higher volatility of the VIX.

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VIX futures were introduced in 2004 and have become heavily traded contracts largely owing to their hedging properties stemming from the strong tendency of implied volatility to rise when equity indexes fall.[1] Nevertheless, the historical performance of VIX exchange traded products that roll over long VIX futures contracts has been extremely poor owing to the negligible predictive power of the VIX futures curve for subsequent (spot) VIX changes and because the VIX futures curve has been upward sloping or in contango roughly 80% of the time since the introduction of VIX futures contracts.[2] Because the VIX does not tend to rise when VIX futures are above the VIX, VIX futures tend to roll down the VIX futures curve to a lower VIX at settlement and lose their value. Likewise, when the VIX futures curve is in backwardation and VIX futures are below the VIX, the VIX does not tend to fall and VIX futures tend to roll up the curve to a higher VIX at settlement. Studies, such as Simon and Campasano (2014), demonstrate that shorting VIX futures contracts when the curve is sufficiently in contango and hedging the risk of a volatility spike with short S&P futures contracts and buying VIX futures when the curve is sufficiently in backwardation and hedging with long S&P futures contracts are highly profitable trading strategies from 2007 through 2012.

The present study examines whether the lack of forecasting power of the VIX futures curve as well as the tendency of VIX futures to build in large volatility premiums can be exploited with outright long VIX option positions that enjoy defined risk. An important factor

[1] See Szado (2009) for an analysis of the hedging properties of VIX futures and VIX options during the financial panic beginning in 2008.

[2] The VIX futures basis, defined in this study as the spread between the front VIX futures contract with at least 10 business days to settlement and the VIX, was in contango over 74% of this study's sample period from January 2007 through March 2014. The iPath S&P 500 VIX ST Futures ETN (ticker symbol VXX), which rolls over front VIX futures contracts, has lost more than 99% of its value since its inception in January 2009 through mid-August 2014. See Alexander and Korovilas (2011) and Whaley (2013) for more evidence on the poor performance of VIX-related exchange traded funds.

affecting the profitability of these strategies is the extent to which VIX options typically are overpriced. The overpricing of S&P 500 index options has been studied far more extensively than the overpricing of VIX options. Studies including Coval and Shumway (2001), Bakshi and Kapadia (2003), Eraker (2009) and Broadie, Chervnov and Johannes (2009) demonstrate that S&P 500 index options build in substantial ex-ante volatility premiums over recent actual volatility. For example, Eraker (2009) reports that the VIX averaged 19% from 1990 through 2007, while the annualized standard deviation of S&P 500 index returns averaged 15.7%, which caused S&P 500 index option selling strategies to be very attractive on a risk-adjusted basis.[3] Because the VIX reflects model-free implied volatilities of S&P 500 index options and because the VIX futures curve frequently is in contango, VIX futures contracts tend to be higher than the VIX and build in more substantial ex-ante volatility premiums than S&P 500 index options or the VIX.

By contrast, only a few studies have focused on the potential overpricing of VIX options, which were introduced in April 2006.[4] Song (2012) examines zero-delta long VIX option straddles and delta-hedged long VIX option portfolios and finds that they earn significantly negative returns.[5] Barnea and Hogan (2012) examine VIX option volatility premiums by creating synthetic variance swaps. They find that the realized variance of VIX futures contracts is on average 3.26% below variance swap rates implicit in VIX options and conclude that selling VIX options on a delta-hedged basis should be profitable. However, they do not test this hypothesis. More recently, Huang and Shaliastovich (2014) examine monthly delta-hedged VIX

[3] Coval and Shumway (2001) demonstrate that zero beta 1-month S&P 500 index straddles lost 3.2% of their values per week from January 1986 through October 1995. Bakshi and Kapadia (2003) show that delta-hedged long S&P 500 index call options with 31 to 60 days to expiration that were at the money to 2.5% out of the money lost on average 4.44% of their values through expiration from 1988 through 1995. Broadie, Chernov and Johannes (2009) show that for 1 month at the money S&P 500 index puts, CAPM adjusted returns were a highly statistically significant -22.5% with Sharpe ratios of -.23 from August 1987 through June 2005.

[4] Much of the literature on VIX options, such as Wang and Daigler (2011), Grunbichler and Longstaff (1996) and Carr and Lee (2009), focuses on the relative explanatory powers of different option pricing models rather than on volatility premiums and the possible overpricing of VIX options.

[5] Song (2012) finds that at the money zero delta VIX option straddles lose an average of 6% per week and delta-hedged 1-month at the money VIX calls lose an average of 12% through expiration.

options returns and find significantly negative returns from 2006 through 2013. They also find that negative returns are greater for close to the money VIX options and when VIX option implied volatility is high, which they argue reflect risk premiums associated with the volatility of volatility.[6]

The present study assesses whether VIX options tend to be overpriced by examining unconditional delta-hedged VIX option returns over 5-business day horizons and then examines the profitability of outright long VIX option trading strategies that exploit the well-known regularities of VIX futures. The findings demonstrate that long delta-hedged VIX call and put P&Ls across several front contract strikes either are not significantly negative or average losses are economically modest over 5-business day horizons.[7] The study then examines delta-hedged 5-business day returns when *ex-ante* VIX option volatility premiums, defined as the spread between VIX option implied volatility and adjusted lagged 10-business day VIX futures volatility are above their top quartile cutoffs, where the adjustment is for the tendency of VIX futures volatility to rise to the typically higher volatility of the VIX as VIX futures contracts move closer to their settlement dates. The results indicate that that while average losses become greater and are almost always statistically significant, they remain relatively modest, which suggests that even in these circumstances VIX options typically are not substantially overpriced.

The evidence that VIX options are not overpriced at all or by much over the sample period suggests that outright purchases of VIX options to exploit the systematic tendencies of VIX futures could be attractive strategies that also enjoy limited risk. This study examines VIX option trading strategies based on the VIX futures roll that purchase VIX calls when the VIX futures curve is in backwardation and purchase VIX puts when the VIX futures curve is in contango, as well as strategies that purchase VIX puts when ex-ante VIX futures volatility

[6] Huang and Shaliastovich (2014) find that delta hedged returns on 1-month VIX options held to expiration range from -3.4% to -22.1% percent for calls and from -6.2% to -17.7% for puts.

[7] Explanations are provided later for the more modest average losses on delta-hedged long VIX option positions found in the present study versus those in Song (2012) and in Huang and Shaliastovich (2014).

premiums are unusually high. The results demonstrate that these strategies are highly profitable for front contract VIX options across several strikes. The results also suggest that VIX futures tendencies play a more important role in predicting attractive VIX option returns than ex-ante volatility premiums of VIX options. The study also shows that long VIX option strategies benefit greatly from a strong tailwind that owes to the tendency of VIX option implied volatilities to rise with increases in the volatilities of underlying VIX futures contracts, as VIX futures move toward settlement and their volatilities rise to the typically higher volatility of the VIX.

The paper proceeds as follows: The first section presents background information on VIX options, describes the methodology used to calculate implied volatility and the greeks and then summarizes the data. The second and third sections examine 5-business day P&Ls of delta-hedged long VIX option positions entered unconditionally and then only when VIX option ex-ante volatility premiums are above their upper quartile cutoffs. The fourth section examines the profitability of outright VIX option purchases that exploit both the VIX futures curve's lack of predictive power for subsequent levels of the VIX and the fifth section examines the profitability of buying VIX puts when VIX futures reflect unusually large ex-ante volatility premiums. The final section discusses the implications of the findings.

I. Background on VIX Options

VIX options were introduced in April 2006 and are European options that are cash-settled based on VIX futures contracts that settle at the same time. Consequently, VIX options are priced off corresponding VIX futures contracts rather than the VIX. VIX futures and VIX options expire on Wednesdays that are 30 days before S&P 500 index options expire and settle

based on opening Wednesday quotes of S&P 500 index options that expire in 30 days.[8] VIX futures are risk neutral measures of expected future 30-day implied volatilities of S&P 500 index options, while VIX option implied volatilities are risk neutral measures of expected future volatilities of VIX futures returns.

This study uses Black's (1976) futures option pricing model to calculate the implied volatilities and the greeks of VIX options. This choice is supported by Wang and Daigler (2011), who find that the Black model used by Whaley (1993) outperforms more sophisticated stochastic volatility models in pricing VIX options, such as those developed by Grunbichler and Longstaff (1996) and Carr and Lee (2009). The present study specifies the Black (1976) model in business rather than calendar days because VIX futures return volatilities from Friday to Monday closes are in line with those from consecutive days during the business week.[9]

The VIX options data are from ivolatility.com and are matched with corresponding VIX futures settlement prices from Bloomberg to calculate implied volatilities and the greeks. Short term interest rates are proxied with interpolated 1 and 3-month Eurodollar deposit rates from the Federal Reserve Board database. The analysis examines the 5 closest to the money VIX calls and puts of the nearest contract with at least 10 business days to expiration. The data are filtered for errors by calculating deviations from put-call parity, taking quoted option bid-ask spreads into account. Observations with deviations greater than 5 cents are excluded from the dataset.[10] Specifically, put-call parity violations are considered present and observations are excluded if

[8] Both VIX futures and VIX options contracts stop trading at the close on the last business day before expiration day. For example, the September 2014 VIX futures contract and September 2014 VIX options settled on Wednesday September 18, 2014 based on opening S&P 500 index option prices that day, but stopped trading at the close on Tuesday September 17. Pavlova and Daigler (2008) demonstrate convergence problems sometimes occur at the final settlement of VIX futures contracts. This is not an issue in the present study because the options examined are no closer than 5 business days to expiration.

[9] The annualized volatility of front VIX futures returns from Friday to Monday closes is 69.6 percent compared to 68.4 percent for close to close returns during consecutive days during the business week over the sample period from January 2007 through March 2014.

[10] For example, the possibility that call prices are too high relative to put prices is tested in ($1^{/}$) by examining potential arbitrage profits from getting short VIX futures synthetically by selling calls at the bid price and buying puts at the ask price and buying VIX futures. The opposite is tested in ($1^{//}$) by examining potential arbitrage profits

$$C_{bid} - P_{ask} - (F-X)\, e^{(-rt)} > .05 \qquad \text{or} \qquad (1')$$

$$C_{ask} - P_{bid} - (F-X)\, e^{(-rt)} < -.05. \qquad (1'')$$

These filters cause less than 1% of quotes for all levels of moneyness for the front contract to be thrown out.

This study defines ex-ante VIX option volatility premiums as the spread between VIX option implied volatilities and lagged 10-business day VIX futures volatilities, with the latter adjusted for the number of business days until settlement. This adjustment is important because VIX futures volatility rises substantially to the typically higher volatility of the VIX as VIX futures move toward settlement. The latter is reflected by the annualized 10-business day standard deviations of the VIX and the front VIX futures contract, which average 104% and 56%, respectively. The former is reflected by the average difference between these volatilities falling from 53 percentage points when front VIX futures are between 25 and 30 business days to settlement to 43 percentage points when the VIX futures contract are between 10 and 15 business days to settlement, with VIX futures volatility increases accounting for the entire change in the gap.[11] Hence, the actual volatility of VIX futures contracts tends to increase substantially as VIX futures move toward expiration and not adjusting for VIX futures contracts having an average of 5 fewer business days to settlement compared to when its volatility is measured (over the previous 10 business days) would bias volatility higher. This bias also would be greater for contracts that are closer to settlement because 5 business days comprise greater fractions of their

from getting long synthetically by buying calls at the ask price and selling puts at the bid price and shorting VIX futures.

[11]Over the intervals from 25 to 30 business days to settlement to 10 to 15 business days to settlement, average 1-day annualized volatilities (annualized absolute returns) of front VIX futures contracts rises from 42% to 55%.

remaining lives. The adjusted 10-business day VIX futures volatility is calculated by interpolating between VIX and VIX futures volatilities and is equal to

$$\sigma_{VIXFADJ} = \frac{5}{n+5}\sigma_{VIX} + \frac{n}{n+5}\sigma_{VIXF}, \quad (2)$$

which is a weighted average of lagged 10-business day VIX volatility and lagged 10-business day VIX futures volatility, where the former is weighted by 5 divided by the number of business days until settlement (n) plus 5 and the latter is weighted by the number of business days until settlement divided by the number of business days until settlement plus 5.[12] Later results show that the tendency of VIX futures volatility to rise to the higher volatility of the VIX as VIX futures move toward settlement is an important tail wind for long VIX option strategies owing to VIX option implied volatilities rising with actual VIX futures volatility.

Figure 1 shows the level of the front VIX futures contract and the implied volatilities of at the money VIX option implied volatilities from January 2007 through March 2014. The figure demonstrates that the implied volatilities of VIX options are well above those of S&P 500 index options, as reflected by the level of the front VIX futures contract. The figure also shows that VIX futures spikes are accompanied by VIX option implied volatility spikes and that VIX option implied volatilities are substantially more volatile than the VIX.

Exhibit 1 shows VIX option mid-point closing quotes, bid-ask spreads, implied volatilities, adjusted lagged 10-business day historical volatilities of corresponding VIX futures returns and ex-ante volatility premiums, defined as the difference between VIX option implied volatilities and adjusted lagged 10-business day VIX futures volatilities. The options examined

[12] If the VIX futures contract has 10 business days until settlement, historical volatility is interpolated from historical VIX volatility and VIX futures volatility, with the later calculated from observations that were on average 15 business days from settlement. As a result, the weights would be 1/3 and 2/3 on the VIX and VIX futures volatilities, respectively. Likewise, if VIX futures have 20 business days until settlement the weights would be 5/25 and 20/25, respectively.

in this study are the closest to expiration calls and puts that have at least 10 business days to expiration with strikes that are closest to being at the money (ATM), one and two strikes below the ATM strike (ATM-1 and ATM-2) and one and two strikes above the ATM strike (ATM+1 and ATM+2). The exhibit shows that average call prices range from 1.32 for out of the money calls to 3.87 for in the money calls, while average put prices range from .77 for out of the money puts to 4.49 for in the money puts. Average closing bid-ask spreads are wide and range from .12 for out of the money calls to .25 for in the money calls and from .10 for out of the money puts to .26 for in the money puts. Traders who pay these average bid-ask spreads on round trip transactions would lose roughly 5 to 10 percent of the value of options, which would undermine the profitability of many short-term VIX option trading strategies including those examined in this study. However, the data also show that closing bid-ask spreads can be as low as a much more manageable .05 point. The trading simulations conducted in this study abstract from the cost of bid-ask spreads, but it is clear that the strategies examined in this study require finessing bid-ask spreads. Bid-ask spreads have fallen sharply over the sample period and this evidence as well as the implications of wide quoted VIX option bid-ask spreads are discussed later in the study.

VIX option implied volatilities exhibit a pronounced volatility skew, with the two strike below the money implied volatilities averaging 74 percent and the two strike above the money implied volatilities averaging 96 percent. The volatility skew is consistent with strong buying pressure in out of the money calls to hedge equity portfolios and strong selling pressure in out of the money puts to defray part of the cost of buying out of the money calls.[13] These average VIX option implied volatilities exceed adjusted 10-business day VIX futures historical volatilities, which average 66 percent over the sample period. The pronounced volatility skew results in a

[13] The volatility skew has substantial effects on option prices. For example, if two strike out of the money calls are priced with the average 85 percent implied volatility of at the money calls rather than their actual average implied volatility of 95.6 percent, their average price falls from $1.32 to $1.07.

wide range of ex-ante volatility premiums across strikes, which average from 7 percentage points for the lowest strike options to 29 percentage points for the highest strike options. These large ex-ante volatility premiums also exhibit a great deal of variation, as the top decile cutoff for at the money calls and puts is 42 percentage points, while the bottom decile cutoff is -10 percentage points, with similarly wide ranges for the other options.

Figure 2 shows the implied volatility of at the money VIX options and adjusted historical 10-business day VIX futures volatility and demonstrates the presence of large ex-ante volatility premiums over most of the sample period. Whether these large ex-ante volatility premiums translate into statistically significant and economically meaningful losses on delta-hedged long VIX call and put positions is examined in the next section.[14]

II. Unconditional VIX option delta-hedged returns

This section provides evidence on whether VIX options are overpriced by examining 5-business day delta-hedged VIX option returns. If the average returns from buying VIX options and delta-hedging with VIX futures are statistically significantly negative and average losses are economically meaningful, they would be consistent with the presence of ex-post volatility premiums. This finding would suggest that VIX option buyers on average overpay for the limited risk offered by VIX options, which would tend to undermine the profitability of buying VIX options to exploit the tendencies of VIX futures. The results reported include P&Ls as well as returns, defined as P&Ls divided by mid-price option quotes at which positions are assumed to be entered. The study focuses on P&Ls because for low option prices, seemingly large

[14] The spread between VIX option implied volatility and adjusted lagged 10-business day VIX futures volatility is referred to as the ex-ante volatility premium to emphasize that even large spreads do not necessarily translate into losses on delta-hedged long VIX option positions, as demonstrated in the next section.

percentage returns could be highly misleading.[15] Because VIX option contracts are specified with 1 point worth $100 and because VIX futures contracts are specified with 1 point worth $1,000, the analysis assumes that 10 option contracts are purchased.[16] The deltas used to set up and rebalance hedges daily as well as the other greeks are calculated from Black's (1976) futures option pricing model on a business day basis. The greeks are re-calculated every day and the impacts of the greeks on profitability are aggregated over each day that trades are open. The reported p-values for the P&Ls and returns are based on randomly drawing with replacement the same number of trades from the results of the 5-business day trades for each option category and forming p-values from resampling 100,000 times. Because of the substantial skewness of VIX option P&Ls and returns, semi-standard deviations and Sortino ratios are shown rather than standard deviations and Sharpe ratios.[17]

Exhibit 2 shows mixed results for 5-business day delta-hedged long VIX call and put positions. For call options, mean P&Ls are significantly negative at the 5% level for 3 of the 5 strikes, while mean returns are not significantly negative at the 5% level for any of the 5 strikes. The statistically significant losses are concentrated in the higher strikes, consistent with the volatility skew and the tendency of the implied volatilities of higher strike VIX options to be greater. Average losses across all strikes are relatively modest and range from $15 to $34, which translate into small average negative returns ranging from -.1% to -2.5% of initial option values. The percentage of winning trades is centered at 40% and average sizes of gains on winning trades and losses on losing trades are about even across strikes. The top and bottom decile P&L cutoffs occur at smaller gains than losses. In terms of the greeks, the small average overall losses

[15] For example, a 50% return resulting from an option rising from .20 to .30 cents could exaggerate the magnitude of dollar gains and thus it is important to get a sense of dollar gains.

[16] For example, a trader who buys ten 50 delta VIX calls for 2.5 points would pay $2,500 and would delta-hedge by shorting 1/2 VIX futures contract. Because position sizes can be grossed up, the analysis allows for fractional VIX futures positions.

[17] The semi-standard deviations reported in this study set positive P&Ls and returns to zero and include these observations in the calculations, while the Sortino ratios reported in this study are equal to mean P&Ls and mean returns scaled by their semi-standard deviations.

can be explained by losses from time decay (theta) outpacing gains from gamma, and with gains from being long vega offsetting much of this differential.[18] The average gains from vega are substantial and average $82 across the 5 strikes and are an important tailwind that substantially cuts into the overall losses that otherwise would have occurred.

The P&Ls on delta-hedged long put positions are very similar to those of delta-hedged long call positions at the same strike. Average losses and returns on delta-hedged long put positions held for 5 business days are significantly negative at the 5% level for 2 of the 5 strikes, with average losses across the 5 strikes ranging from -$8 to -$33. Corresponding average returns are significantly negative at the 5% level for only 1 of the 5 strikes, with average returns ranging from -.2% percent to -1.2%. Once more, the scattered statistically significant losses and negative returns occur at the high strike options, consistent with the volatility skew causing these options to be more expensive. Across all strikes, gains occur in about 40% of the trades, while the average size of gains exceeds the average size of losses by a small margin. As was the case with calls, average losses on puts stem from time decay losses exceeding gains from being long gamma, and with much of this difference offset by the substantial benefits of being long vega, which range from an average of $48 to $109. [19]

Overall, the results indicate that average ex-post VIX option volatility premiums are economically modest over 5-business day horizons, which suggests that VIX option buyers typically do not overpay either at all or by much for the limited risk associated with being long

[18] The results presented here are not directly comparable to those of Song (2012) or Huang and Shaliastovich (2014) because the former examines one week returns on long straddle positions that are delta-hedged only at the outset, while the latter examine delta-hedged returns on 1-month VIX options held through expiration. In addition, the sample period of the present paper extends 3 years beyond the sample period of Song (2012) and 1 year beyond that of Huang and Shaliastovich (2014). However, the outcomes of delta-hedged VIX call and put long positions shown in exhibit 2 tend to be more negative if the sample period is truncated in April 2011 when Song's (2012) sample period ends.

[19] Unreported results demonstrate that adjusting delta-hedges for the volatility skew or for the tendency of VIX option implied volatilities to increase when VIX futures rise, along the lines of Crépey (2004), Vähämaa (2004) and Simon (2013), has little effect on the results. The adjustment to the Black delta is equal to vega times the change in VIX option implied volatility for a given change in VIX futures. Because the latter is positive with VIX options, the adjustment involves selling more VIX futures contracts against long VIX call positions and buying fewer VIX futures contracts against long VIX put positions.

VIX options.[20] More importantly, the results increase the likelihood that long VIX option strategies can be used effectively to exploit the well-known regularities of VIX futures contracts. However, the results do not rule out the possibility that VIX options are substantially overpriced at times and that avoiding outright purchases of VIX options under these circumstances might improve the trading strategies later examined. The next section examines this issue.

III. Conditional VIX option delta-hedged returns

The previous section demonstrates that average ex-post VIX option volatility premiums are fairly small over the sample period. This section examines whether losses on 5-business day delta-hedged long VIX option positions are substantially greater when ex-ante VIX option volatility premiums are high. Given the pronounced implied volatility skew, the thresholds for entering trades are that the spreads between implied volatility for each moneyness category and adjusted lagged 10-business day VIX futures volatility are above their highest quartile cutoffs over the sample period. These thresholds range from a low of 29.02 percentage points for calls and puts that are two strikes below at the money strikes to a high of 51.56 percentage points for calls and puts that are two strikes above at the money strikes.[21] Again, long VIX option positions are delta-hedged at the outset and deltas are rebalanced daily.

While it would be more natural for high ex-ante volatility premiums to trigger short rather than long delta-hedged VIX option trades, the assumption that traders buy VIX options conforms to the previous analysis and provides information about whether the small average losses on delta-hedged long VIX option positions increase substantially when ex-ante volatility

[20] While this claim may appear overly subjective, it is made in light of the losses being inadequate to spur attractive unconditional VIX option selling strategies and in the context of the much greater profitability of trading strategies examined later that take advantage of VIX futures tendencies.

[21] The cutoffs for the highest quartile VIX option volatility premiums are roughly 29.02, 37.30, 41.50, 46.13 and 51.56 percentage points for the ATM-2, ATM-1, ATM, ATM+1 and ATM+2 strikes, respectively.

premiums are in their highest quartiles. The results also provide indirect evidence about the profitability of shorting VIX options when ex-ante VIX option volatility premiums are high, which is a useful benchmark for assessing the profitability of long VIX option strategies aimed at exploiting the VIX futures roll and the often large ex-ante volatility premiums in VIX futures.

Exhibit 3 shows the results for VIX calls and puts. The p-values are the significance levels for the null hypothesis that losses or negative returns are not significantly greater when trades are entered only when ex-ante volatility premiums are in their highest quartiles rather than unconditionally.[22] The results for calls indicate that the incremental effects of the conditional entry rule are significant at the 5% level for mean P&Ls for only 1 of the 5 strikes and for mean returns for only 2 of the 5 strikes. Nonetheless, average losses are $21 to $90 greater than those in exhibit 2 and range from -$50 to -$121, with corresponding 5-business day returns ranging from -1.3% to -7.7%. The greater losses can be attributed largely to the frequency of winning trades ranging from 23% to 42% and to the tendency of the average size of losses to be greater than the average size of gains. As was the case with unconditionally entered long VIX call 5-business day trades, losses from theta outpace gains from gamma. However, with VIX call implied volatilities very high relative to recent actual volatility, gains from positive vega are lower and now offset less of these losses.

The 5-business day results for delta-hedged long VIX puts are fairly similar. The hypothesis that high ex-ante volatility premiums cause mean losses and mean negative returns to be greater is rejected at the 5% level for 2 of the 5 put options. However, once more mean losses

[22] These tests are run by randomly drawing with replacement from the outcomes of long delta-hedged VIX option positions shown in exhibit 2, where trades are entered and exited unconditionally every 5-business days. The p-values represent the probability of mean losses and negative returns from random draws being greater than those when VIX option volatility premiums are in their top quartiles. For example, in the case of the 2 strike in the money VIX calls, 87 random draws with replacement are made from the 345 trades summarized in exhibit 2, where 87 corresponds to the number of trades for 2 strike in the money calls in exhibit 3. The mean P&Ls and returns are calculated and the procedure is repeated 100,000 times. The reported p-value of .072 for the mean P&L indicates that 7.2% of the 100,000 randomly generated samples had greater mean losses than the mean loss of $49.72 in exhibit 3.

are greater with the entry rule and range from -$30 to -$107 and negative returns range from -1.3% to -10.3%. Across the strikes, the ratio of losing to winning trades tends to be roughly 3:1 and the average sizes of gains and losses tend to be about equal. Again, losses from time decay outpace gains from gamma and with gains from vega once more offsetting less of this difference.

The results for both calls and puts suggest that even when ex-ante VIX option volatility premiums are in their highest quartiles, average losses on 5-business day delta-hedged long VIX option positions tend to remain fairly small. Although this study does not focus on VIX option selling strategies, the results indicate that the average gains from selling VIX options are modest--even when ex-ante VIX option volatility premiums are high.[23]

The sometimes statistically significant greater average losses on delta-hedged long VIX option positions when VIX option ex-ante volatility premiums are in their highest quartiles suggest that strategies of purchasing VIX options to exploit VIX futures tendencies would benefit from avoiding these trades when ex-ante VIX option volatility premiums are in their highest quartiles and VIX options are unusually expensive. However, augmenting the trading strategies examined later with the entry condition that VIX option volatility premiums are below their top quartile cutoffs has mixed and only small effects on the outcomes and consequently are not reported. For the purpose of this study, the average ex-post VIX option volatility premiums are modest and hence should not undermine the profitability of using long VIX option positions to exploit VIX futures tendencies examined in the next section.

IV. Trading the roll with VIX options

[23] Downside risk-adjusted returns for short delta-hedged VIX options can not be inferred from the table because the Sortino ratio is based on the assumption that the risk is that the values of delta-hedged positions falls, which would be beneficial for traders with delta-hedged short VIX option positions.

This section examines VIX option strategies that exploit the lack of forecasting power of the VIX futures curve for subsequent VIX changes, which results in a tendency of VIX futures to rise when the VIX futures curve is in backwardation and to fall when the VIX futures curve is in contango. Simon and Campasano (2014) demonstrate this lack of forecasting power and the profitability of strategies that buy VIX futures contracts hedged by long mini-S&P futures positions when the VIX futures curve is in backwardation and sell VIX futures contracts hedged by short mini-S&P futures positions when the VIX futures curve is in contango. While hedging with offsetting mini-S&P futures positions greatly reduces the tail risk associated with buying or selling VIX futures contracts, these strategies do not enjoy limited risk. By contrast, buying VIX calls when the VIX futures curve is in backwardation and buying VIX puts when the VIX futures curve is in contango are limited risk strategies.

Along the lines of Simon and Campasano (2014), option trades are triggered when the daily roll--the spread between front VIX futures and the VIX, divided by the number of business days until the settlement of the VIX futures contract--is less than -.10 VIX futures point in the case of backwardation and greater than .10 point in the case of contango. A daily roll of .10 corresponds to $100 per business day as the value of one VIX futures point is $1,000. These positions are not delta-hedged because they are bets that VIX futures are going to rise when the curve is in backwardation and fall when the curve is in contango. The profitability of these trades is examined assuming 5-business day holding periods to focus on the impact of entry rules on profitability. As earlier, trades are entered and exited at the mid-point of closing bid-ask quotes and new trades are entered as soon as they are triggered, which could be on the same day that the previous trade is exited. Because of the pronounced skewness in VIX option returns, bootstrapped p-values once more are used to test the hypothesis that the results could have been

generated randomly and risk and risk-adjusted returns are assessed with semi-standard deviations and Sortino ratios.[24]

Because the performance of these strategies is compared to the performance of randomly entered long VIX option positions without delta-hedging, it is instructive first to get a sense of the performance of unconditional strategies. Exhibit 4 shows the results of rolling over long front month VIX call and put options for 5 business days without delta-hedging. Long VIX call positions are associated with average losses ranging from $68 to $104 and associated returns ranging from -1.9% to -5.6%, with none of the losses or negative returns statistically significant at the 5% level.[25] The average losses stem from the roughly 3:1 ratio of losing to winning trades, which is only partly offset by the greater average size of gains relative to the average size of losses. In terms of the greeks, much of the losses owe to positive delta. Gains from positive gamma and from being long vega with implied volatilities tending to rise, offset much of the losses from time decay.

By contrast, unconditionally rolling 5-business day VIX put long positions without delta-hedging results in mean gains ranging from $40 to $82 and positive returns ranging from .7% to 2%, but none statistically significant at the 5% level. In terms of the greeks, average gains can be more than explained by negative deltas, while once more the benefits of being long gamma and vega offset much of the loss from time decay. Despite their lack of statistical significance, the negative P&Ls of long VIX call positions and the positive P&Ls of long VIX put positions (both without delta-hedging) are consistent with the VIX futures curve being in contango during most of the sample period and the tendency of VIX futures to roll down the curve, leading to gains and losses for unconditional VIX put and VIX call positions, respectively.

[24] The procedure for calculating p-values for the trades based on the roll is as follows: P&L and return series are constructed for *all* possible overlapping 5-business day trades for calls and puts for each moneyness category. Random draws from these series equal to the number of trades based on the roll are made and mean P&Ls and mean returns are calculated. This procedure is repeated 100,000 times and the p-values are based on the frequency that the mean performance of each strategy is exceeded by randomly entered trades. Thus, a p-value of .01 implies that the actual strategy outperformed all but 1% of the randomly generated samples.

[25] The significance of P&Ls and returns is based on the same resampling procedures used in exhibit 2.

Exhibit 5 shows the results of buying VIX calls and holding for 5 business days when the VIX futures curve is in backwardation and the daily roll up inverted VIX futures curves is worth at least .10 VIX futures points or $100 per business day. Mean profits and mean returns are large and significantly positive at the 1% level for all strikes. Average gains range from $460 for 2 strike out of the money calls to $1,349 for 2 strike in the money calls, while mean returns range from 29% to 42%. The large average profits owe to the average size of gains being more than twice the average size of losses, as the percentage of winning trades ranges from 41% to 49%. The results also indicate favorably skewed outcomes with top decile P&L cutoffs at gains generally 3 times greater than the losses at bottom decile cutoffs.

The average overall gains are more than accounted for by the gains from delta, consistent with long VIX call positions profiting from VIX futures rolling up inverted VIX futures curves. The much greater gains from in the money calls relative to out of the money calls owes primarily to their larger deltas. Gains from gamma offset much of the losses from time decay and the effects of vega are small as VIX option implied volatilities do not tend to rise when VIX futures curves are strongly in backwardation, which can be explained by the already substantially elevated VIX futures volatilities and VIX option implied volatilities.[26] In addition to having much higher average P&Ls, long positions in the two in the money VIX calls also have the greatest downside risk-adjusted gains with Sortino ratios from .83 to .99, versus .60 to .66 for long positions in the two out of the money VIX calls. Overall, the results demonstrate that the profitability of these trades owes largely to using VIX calls as a substitute for buying VIX futures, consistent with both mean returns and risk-adjusted returns being enhanced by taking on more delta exposure. The relative outperformance of in the money calls also is consistent with

[26] When long VIX call trades are entered because the curve is in backwardation versus long VIX put trades entered when the curve is in contango, average adjusted lagged 10-business day VIX futures volatilities are 101% versus 59% and average at the money VIX option implied volatilities are 105% versus 83%. Consistent with the greater uncertainty when the VIX futures curve is strongly in backwardation versus contango, the average level of the front VIX futures contract is 32.6% versus 23.4%.

the volatility skew, which causes in the money VIX calls to have lower implied volatilities than out of the money VIX calls.[27]

Exhibit 6 shows the results of 5-business day trades involving buying the closest to expiration VIX puts when the VIX futures curve is in contango and the daily roll is greater than .10 point. All trades are all significantly profitable at better than the 5% significance level with mean P&Ls ranging from $142 for two strike out of the money puts to $374 for two strike in the money puts. These average profits correspond to significantly positive returns for 4 of the 5 strikes, with mean returns ranging from 6.8% to 11.4%. The profitability stems largely from the average size of gains being 1/2 to 2 times greater than the average size of losses and to the slightly higher frequency of winning versus losing trades. Large gains are also far more prevalent than large losses, as reflected by the top decile P&L cutoffs at gains typically about twice the losses at bottom decile cutoffs.

The profitability of these trades is more than explained by the negative delta of long VIX put positions and buying 2 strike in the money puts rather than 2 strike out of the money puts leads to greater mean profits, owing to the greater negative delta of in the money puts. However, Sortino ratios indicate that downside risk-adjusted gains tend to be smaller for the 2 strike out of the money puts versus the two strike in the money puts (.64 versus .72). This likely owes to the volatility skew, which causes in the money VIX puts to trade at considerably higher implied volatilities than out of the money VIX puts.[28]

In terms of the other greeks, time decay is a considerable drag on performance, but much of its effect is offset by the benefits of positive gamma and vega. Positive vega exposure contributes from $76 to $146 to average P&Ls, owing to the tendency of VIX option implied

[27] Long call trades are fairly well spread out throughout the sample period rather than heavily concentrated during the financial panic. For example, only 20 of the 42 trades for at the money calls are entered in 2008 and 2009.

[28] Unreported results indicate that buying VIX bear put spreads or buying VIX bull call spreads are not efficient ways to exploit the roll over 5 business day horizons when the VIX futures curve is in contango or backwardation, as losses from the options sold offset much of the gains on options purchased.

volatility to rise substantially when the VIX futures curve is in contango. This contrasts with the previous results that show that positive vega exposure has little effect on the profitability of long call positions when the VIX futures curve is in backwardation. Overall, the results suggest that buying VIX puts to take advantage of the tendency of VIX futures to roll down upward sloped VIX futures curves offers favorable risk reward tradeoffs and with limited risk.

V. Trading the VIX futures volatility premium with VIX put options

This section examines whether when VIX futures (and S&P 500 index option implied volatility) are unusually high relative to recent S&P 500 index actual volatility, a tendency of VIX futures to fall toward recent S&P 500 volatility and to a more typical ex-ante volatility premium can be exploited by buying VIX puts and holding for 5 business days without delta hedging. To determine whether VIX futures embed unusually large ex-ante volatility premiums, VIX futures are compared to the lagged 10-business day historical volatility of S&P 500 index returns and a threshold of 10 percentage points is chosen, which causes trades to be open during roughly 1/4 of the sample period.

Exhibit 7 shows that mean P&Ls and returns are highly significantly positive for all 5 strikes that are examined. Mean P&Ls range from $176 for two strike out of the money puts to $450 for two strike in the money puts. These average gains correspond to 10% to 21% returns, respectively. The profitability of the trades stems largely from average gains on winning trades being roughly 50% greater than average losses on losing trades, as the frequency of winning versus losing trades tends to be only somewhat higher than even. Consistent with the limited losses associated with buying VIX puts, the cutoffs for top versus bottom P&L deciles occur at considerably greater gains than losses. As was the case for buying VIX puts when the VIX futures curve is in contango, the results here show much greater average profitability for 2 strike

in the money puts versus 2 strike out of the money puts, which again owes to the much larger negative deltas of in the money puts. However, the Sortino ratios are fairly flat across strikes and range from .52 to .57, indicating that downside risk-adjusted returns across strikes are roughly equal, which likely owes to the volatility skew.

In terms of the greeks, the strong gains owe to the large VIX futures declines, as average gains from delta more than account for total average gains. Gains from positive gamma offset about half of the losses from theta and the benefits of being long vega are substantial as the implied volatility of VIX puts rises substantially and contribute average gains ranging from $64 to $153. The tendency of VIX put implied volatility to rise substantially, while VIX futures fall, seems counterintuitive and likely stems from VIX futures volatility increasing as contracts move toward settlement dates and VIX option implied volatility rising in sympathy. This is consistent with a tendency of VIX futures curves to be strongly in contango when trades based on VIX futures volatility premiums are triggered, which indicates a meaningful overlap between these trades and those triggered by contango.[29]

VI. Conclusion

This study examines whether substantial volatility premiums are built into VIX options and then assesses whether buying VIX calls and puts are effective strategies for exploiting the systematic tendencies of VIX futures. The study finds that mean losses on delta-hedged front month long call and long put positions held for 5 business days are relatively modest and often not statistically significant over the sample period from January 2007 through March 2014. The results further demonstrate that when ex-ante VIX option volatility premiums are in their highest

[29] For long VIX put trades triggered by large VIX futures volatility premiums, the spread at the outset of trades between the front VIX futures and the VIX averages 2.27 percentage points versus 2.67 percentage points for the long VIX put trades triggered by contango.

quartiles, mean losses tend to be highly statistically significant but remain relatively small. The overall modest losses are surprising in light of the large average spreads between VIX option implied volatilities and adjusted lagged 10-business day VIX futures volatilities, which range from 7 to 29 percentage points for low and high strike VIX options, respectively.

An important issue is why the roughly 3 percentage point difference between S&P 500 index option implied volatility and S&P 500 historical volatility reported by Eraker (2009) translates into outsized negative returns on delta-hedged long S&P 500 index option positions, while the much larger ex-ante volatility premiums in VIX options translate into only modest losses on delta-hedged long VIX option positions. A major factor responsible for the moderate losses on VIX options is that being long vega over the sample period contributes substantially to the returns of delta-hedged VIX option long positions, as VIX option implied volatility increases offset much of the net negative effect rising from greater losses from time decay relative to gains from gamma. While the large profits from vega could be sample-specific, they occur against a backdrop of both the VIX and VIX futures *not* rising on balance over the sample period as average 5-business day VIX and VIX futures changes are -.0014 and -.15 percentage points, respectively, while average vega gains from rolling over long VIX put positions every 5 business days range from $48 to $109.[30] These average gains from vega have substantial impacts on overall profitability given that overall average losses on delta-hedged long VIX option positions held for 5 business days reach only as high as $34. An explanation for the vega gains is that VIX futures implied volatility increases with the strong tendency of VIX futures to be more volatile as VIX futures move closer to settlement, which makes sense to the extent that VIX option implied volatilities are set in light of *near-term* tradeoffs between gamma and theta.

The findings that market participants do not overpay at all or by much for the limited risk associated with being long VIX options contributes to the effectiveness of outright purchases of

[30] The greater average declines in VIX futures relative to the VIX owe to the tendency of the VIX futures curve to be in contango and for VIX futures to roll down the curve.

VIX options to exploit the tendencies of VIX futures. Along these lines, the study shows that buying VIX calls and holding for 5 business days to take advantage of the tendency of VIX futures to roll up VIX futures curves when in backwardation and the daily roll is worth at least $100 are highly significantly profitable strategies with mean profits across the 5 closest to the money strikes of the front contract ranging from $460 to $1,348 and mean returns ranging from 29% to 42%. Likewise, buying VIX puts to exploit the roll of VIX futures contracts down the VIX futures curve when in contango and the daily roll is worth at least $100 provides highly significant mean profits over 5 business days ranging from $142 to $374 across the 5 closest to the money strikes of the front contract and corresponding mean returns ranging from 7% to 11%. The results also indicate that buying VIX put options when VIX futures build in ex-ante volatility premiums relative to the lagged 10-business day volatility of S&P 500 index returns greater than 10 percentage points is also a highly significantly profitable strategy with 5-business day mean profits ranging from $176 to $450 and mean returns ranging from 10% to 21%. Overall, the results show that the systematic tendencies of VIX futures have far more power for predicting attractive VIX option returns than ex-ante VIX option volatility premiums.

The examined VIX option strategies have assumed that options trades are entered and exited at the mid-point of bid-ask spreads, which raises issues about the profitability of these trades after transactions costs. Given the large mean bid-ask spreads of VIX options reported in exhibit 1, many of the strategies examined in this study would not be robust to incurring the full costs of the quoted closing bid-ask spreads. However, the profitability of many of the strategies would remain robust to .10 point bid-ask spreads, which is roughly the average quoted bid-ask spread for at the money and out of the money VIX options over the last 2 years of the sample period.[31] In the case of in the money VIX options, traders could avoid their larger bid-ask

[31] Over subsamples from January 2007 through December 2011 and from January 2012 through March 2014 average at the money VIX option bid-ask spread quotes fell from .18 to .11 and average bid-ask spreads of 2 strike out of the money VIX calls fell from .13 to .10 and 2 strike out of the money VIX puts fell from .11 to .08.

spreads by positioning in equivalent synthetic positions with out of the money options. For example, instead of buying in the money VIX puts, traders could short VIX futures and buy out of the money VIX calls and instead of buying in the money VIX calls, traders could buy VIX futures and buy out of the money VIX puts. In any event, the success of many of the strategies examined in this study would have required traders to finesse VIX option bid-ask spreads, especially early in the sample period.

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Figure 1. VIX Futures (solid line) and the Implied Volatilities of at the money VIX options (dashed line) from January 2007 through March 2014

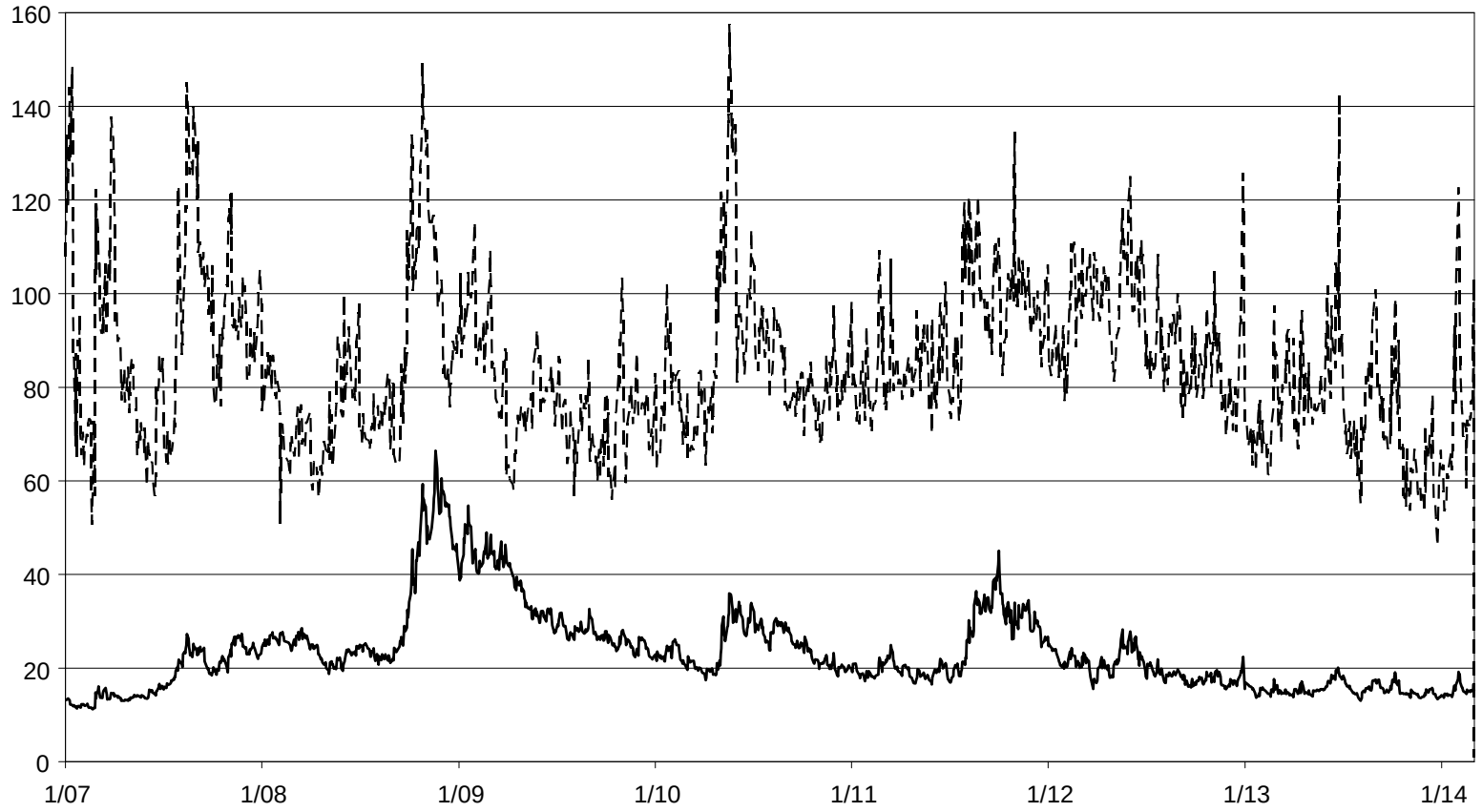

Figure 2. VIX Option at the money implied volatility (solid line) and adjusted lagged 10-business day historical volatility (dashed line) from January 2007 through March 2014

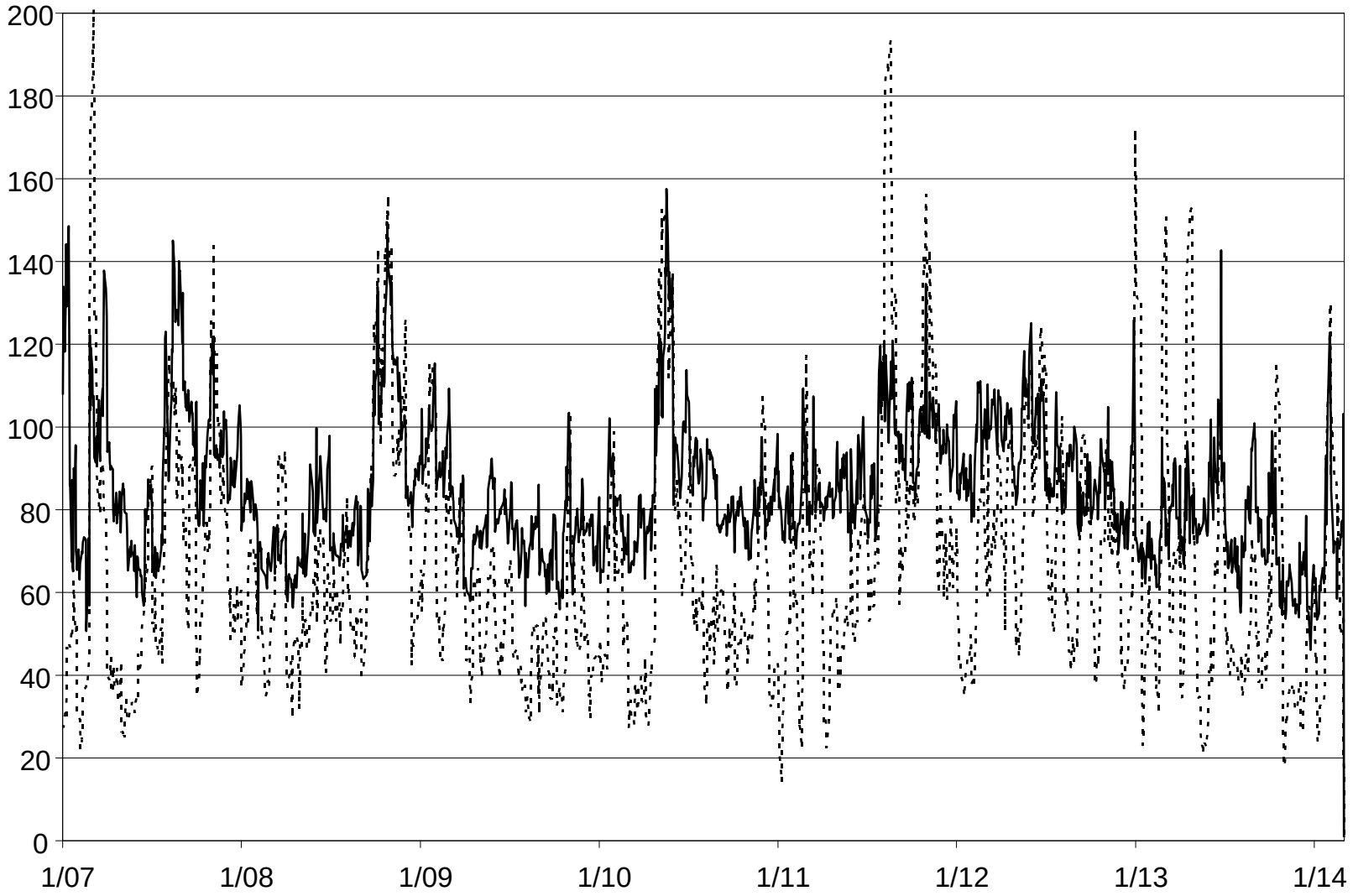

Exhibit 1. VIX option data from January 2007-March 2014. The exhibit shows mid-point daily closing quotes, closing bid-ask spreads and implied volatilities for calls and puts for the front contract month that has at least 10 business days to expiration and for the 5 closest to the money strikes, ranging from 2 strikes below the at the money strike (ATM-2) to 2 strikes above the at the money strike (ATM+2). Implied volatilities are calculated from the Black (1976) futures option pricing model on a business day basis. Adjusted 10-business day historical volatilities are calculated from the corresponding VIX futures contracts and are adjusted to reflect the tendency of VIX futures volatility to rise toward the typically higher volatility of the VIX as contracts move toward settlement. Volatility premiums are the spreads between implied volatility and adjusted lagged 10-business day historical volatility.

	Calls					Puts				
	ATM-2	**ATM-1**	**ATM**	**ATM+1**	**ATM+2**	**ATM-2**	**ATM-1**	**ATM**	**ATM+1**	**ATM+2**
Mid-point Quote										
mean	3.87	2.99	2.26	1.72	1.32	.77	1.36	2.25	3.40	4.79
(std. dev)	(1.86)	(1.49)	(1.16)	(.92)	(.74)	(.67)	(.90)	(1.20)	(1.67)	(2.32)
top decile	6.25	4.75	3.70	2.93	2.33	1.68	2.53	3.80	5.50	7.40
bottom decile	2.20	1.60	1.15	.83	.58	.13	.45	1.08	1.83	2.63
Bid-Ask Spread										
mean	.25	.20	.15	.13	.12	.10	.12	.16	.21	.26
(std. dev)	(.15)	(.13)	(.11)	(.09)	(.08)	(.07)	(.09)	(.11)	(.13)	(.16)
top decile	.40	.30	.30	.20	.20	.15	.20	.30	.30	.40
bottom decile	.10	.10	.05	.05	.05	.05	.05	.05	.10	.10
Implied Volatility										
mean	73.51	79.08	84.93	90.32	95.58	73.82	78.74	85.05	90.72	95.94
(std. dev)	(19.04)	(17.48)	(16.57)	(16.04)	(15.96)	(17.88)	(17.34)	(16.78)	(16.24)	(16.19)
top decile	96.47	100.73	106.22	111.79	116.71	96.37	100.98	106.75	11.80	117.09
bottom decile	51.58	59.60	66.40	72.24	77.76	53.18	58.90	65.68	72.37	77.87
Adjusted VIX Futures Volatility										
mean	66.07	66.03	66.35	66.31	66.51	66.40	66.03	66.35	66.31	66.51
(std. dev)	(29.76)	(29.81)	(30.04)	(29.92)	(30.16)	(29.75)	(29.81)	(30.04)	(29.92)	(30.02)
top decile	106.68	107.02	108.29	107.68	108.34	107.21	107.02	108.28	107.68	108.34
bottom decile	36.34	36.41	36.09	36.27	36.26	36.70	36.41	36.09	36.28	36.26
Volatility Premium										
mean	7.44	13.05	18.58	24.01	29.06	7.42	12.72	18.69	24.41	29.43
(std. dev)	(25.23)	(24.01)	(23.70)	(23.59)	(23.74)	(24.04)	(23.15)	(23.57)	(23.68)	(23.78)
top decile	32.61	37.15	42.17	47.92	53.36	32.28	36.73	42.22	48.13	54.21
bottom decile	-21.03	-13.89	-10.17	-5.79	-9.58	-20.32	-13.34	-9.40	-4.97	-1.10
NOBS	1750	1728	1747	1775	1774	1730	1728	1747	1775	1774

Exhibit 2. Five-business day delta-hedged P&Ls and returns on front month VIX call and put long positions. Options are assumed to be purchased and sold at the mid-point of closing bid-ask spreads with returns equal to P&Ls scaled by option purchase prices. Bootstrapped p-values are shown and are based on 100,000 draws with replacement. Semi-standard deviations set positive P&Ls and returns equal to zero, which are included in calculations and Sortino ratios are equal to mean P&Ls and returns scaled by semi-standard deviations. The closest to the money (ATM) strike and the two lower (ATM-1 and ATM-2) and two higher (ATM+1 and ATM+2) strikes for the front contract that has at least 10 business days to expiration are examined. The greeks are recalculated each day with the Black (1976) model adjusted to a business day basis with the deltas re-hedged each day and with the P&Ls each day from the greeks accumulated over the holding period. The sample period is from January 2007 through March 2014.

Front Month Calls

	ATM-2	ATM-1	ATM	ATM+1	ATM+2
$ P&L	-14.69	-26.42	-27.58	-32.03	-34.46
(p-value)	(.116)	(.366)	(.040)	(.017)	(.010)
Semi-Std Dev	127.73	147.87	157.54	163.23	143.35
Sortino Ratio	-0.115	-0.179	-0.175	-0.196	-0.240
Return	-.001	-.006	-.010	-.016	-.025
(p-value)	(.344)	(.136)	(.114)	(.074)	(.051)
Semi-Std Dev	.296	.045	.066	.085	.111
Sortino Ratio	-.003	-.133	-.152	-.188	-.225
Pct. Gains	43%	42%	40%	37%	36%
Avg. Gain	163.37	189.69	214.08	221.86	202.00
Avg. Loss	-148.46	-184.82	-189.86	-182.11	-169.43
Top decile	203.07	217.23	262.03	267.71	238.19
Bot. Decile	-266.93	-302.54	-310.18	-288.07	-296.79
Greeks P&L					
Gamma	159.07	195.35	198.31	187.82	170.13
Vega	18.97	58.60	96.19	112.95	122.12
Theta	-192.47	-267.60	-308.88	-323.43	-320.10
NOBS	345	331	346	352	355

Front Month Puts

	ATM-2	ATM-1	ATM	ATM+1	ATM+2
$ P&L	-8.45	-18.78	-26.17	-27.59	-33.24
(p-value)	(.229)	(.093)	(.052)	(.034)	(.018)
Semi-Std Dev	118.84	133.04	156.96	160.7	167.41
Sortino Ratio	-.071	-.141	-.167	-.172	-.199
Return	-.012	-.002	-.005	-.006	-.006
(p-value)	(.630)	(.446)	(.264)	(.100)	(.042)
Semi-Std Dev	.432	.128	.067	.040	.029
Sortino Ratio	-.028	-.016	-.074	-.149	-.208
Pct. Gains	45%	41%	40%	38%	36%
Avg. Gain	149.35	199.50	226.75	225.95	216.82
Avg. Loss	-138.69	-171.01	-193.97	-179.71	-175.98
Top decile	200.48	257.83	289.79	302.54	253.71
Bot. Decile	-233.62	-290.47	-306.37	-300.94	-294.28
Greeks P&L					
Gamma	161.66	195.11	197.76	187.22	169.06
Vega	48.32	75.16	97.42	105.30	108.67
Theta	-195.96	-268.58	-309.61	-323.97	-319.79
NOBS	345	331	346	352	355

Exhibit 3. Five-business day P&Ls and returns of front month delta-hedged VIX call and put positions when ex-ante volatility premiums are above their highest quartile cutoffs over the sample period. Options are assumed to be purchased and sold at the mid-point of closing bid-ask spreads with returns equal to P&Ls scaled by option purchase prices. Ex-ante volatility premiums are defined for each option moneyness category as implied volatilities minus adjusted lagged 10-business day volatilities of the corresponding VIX futures contracts. Bootstrapped p-values test the hypothesis that the mean results from entering trades when ex-ante volatility premiums are in their highest quartiles are worse than when trades are entered unconditionally as in exhibit 2 and are based on 100,000 draws with replacement. Semi-standard deviations set positive P&Ls and returns equal to zero, which are included in calculations and Sortino ratios are equal to mean P&Ls or returns scaled by semi-standard deviations. The at the money (ATM) strike and the two lower (ATM-1 and ATM-2) and two higher (ATM+1 and ATM+2) strikes are examined for the front contract that has at least 10 business days until expiration. The greeks are recalculated each day with the Black (1976) model adjusted to a business day basis with the deltas re-hedged each day and with the P&Ls each day from the greeks accumulated over the holding period. The sample period is from January 2007 through March 2014.

VIX call option ex-ante volatility premiums are above their highest quartile cutoffs

	ATM-2	ATM-1	ATM	ATM+1	ATM+2
$ P&L					
mean	-49.72	-62.42	-61.19	-120.52	-65.64
(p-value)	(.072)	(.104)	(.143)	(.001)	(.135)
Semi-Std Dev	137.67	173.32	153.127	205.50	138.51
Sortino Ratio	-.361	-.360	-.400	-.586	-.474
Return					
mean	-.0129	-.0185	-.0313	-.0770	-.0436
(p-value)	(.033)	(.128)	(.093)	(<.001)	(.270)
Semi-Std Dev	.0356	.0491	.0711	.0879	.1198
Sortino Ratio	-.362	-.377	-.440	-.876	-.364
Freq. Gains	39%	42%	40%	23%	29%
Avg. Gain	126.53	152.24	155.09	144.23	200.22
Avg. Loss	-162.80	-218.94	-202.60	-198.39	-175.36
Top decile	153.51	203.13	186.77	104.21	127.98
Bot. Decile	-280.35	-322.32	-350.24	-350.05	-265.93
Greeks P&L					
Gamma	110.11	157.36	126.75	123.26	148.05
Vega	26.27	38.36	84.08	66.60	87.95
Theta	-199.44	-264.81	-269.94	-299.07	-274.67
NOBS	87	83	86	88	89

VIX put option ex-ante volatility premiums are above their highest quartile cutoffs

	ATM-2	ATM-1	ATM	ATM+1	ATM+2
$ P&L					
mean	-30.42	-49.16	-78.01	-107.17	-58.83
(p-value)	(.165)	(.136)	(.048)	(<.001)	(.205)
Semi-Std Dev	117.99	149.27	135.51	186.19	162.46
Sortino Ratio	-.258	-.329	-.576	-.576	-.362
Return					
mean	-.1032	-.0397	-.0396	-.0332	-.0130
(p-value)	(.060)	(.122)	(.016)	(<.001)	(.142)
Semi-Std Dev	.7057	.1306	.0780	.0467	.0321
Sortino Ratio	-.146	-.304	-.508	-.711	-.405
Freq. Gains	39%	39%	30%	23%	25%
Avg. Gain	151.20	195.58	199.70	186.30	265.44
Avg. Loss	-148.14	-202.72	-199.49	-193.49	-166.92
Top decile	195.99	284.80	195.88	138.05	266.44
Bot. Decile	-254.64	-323.98	-324.76	-392.02	-314.53
Greeks P&L					
Gamma	149.66	160.13	142.37	124.73	133.85
Vega	26.06	52.69	54.32	48.40	79.86
Theta	-203.89	-266.12	-278.65	-300.05	-279.17
NOBS	89	83	86	88	88

Exhibit 4. Five-business day P&Ls and returns without delta-hedging on front month VIX call and put long positions.

Options are assumed to be purchased and sold at the mid-point of closing bid-ask spreads with returns equal to P&Ls scaled by option purchase prices. Bootstrapped p-values are shown and are based on 100,000 draws with replacement. Semi-standard deviations set positive P&Ls and returns equal to zero, which are included in calculations and Sortino ratios are equal to mean P&Ls or returns scaled by semi-standard deviations. The at the money (ATM) strike and the two lower (ATM-1 and ATM-2) and two higher (ATM+1 and ATM+2) strikes are examined for the front contract that has at least 10 business days until expiration. The greeks are recalculated each day with the Black (1976) model adjusted to a business day basis and the P&Ls each day from the greeks are cumulated over the holding period. The sample period is from January 2007 through March 2014.

Front Month Calls

	ATM-2	ATM-1	ATM	ATM+1	ATM+2
$ P&L	-104.35	-113.67	-65.39	-82.10	-68.03
(p-value)	(.195)	(.153)	(.054)	(.156)	(.183)
Semi-Std Dev	1097.77	916.11	730.40	592.71	470.47
Sortino Ratio	-.095	-.124	-.090	-.139	-.145
Return	-.0220	-.0322	-.0191	-.0426	-.0559
(p-value)	(.235)	(.188)	(.321)	(.161)	(.148)
Semi-Std Dev	.229	.244	.260	.268	.275
Sortino Ratio	-.096	-.132	-.074	-.159	-.204
Freq. Gains	39%	37%	34%	31%	30%
Avg. Gain	1,797.18	1,554.03	1,588.98	1,271.79	1,067.99
Avg. Loss	-1,297.29	-1,112.68	-921.60	-689.40	-558.17
Top decile	1,900	1,675	1,550	1,000	750
Bot. Decile	-2,150	-1,825	-1,525	-1,200	-1,050
Greeks P&L					
Delta	-89.66	-87.25	-37.81	-50.07	-33.57
Gamma	159.08	195.35	198.31	187.82	170.13
Vega	18.97	58.60	96.19	112.95	122.12
Theta	-192.47	-267.60	-308.87	-323.43	-320.10
NOBS	345	331	346	352	355

Front Month Puts

	ATM-2	ATM-1	ATM	ATM+1	ATM+2
$ P&L	40.29	40.26	62.14	74.22	82.18
(p-value)	(.108)	(.195)	(.151)	(.175)	(.169)
Semi-Std Dev	340.58	503.28	653.51	859.86	999.59
Sortino Ratio	.118	.080	.095	.086	.082
Return	.0140	.0072	.0201	.0196	.0171
(p-value)	(.357)	(.406)	(.204)	(.168)	(.149)
Semi-Std Dev	.301	.276	.245	.210	.179
Sortino Ratio	.047	.026	.082	.093	.096
Freq. Gains	49%	48%	52%	53%	54%
Avg. Gain	420.00	658.81	828.89	1,050.27	1,124.09
Avg. Loss	-328.57	-531.54	-769.28	-1,007.04	-1,145.09
Top decile	725	1,050	1,300	1,650	1,700
Bot. Decile	-525	-750	-1,100	-1,475	-1,600
Greeks P&L					
Delta	48.74	59.03	88.31	101.81	115.43
Gamma	161.66	195.11	197.76	187.22	169.07
Vega	48.32	75.16	97.42	105.30	108.67
Theta	-195.96	-268.58	-309.61	-323.97	-319.79
NOBS	345	331	346	352	355

Exhibit 5. Five-business day P&Ls from buying front month VIX call options when the VIX futures curve is in backwardation and the average daily roll is greater than .10 point or $100 per business day. The roll is defined as the spread between VIX futures and the VIX divided by the number of business days to settlement. Options are assumed to be purchased and sold at the mid-point of closing bid-ask spreads with returns equal to P&Ls scaled by option purchase prices. Bootstrapped p-values are based on 100,000 sets of randomly drawn 5-business day returns, where the number of draws is equal to the actual number of trades for each category. Semi-standard deviations set positive P&Ls and returns equal to zero, which are included in calculations and Sortino ratios are equal to mean P&Ls or returns scaled by semi-standard deviations. The at the money (ATM) strike and the two lower (ATM-1 and ATM-2) and two higher (ATM+1 and ATM+2) strikes are examined for the front contract that has at least 10 business days until expiration. The greeks are recalculated each day with the Black (1976) model adjusted to a business day basis and the P&Ls each day from the greeks are cumulated over the holding period. The sample period is from January 2007 through March 2014.

	ATM-2	ATM-1	ATM	ATM+1	ATM+2
$ P&L					
mean	1,348.84	1,311.88	974.40	617.61	460.33
(p-value)	(<.001)	(<.001)	(<.001)	(.003)	(.005)
Semi-Std Dev	1,623.87	1,331.17	1,458.89	939.58	765.30
Sortino Ratio	.831	.986	.668	.657	.602
Return	.293	.378	.386	.421	.309
(p-value)	(<.001)	(<.001)	(<.001)	(.001)	(.008)
Semi-Std Dev	.229	.254	.269	.271	.279
Sortino Ratio	1.279	1.491	1.437	1.555	1.110
Freq. Gains	49%	48%	48%	41%	41%
Avg. Gain	4,871.43	4,806.58	3,971.25	3,233.33	2,571.05
Avg. Loss	-2,013.64	-1,850.00	-1,750.00	-1,193.27	-1,025.00
Top decile	8,325	7,750.00	7,650.00	5,550	3,400
Bot. Decile	-2,500	-3,012.50	-2,025.00	-1,775	-1,400
Greeks P&L					
Delta	1,436.69	1,426.08	1,068.14	731.60	556.79
Gamma	351.82	430.94	469.06	459.75	421.41
Vega	-17.27	-10.91	4.37	7.46	32.07
Theta	-344.14	-456.68	-520.23	-572.11	-551.83
NOBS	43	40	42	44	46

Exhibit 6. Five-business day P&Ls from buying VIX put options when the VIX futures curve is in contango and the average daily roll is greater than .10 point or $100 per business day. The roll is defined as the spread between VIX futures and the VIX divided by the number of business days to settlement. Options are assumed to be purchased and sold at the mid-point of closing bid-ask spreads with returns equal to P&Ls scaled by option purchase prices. Bootstrapped p-values are based on 100,000 sets of randomly drawn 5-business day returns, where the number of draws is equal to the actual number of trades for each category. Semi-standard deviations set positive P&Ls and returns equal to zero, which are included in calculations and Sortino ratios are equal to mean P&Ls or returns scaled by semi-standard deviations. The at the money (ATM) strike and the two lower (ATM-1 and ATM-2) and two higher (ATM+1 and ATM+2) strikes are examined for the front contract that has at least 10 business days until expiration. The greeks are recalculated each day with the Black (1976) model adjusted to a business day basis and the P&Ls each day from the greeks are cumulated over the holding period. The sample period is from January 2007 through March 2014.

	ATM-2	ATM-1	ATM	ATM+1	ATM+2
$ P&L	142.03	255.41	267.78	331.21	373.78
(p-value)	(.023)	(.003)	(.012)	(.011)	(.013)
Semi-Std Dev	196.58	253.64	384.60	493.41	585.40
Sortino Ratio	.723	1.007	.696	.671	.639
Return	.103	.114	.090	.077	.068
(p-value)	(.121)	(.033)	(.031)	(.029)	(.024)
Semi-Std Dev	.267	.230	.190	.157	.132
Sortino Ratio	.386	.497	.474	.492	.514
Freq. Gains	54%	53%	56%	58%	60%
Avg. Gain	466.55	779.23	887.81	1,061.28	1,159.88
Avg. Loss	-229.62	-334.92	-532.26	-683.47	-812.28
Top decile	850	1150	1400	1700	1950
Bot. Decile	-300	-500	-725	-950	-1150
Greeks P&L					
Delta	156.05	286.68	301.00	376.53	421.22
Gamma	115.39	132.99	138.38	129.29	114.44
Vega	75.58	105.83	132.41	136.20	146.01
Theta	-194.74	-255.25	-302.72	-313.30	-306.46
NOBS	138	134	142	141	143

Exhibit 7. Five-business day P&Ls from buying VIX put options when the spread between VIX futures and 10-business day lagged S&P 500 volatility is greater than 10 percentage points. Options are assumed to be purchased and sold at the mid-point of closing bid-ask spreads with returns equal to P&Ls scaled by option purchase prices. Bootstrapped p-values are based on 100,000 sets of randomly drawn 5-business day returns, where the number of draws is equal to the actual number of trades for each category. Semi-standard deviations set positive P&Ls and returns equal to zero, which are included in calculations and Sortino ratios are equal to mean P&Ls or returns scaled by semi-standard deviations. The at the money (ATM) strike and the two lower (ATM-1 and ATM-2) and two higher (ATM+1 and ATM+2) strikes are examined for the front contract that has at least 10 business days until expiration. The greeks are recalculated each day with the Black (1976) model adjusted to a business day basis and the P&Ls each day from the greeks are cumulated over the holding period. The sample period is from January 2007 through March 2014.

	ATM-2	ATM-1	ATM	ATM+1	ATM+2
$ P&L					
mean	175.83	229.84	297.53	360.75	450.00
(p-value)	(.017)	(.021)	(.019)	(.020)	(.012)
Semi-Std Dev	310.52	423.51	558.23	695.67	824.81
Sortino Ratio	.566	.543	.533	.519	.546
Return					
mean	.206	.183	.141	.107	.096
(p-value)	(.012)	(.004)	(.005)	(.010)	(.004)
Semi-Std Dev	.246	.214	.195	.170	.147
Sortino Ratio	.839	.854	.722	.629	.651
Freq. Gains	53%	58%	59%	59%	62%
Avg. Gain	634.90	780.56	1,005.09	1,222.73	1,375.00
Avg. Loss	-348.81	-532.69	-735.14	-886.84	-1,082.86
Top decile	1,050	1,150	1,650.00	1,875.00	1,375.00
Bot. Decile	-500	-775	-1,000.00	-1,300.00	-1,082.86
Greeks P&L					
Delta	210.28	237.91	319.52	395.39	480.14
Gamma	134.29	159.05	163.24	152.07	133.58
Vega	64.08	118.73	135.98	138.54	152.80
Theta	-225.27	-277.31	-315.94	-326.10	-317.85
NOBS	90	93	91	93	93