The Portfolio Diversification Potential of Long VIX® Futures and Options Strategies

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ABSTRACT

It is well established that the VIX® Index tends to be negatively correlated with equity markets. This suggests that VIX futures and options may have the potential to provide significant diversification benefits for traditional portfolios. However, since the term structure of VIX futures is generally upward sloping (in contango), long VIX futures positions can place a significant drag on portfolio performance.

In this paper we consider the performance of strategies that buy VIX futures or VIX call options in a portfolio context in 2008 and 2016, as well as over a 10+ year period beginning in 2006. In addition, we consider alternative strategies including long S&P 500® protective put strategies and the dynamic S&P 500 plus VIX call buying strategy of the VXTH index.

Meaningful portfolio diversification benefits for risk-averse investors are possible over particular time periods with small allocations to long VIX futures or call options, but there can be a substantial reduction in portfolio returns if large allocations are made over long time periods during which there are flat to rising stock markets.

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1.0 Introduction to the Spot VIX Index and Select Literature

The Cboe Volatility Index® (the VIX® Index) was initially developed in 1993 (see Whaley [1993]) as a forward-looking measure of expected market volatility. More specifically, the spot VIX index represents the constant maturity 30-day expected volatility of the entire range of out-of-the-money (OTM) S&P 500® (SPX®) put and call options with more than 23 days to expiration and less than 37 days to expiration. In 2014, the methodology was updated to include weekly SPX options thus reducing the range of tenor of the options used. Additional details and historical data can be found at www.cboe.com/VIX.

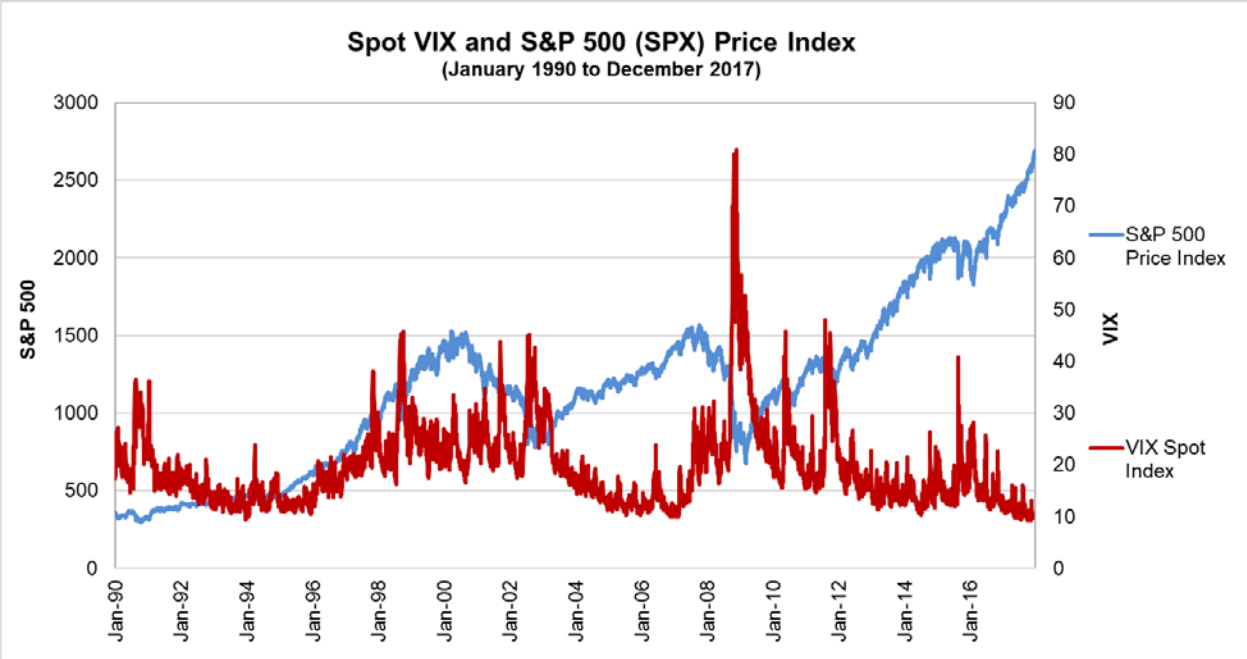
As the principal gauge of expected volatility of the U.S. equity market, the VIX index has received significant attention in periods of market distress. Additionally, recent years have experienced historically low levels of VIX and low levels of realized volatility, resulting in increased interest in VIX-based trading strategies, including long positions in VIX futures and options (because the VIX Index tends to be mean-reverting) and short (inverse) VIX futures strategies (because the VIX Index tends to be in contango when it is much lower than its long-term average).

A number of studies have considered the potential diversification benefits of spot VIX exposure to equity portfolios. Daigler and Rossi [2006] find that the spot VIX index tends to be negatively correlated with the SPX, and Szado [2009] finds that a small exposure to long VIX-based products may provide significant diversification benefits in times of equity market distress. Spot VIX can also provide benefits to portfolios containing alternative investments. Dash and Moran [2005] illustrate the potential diversification benefits of adding spot VIX exposure to hedge fund portfolios. In addition to the diversification benefits of spot VIX, Black [2006] suggests that the skew and excess kurtosis of many hedge fund strategies can be eliminated by a small long exposure to spot VIX. Since spot VIX is not directly investable, this analysis will consider the benefits of a long exposure to VIX futures and call options.

Furthermore, Bollen, O'Neill, and Whaley [2017] contend that VIX futures have become the standard tool for volatility risk hedging, however, an increasing number of researchers have documented the significant portfolio drag of long VIX futures, including Toikka et al. [2004], Mencia and Sentana [2013] and Korovilas [2013].

A 2007 paper by Grant, Gregory and Lui of Goldman Sachs considers the payout ratios of VIX calls and SPX puts across all strikes and expirations in the period of July to August, 2007. The results suggest that VIX calls have the potential to provide particularly effective diversification of equity risk, exhibiting far higher payouts per dollar then S&P 500 puts over the period of the study. In fact, nine out of the top ten payout ratios came from OTM VIX calls.

Exhibit 1: Spot VIX Index and S&P 500 (SPX) Price Index



1990 to 2018	
Mean Daily VIX	19.3
Median Daily VIX	17.4
Highest VIX Close	80.9
Lowest VIX Close	9.1

Average Daily Close by Year

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2018
S&P 500	1207.2	1310.5	1477.2	1220.0	948.0	1140.0	1267.6	1379.4	1643.8	1931.4	2061.1	2094.7	2746.2
Spot VIX	12.8	12.8	17.5	32.7	31.5	22.5	24.2	17.8	14.2	14.2	16.7	15.8	16.6

Source: Cboe Exchange, Inc., Bloomberg

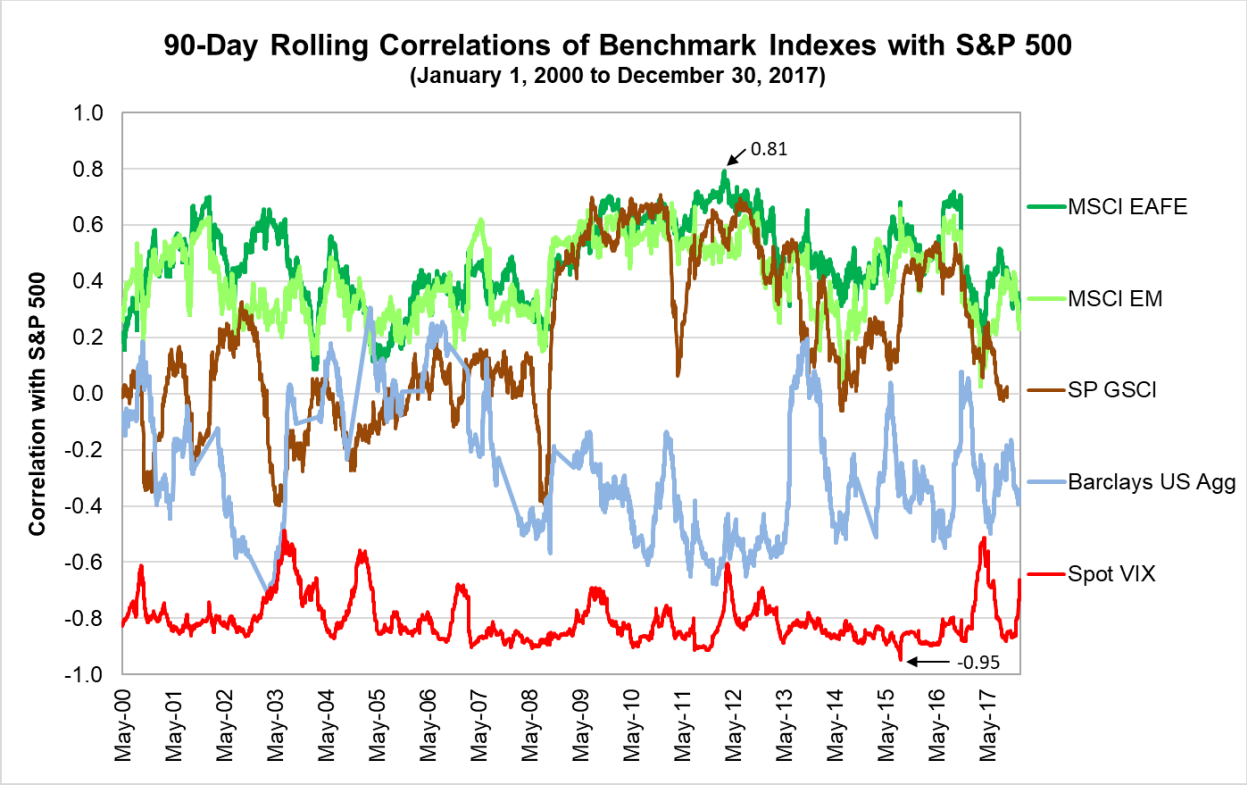
Exhibit 1: *This exhibit illustrates the historical levels of the spot VIX and S&P 500 Price Indexes from 1990 to December 2017. Spikes in the level of the VIX are often accompanied by drawdowns in the S&P 500 index.*

Thus, research suggests that, over the long term, a long VIX futures position is expected to result in negative excess returns (see Whaley [2013]). However, long VIX futures may provide significant diversification benefits in large downward moves of the market. Additionally, the conditional nature of the negative correlation between SPX and VIX (as well as the research results which suggest that VIX calls may have higher payouts than SPX puts) suggests that VIX calls may provide more "bang for the buck" than SPX puts in diversifying a typical portfolio. These observations suggest that a long-term passive long VIX futures position may return negative excess returns. However, a selectively applied long VIX futures position may provide

significant diversification benefits, particularly in times when the diversification benefits of other assets break down, such as in the last two quarters of 2008.

Exhibit 2 presents 90-day rolling correlations (based on daily returns) between the S&P 500 index and a number of benchmark indexes, including the VIX index. It is clear that the correlations between the indexes and the S&P 500 generally increased during the 2008 financial crisis. The exceptions were the Barclays U.S. Aggregate Bond index and the VIX index. Bonds were one of the few traditional asset classes that provided significant diversification benefits in 2008. However, it is questionable whether bonds could provide similar diversification benefits in the near future since yields are currently near historically low levels, leaving little room for them to fall. It is worth noting that not only was the rolling correlation between the VIX index and the S&P 500 consistently negative over the entire period, but the correlation also remained below -0.65 throughout the financial crisis.

Exhibit 2: 90-Day Rolling Correlations of Benchmark Indexes with the S&P 500

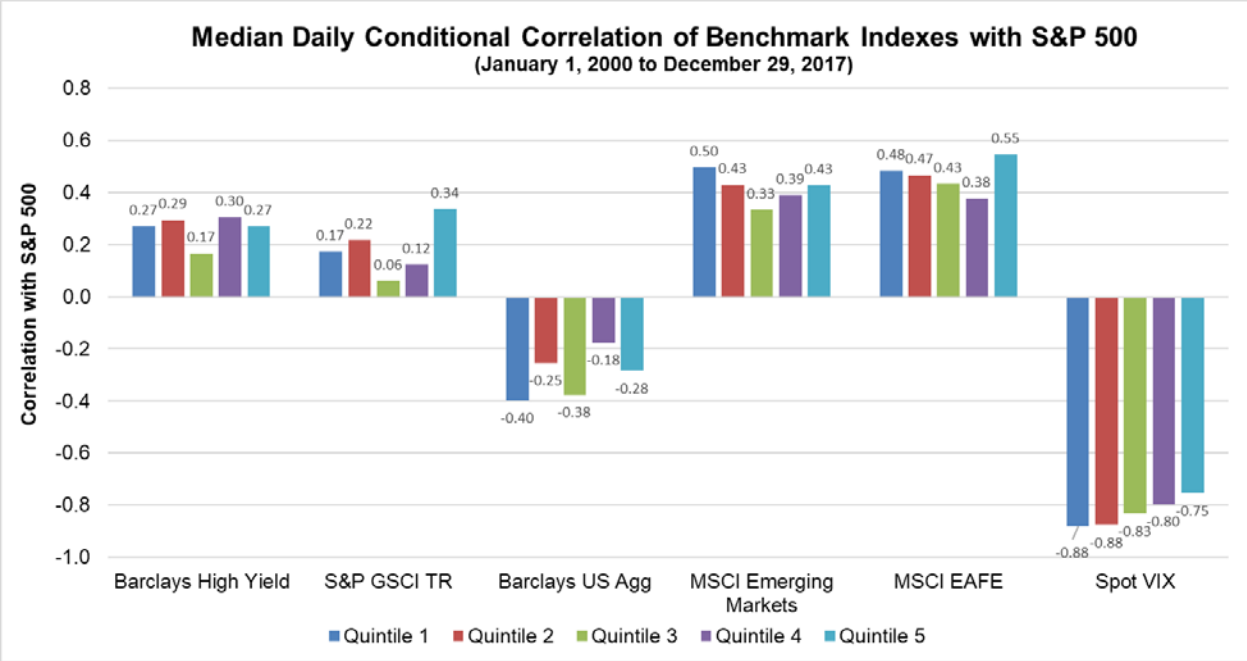


Source: Cboe Exchange, Inc., Bloomberg

Exhibit 2: *This exhibit provides 90-day rolling correlations of a number of benchmark indexes and spot VIX versus the S&P 500 price index, based on daily data. With the exception of the Barclays U.S. Aggregate bond index and the VIX index, the correlations with the S&P 500 increased significantly in the 2008 financial crisis and were quite consistent across the indexes.*

While the VIX index is negatively correlated with the S&P 500 index, it is well documented that this correlation is particularly strong for large negative returns in the S&P 500 (see Szado [2009]). Exhibit 3 provides the median within-month correlations of benchmark indexes with the S&P 500 by quintile of S&P 500 monthly returns. Months are ranked based on S&P 500 return and correlations are calculated within each month based on daily returns. The median correlation is calculated for each quintile and presented in the exhibit. The exhibit once again, illustrates the strong negative correlation between the S&P 500 and the VIX index. It is also clear that the correlation tends to be strongest in the lowest-return quintile of S&P 500 monthly returns.

Exhibit 3: Conditional Correlations of Benchmark Indexes with the S&P 500



Source: Cboe Exchange, Inc., Bloomberg

Exhibit 3: *This exhibit provides median monthly conditional correlations of a number of indexes with the S&P 500 price index based on daily data. The quintiles are based on monthly S&P 500 returns, ranked from low to high. The correlation between the VIX index and the S&P 500 tends to be most negative in months with the lowest S&P 500 returns.*

2.0 Introduction to VIX Futures and Options and VIX-Based Benchmark Indexes

The previous section illustrated the potential diversification benefits of the spot VIX index. However the spot VIX index is not investable. There are a number of alternatives to gain exposure to the VIX index, including VIX futures, VIX options and a variety of VIX-based exchange-traded products and funds which are based on VIX futures and options. Key

specifications of VIX futures and options are provided in Exhibit 4. Additional unique characteristics of VIX futures and options are described in Szado [2018a]. It is worth noting that VIX options often are priced based on the prices of the corresponding VIX futures contract. As with VIX futures, VIX options typically expire on the Wednesday which is 30 days prior to the SPX option Friday expiration. In addition, VIX options are European-style options so they can only be exercised at expiration. The settlement values at expiration for VIX futures and options are based on a Special Opening Quotation (SOQ) that usually is calculated on Wednesday mornings.

Exhibit 4: Key Specifications of VIX Futures and Options

	VIX Futures	VIX Options
Exchange	Cboe Futures Exchange (CFE®)	Cboe Options Exchange
Year of Introduction	2004	2006
Ticker	VX and VX01 through VX53	VIX
Multiplier	$1,000	$100
Extended Trading Hours CT (Chicago Time)	5:00 p.m. (previous day) to 8:30 a.m. and 3:30 p.m. to 4:00 p.m.	2:00 a.m. to 8:15 a.m.
Regular Trading Hours CT (Chicago Time)	8:30 a.m. to 3:15 p.m.	
Last Trading Date	Trading hours for expiring VX futures contracts end at 8:00 a.m. Chicago time on the Final Settlement Date.	The last trading day (usually a Tuesday) is the business day prior to the Expiration Date of each contract expiration.
Expiration and Settlement	Usually on a Wednesday morning (30 days before a Friday settlement for SPX options)	
Settlement Value	The exercise-settlement value for VIX futures and options (Ticker: VRO) shall be a Special Opening Quotation (SOQ) of VIX calculated from the sequence of opening prices during regular trading hours for SPX of the options used to calculate the index on the settlement date.	
Number of Contract Expirations	Up to six near-term expiration weeks, nine near-term serial months and five months on the February quarterly cycle (February, May, August, November) for the VX futures contract.	Up to six weekly expirations and up to twelve standard (monthly) expirations in VIX options may be listed.
Options Exercise Style	Not applicable.	European - VIX options generally may be excercised only on the Expiration Date.

Source: Cboe Global Markets. www.Cboe.com/VIX

Exhibit 4: *This exhibit provides key specifications of VIX futures and options contracts.*

A variety of VIX-based investment products are based on a series of benchmark indexes that represent the returns to VIX futures and options trading strategies, including those published by Cboe Exchange and S&P Dow Jones Indices. These indexes include:

VPD[SM] - Cboe VIX Premium Strategy Index - overlays a sequence of short one-month VIX futures on a money market account; the short VIX futures positions are held until expiration and new VIX futures are then sold (see www.cboe.com/VPD).

VPN[SM] - Cboe Capped VIX Premium Strategy Index - tracks the performance of a strategy that systematically sells 1-month VIX futures, capped by the purchase of a VIX call option; the short VIX futures position is capped with long VIX calls struck about 25 points higher than the VIX futures price (see www.cboe.com/VPN).

VSTG[SM] - Cboe VIX Strangle Index - a premium capture index that overlays short VIX call and put options with a capped long VIX call option position. The position is collateralized by fixing the number of strangles such that 80% of capital is reserved (see www.cboe.com/VSTG).

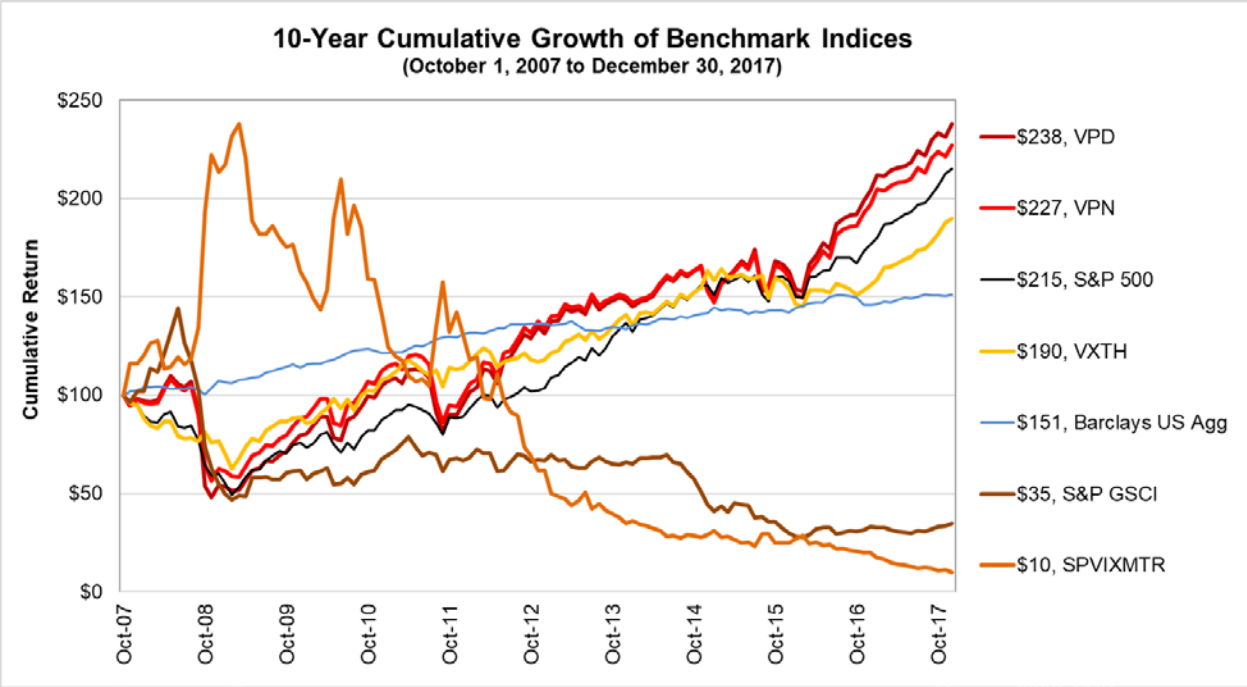
VXTH[SM] - Cboe VIX Tail Hedge Index - buys and holds S&P 500 stocks, and also often buys 30-delta call options on the Cboe Volatility Index (VIX) (see www.cboe.com/VXTH).

SPVIXMTR - S&P 500 VIX Mid-term Futures Index buys a combination fourth, fifth, sixth and seventh month VIX futures in order to reflect the expectations of the VIX Index level in five months. A portion of the VIX futures are rolled daily to maintain a constant average weighted five-month term (see us.spindexes.com/SPVIXMTR).

SPVIXSTR - S&P 500 VIX Short-term Futures Index buys a combination of first and second month VIX futures in order to reflect the expectations of the VIX Index level in one-month. A portion of the VIX futures are rolled daily to maintain a constant average weighted one-month term (see us.spindexes.com/SPVIXSTR).

Exhibit 5 provides an illustration of the historical performance of a selection of VIX-based indexes along with a selection of benchmark indexes. The high volatility and drawdown of the S&P 500 VIX Mid-term futures index is evident in the exhibit. In contrast, two indexes which sell VIX futures (VPD and VPN) outperformed the S&P 500 on a raw return basis, albeit with increased volatility. The VPD and VPN indexes sell VIX futures and therefore may be exposed to significant tail risk in the case of a major volatility event. To mitigate this tail risk exposure, the VPN index includes a long OTM VIX call option exposure, and both the VPD and VPN indexes hold money market instruments. While the long call results in a drag on performance in periods in which VIX does not increase significantly, it does provide some protection against catastrophic volatility risk. The VPD and VPN indexes are discussed in further detail in Szado [2018b].

Exhibit 5: 10-Year Cumulative Growth of Benchmark Indexes



Source: Cboe Exchange, Inc., Bloomberg

Exhibit 5: *This exhibit illustrates the cumulative growth of a variety of benchmark total return indexes (pre-tax, with reinvested dividends) over the past 10+ years. While the long VIX futures-based index (SPVIXMTR) experienced significant drawdowns and volatility, the short (inverse) VIX futures indexes (VPN and VPD) experienced strong performance, albeit with high volatility and significant tail risk exposure.*

3.0 Long VIX Futures and Long VIX Call-Based Strategies in Two Key Years – 2008 and 2016

The analyses in the following sections of the paper focus on trading VIX futures and options. For this purpose, we construct the returns to a series of VIX futures strategies rather than relying on the published benchmarks. The two main VIX futures trading strategy indexes used in the analyses represent the returns to strategies that take long positions in:

1) One-month VIX futures held until the market close on the day prior to the VIX futures morning expiration, at which time they are rolled into new one-month VIX futures, and
2) Three-month VIX futures held until the market close on the day prior to the next VIX futures morning expiration, at which time the (now two-month) VIX futures are rolled into three-month VIX futures.

In addition to the two long VIX futures trading strategies outlined above, we also similarly create two long VIX call option strategies which:

1) Purchase one-month at-the-money (ATM) and,
2) Purchase one-month 25% out-of-the-money (OTM) options.

We will begin by considering the long VIX futures strategies. The long VIX call option strategies will be discussed later in the paper. For a discussion of corresponding short VIX futures and written call option strategies, see Szado [2018b]. It is important to note that no adjustment for transactions costs has been made throughout this analysis.

As indicated in Szado [2018a], the VIX futures term structure is generally in contango. The often significant cost of holding futures in contango (when spot price is below futures price) suggests that long VIX futures and long VIX call option positions may be best suited to selective uses rather than large long-term buy-and-hold allocations. On the other hand, the convex relationship and strong negative conditional correlation between the VIX index and the S&P 500 index suggests long VIX futures and long call options may provide cost effective diversification benefits for traditional portfolios when used selectively. Since long volatility positions are expected to earn negative excess returns in the long-term, an active approach rather than a passive long volatility exposure may be appropriate.

The following section considers the impact of a 5% allocation of long VIX futures and a 1% allocation to long VIX options to a traditional stock and bond portfolio and a hypothetical endowment portfolio. The size of the VIX futures allocation was chosen not as a typical allocation, but rather as an oversized allocation for the purposes of illustrating hypothetical impacts of a VIX futures allocation. The base portfolios were chosen to represent a traditional 60/40 stock/bond portfolio (60% S&P 500 index and 40% Barclays U.S. Aggregate Bond index) and a hypothetical endowment portfolio which is based on the published annual allocations of a well-known endowment applied to a series of indexes which proxy for the asset classes represented in the allocations (S&P 500 index, Barclays U.S. Aggregate Bond index, Barclays High Yield U.S. Corporate index, HFR Global Hedge Fund index, SG CTA index (formerly the Newedge CTA index for managed futures), S&P GSCI Index (for commodities), S&P Listed Private Equity index, Dow Jones Equity REIT index, MSCI EAFE® index, MSCI Emerging Markets Index, and the 3-Month Treasury Bill Secondary Market Rate).

While we consider long-term long VIX futures and options allocations later in the paper, in the following sections we consider two years in which we expect a long VIX futures or options allocation to provide a short-term diversification benefit or generate a drag on a portfolio. Two years were chosen to represent periods favorable to long positions in VIX futures and call options (2008) in which we expect to see diversification benefits and generally unfavorable to long positions in VIX futures and call options (2016) in which we expect to see them place a drag on the portfolio.

The choice of 2008 as a potentially favorable year for long VIX futures and call option exposure is quite obvious due to the high market volatility and large drawdowns that the base portfolios experienced in the last quarter of the year. The choice of an unfavorable year for long VIX exposure is less clear. A number of factors were considered in the choice (see Exhibit 6) including the number of days in which VIX futures were in contango, the average return to VIX futures, the maximum drawdown of a VIX futures strategy and the slope of the VIX term

structure (the futures basis). Overall, 2016 appears to be a relatively unfavorable year for a long VIX futures or call option exposure. It should be noted that 2016 was not chosen as a worst-case scenario, but rather as a representative relatively unfavorable year. It is not the most unfavorable year based on any single measure considered but rather exhibits a variety of unfavorable characteristics. Furthermore, 2016 has the advantage of being more recent than some other alternative years (and thus may possibly be more reflective of the current market microstructure).

Exhibit 6: Select Annual Summary Statistics for Spot VIX, SPX and VIX Futures

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Average Spot VIX Index	17.5	32.7	31.5	22.5	24.2	17.8	14.2	14.2	16.7	15.8	11.1
% in Contango vs Front Month Only	61%	54%	76%	79%	71%	90%	87%	84%	80%	86%	94%
Average VIX Basis (VIX points per day)	-0.003	0.026	-0.006	-0.033	-0.013	-0.042	-0.025	-0.019	-0.014	-0.024	-0.032
Average S&P 500 Realized 30-Day Volatility Risk Premium	1.7%	-2.7%	7.5%	6.0%	3.2%	5.2%	3.5%	3.1%	1.7%	4.5%	4.4%
Spot VIX Average Daily % Change	0.04%	0.07%	-0.07%	-0.02%	0.02%	-0.02%	-0.02%	0.02%	0.00%	-0.02%	-0.01%
Spot VIX Minimum Daily % Change	-6.99%	-17.36%	-10.23%	-12.11%	-12.94%	-4.70%	-3.95%	-4.13%	-5.70%	-5.10%	-3.79%
Spot VIX Maximum Daily % Change	7.16%	16.54%	10.54%	10.47%	16.00%	3.25%	5.21%	4.37%	12.71%	8.51%	4.94%
Spot VIX Annualized Return Volatility	139%	127%	91%	119%	140%	98%	112%	122%	144%	127%	114%
3 Month VIX Futures Average Daily Return	0.23%	0.35%	-0.12%	-0.17%	0.01%	-0.39%	-0.27%	-0.09%	-0.05%	-0.16%	-0.40%
3 Month VIX Futures Minimum Daily Return	-8%	-7%	-7%	-10%	-13%	-11%	-8%	-9%	-9%	-13%	-11%
3 Month VIX Futures Maximum Daily Return	12%	11%	10%	11%	15%	9%	10%	10%	16%	20%	11%
3 Month VIX Futures Maximum Drawdown	-17%	-22%	-47%	-50%	-36%	-69%	-53%	-43%	-37%	-57%	-65%
Average VIX Futures Open Interest	56,019	48,570	31,645	93,591	181,028	320,111	392,584	388,832	332,028	414,813	572,744
Average VIX Futures Volume	4,169	4,301	4,543	17,432	47,744	95,143	158,508	200,521	204,986	238,773	297,694

Source: Cboe, Bloomberg

Exhibit 6: *This exhibit provides a wide variety of annual summary statistics from 2007 through 2017 for the spot VIX index, the S&P 500 index and VIX futures. The year 2008 was chosen as a sample year to explore potential diversification benefits of long VIX futures and call options allocations due to the large drawdowns in the S&P 500 index in 2008. The choice of an unfavorable year for long VIX futures and call options allocations is somewhat less obvious. The year 2016 was chosen based on a number of measures including number of days in contango, average return, maximum drawdown and the slope of the VIX term structure (futures basis).*

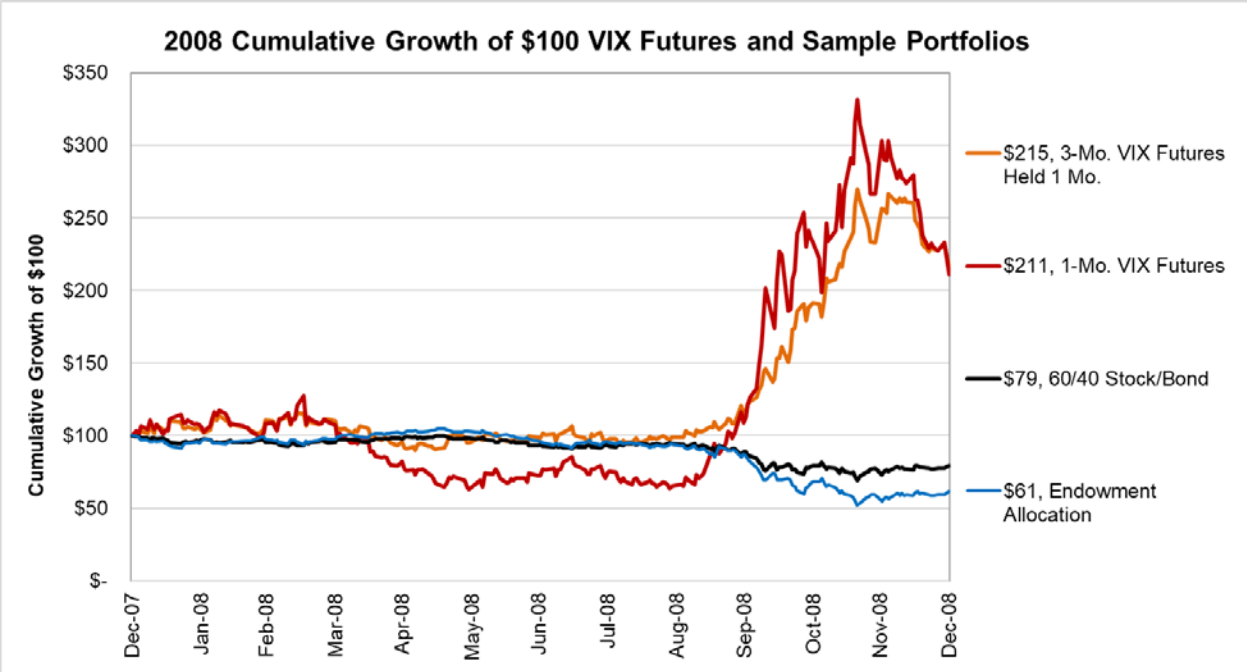
3.1 Long VIX Futures and Long VIX Call-Based Strategies in 2008

We begin by considering a 5% allocation to long VIX futures and 1% allocation to long VIX call options in 2008. As discussed above, 2008 was chosen as we expect that a long VIX futures or call exposure would provide diversification benefits as equity markets and many other asset classes incurred significant drawdowns at the start of the global financial crisis. Furthermore, in 2008, VIX futures experienced fewer days in contango than in any other year in the period of study (see Exhibit 6).

Exhibit 7 illustrates the 2008 cumulative performance of the two long VIX futures portfolios along with the two base portfolios. While the VIX portfolios experienced drawdowns in the first half of the year, they experienced very strong growth in the period from September through November. In fact, the magnitude of the gains of the VIX futures strategies in this three-month-period eclipses the magnitude of the losses of the base portfolios during one of the worst

equity drawdowns in history. This is consistent with the conditional correlations and high volatility of volatility discussed previously in the paper.

Exhibit 7: 100% Allocations to Long VIX Futures-Based Strategies in 2008

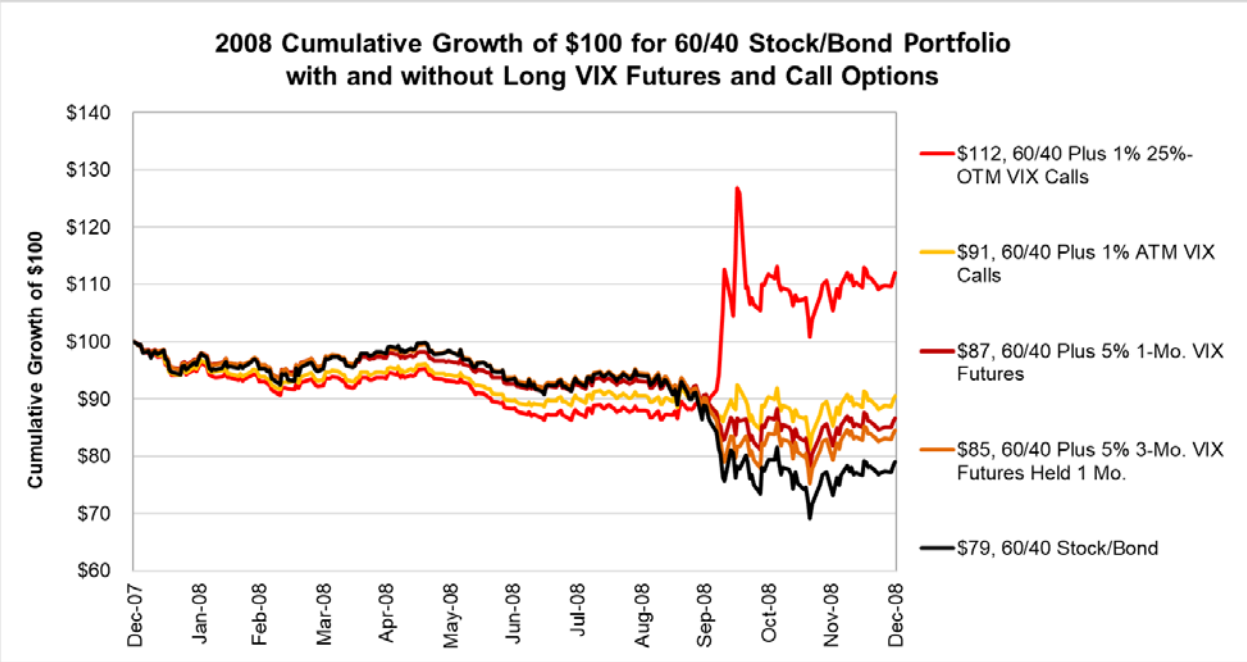


Summary Statistics for the Year 2008	60/40 Stock/Bond Portfolio	Endowment	100% Allocation to 1-Mo. VIX Futures	100% Allocation to 3-Mo. VIX Futures Held 1 Mo.
Annualized Return	-20.9%	-38.6%	111.1%	114.9%
Annualized Standard Deviation	24.1%	31.0%	83.1%	48.2%
Sharpe Ratio	-0.87	-1.25	1.34	2.39
Maximum Drawdown	-30.9%	-50.4%	-50.8%	-22.3%
Skewness	0.16	-0.13	0.52	0.61
Kurtosis	4.14	3.21	1.30	1.03
Correlation w SPX	1.00	0.92	-0.82	-0.83
Beta	0.58	0.69	-1.66	-0.97
Alpha	1.53%	-17.63%	45.85%	51.19%
Alpha P-Value	0.501	0.158	0.338	0.061

Source: Cboe Options Exchange, CFE, Bloomberg

Exhibit 7: *This exhibit illustrates the performance of two traditional portfolios as well as two portfolios with a 100% allocation to long VIX futures-based portfolios in 2008. The one-month portfolio invests in one-month VIX futures and rolls out on the close the night before expiration. The three-month VIX futures portfolio purchases three-month VIX futures and rolls into a new three-month VIX futures contract after one month at the close before the front month VIX futures contract expires. The traditional portfolios consist of a 60/40 stock/bond portfolio and a hypothetical endowment portfolio which invests in a variety of indexes based on the average yearly asset allocation of a representative endowment. It is clear from the exhibit that 2008 was favorable year for a long VIX futures exposure. The hypothetical endowment portfolio is constructed by using annually reported asset allocation from an actual endowment and applying them to a set of total return indexes representing the corresponding asset classes.*

Exhibit 8: 60/40 Portfolio Performance in 2008 with Small Allocations to Long VIX Futures and Options



Summary Statistics for the Year 2008	60/40 Stock/Bond Portfolio	60/40 Plus 5% 1-Mo. Futures	60/40 Plus 5% 3-Mo. Futures Held 1 Mo.	60/40 Plus 1% 25%-OTM VIX Calls	60/40 Plus 1% ATM VIX Calls
Annualized Return	-20.9%	-13.4%	-15.4%	12.1%	-9.4%
Annualized Standard Deviation	24.1%	18.4%	20.4%	27.6%	17.9%
Sharpe Ratio	-0.87	-0.73	-0.76	0.44	-0.53
Maximum Drawdown	-30.9%	-22.1%	-24.7%	-20.4%	-18.8%
Skewness	0.16	0.36	0.26	0.29	0.49
Kurtosis	4.14	4.08	4.25	22.41	4.46
Correlation w SPX	1.00	0.97	0.99	0.21	0.89
Beta	0.58	0.44	0.49	0.14	0.39
Alpha	1.53%	3.81%	3.97%	20.54%	6.24%
Alpha P-Value	0.501	0.357	0.122	0.447	0.454

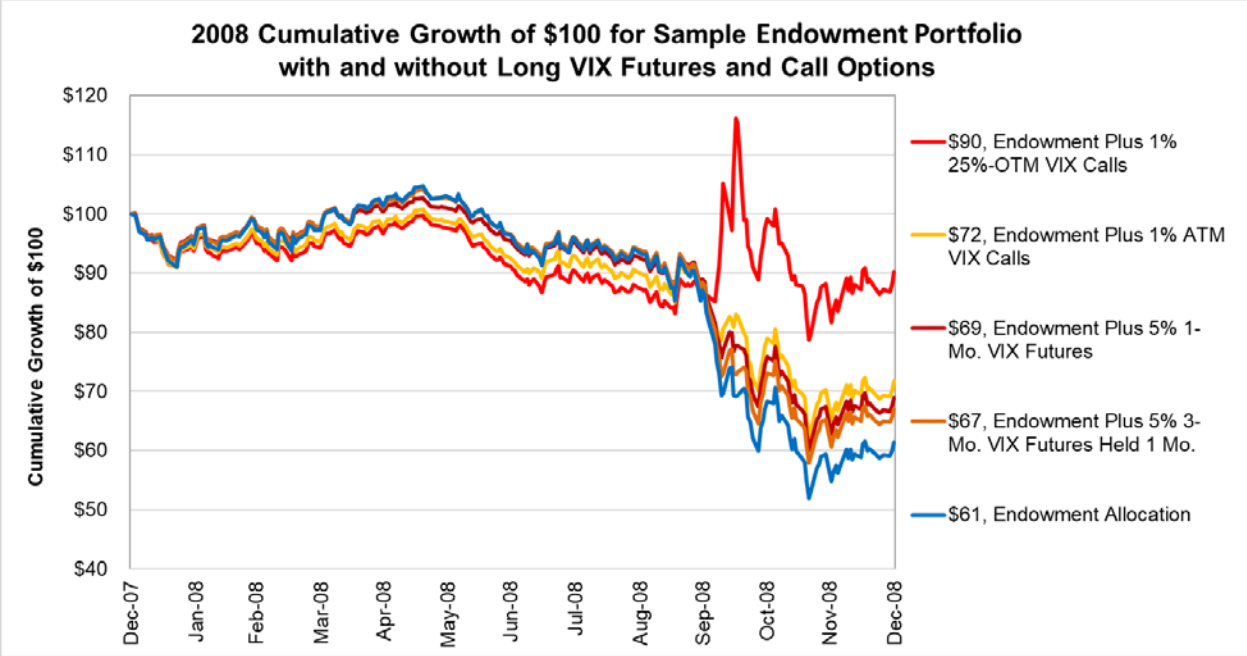
Source: Cboe Exchange, Inc., Bloomberg

Exhibit 8: *This exhibit illustrates the performance of a traditional 60/40 portfolio with and without a small allocation to long VIX futures or long VIX call options. A 1% allocation to 25%-OTM VIX calls increases 2008 returns from a 21% loss to a 12% gain, with a small increase in volatility. The other VIX-based allocations also improve 2008 returns while also reducing volatility and drawdowns.*

Exhibit 8 provides an illustration of the 2008 cumulative growth and summary statistics of the 60/40 stock/bond portfolio with and without a 5% allocation to long VIX futures (one-month or three-month VIX futures) and a 1% allocation to long VIX calls (ATM or 25%-OTM one-month VIX calls). The base 60/40 portfolio lost 21% over the period at a 24% annual standard deviation and a -31% maximum drawdown. The portfolios with a 5% allocation to long one- and three-month VIX futures performed similarly to each other, reducing the loss of the base portfolio from 21%

to 13% and 15%, respectively. In addition to improving returns, the one- and three-month VIX futures allocations reduced standard deviation from 24% to 18% and 20%, respectively and maximum drawdown from -31% to -22% and -25%, respectively. The ex-post skewness was also improved by adding the long VIX futures allocation to the base portfolio. Thus the long VIX futures allocation reduced risk in 2008 while also improving returns.

Exhibit 9: Endowment Portfolio Performance in 2008 with Long VIX Futures and Options



Summary Statistics for the Year 2008	Endowment	Endowment Plus 5% 1-Mo. Futures	Endowment Plus 5% 3-Mo. Futures Held 1 Mo.	Endowment Plus 1% 25%-OTM VIX Calls	Endowment Plus 1% ATM VIX Calls
Annualized Return	-38.6%	-31.1%	-32.9%	-9.8%	-28.3%
Annualized Standard Deviation	31.0%	25.2%	27.1%	32.8%	25.1%
Sharpe Ratio	-1.25	-1.23	-1.22	-0.30	-1.13
Maximum Drawdown	-50.4%	-41.5%	-44.4%	-32.2%	-38.2%
Skewness	-0.13	-0.02	-0.08	-0.31	0.01
Kurtosis	3.21	3.61	3.26	13.65	4.08
Correlation w SPX	0.92	0.87	0.90	0.30	0.80
Beta	0.69	0.54	0.59	0.24	0.49
Alpha	-17.63%	-13.72%	-13.75%	4.25%	-11.58%
Alpha P-Value	0.158	0.269	0.249	0.892	0.445

Sources: Cboe Exchange, Inc., Bloomberg

Exhibit 9: *This exhibit illustrates the performance of a hypothetical endowment portfolio with and without a small allocation to long VIX futures or long VIX call options. Similar to the 60/40 portfolio, a 1% allocation to 25%-OTM VIX calls provides the largest improvement in 2008 returns from a 39% loss to a 10% loss, with a small increase in volatility. The other VIX-based allocations also improve returns while also reducing volatility and drawdowns.*

The results for adding a long VIX call option allocation are more extreme. The 1% long one-month ATM VIX call allocation improved returns from -21% to -9% and reduced standard

deviation from 24% to 18%, and maximum drawdown from -31% to -19%, thus providing improvements in risk and return similar to (but greater than) the long VIX futures allocations. In contrast, the 1% allocation to long one-month 25%-OTM VIX calls further improved returns to a 12% gain (from a 21% loss for the base portfolio), but did so at a higher standard deviation (28% versus 24% for the base portfolio), albeit at an improved maximum drawdown (down -20% versus down -31% for the base portfolio).

The results above suggest that a long VIX futures or call option allocation could have provided diversification benefits to a 60/40 portfolio in 2008; however, institutional investors typically hold well-diversified portfolios that contain other asset classes beyond equity and fixed income. Exhibit 8 presents results which reflect the impact of an addition of long VIX futures and call options to a well-diversified hypothetical endowment portfolio in 2008. The hypothetical endowment portfolio is based on the published annual asset allocation of a sample endowment portfolio applied to a series of total return indexes to proxy for the corresponding asset class returns. While one would typically expect that a more diversified portfolio (endowment portfolio) would suffer a smaller loss than a less diversified portfolio (60/40 portfolio) in times of equity market drawdowns, this was not the case in 2008. The base endowment portfolio lost far more than the 60/40 portfolio (-39% versus -21%). This is largely due to the lower fixed income allocation of the endowment portfolio. In 2008, many asset classes experienced increased correlations with equity markets and thus did not provide the diversification benefits one would expect based on historical correlations (one of the few exceptions was fixed income).

While the base endowment portfolio underperformed the base 60/40 portfolio in 2008, the impact of the long VIX allocations were similar for both base portfolios. Exhibit 9 provides an illustration of the 2008 cumulative growth and summary statistics of the base hypothetical endowment portfolio with and without a 5% allocation to long VIX futures (one-month or three-month VIX futures) and a 1% allocation to long VIX calls (ATM or 25%-OTM one-month VIX calls). The base endowment portfolio lost 39% over the period at a 31% annual standard deviation and a -50% maximum drawdown. The portfolios with a 5% allocation to long one- and three-month VIX futures performed similarly to each other, reducing the loss of the base portfolio from -39% to -31% and -33%, respectively. In addition to improving returns, the one- and three-month VIX futures allocations reduced standard deviation from 31% to 25% and 27%, respectively and maximum drawdown from -50% to -42% and -44%, respectively. The ex-post skewness was also improved by adding the long VIX futures allocation to the base endowment portfolio. Thus the long VIX futures allocation reduced risk in 2008 while also improving returns.

As with the 60/40 portfolio, the results for adding a long VIX call option allocation are more extreme than those from adding long VIX futures. The 1% long one-month ATM VIX call allocation improved returns from -39% to -28% and reduced standard deviation from 31% to 25%, and maximum drawdown from -50% to -38%, thus providing improvements in risk and return similar to (but somewhat greater than) the long VIX futures allocations. In contrast, the 1% allocation to long one-month 25%-OTM VIX calls further improved returns to a 10% loss

(from a 39% loss for the base portfolio), but did so at a somewhat higher standard deviation (33% versus 31% for the base portfolio), albeit at a much improved maximum drawdown (-32% versus -50% for the base endowment portfolio).

Thus, for both base portfolios, a long VIX futures or call allocation provided improved returns and generally reduced risk, although the 25%-OTM call allocation resulted in an increased standard deviation. Generally speaking, the 1% long VIX call allocations had much larger impacts than the 5% long VIX futures allocations, particularly for the OTM calls.

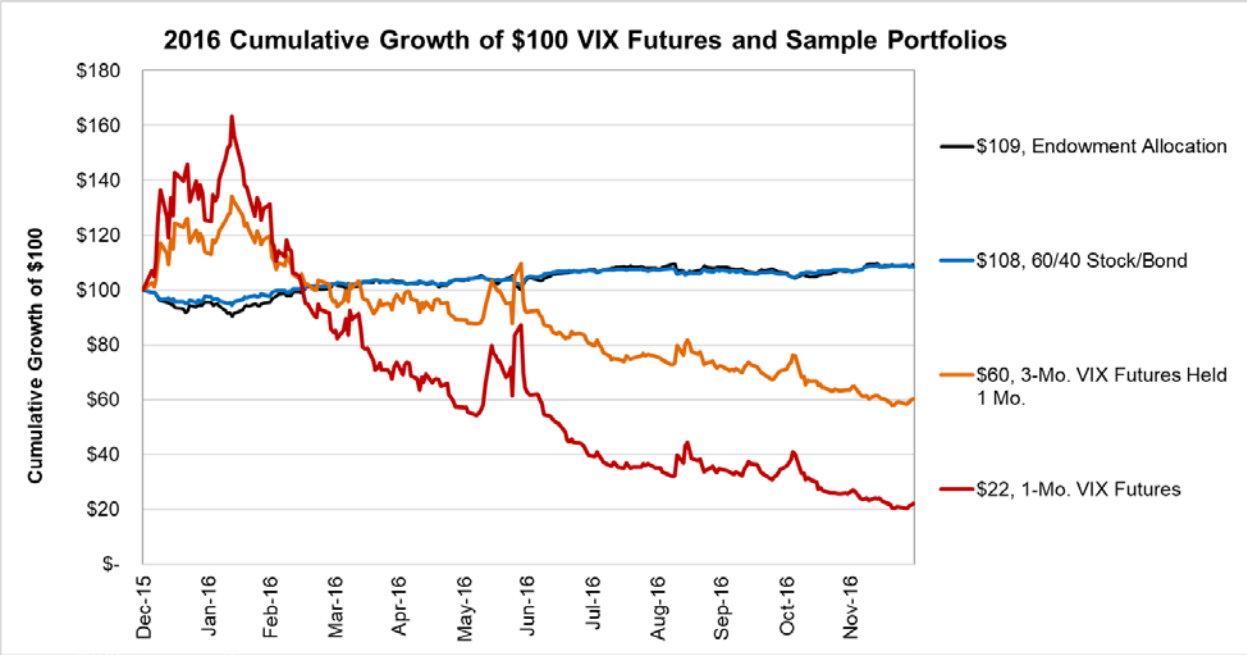
3.2 Long VIX Futures and Long VIX Call-Based Strategies in 2016

As discussed earlier, 2016 was chosen as a sample year which one would expect would be far less than ideal for a long VIX futures or call option allocation. The following section considers the impact of a 5% allocation to VIX futures or 1% allocation to VIX call options on the two base portfolios (the 60/40 portfolio and the hypothetical endowment portfolio).

Exhibit 10 provides a graphical representation and summary statistics of the 2016 cumulative performance of the one-month and three-month long VIX futures strategies along with the two base portfolios. It is clear that 2016 was not a favorable year for exposure to long VIX futures. While the futures strategies performed strongly at the start of the year, both futures strategies experienced very large drawdowns over the remainder of the year. In fact, the one-month long VIX futures strategy experienced a loss of -80% over the year, with a maximum drawdown of -88%.

The following section provides an analysis of the impact of an addition of a long VIX futures or call option allocation to the two base portfolios in 2016. We begin by considering a 5% allocation to long VIX futures and 1% allocation to long VIX call options in 2016. As mentioned earlier, 2016 was chosen as an example of an unfavorable year for a long VIX allocation as we expect that a long VIX futures or call exposure would incur significant drag due to relatively strong and consistent contango in VIX futures (see Exhibit 6).

Exhibit 10: 100% Allocations to Long VIX Futures-Based Strategies in 2016

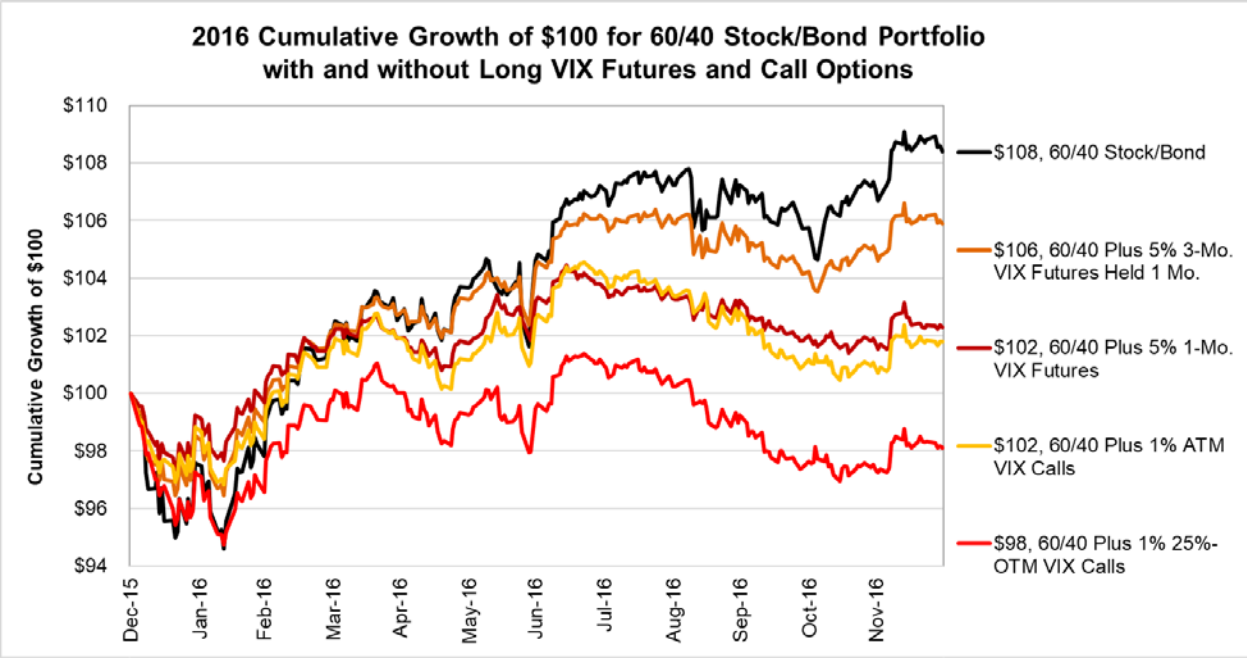


Summary Statistics for the Year 2016	60/40 Stock/Bond Portfolio	Endowment	100% Allocation to 1-Mo. VIX Futures	100% Allocation to 3-Mo. VIX Futures Held 1 Mo.
Annualized Return	8.4%	9.2%	-77.9%	-39.8%
Annualized Standard Deviation	7.6%	10.0%	88.2%	47.4%
Sharpe Ratio	1.11	0.92	-0.88	-0.84
Maximum Drawdown	-5.4%	-9.6%	-87.5%	-56.9%
Skewness	-0.29	-0.48	1.63	1.12
Kurtosis	2.23	2.56	9.46	9.18
Correlation w SPX	0.99	0.82	-0.83	-0.84
Beta	0.57	0.62	-5.58	-3.05
Alpha	1.42%	1.74%	-45.61%	-2.57%
Alpha P-Value	0.240	0.765	0.357	0.921

Source: Cboe Exchange, Inc., Bloomberg

Exhibit 10: *This exhibit illustrates the performance of two traditional portfolios as well as two VIX futures-based portfolios in 2016. The VIX portfolios are both fully collateralized and rebalanced daily. The one-month portfolio invests in one-month VIX futures and rolls out on the close the night before expiration. The three-month VIX futures portfolio purchases three-month VIX futures and rolls into a new three-month VIX futures contract after one month at the close before the front month VIX futures contract expires. The traditional portfolios consist of a 60/40 stock/bond portfolio and a hypothetical endowment portfolio which invests in a variety of indexes based on the average yearly asset allocation of a representative endowment.*

Exhibit 11: 60/40 Portfolio Performance in 2016 with Small Allocations to Long VIX Futures and Options



Summary Statistics for the Year 2016	60/40 Stock/Bond Portfolio	60/40 Plus 5% 1-Mo. Futures	60/40 Plus 5% 3-Mo. Futures Held 1 Mo.	60/40 Plus 1% 25%-OTM VIX Calls	60/40 Plus 1% ATM VIX Calls
Annualized Return	8.4%	2.3%	5.9%	-1.9%	1.8%
Annualized Standard Deviation	7.6%	4.4%	5.4%	5.7%	5.3%
Sharpe Ratio	1.11	0.52	1.09	-0.34	0.34
Maximum Drawdown	-5.4%	-2.9%	-3.5%	-5.3%	-3.9%
Skewness	-0.29	0.57	0.05	0.21	0.38
Kurtosis	2.23	1.77	1.69	1.75	1.86
Correlation w SPX	0.99	0.81	0.95	0.78	0.77
Beta	0.57	0.27	0.39	0.34	0.31
Alpha	1.42%	-0.94%	1.09%	-5.86%	-1.87%
Alpha P-Value	0.240	0.714	0.517	0.099	0.580

Source: Cboe Exchange, Inc., Bloomberg

Exhibit 11: *This exhibit illustrates the performance of a traditional 60/40 portfolio with and without a small allocation to long VIX futures or long VIX call options. While a 5% long allocation to VIX futures or a 1% allocation to ATM or 25%-OTM VIX calls significantly reduces 2016 returns, they provide a reduction in volatility and drawdowns.*

Exhibit 11 provides an illustration of the 2016 cumulative growth and summary statistics of the 60/40 stock/bond portfolio with and without a 5% allocation to long VIX futures (one-month or three-month VIX futures) and a 1% allocation to long VIX calls (at-the-money (ATM) or 25% out-of-the money (OTM) one-month VIX calls). The base 60/40 portfolio gained 8% over the period at an 8% annual standard deviation and a -5% maximum drawdown. The portfolios with a 5% allocation to long one- and three-month VIX futures underperformed the base portfolio,

reducing the gains of the base portfolio from 8% to 2% and 6%, respectively. However, the one- and three-month VIX futures allocations reduced standard deviation from 8% to 4% and 5%, respectively and maximum drawdown from -5% to -3% and -4%, respectively. The ex-post skewness was also improved by adding the long VIX futures allocation to the base portfolio. Thus, while the long VIX futures allocation reduced risk in 2016, it did so at the expense of reduced returns. Furthermore, the return to risk tradeoff (as measured by the Sharpe ratio) of the base portfolio was reduced by the addition of long VIX futures (from 1.11 to 0.52 and 1.09, respectively).

The results for adding a long VIX call option allocation are similar, yet more extreme. The 1% long one-month ATM VIX call allocation reduced returns from 8% to 2% and standard deviation from 8% to 5%, and maximum drawdown from -5% to -4%, thus providing improvements in risk at the cost of reduced returns. While the reductions in risk are similar to the long VIX futures allocations, the reductions in returns are greater for the long call allocations, particularly for the OTM calls. The return to risk tradeoff (as measured by the Sharpe ratio) of the base portfolio was greatly reduced by the addition of long VIX call options (from 1.11 to 0.34 and 1.09, respectively).

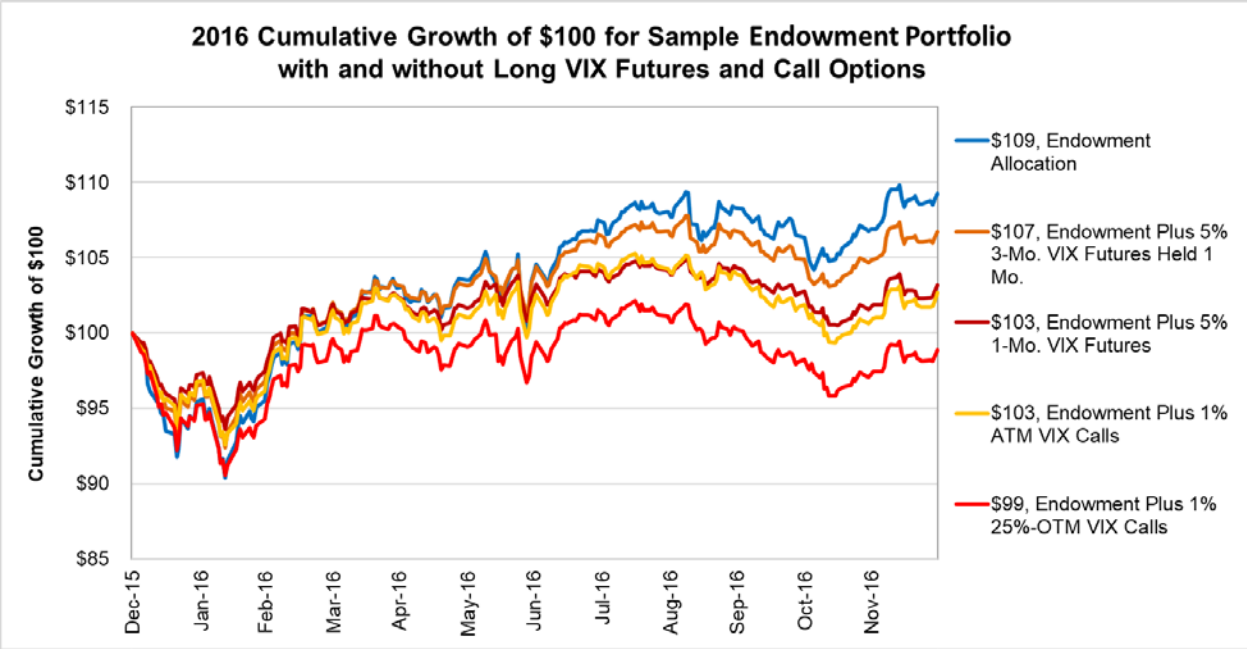
Thus, in 2016 the addition of long VIX futures or call options to the 60/40 base portfolio resulted in reduced risk-adjusted returns based on the Sharpe ratio. Similar results are found when considering alpha (although all measured alphas are statistically insignificant at 10%, with the exception of the 60/40 + OTM call portfolio).

The results above suggest that an addition of a long VIX futures or call option allocation clearly reduces risk, absolute returns and risk-adjusted returns for a 60/40 portfolio in 2016. We now consider the addition of long VIX futures and call options to a well-diversified portfolio that contains other asset classes beyond equity and fixed income. Exhibit 12 presents an analysis of an addition of long VIX futures and call options to a well-diversified hypothetical endowment portfolio in 2016.

As in 2008, in 2016 the impact of the long VIX allocations were similar for both base portfolios. Exhibit 12 provides an illustration of the 2016 cumulative growth and summary statistics of the base hypothetical endowment portfolio with and without a 5% allocation to long VIX futures (one-month or three-month VIX futures) and a 1% allocation to long VIX calls (ATM or 25%-OTM one-month VIX calls). The base endowment portfolio gained 9% over the period at a 10% annual standard deviation and a -10% maximum drawdown. The portfolios with a 5% allocation to long one- and three-month VIX futures both underperformed the base portfolio, reducing the gains of the base portfolio from 9% to 3% and 7%, respectively. In addition to reducing returns, the one- and three-month VIX futures allocations reduced standard deviation from 10% to 7% and 8%, respectively and maximum drawdown from -10% to -6% and -8%, respectively. The ex-post skewness was also improved by adding the long VIX futures allocation to the base endowment portfolio. Thus, once again the long VIX futures allocation reduced returns in 2016, albeit with a reduction in risk. From a risk-adjusted return basis, the addition of long VIX futures reduced

performance (as measured by the Sharpe ratio) of the base portfolio (from 0.92 to 0.44 and 0.84, respectively).

Exhibit 12: Endowment Portfolio Performance in 2016 with Small Allocations to Long VIX Futures and Options



Summary Statistics for the Year 2016	Endowment	Endowment Plus 5% 1-Mo. Futures	Endowment Plus 5% 3-Mo. Futures Held 1 Mo.	Endowment Plus 1% 25%-OTM VIX Calls	Endowment Plus 1% ATM VIX Calls
Annualized Return	9.2%	3.2%	6.7%	-1.1%	2.6%
Annualized Standard Deviation	10.0%	7.3%	8.1%	8.8%	8.3%
Sharpe Ratio	0.92	0.44	0.84	-0.13	0.32
Maximum Drawdown	-9.6%	-6.4%	-7.6%	-9.5%	-7.4%
Skewness	-0.48	-0.27	-0.35	-0.49	-0.41
Kurtosis	2.56	1.79	1.90	1.67	1.72
Correlation w SPX	0.82	0.58	0.72	0.58	0.58
Beta	0.62	0.32	0.44	0.39	0.36
Alpha	1.74%	-0.53%	1.45%	-5.50%	-1.47%
Alpha P-Value	0.765	0.928	0.796	0.443	0.829

Source: Cboe Exchange, Inc., Bloomberg

Exhibit 12: *This exhibit illustrates the 2016 performance of a hypothetical endowment portfolio with and without a small allocation to long VIX futures or long VIX call options. Similar to the 60/40 portfolio, a 5% long allocation to VIX futures or a 1% allocation to ATM or 25%-OTM VIX calls significantly reduces 2016 returns, while also reducing volatility and drawdowns.*

As with the 60/40 portfolio, the results for adding a long VIX call option allocation are more extreme than those from adding long VIX futures. The 1% long one-month ATM VIX call allocation reduced returns from 9% to 3% and reduced standard deviation from 10% to 8%, and

maximum drawdown from -10% to -7%, thus providing improvements in risk and return similar to the long VIX futures allocations. In contrast, the 1% allocation to long one-month 25%-OTM VIX calls further reduced returns to a 1% loss (from a 9% gain for the base portfolio), and did so at a somewhat lower standard deviation (9% versus 10% for the base portfolio), and at an essentially identical maximum drawdown (-9.5% versus -9.6% for the base endowment portfolio).

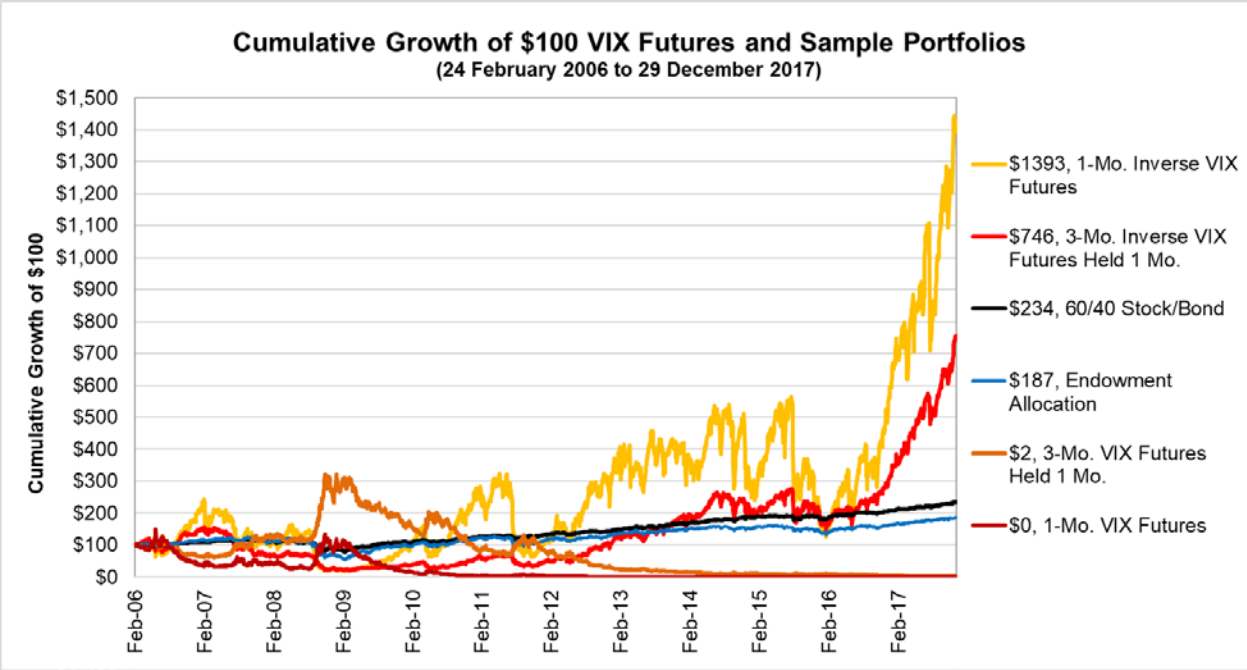
Thus, for both base portfolios, a long VIX futures or call allocation resulted in an economically significant reduction in returns and a smaller reduction in risk, resulting in lower Sharpe ratios. Similar results are found when considering alpha (although all measured alphas are statistically insignificant at 10%). It is worth noting that the 1% long VIX call allocations had much larger impacts than the 5% long VIX futures allocations, particularly for the OTM calls.

4.0 Performance of Long Term Buy-and-Hold Long VIX-Based Strategies from 2006 to 2017

As mentioned above, the relatively persistent contango in VIX futures and the high volatility of volatility would likely make a large long-term Buy-and-Hold allocation to long VIX futures challenging for most growth-oriented investors. For this reason, the previous analysis focused on VIX futures or call option investments in a portfolio context over single-year time periods. For the sake of completeness, this section expands the analysis by considering the performance of these strategies over the 10+ years since the introduction of VIX options.

Exhibit 13 provides a graphical representation and summary statistics of the cumulative performance of the one-month and three-month long and inverse VIX futures strategies along with the two base portfolios since the inception of VIX options. It is evident that the overall period was favorable for an inverse VIX futures exposure from a total return perspective and unfavorable for a long VIX futures exposure. However, the volatility of the long and inverse VIX exposures were exceedingly high (ranging from 32% to 78%) as were the maximum drawdowns (ranging from -90% to -100%). The following sections will consider the full period performance of long and inverse VIX futures and call options in a portfolio context.

Exhibit 13: Large Long-term Allocations to VIX Futures-Based Strategies from 2006 to 2017



24 Feb 2006 to 29 Dec 2017	60/40 Stock/Bond Portfolio	Endowment	1-Mo. VIX Futures	3-Mo. VIX Futures Held 1-Mo.	3-Mo. Inverse VIX Futures Held 1 Mo.	3-Mo. Inverse VIX Futures Held 1 Mo.
Annualized Return	7.5%	5.4%	-55.8%	-28.8%	25.0%	18.5%
Annualized Standard Deviation	11.4%	16.5%	77.9%	43.6%	77.9%	43.6%
Sharpe Ratio	0.65	0.33	-0.73	-0.68	0.31	0.40
Maximum Drawdown	-34.8%	-57.4%	-100.0%	-99.4%	-92.3%	-86.5%
Skewness	-0.10	-0.24	1.04	0.64	-1.05	-0.64
Kurtosis	12.38	10.18	5.47	4.02	5.47	4.02
Correlation w SPX	0.99	0.89	-0.74	-0.74	0.74	0.74
Beta	0.58	0.75	-2.94	-1.66	2.94	1.66
Alpha	1.95%	-1.00%	-21.80%	-7.54%	23.94%	9.67%
Alpha P-Value	0.000	0.648	0.155	0.373	0.118	0.254

Source: Cboe Exchange, Inc., Bloomberg

Exhibit 13: *This exhibit illustrates the performance of two traditional portfolios as well as two long VIX futures-based portfolios and two inverse VIX futures-based portfolios over the entire, almost 12-year, period of study. The volatility and drawdowns of the four VIX futures-based portfolios suggest that VIX futures may be best suited for smaller or shorter-term strategic portfolio risk management or return enhancement rather than large long-term Buy-and-Hold strategies.*

4.1 Performance of Long VIX Futures and Options-Based Strategies from 2006 to 2017

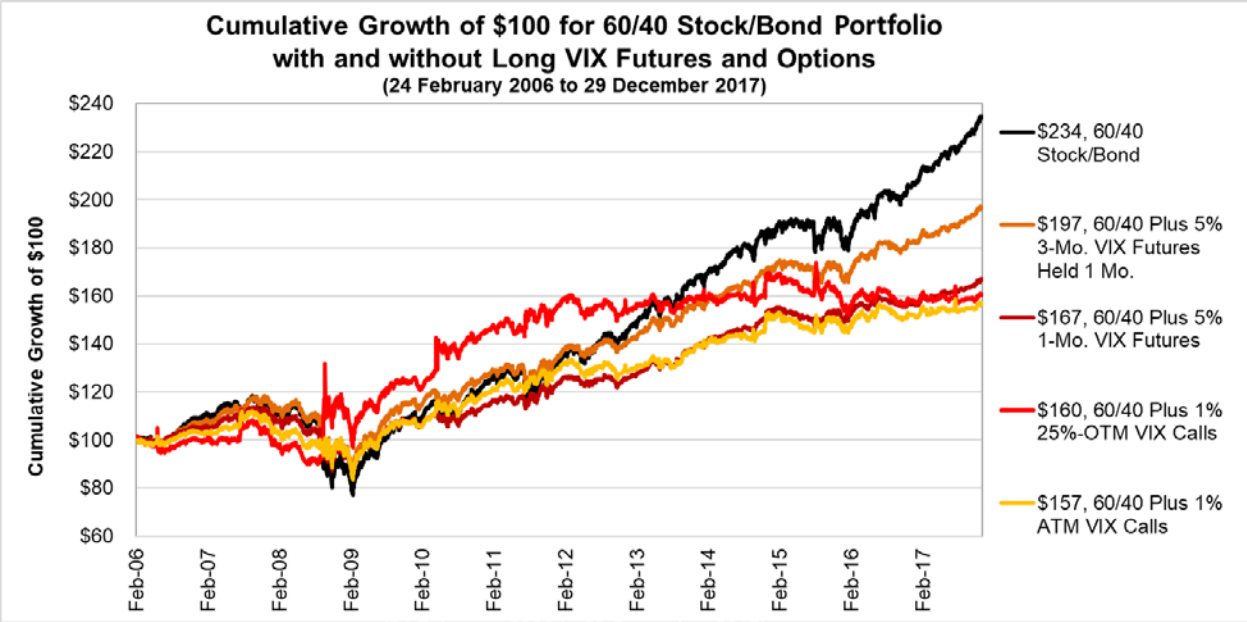
This section considers the 10+ year impact of a 5% allocation to long one-month or three-month VIX futures or a 1% allocation to long one-month ATM or 25%-OTM VIX call options to a traditional stock and bond portfolio and hypothetical endowment portfolios.

Exhibit 14 provides an illustration of the 10+ year cumulative growth and summary statistics of the 60/40 stock/bond portfolio with and without a 5% allocation to long VIX futures (one-month or three-month VIX futures) and a 1% allocation to long VIX calls (ATM or 25%-OTM one-month VIX calls). The base 60/40 portfolio generated an 8% annualized return over the period at an 11% annualized standard deviation with a -35% maximum drawdown. Both of the 5% long VIX futures allocations decreased the returns of the base portfolio (from 8% to 4% and 6%, respectively). However, the one- and three-month long VIX futures allocations decreased standard deviation from 11% to 8% and 9%, respectively and maximum drawdown from -35% to -27% and -28%, respectively. The ex-post skewness was also improved by adding the long VIX futures allocations to the base portfolio. Thus over the full period, the long VIX futures allocation reduced absolute returns and risk. Based on the Sharpe ratio, the long VIX futures allocation reduced risk-adjusted returns (Sharpe ratio decreased from 0.65 to 0.54 and 0.64, respectively). Similar results are found in alpha (although the alpha for the one-month VIX allocation is statistically insignificant).

The results for adding a long VIX call option allocation are generally similar to the results for the long VIX futures allocations. The 1% long one-month ATM VIX call allocation reduced returns from 8% to 4% and reduced standard deviation from 11% to 9%, and maximum drawdown from -35% to -26%. While the 1% allocation to long one-month 25%-OTM VIX calls had similar return impacts to the other long VIX allocations, it actually increased standard deviation. Returns were reduced from 8% to 4% while standard deviation increased from 11% to 13%, although another measure of risk, maximum drawdown, decreased from -35% to -27%. From a risk-adjusted return perspective, the Sharpe ratio and alpha of the 1% long ATM call allocation portfolio were worse than those of the base portfolio (0.44 versus 0.65 and 1.1% versus 2.8%, respectively). However, the results are mixed for the OTM call allocation portfolio, with the Sharpe ratio decreasing from 0.65 to 0.32 while alpha increases from 2.8% to 3.9% (although alphas of the long call portfolios are statistically insignificant).

The results above suggest that a long VIX futures or long call allocation would have reduced performance from a raw return perspective and, by most measures, from a risk-adjusted return perspective. This finding reinforces the idea that permanent Buy-and-Hold allocations to long VIX futures or calls may place a meaningful drag on portfolio performance, although they may provide risk mitigation benefits over the long term.

Exhibit 14: 60/40 Portfolio Performance with Small Allocations to Long VIX Futures and Long VIX Calls from 2006 to 2017



24 Feb 2006 to 29 Dec 2017	60/40 Stock/Bond Portfolio	60/40 Plus 5% 1-Mo. Futures	60/40 Plus 5% 3-Mo. Futures Held 1 Mo.	60/40 Plus 1% 25%-OTM VIX Calls	60/40 Plus 1% ATM VIX Calls
Annualized Return	7.5%	4.4%	5.9%	4.1%	3.9%
Annualized Standard Deviation	11.4%	8.1%	9.2%	12.5%	8.7%
Sharpe Ratio	0.65	0.54	0.64	0.32	0.44
Maximum Drawdown	-34.8%	-26.5%	-28.2%	-26.5%	-25.6%
Skewness	-0.10	0.35	0.10	-0.01	0.40
Kurtosis	12.38	16.25	15.20	62.89	12.68
Correlation w SPX	0.99	0.92	0.97	0.32	0.75
Beta	0.58	0.38	0.46	0.20	0.33
Alpha	1.95%	0.78%	1.47%	2.72%	0.79%
Alpha P-Value	0.000	0.408	0.013	0.430	0.641

Source: Cboe Exchange, Inc., Bloomberg

Exhibit 14: *This exhibit illustrates the performance of a 60/40 traditional portfolio with and without a small allocation to long VIX futures or VIX call options. The base 60/40 portfolio provides the highest return without a long VIX-based allocation. While the long VIX-based allocations generally reduce volatility and drawdowns they do so while reducing returns.*

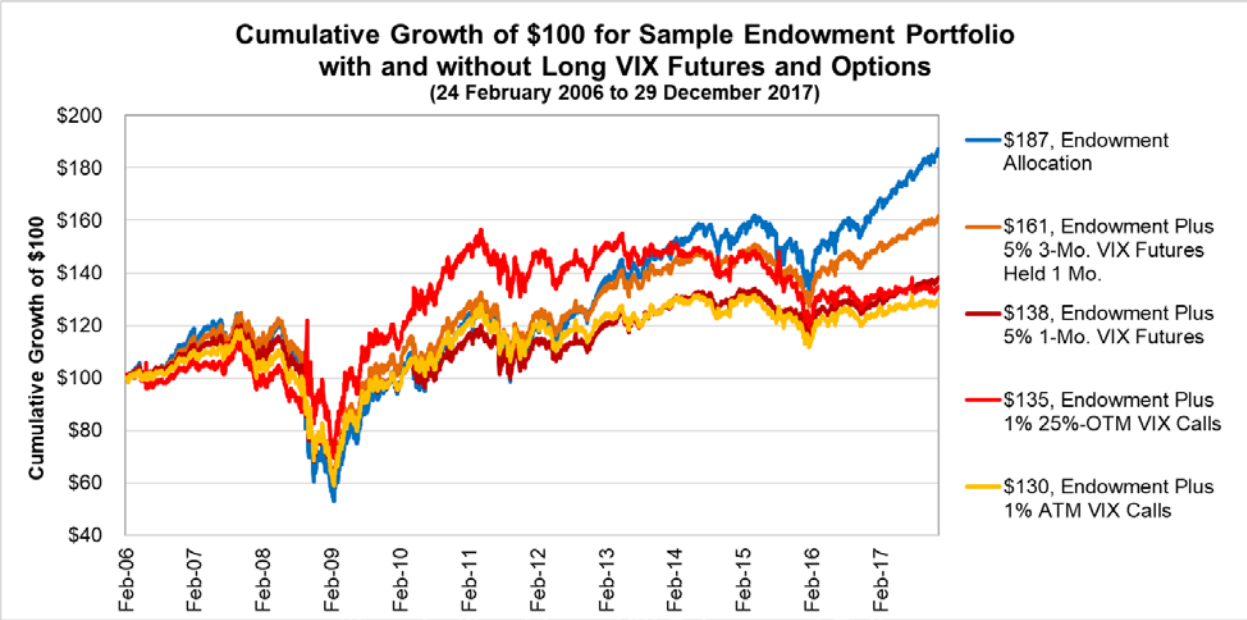
This section considers the impact of an addition of long VIX futures or call options to a well-diversified hypothetical endowment portfolio over the full period. The impact of the long VIX allocations to the endowment portfolio were generally similar to the impacts for the 60/40 base portfolio. Exhibit 15 provides an illustration of the full period cumulative growth and summary statistics of the base hypothetical endowment portfolio with and without a 5% allocation to long VIX futures (one-month or three-month VIX futures) or a 1% allocation to long VIX calls (ATM or 25%-OTM one-month VIX calls). The base endowment portfolio experienced a 5% annualized return over the period at a 17% annual standard deviation and a -57% maximum

drawdown. The portfolios with a 5% allocation to long one- and three-month VIX futures all experienced lower returns and standard deviations than the base endowment portfolio, to varying degrees. The one- and three-month long VIX futures allocations moderately reduced annualized returns from 5% to 3% and 4%, respectively. The one- and three-month VIX futures allocations also reduced standard deviation from 17% to 13% and 14%, respectively and maximum drawdown from -57% to -50% and -52%, respectively. The ex-post skewness was also improved by adding the long VIX futures allocations to the base endowment portfolio. Thus the long VIX futures allocations reduced both risk and return in the overall period. From a risk-adjusted return perspective, the long VIX futures allocations reduced performance of the endowment portfolio with the Sharpe ratio dropping from 0.33 to 0.21 and 0.29 and alpha decreasing from -1.4% to -2.8% and -1.8%, respectively.

The results for adding a long VIX call option allocation are very similar to the results for adding a one-month VIX futures allocation. The 1% written one-month ATM or OTM VIX call allocation reduced returns from 5% to 2% and 3% and increased standard deviation from 17% to 14% and 16%, respectively and maximum drawdown from -57% to -50% and -43%, respectively. From a risk-adjusted return perspective, the long VIX call allocations reduced performance of the endowment portfolio based on the Sharpe ratio (dropping from 0.33 to 0.16 for both call strategies). However the results for alpha are mixed, with alpha decreasing from -1.4% to -2.8% and increasing from -1.4% to +0.2%, respectively (although the alphas are not statistically significant).

Thus, for both base portfolios, a long VIX futures or call allocations reduced absolute returns and reduced risk. On balance, with the exception of the increase in the (statistically insignificant) alpha, the long VIX futures or call allocations reduced risk-adjusted returns.

Exhibit 15: Endowment Portfolio Performance with Small Allocations to Long VIX Futures and Long VIX Calls from 2006 to 2017



24 Feb 2006 to 29 Dec 2017	Endowment	Endowment Plus 5% 1-Mo. Futures	Endowment Plus 5% 3-Mo. Futures Held 1 Mo.	Endowment Plus 1% 25%-OTM VIX Calls	Endowment Plus 1% ATM VIX Calls
Annualized Return	5.4%	2.8%	4.1%	2.6%	2.2%
Annualized Standard Deviation	16.5%	13.1%	14.2%	16.2%	13.7%
Sharpe Ratio	0.33	0.21	0.29	0.16	0.16
Maximum Drawdown	-57.4%	-50.4%	-51.7%	-42.9%	-50.2%
Skewness	-0.24	0.02	-0.13	-0.40	0.04
Kurtosis	10.18	12.41	11.25	28.10	11.36
Correlation w SPX	0.89	0.80	0.85	0.44	0.71
Beta	0.75	0.54	0.62	0.37	0.50
Alpha	-1.00%	-1.92%	-1.27%	0.11%	-1.96%
Alpha P-Value	0.648	0.397	0.553	0.978	0.482

Source: Bloomberg, CFE, Cboe Options Exchange, Optionmetrics

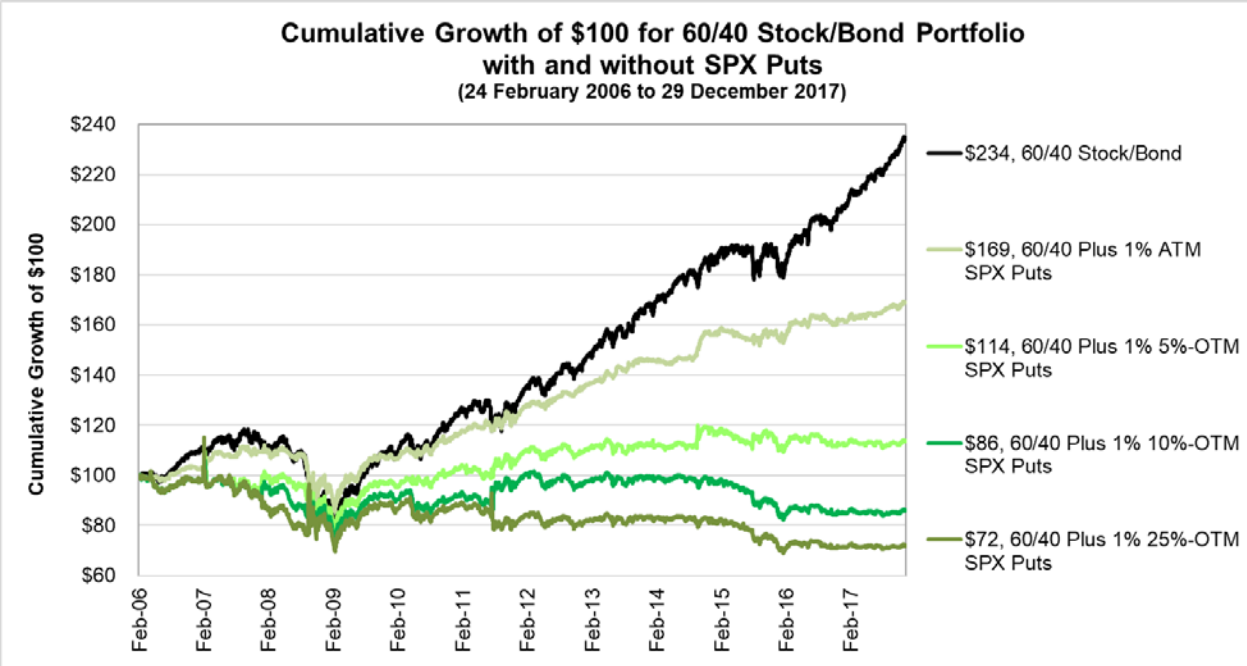
Exhibit 15: *This exhibit illustrates the performance of a hypothetical endowment portfolio with and without a small allocation to long VIX futures or VIX call options. Similar to the 60/40 portfolio, the base endowment portfolio provides the highest return without a long VIX-based allocation, while the long VIX-based allocations reduce volatility and drawdowns.*

5.0 SPX Puts versus VIX Calls

As previously discussed, much of the appeal of long VIX futures and call exposure is due to the ability of long volatility to act as a diversifier for traditional portfolios. One popular risk management alternative to the use of long VIX futures or calls is the use of long equity put options. The following sections compare the performance of long S&P 500 (SPX) put option allocations to long VIX call option allocations. While a wide variety of long put implementations are possible, for the sake of clarity, the following analyses consider a 1% allocation to 5%-OTM

SPX puts or a 1% allocation to 10%-OTM SPX puts. It is worth noting that no attempt was made to scale the moneyness or percentage allocation to match the portfolio impact of the VIX call allocations. Such an analysis is beyond the scope of this paper. We chose 5%-OTM puts as the near-the-money alternative rather than ATM puts to somewhat mitigate the cost of protection, while 10%-OTM puts where chosen as the far out-of-the-money alternative to somewhat reflect the relative volatility of SPX versus VIX.

Exhibit 16: 60/40 Stock/Bond Portfolio with and without 1% Allocations to Long SPX Puts



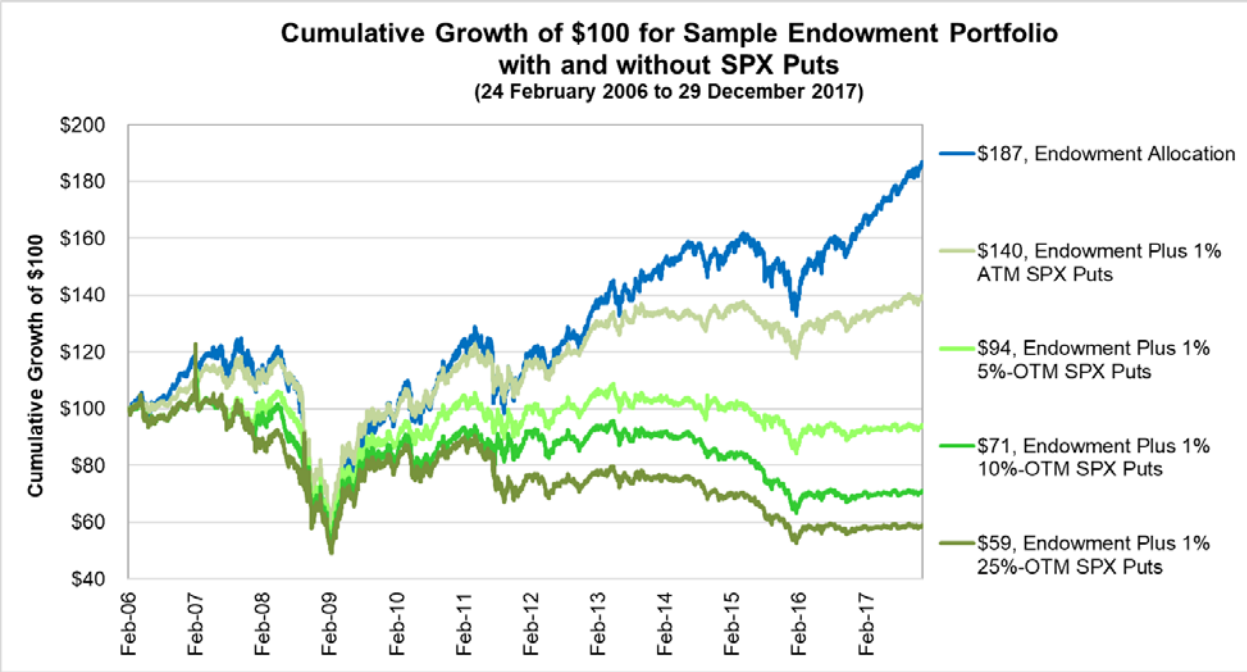
24 Feb 2006 to 29 Dec 2017	60/40 Stock/Bond Portfolio	60/40 Plus 1% 25%-OTM SPX Puts	60/40 Plus 1% 10%-OTM SPX Puts	60/40 Plus 1% 5%-OTM SPX Puts	60/40 Plus 1% ATM SPX Puts
Annualized Return	7.5%	-2.8%	-1.3%	1.1%	4.5%
Annualized Standard Deviation	11.4%	16.7%	10.2%	9.5%	7.6%
Sharpe Ratio	0.65	-0.17	-0.13	0.11	0.59
Maximum Drawdown	-34.8%	-40.1%	-31.0%	-29.3%	-23.7%
Skewness	-0.10	2.37	0.65	0.71	0.28
Kurtosis	12.38	168.77	27.47	30.01	19.15
Correlation w SPX	0.99	0.24	0.50	0.53	0.84
Beta	0.58	0.20	0.26	0.26	0.33
Alpha	1.95%	-3.48%	-3.41%	-1.10%	1.39%
Alpha P-Value	0.000	0.460	0.182	0.640	0.245

Source: Bloomberg, CFE, Cboe Options Exchange, Optionmetrics

Exhibit 16: *This exhibit illustrates the 10+ year performance of the sample endowment portfolio with and without the addition of a 1% allocation to one-month SPX puts of varying moneyness. It is worth noting that the strategy with ATM puts out-performed the strategies with OTM puts during the bull market since 2009, despite the fact that ATM puts are more expensive than OTM puts and neither puts experienced frequent payoffs. This is due to the fact that all the presented strategies had an equal 1% allocation to options (regardless of the price of the puts), and the ATM puts experienced more frequent put payoffs than the OTM puts.*

Exhibits 16 and 17 provide graphical representations and summary statistics of the cumulative 10+ year performance of the 60/40 stock/bond portfolio and the sample endowment portfolio, respectively, with an without the addition of a 1% allocation to long one-month SPX puts of varying moneyness (ATM and 1%, 5%, 10% and 25%-OTM). The long-term impact of the 1% allocations are clear in the exhibits as is the importance of the choice of moneyness. While Exhibits 16 and 17 report results for four different moneyness levels, the subsequent analysis will only consider the 5% and 10%-OTM puts for the sake of clarity.

Exhibit 17: Endowment Portfolio with and without 1% Allocations to Long SPX Put Options



24 Feb 2006 to 29 Dec 2017	Endowment	Endowment Plus 1% 25%-OTM SPX Puts	Endowment Plus 1% 10%-OTM SPX Puts	Endowment Plus 1% 5%-OTM SPX Puts	Endowment Plus 1% ATM SPX Puts
Annualized Return	5.4%	-4.4%	-1.3%	1.1%	2.9%
Annualized Standard Deviation	16.5%	20.4%	10.2%	9.5%	13.2%
Sharpe Ratio	0.33	-0.22	-0.13	0.11	0.21
Maximum Drawdown	-57.4%	-60.0%	-31.0%	-29.3%	-49.1%
Skewness	-0.24	0.92	0.65	0.71	0.00
Kurtosis	10.18	94.00	27.47	30.01	13.58
Correlation w SPX	0.89	0.34	0.50	0.53	0.73
Beta	0.75	0.36	0.26	0.26	0.49
Alpha	-1.00%	-6.05%	-3.41%	-1.10%	-1.32%
Alpha P-Value	0.648	0.277	0.182	0.640	0.615

Source: Bloomberg, CFE, Cboe Options Exchange, Optionmetrics

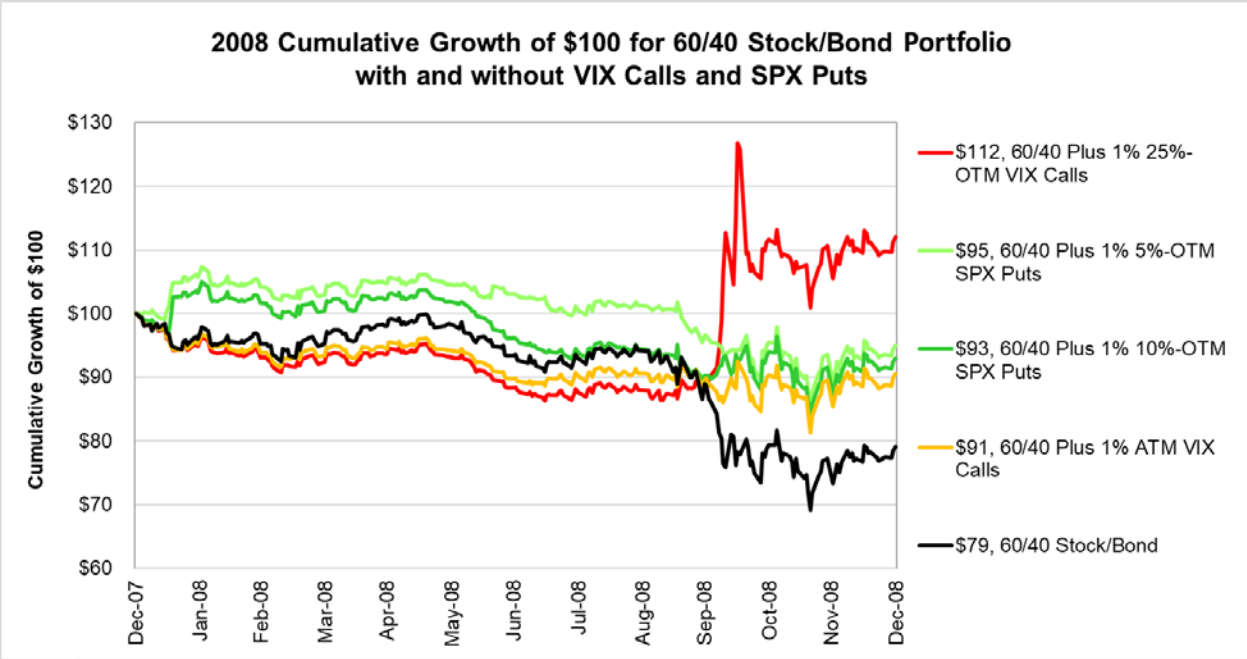
Exhibit 17: *This exhibit illustrates the 10+ year performance of the sample endowment portfolio with and without the addition of a 1% allocation to one-month SPX puts of varying moneyness. It is worth noting that the relative performance of strategies with varying option moneyness is largely driven by the frequency and degree of option payoffs as well as the relative cost of the purchased options.*

5.1 SPX Puts versus VIX Calls in 2008

Exhibit 18 provides an illustration of the 2008 cumulative growth and summary statistics of the 60/40 stock/bond portfolio with and without a 1% allocation to long one-month SPX 5%-OTM or 10%-OTM puts as well as with a 1% allocation to long one-month VIX ATM or 25%-OTM calls. The base 60/40 portfolio lost 21% over the period at a 24% annual standard deviation and a -31% maximum drawdown. Both SPX put allocations and both VIX call allocations provided significant risk mitigation in 2008, although the impact varied widely across the different allocations. The portfolios with a 1% allocation to long one-month SPX 10%-OTM and 5%-OTM puts generated returns of -7% and -5%, respectively at standard deviations of 17.8% and 16.6%, respectively. The portfolio with a 1% allocation to long one-month VIX ATM calls generated lower returns (-9%) and a higher standard deviation (17.9%) than both SPX put allocation portfolios, although its alpha lies between the alphas of the long one-month SPX 10%-OTM and 5%-OTM put allocations (9% versus 5% and 11%, respectively). The 25%-OTM VIX call allocation portfolio is the outlier of the four risk-mitigated portfolios. It generated a gain of 12% versus the losses of -5% to -9% for the other three portfolios and the loss of -21% for the base portfolio. The 25%-OTM VIX call allocation also increases standard deviation of the base portfolio from 24% to 28% while the other three portfolios reduce standard deviation by about 1/3. Furthermore, the 25%-OTM VIX call allocation portfolio provides a very large improvement in risk-adjusted returns over the base portfolio (and the other three portfolios), increasing the Sharpe ratio from -0.87 to +0.44 and alpha from 2.2% to 29.8% (although the alphas are statistically insignificant).

Results for the additions to the endowment portfolio in 2008 are similar to those of the 60/40 portfolio (see Exhibit 19). Once again, all four portfolios reduced losses of the base portfolio and increased alpha, with the 25%-OTM VIX call allocation portfolio providing the greatest improvement. In contrast to the other three portfolios, the 25%-OTM VIX call allocation increases the risk of the endowment portfolio in terms of standard deviation, although it does reduce the maximum drawdown.

Exhibit 18: 60/40 Portfolio with and without VIX Calls or SPX Puts in 2008

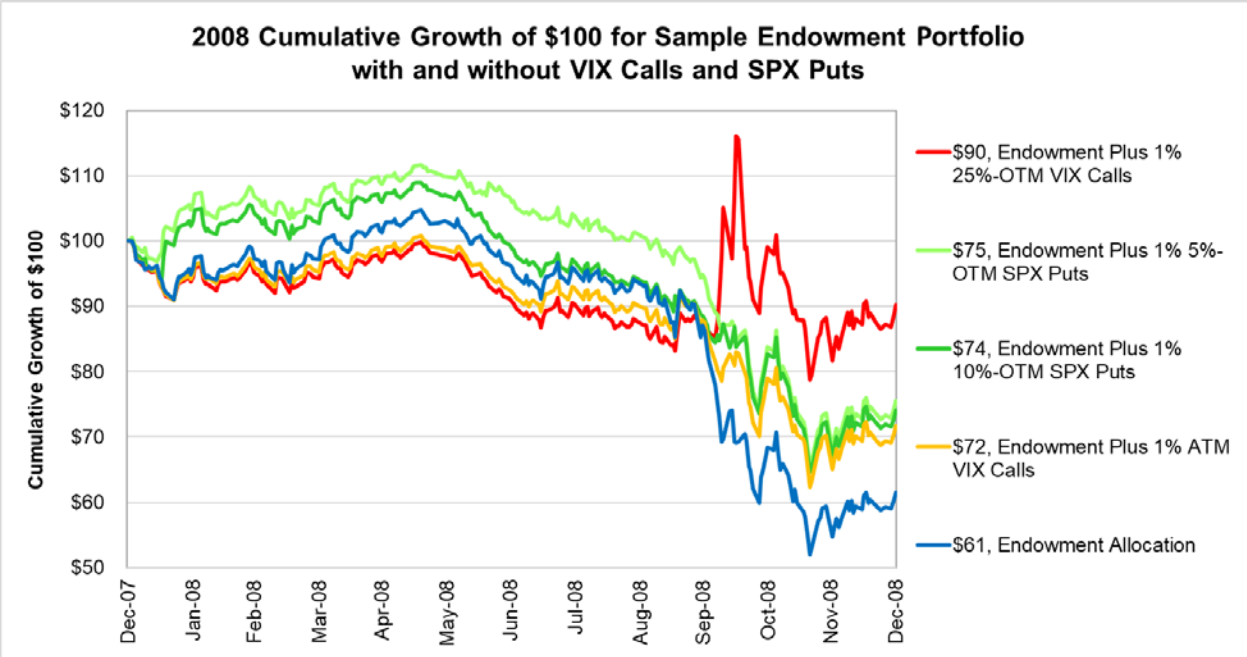


Summary Statistics for the Year 2008	60/40 Stock/Bond Portfolio	60/40 Plus 1% 10%-OTM SPX Puts	60/40 Plus 1% 5%-OTM SPX Puts	60/40 Plus 1% 25%-OTM VIX Calls	60/40 Plus 1% ATM VIX Calls
Annualized Return	-20.9%	-7.0%	-4.9%	12.1%	-9.4%
Annualized Standard Deviation	24.1%	17.8%	16.6%	27.6%	17.9%
Sharpe Ratio	-0.87	-0.39	-0.30	0.44	-0.53
Maximum Drawdown	-30.9%	-20.1%	-20.5%	-20.4%	-18.8%
Skewness	0.16	0.30	0.36	0.29	0.49
Kurtosis	4.14	4.06	5.13	22.41	4.46
Correlation w SPX	1.00	0.55	0.74	0.21	0.89
Beta	0.58	0.24	0.30	0.14	0.39
Alpha	1.53%	3.38%	7.60%	20.54%	6.24%
Alpha P-Value	0.501	0.820	0.495	0.447	0.454

Source: Bloomberg, CFE, Cboe Options Exchange, Optionmetrics

Exhibit 18: *This exhibit illustrates the 2008 performance of a 60/40 portfolio with and without the addition of VIX calls and SPX puts. While the OTM VIX call allocation provides the largest improvement of returns (increasing returns from a 21% loss to a 12% gain), it also results in an increase in standard deviation.*

Exhibit 19: Endowment Portfolio with and without VIX Calls or SPX Puts in 2008



Summary Statistics for the Year 2008	Endowment	Endowment Plus 1% 10%-OTM SPX Puts	Endowment Plus 1% 5%-OTM SPX Puts	Endowment Plus 1% 25%-OTM VIX Calls	Endowment Plus 1% ATM VIX Calls
Annualized Return	-38.6%	-25.9%	-24.5%	-9.8%	-28.3%
Annualized Standard Deviation	31.0%	25.4%	24.1%	32.8%	25.1%
Sharpe Ratio	-1.25	-1.02	-1.02	-0.30	-1.13
Maximum Drawdown	-50.4%	-40.6%	-41.1%	-32.2%	-38.2%
Skewness	-0.13	-0.01	-0.02	-0.31	0.01
Kurtosis	3.21	4.08	5.22	13.65	4.08
Correlation w SPX	0.92	0.53	0.67	0.30	0.80
Beta	0.69	0.33	0.39	0.24	0.49
Alpha	-17.63%	-14.21%	-10.26%	4.25%	-11.58%
Alpha P-Value	0.158	0.509	0.567	0.892	0.445

Source: Bloomberg, CFE, Cboe Options Exchange, Optionmetrics

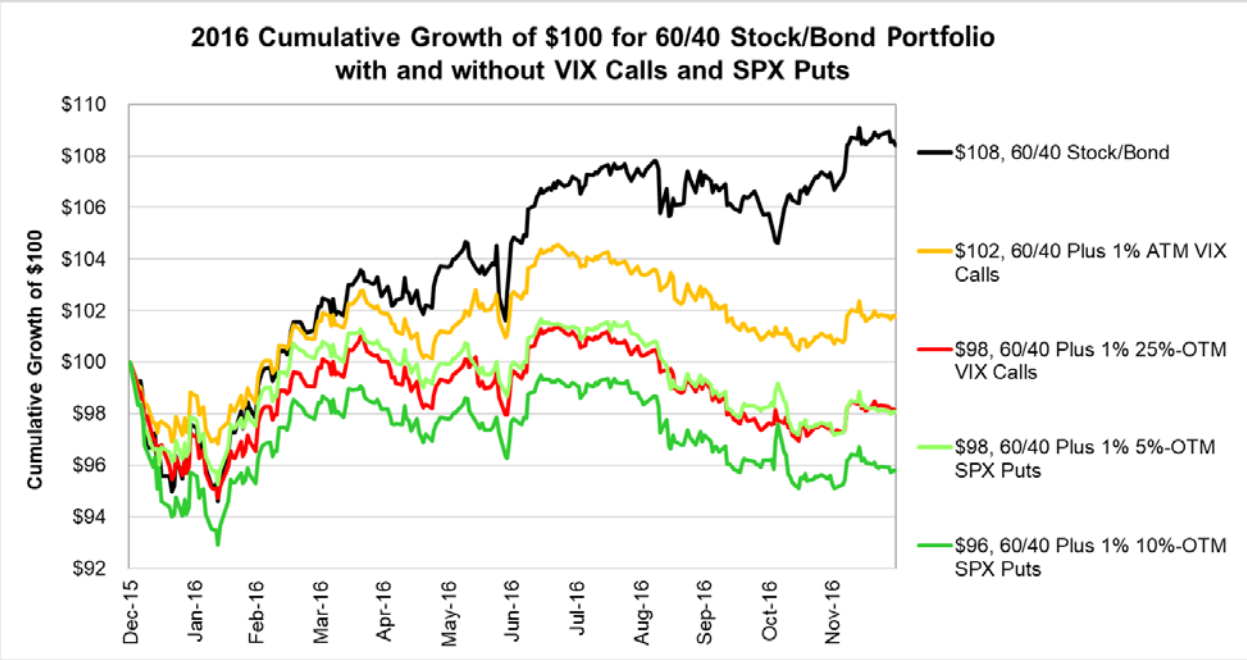
Exhibit 19: *This exhibit illustrates the 2008 performance of a theoretical endowment portfolio with and without the addition of VIX calls and SPX puts. As with the 60/40 portfolio, the OTM VIX call allocation provides the largest improvement in returns, albeit with a small increase in standard deviation.*

5.2 SPX Puts versus VIX Calls in 2016

The previous section indicated that the 1% ATM VIX call allocation provided generally similar risk reduction in 2008 to the two 1% SPX put allocations for both base portfolios, while the 25%-OTM VIX call allocation provided far better returns and risk-adjusted returns but moderately increased standard deviation. This section considers whether the impact of the VIX call allocations and the SPX put allocations are also similar in a relatively strong market environment as experienced in 2016.

In 2016, the base 60/40 portfolio outperformed the other four portfolios, with higher returns, Sharpe ratio and alpha, although it did so at a somewhat higher standard deviation (see Exhibit 20). The 10%-OTM SPX put allocation portfolio underperformed the other portfolios in 2016 by all measures. Returns were -4% versus -2%, -2% and +2% for the 10%-OTM SPX put, 25%-OTM VIX call, and ATM VIX call allocations, respectively. The standard deviation of the 10%-OTM SPX put allocation portfolio was also higher than all but the base portfolio, while the maximum drawdown was lower than that of all of the other four portfolios (including the base portfolio). The alpha was also far lower than that of the other four portfolios.

Exhibit 20: 60/40 Portfolio with and without VIX Calls or SPX Puts in 2016



Summary Statistics for the Year 2016	60/40 Stock/Bond Portfolio	60/40 Plus 1% 10%-OTM SPX Puts	60/40 Plus 1% 5%-OTM SPX Puts	60/40 Plus 1% 25%-OTM VIX Calls	60/40 Plus 1% ATM VIX Calls
Annualized Return	8.4%	-4.2%	-1.9%	-1.9%	1.8%
Annualized Standard Deviation	7.6%	6.5%	5.5%	5.7%	5.3%
Sharpe Ratio	1.11	-0.65	-0.35	-0.34	0.34
Maximum Drawdown	-5.4%	-7.1%	-4.7%	-5.3%	-3.9%
Skewness	-0.29	-0.25	0.14	0.21	0.38
Kurtosis	2.23	2.39	2.67	1.75	1.86
Correlation w SPX	0.99	0.80	0.68	0.78	0.77
Beta	0.57	0.40	0.29	0.34	0.31
Alpha	1.42%	-8.95%	-5.27%	-5.86%	-1.87%
Alpha P-Value	0.240	0.024	0.190	0.099	0.580

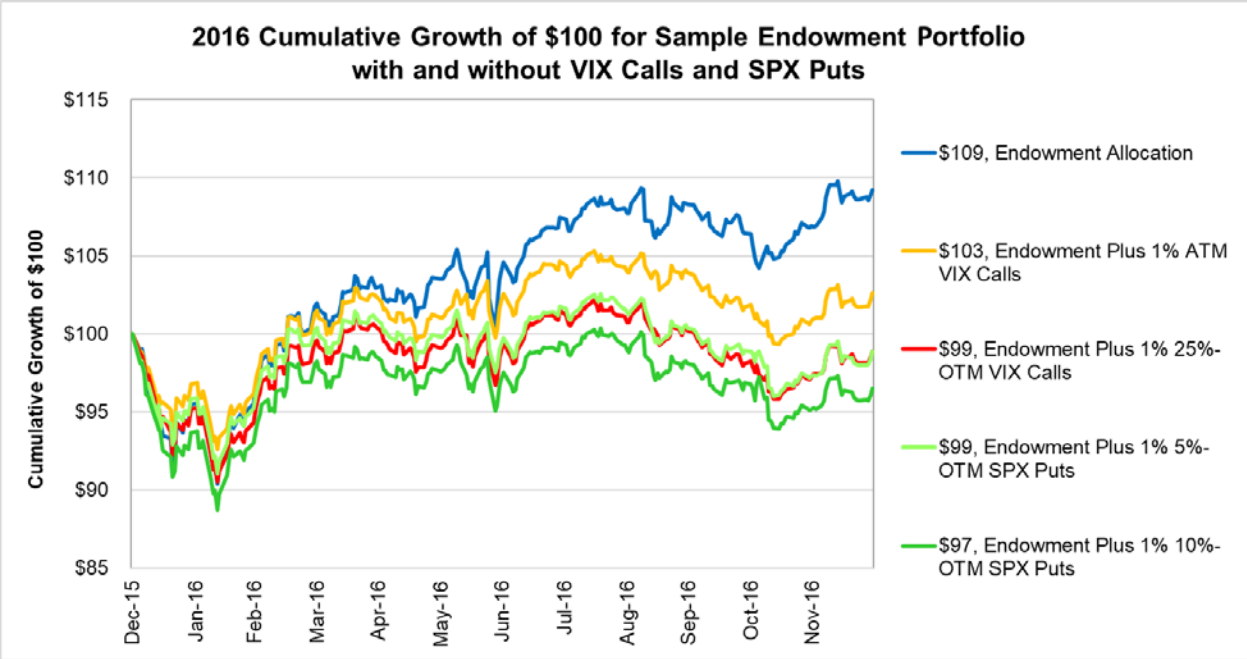
Source: Bloomberg, CFE, Cboe Options Exchange, Optionmetrics

Exhibit 20: *This exhibit illustrates the 2016 performance of a 60/40 portfolio with and without the addition of VIX calls and SPX puts. The 60/40 base portfolio provided the highest 2016 returns without SPX puts or VIX calls. The ATM VIX call allocation provided the smallest return reduction and largest standard deviation reduction in 2016.*

The performance of the 5%-OTM SPX put allocation portfolio was very similar to the performance of the 25%-OTM VIX call allocation portfolio on both absolute measures and risk-adjusted return measures. However, the ATM VIX call allocation portfolio outperformed both SPX put portfolios and the 25%-OTM VIX call portfolio by a large margin (although it underperformed the base portfolio). The ATM VIX call allocation portfolio generated a return almost 4% higher than the 5%-OTM SPX put allocation portfolio (+1.9% versus -1.9%) at a slightly lower standard deviation (5.3% versus 5.5%), smaller maximum drawdown (-2.7% versus -7.6%) and higher alpha (-2.7% versus -7.6%). In summary, the VIX call allocations either performed equally to or far better than the SPX put allocations in 2016 when applied to the 60/40 base portfolio.

Results for the long VIX call and SPX put additions to the endowment portfolio in 2016 are similar to those of the 60/40 portfolio (see Exhibit 21). All four allocation additions reduced returns of the base endowment portfolio and decreased Sharpe ratio and alpha, while reducing standard deviation and maximum drawdown (with the exception of the 10%-OTM SPX put allocation). Again, the 25%-OTM VIX call allocation portfolio provided the highest return of the non-base portfolios, the lowest standard deviation, and the best maximum drawdown and alpha (although the alphas are not statistically significant). Thus, once again, the VIX call allocations performed equal to or far better than the SPX put allocations.

Exhibit 21: Endowment Portfolio with and without VIX Calls or SPX Puts in 2016



Summary Statistics for the Year 2016	Endowment	Endowment Plus 1% 10%-OTM SPX Puts	Endowment Plus 1% 5%-OTM SPX Puts	Endowment Plus 1% 25%-OTM VIX Calls	Endowment Plus 1% ATM VIX Calls
Annualized Return	9.2%	-3.5%	-1.1%	-1.1%	2.6%
Annualized Standard Deviation	10.0%	9.2%	8.8%	8.8%	8.3%
Sharpe Ratio	0.92	-0.38	-0.13	-0.13	0.32
Maximum Drawdown	-9.6%	-11.3%	-9.0%	-9.5%	-7.4%
Skewness	-0.48	-0.45	-0.42	-0.49	-0.41
Kurtosis	2.56	1.52	1.51	1.67	1.72
Correlation w SPX	0.82	0.64	0.50	0.58	0.58
Beta	0.62	0.45	0.34	0.39	0.36
Alpha	1.74%	-8.64%	-4.87%	-5.50%	-1.47%
Alpha P-Value	0.765	0.223	0.524	0.443	0.829

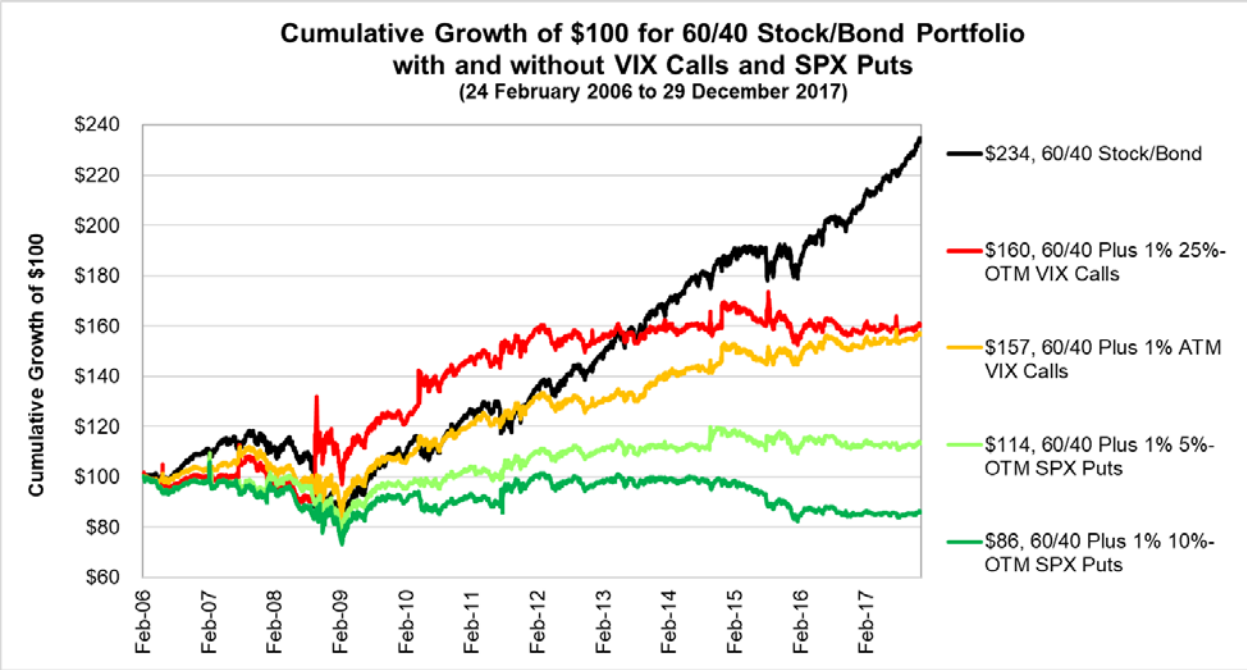
Source: Bloomberg, CFE, Cboe Options Exchange, Optionmetrics

Exhibit 21: *This exhibit illustrates the 2016 performance of a theoretical endowment portfolio with and without the addition of VIX calls and SPX puts. Once again, the base portfolio provided the highest 2016 return, while the ATM VIX call allocation provided the smallest return reduction with the largest standard deviation reduction of the four alternative allocations.*

5.3 SPX Puts versus VIX Calls from 2006 to 2017

This section considers the impact of adding a 1% allocation of long one-month SPX puts or long one-month VIX calls to a traditional stock and bond portfolio and a hypothetical endowment portfolio over a period of more than 10 years. The results in the previous sections suggest that the VIX call allocations considered generally performed approximately as well or much better than the SPX put allocations in 2008 and 2016. This section extends the analysis beyond those two select years to the 10+ year period since the inception of VIX options.

Exhibit 22: 60/40 Portfolio with Long VIX Calls or SPX Puts from 2006 to 2017



24 Feb 2006 to 29 Dec 2017	60/40 Stock/Bond Portfolio	60/40 Plus 1% 10%-OTM SPX Puts	60/40 Plus 1% 5%-OTM SPX Puts	60/40 Plus 1% 25%-OTM VIX Calls	60/40 Plus 1% ATM VIX Calls
Annualized Return	7.5%	-1.3%	1.1%	4.1%	3.9%
Annualized Standard Deviation	11.4%	10.2%	9.5%	12.5%	8.7%
Sharpe Ratio	0.65	-0.13	0.11	0.32	0.44
Maximum Drawdown	-34.8%	-31.0%	-29.3%	-26.5%	-25.6%
Skewness	-0.10	0.65	0.71	-0.01	0.40
Kurtosis	12.38	27.47	30.01	62.89	12.68
Correlation w SPX	0.99	0.50	0.53	0.32	0.75
Beta	0.58	0.26	0.26	0.20	0.33
Alpha	1.95%	-3.41%	-1.10%	2.72%	0.79%
Alpha P-Value	0.000	0.182	0.640	0.430	0.641

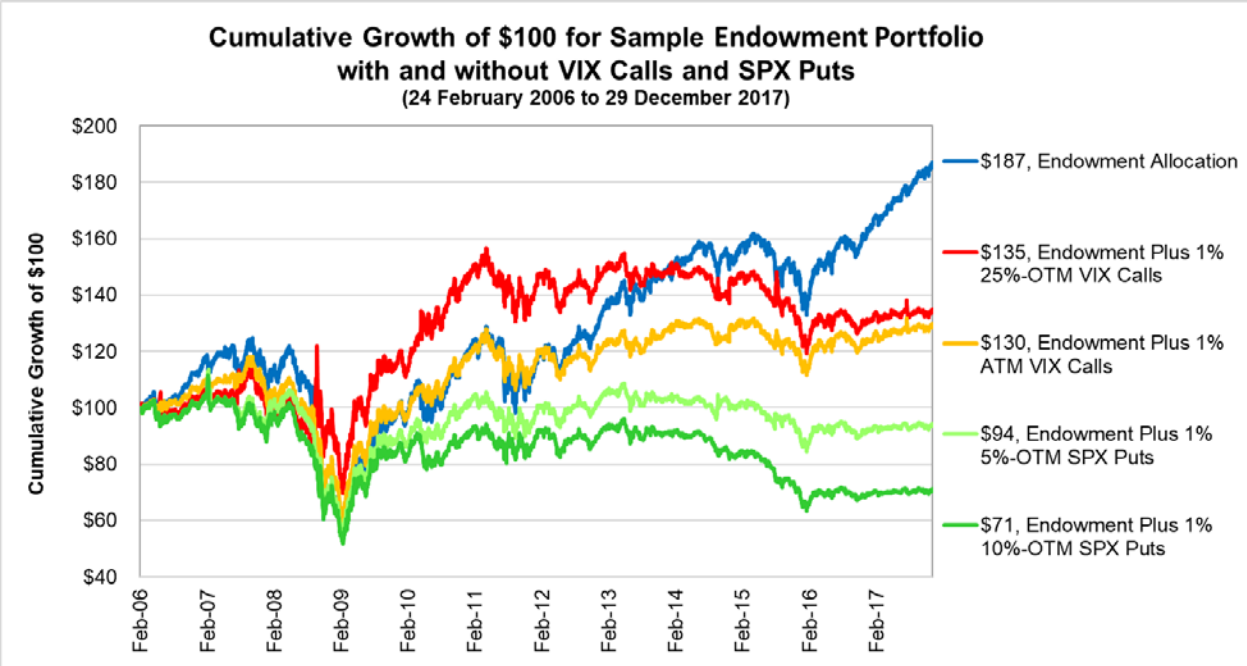
Sources: Bloomberg, CFE, Cboe Options Exchange, Optionmetrics

Exhibit 22: *This exhibit illustrates the performance of a 60/40 portfolio with and without the addition of VIX calls and SPX puts over the full period of the study. The base 60/40 portfolio provided the highest return over the period. The ATM VIX call allocations generated higher returns and smaller drawdowns than the SPX put allocations, although standard deviation results are mixed.*

Exhibit 22 provides the 10+ year cumulative growth and summary statistics of the base 60/40 stock/bond portfolio with and without a 1% allocation to long one-month SPX puts (5%-OTM or 10%-OTM) or VIX calls (ATM or 25%-OTM). Over the full period, when compared to the four options-based portfolios, the base 60/40 portfolio had higher returns, Sharpe ratio and alpha (with the exception of the 25%-OTM VIX call allocation portfolio), although it did so at a somewhat higher standard deviation (again, with the exception of the 25%-OTM VIX call allocation portfolio) and a higher maximum drawdown. This is not surprising since one would expect that a VIX-based risk-mitigation strategy had the potential to reduce returns and risk. A

particularly interesting result presented in Exhibit 22 is the outperformance of the VIX call allocation portfolios over the SPX put allocation portfolios. The returns of the 25%-OTM and ATM VIX call allocation portfolios were above the returns of the 10%-OTM and 5%-OTM SPX put allocation portfolios (4.1% and 3.9% versus -1.3% and 1.1%, respectively), standard deviations were generally similar (12.5% and 8.7% versus 10.2% and 9.5%, respectively), maximum drawdowns were lower (-27% and -26% versus -31% and -30%, respectively), and higher alphas (3.9% and 1.1% versus -4.9% and -1.6%, respectively, although the alphas are statistically insignificant). In summary, over the long-term period of study the VIX call allocation portfolios outperformed the SPX put allocation portfolios by a meaningful margin.

Exhibit 23: Endowment Portfolio with VIX Calls or SPX Puts from 2006 to 2017



24 Feb 2006 to 29 Dec 2017	Endowment	Endowment Plus 1% 10%-OTM SPX Puts	Endowment Plus 1% 5%-OTM SPX Puts	Endowment Plus 1% 25%-OTM VIX Calls	Endowment Plus 1% ATM VIX Calls
Annualized Return	5.4%	-1.3%	1.1%	2.6%	2.2%
Annualized Standard Deviation	16.5%	10.2%	9.5%	16.2%	13.7%
Sharpe Ratio	0.33	-0.13	0.11	0.16	0.16
Maximum Drawdown	-57.4%	-31.0%	-29.3%	-42.9%	-50.2%
Skewness	-0.24	0.65	0.71	-0.40	0.04
Kurtosis	10.18	27.47	30.01	28.10	11.36
Correlation w SPX	0.89	0.50	0.53	0.44	0.71
Beta	0.75	0.26	0.26	0.37	0.50
Alpha	-1.00%	-3.41%	-1.10%	0.11%	-1.96%
Alpha P-Value	0.648	0.182	0.640	0.978	0.482

Source: Bloomberg, CFE, Cboe Options Exchange, Optionmetrics

Exhibit 23: *This exhibit illustrates the performance of a theoretical endowment portfolio with and without the addition of VIX calls and SPX puts over the full period of the study. Again, the base portfolio provided the highest return over the period. While the VIX call allocations generated higher returns than the SPX put allocations, they did so with larger drawdowns and standard deviations.*

Results for the long VIX call and SPX put additions to the endowment portfolio over the 10+ year period are similar to those of the 60/40 portfolio (see Exhibit 23). The VIX call allocations and SPX put allocations reduced returns of the base endowment portfolio and decreased Sharpe ratio and alpha (with the exception of the 25%-OTM VIX call allocation), while reducing standard deviation and maximum drawdown. Again, the VIX call allocation portfolios (with the exception of the ATM VIX call allocation portfolio) had higher returns, Sharpe ratios and alphas than the SPX put allocation portfolios, although they exhibited higher standard deviations and maximum drawdowns.

In summary, over the long-term period of study, the VIX call allocation portfolios had higher returns than the SPX put allocation portfolios by a meaningful margin for both base portfolios, although they did so at higher levels of risk. It is worth noting that the VIX call allocation portfolios and the SPX put allocation portfolios underperformed the corresponding base portfolios, albeit at generally much lower risk.

6.0 A Dynamic Allocation to Long VIX Calls - the VXTH Index

This section considers an example of a dynamic methodology for diversifying equity exposure with long VIX futures as represented by the Cboe VIX Tail Hedge Index (VXTH). The VXTH index represents the theoretical returns to a long exposure to the S&P 500 combined with a dynamic long allocation to VIX call options, ranging from a 0 to 1% portfolio weight.

More specifically, the VXTH Index represents the returns to a strategy that earns the total returns to a long position in the S&P 500 index (including reinvested dividends), while purchasing one-month 30-delta (OTM) VIX call options on a monthly basis. The percentage allocation to VIX call options varies each month (between 0% and 1%) and is determined on the roll date based on the value of the VIX futures. The rationale for the strategy is that the level of one-month VIX futures is indicative of the likelihood of a major drop in the S&P 500. The long VIX 30-delta call weights are determined based on the following table on each roll date.

Decision Rule Based on One-Month VIX Futures	Allocation to VIX Calls
If VIX Futures <= 15.0	0.0%
If 15.0 < VIX Futures <= 30.0	1.0%
If 30.0 < VIX Futures <= 50.0	0.5%
If VIX Futures > 50.0	0.0%

According to the Cboe, “The power of the VXTH index comes from the exceptionally high returns garnered by VIX calls in times of steep stock market declines. This means few VIX calls need to be purchased. To further increase efficiency, the VXTH is carefully calibrated: the weight

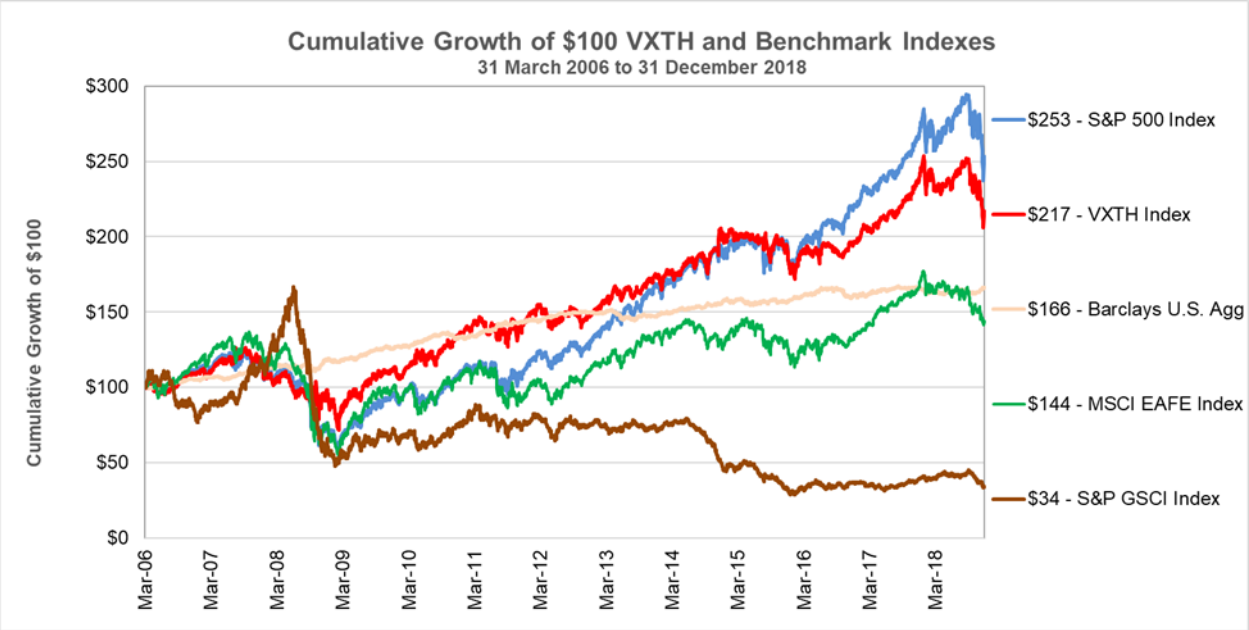
of the VIX calls in the portfolio varies at each roll depending on the likelihood that a "black swan" event is about to occur. This has the effect of reducing hedging costs and monetizing VIX option profits when extreme volatility levels are reached. This monetizing of the VIX option position in turn means that overall capital can be preserved" (see www.cboe.com/VXTH).

6.1 Performance of the VXTH Index from 2006 to 2017

This section considers the 10+ year performance of the VXTH index from the inception of the VXTH index on 31 March 2006 to the end of 2017 relative to a variety of benchmark indexes as well as a 60/40 portfolio with a 5% allocation to long one-month or three-month (held for one month) VIX futures.

Exhibits 24 and 25 provide illustrations of the 10+ year cumulative growth and summary statistics of the VXTH index and four traditional benchmark total return indexes (S&P 500, Barclays U.S. Aggregate bond index, MSCI EAFE equity index, and S&P GSCI commodity index). The VXTH index generated a 6% annualized return over the period at a 17% annualized standard deviation with a -43% maximum drawdown. Of the four traditional benchmark indexes, only the S&P 500 index generated higher returns than the VXTH index (7.6% versus 6.3%), although it did so at a higher standard deviation (19.4% versus 16.6%) and a much larger maximum drawdown (-55% versus -43%). From a risk-adjusted perspective, the VXTH and S&P 500 exhibited similar Sharpe ratios (0.37 and 0.38), although the VXTH provided a 0.5% annual alpha (relative to the S&P 500), although the alpha is not statistically significant. In contrast, the Barclays U.S. Aggregate bond index outperformed both the VXTH and S&P 500 indexes in terms of the Sharpe ratio and alpha by a large margin. However, with interest rates at historically low levels at the end of 2018, it is difficult to imagine an environment in which bonds perform as well over the following 10 years as they did in the previous 10 years.

Exhibit 24: VXTH Index and Benchmark Indexes from 2006 to 2018

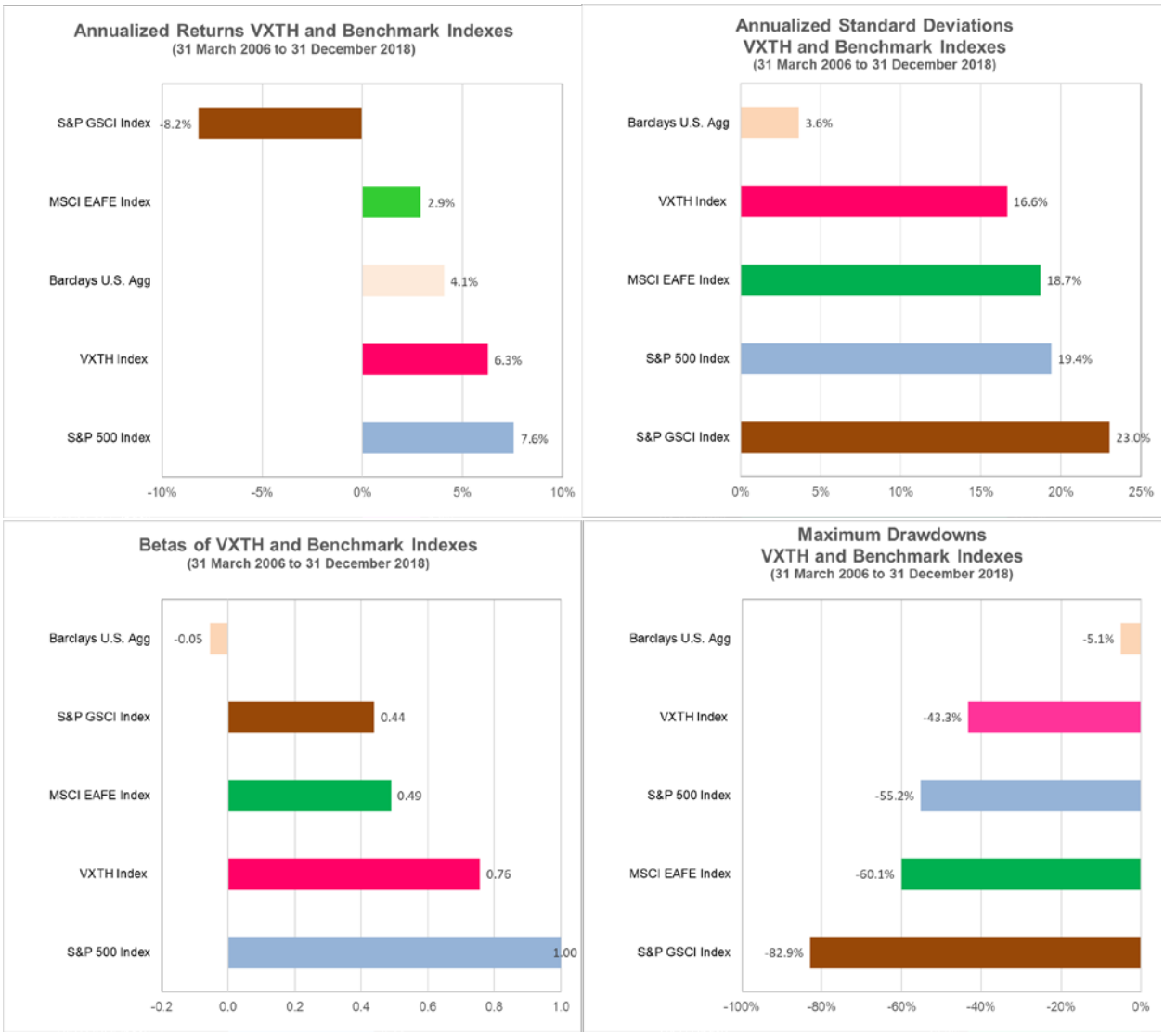


31 Mar 2006 to 31 Dec 2018	VXTH Index	S&P 500 Index	Barclays U.S. Agg	S&P GSCI Index	MSCI EAFE Index
Annualized Return	6.3%	7.6%	4.1%	-8.2%	2.9%
Annualized Standard Deviation	16.6%	19.4%	3.6%	23.0%	18.7%
Sharpe Ratio	0.37	0.38	1.10	-0.36	0.15
Maximum Drawdown	-43.3%	-55.2%	-5.1%	-82.9%	-60.1%
Skewness	0.16	-0.11	-0.11	-0.18	-0.28
Kurtosis	10.72	11.30	1.99	3.17	7.70
Correlation w SPX	0.88	1.00	-0.29	0.37	0.51
Beta	0.76	1.00	-0.05	0.44	0.49
Alpha	0.50%		4.57%	-9.92%	0.13%
Alpha P-Value	0.820		0.000	0.099	0.977

Source: Cboe, Bloomberg

Exhibit 24: *This exhibit illustrates the performance of the VXTH index as well as a variety of traditional benchmark indexes from the inception of the VXTH index to the end of 2017. The VXTH index exhibited lower volatility than the traditional indexes (with the exception of the Barclays U.S. Aggregate Bond index) and higher returns than all indexes except for the S&P 500 index. Only the Barclays U.S. Aggregate Bond index exhibited a higher Sharpe ratio and alpha than the VXTH index.*

Exhibit 25: VXTH and Benchmark Indexes Summary Statistics from 2006 to 2018



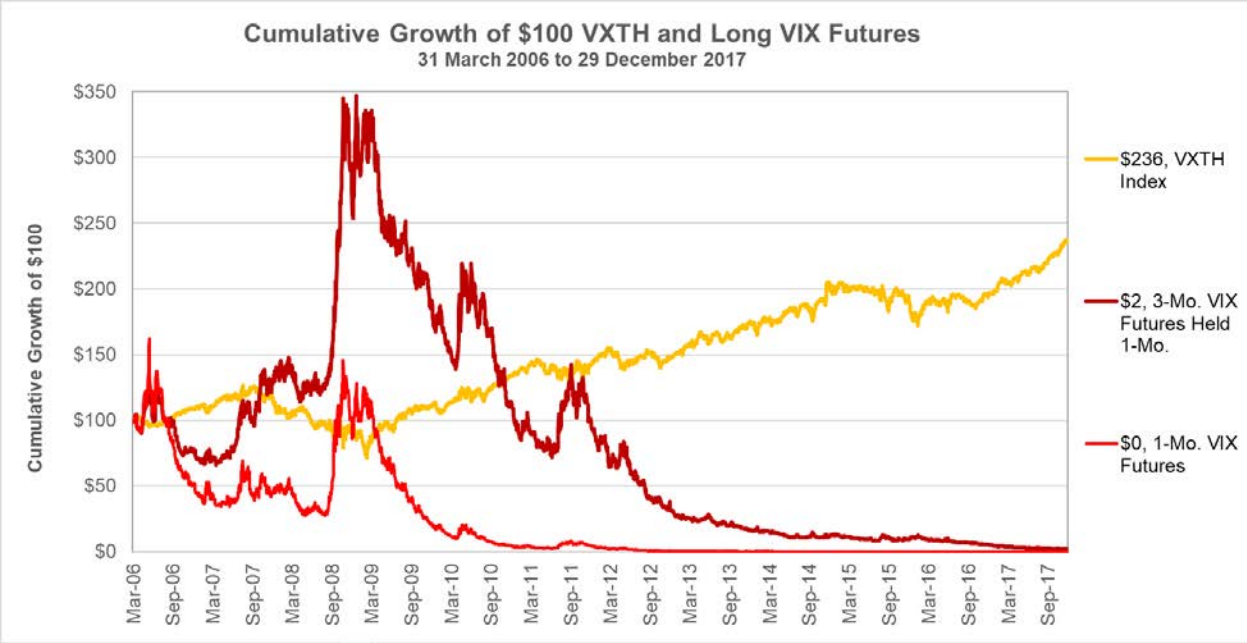
Source: Bloomberg, CFE, Cboe Exchange Inc.

Exhibit 25: *This exhibit illustrates the performance of the VXTH index as well as a variety of traditional benchmark indexes from the inception of VIX options on 31 March 2006 to the end of 2018. The VXTH index exhibited similar volatility to the traditional indexes (with the exception of the Barclays U.S. Aggregate Bond index) and higher returns than all indexes except for the S&P 500 index. The VXTH Index had less severe maximum drawdowns than the stock and commodity indexes.*

Exhibit 26 details the performance of the VXTH Index relative to long one-month and three-month VIX futures strategies from 31 March 2006 to 29 December 2017. The return of the VXTH Index is higher than those of the three-month and one-month VIX futures strategies. The standard deviations of the VXTH Index is also much lower than those of the three-month and one-month VIX futures strategies. From a risk adjusted return perspective, the VXTH Index had a

lower Sharpe ratio than the two VIX futures strategies, although its alpha was above that of the one-month VIX futures strategy and below that of the three-month VIX futures strategy.

Exhibit 26: VXTH Index and Long VIX Futures from 2006 to 2017



31 March 2006 to 29 Dec 2017	VXTH Index	1-Month VIX Futures Held 1 Month	3-Month VIX Futures Held 1 Month
Annualized Return	7.6%	-55.8%	-28.5%
Annualized Standard Deviation	16.8%	78.2%	43.7%
Sharpe Ratio	0.44	-0.73	-0.67
Maximum Drawdown	-43.3%	-100.0%	-99.4%
Skewness	0.20	1.04	0.64
Kurtosis	10.99	5.40	3.96
Correlation w SPX	0.88	-0.74	-0.74
Beta	0.75	-2.94	-1.66
Alpha	1.04%	-21.43%	-7.04%
Alpha P-Value	0.660	0.165	0.409

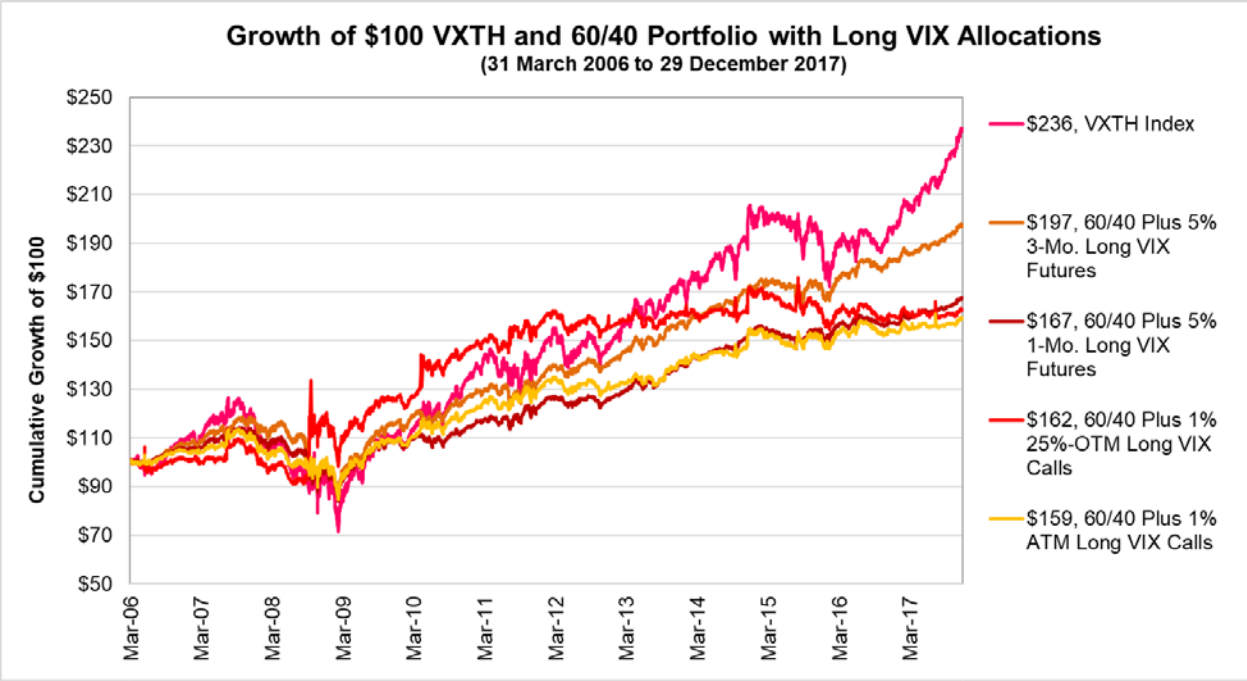
Sources: Cboe Exchange Inc., Bloomberg

Exhibit 26: *This exhibit illustrates the performance of the VXTH Index as well as the one-month and three-month VIX futures strategies. The superior performance of the VXTH Index in the full period is clearly evident.*

This section considers the performance of the VXTH index relative to a 60/40 portfolio with a long VIX exposure. While the previous comparison with traditional benchmark indexes is of great interest, VXTH index is arguably more appropriately compared to an equity or 60/40 equity/bond portfolio with or without long VIX exposure. Exhibit 27 provides an illustration of the 10+ year cumulative growth and summary statistics of the VXTH index and a 60/40

stock/bond portfolio with a 1% allocation to long VIX calls (ATM or 25%-OTM one-month VIX calls) or a 5% allocation to long VIX futures (one-month or three-month VIX futures).

Exhibit 27: VXTH Index and 60/40 Portfolio with Long VIX Allocations from 2006 to 2017



31 Mar 2006 to 29 Dec 2017	VXTH Index	60/40 Plus 1% 25%-OTM Long VIX Calls	60/40 Plus 1% ATM Long VIX Calls	60/40 Plus 5% 1-Mo. Long VIX Futures	60/40 Plus 5% 3-Mo. Long VIX Futures
Annualized Return	7.6%	4.2%	4.0%	4.5%	6.0%
Annualized Standard Deviation	16.8%	12.5%	8.7%	8.1%	9.2%
Sharpe Ratio	0.44	0.33	0.45	0.54	0.64
Maximum Drawdown	-43.3%	-26.5%	-25.6%	-26.5%	-28.2%
Skewness	0.20	-0.01	0.40	0.35	0.11
Kurtosis	10.99	62.67	12.62	16.16	15.11
Correlation w SPX	0.88	0.32	0.75	0.92	0.98
Beta	0.75	0.20	0.33	0.38	0.46
Alpha	1.04%	2.86%	0.92%	0.84%	1.53%
Alpha P-Value	0.660	0.410	0.588	0.375	0.010

Source: Bloomberg, CFE, Cboe Options Exchange, Optionmetrics

Exhibit 27: *This exhibit illustrates the performance of the VXTH index as well as four 60/40 stock/bond portfolios with allocations to long VIX futures or VIX calls. The VXTH index exhibited higher returns than the 60/40-based portfolios, albeit at much higher volatility and maximum drawdowns.*

The VXTH index generated an 8% annualized return over the period at a 17% annualized standard deviation with a -43% maximum drawdown. The four 60/40-based portfolios with long VIX futures or call allocations generated lower returns than the VXTH index, but did so at far lower risk as measured by standard deviation and maximum drawdown. When compared to the

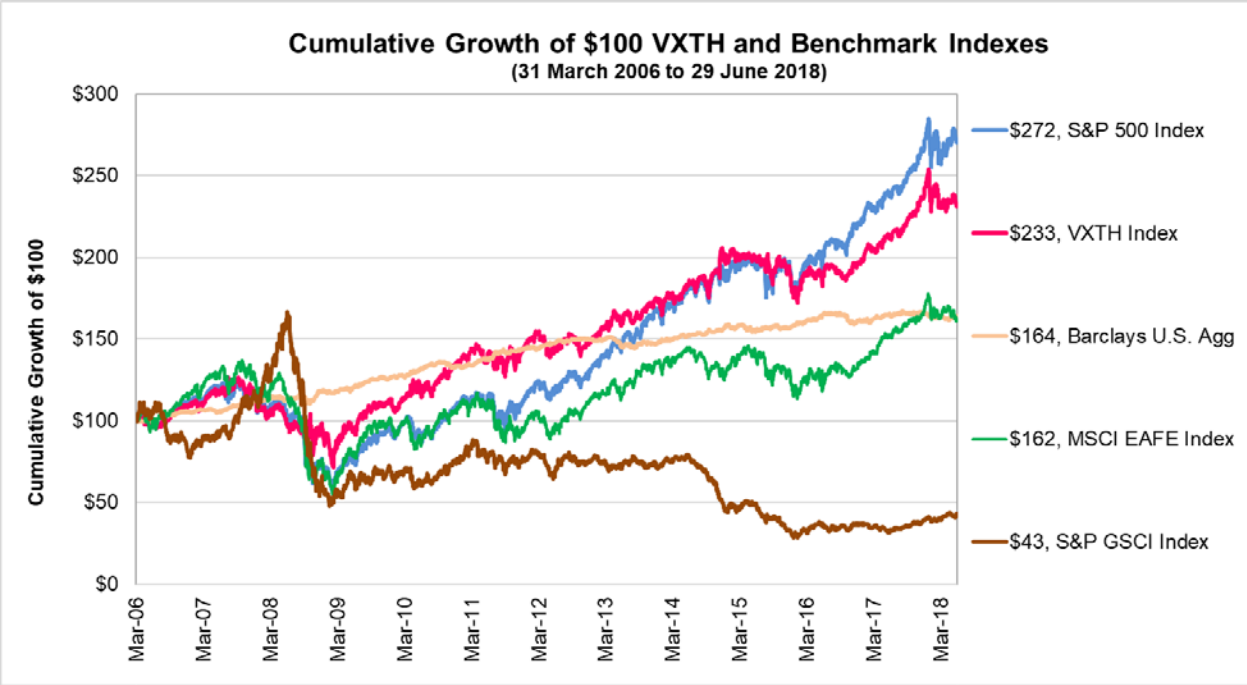
60/40 portfolio with 1% allocations to long ATM VIX calls, the VXTH index generated virtually identical risk-adjusted returns, with a Sharpe ratio of 0.44 versus 0.45 and an alpha of 1.04% versus 0.92%. However, the results are mixed when compared to the 60/40 portfolio with 1% allocations to long 25%-OTM VIX calls. The Sharpe ratio was higher for the VXTH index at 0.44 versus 0.33, while the alpha was much lower at 1.04% versus 2.86%, although the alphas were not statistically significant. In addition, the beta of the VXTH was much higher than those of either of the 60/40 portfolios with the long VIX call allocations. Thus over the period of study, the performance of the VXTH index was quite similar to that of the 60/40 portfolios with long VIX call allocations from a risk-adjusted basis, despite generating higher absolute returns. It is worth noting that the VXTH index and 60/40 portfolios do not provide a direct comparison of the benefits of the VXTH methodology since the 60/40 portfolios likely include diversification benefits provided by the 40% allocation to bonds which are not present in the VXTH index. It is possible that the addition of a bond allocation to a VXTH index-based portfolio may provide additional diversification benefits.

6.2 Performance of the VXTH Index through mid-2018

The VIX index was near record low levels near the end of 2017. In the first half of 2018, the VIX index experienced higher levels and a very sharp spike in the month of February. In the following sections, we consider the performance of the VXTH index in the first half of 2018 followed by performance in February 2018.

Exhibit 28 provides cumulative performance and summary statistics for the VXTH index and traditional benchmark indexes from the inception of the VXTH index through the second quarter of 2018. The results through mid-2018 are largely consistent with the previously presented results through the end of 2017. Once again, the VXTH index generated somewhat lower returns and risk than the S&P 500 index and the same Sharpe ratio while also generating a 1% positive alpha relative to the S&P 500 index.

Exhibit 28: VXTH Index and Benchmark Indexes from 2006 to Mid-2018



31 Mar 2006 to 29 June 2018	VXTH Index	S&P 500 Index	Barclays U.S. Agg	S&P GSCI Index	MSCI EAFE Index
Annualized Return	7.1%	8.5%	4.1%	-6.6%	4.0%
Annualized Standard Deviation	16.7%	19.5%	3.6%	23.1%	18.9%
Sharpe Ratio	0.42	0.43	1.09	-0.29	0.21
Maximum Drawdown	-43.3%	-55.2%	-5.1%	-82.9%	-60.1%
Skewness	0.16	-0.11	-0.10	-0.16	-0.28
Kurtosis	10.93	11.51	1.96	3.20	7.63
Correlation w SPX	0.88	1.00	-0.30	0.37	0.51
Beta	0.75	1.00	-0.06	0.44	0.50
Alpha	0.70%		4.66%	-8.64%	0.73%
Alpha P-Value	0.759		0.000	0.160	0.875

Source: Bloomberg, CFE, Cboe Options Exchange

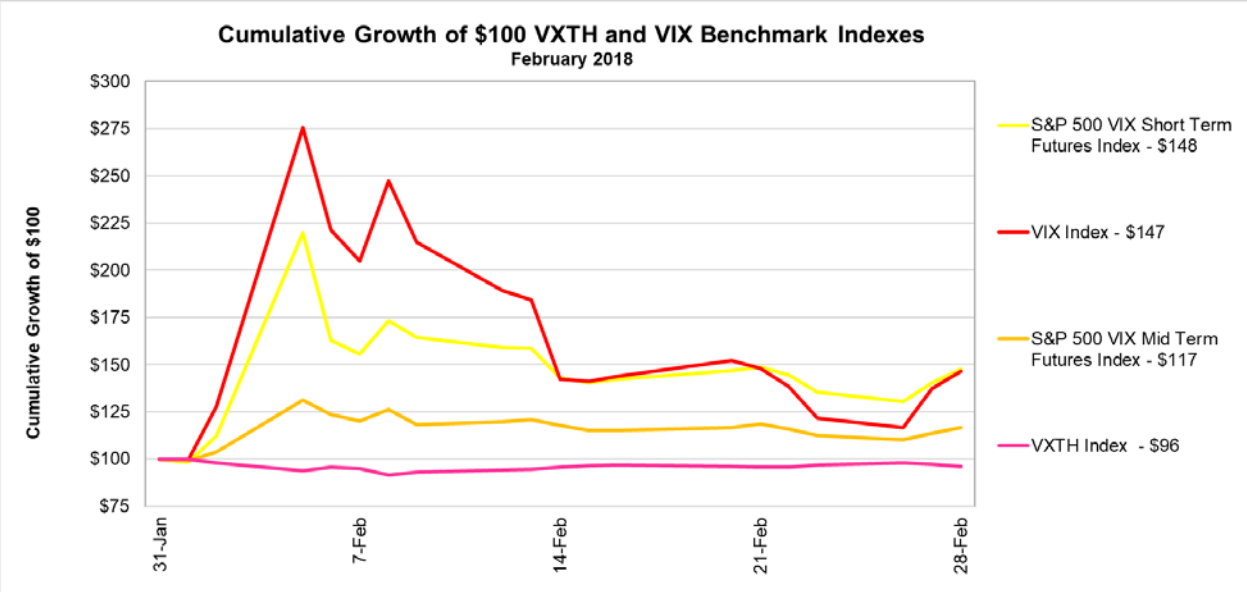
Exhibit 28: *This exhibit illustrates the performance of the VXTH index as well as a variety of traditional benchmark indexes from the inception of the VXTH index on 31 March 2006 to the end of the second quarter of 2018. The VXTH index exhibited lower volatility than the traditional indexes (with the exception of the Barclays U.S. Aggregate Bond index) and higher returns than all indexes except for the S&P 500 index. Only the Barclays U.S. Aggregate Bond index exhibited a higher Sharpe ratio and alpha than the VXTH index.*

6.3 The Volatility Spike of February 2018

Exhibit 29 illustrates the performance of the VXTH index as well the spot VIX index and two VIX futures indexes over the month of February 2018. The February 5, 2018 spike in the VIX index is clearly visible. On that day, the VIX index had its largest ever daily return of over 100%. While

the spot VIX index level more than doubled in a single day, the increases in the VIX futures indexes were far less extreme while the VXTH index decreased in value.

Exhibit 29: VXTH Index and VIX Futures Index Performance in February 2018

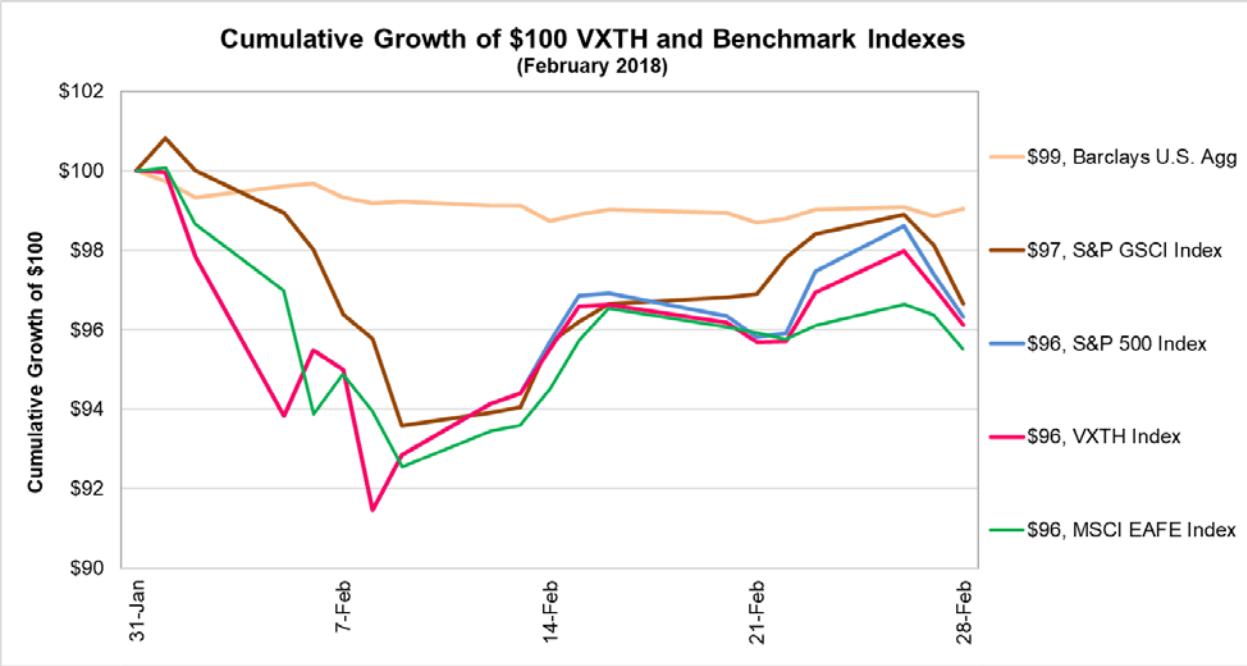


Analysis of the Month of February 2018	VXTH Index	S&P 500 VIX Mid Term Futures Index	S&P 500 VIX Short Term Futures Index
Period Return	-3.9%	16.5%	47.6%
Annualized Standard Deviation	26.4%	110.1%	379.1%
Sharpe Ratio	-0.15	0.15	0.13
Maximum Drawdown	-8.5%	-16.0%	-40.8%
Skewness	-1.14	2.94	3.42
Kurtosis	0.94	10.90	13.85
Correlation w SPX	1.00	-0.80	-0.75
Beta	0.97	-3.24	-10.49
Period Alpha	-0.33%	7.93%	38.40%
Alpha P-Value	0.538	0.676	0.594

Source: Bloomberg, CFE, Cboe Options Exchange

Exhibit 29: *This exhibit illustrates the performance of the VXTH index as well the spot VIX index and two VIX futures indexes over the month of February 2018, based on daily data. The February 5, 2018 spike in the VIX index in which the VIX index had its largest ever daily return of over 100% is clearly visible. While the spot VIX index level more than doubled in a single day, the increases in the VIX futures indexes were far less extreme while the VXTH index decreased in value on the same day.*

Exhibit 30: VXTH and Benchmark Performance in February 2018



Summary Statistics for the Month of February 2018	VXTH Index	S&P 500 Index	Barclays U.S. Agg	S&P GSCI Index	MSCI EAFE Index
Period Return	-3.9%	-3.7%	-0.9%	-3.3%	-4.5%
Annualized Standard Deviation	26.4%	27.3%	3.5%	16.4%	18.4%
Sharpe Ratio	-0.15	-0.14	-0.31	-0.21	-0.25
Maximum Drawdown	-8.5%	-8.5%	-1.3%	-7.2%	-7.5%
Skewness	-1.14	-1.02	-0.24	-0.33	-0.88
Kurtosis	0.94	0.56	-1.15	-0.43	0.73
Correlation w SPX	1.00	1.00	0.08	0.35	0.32
Beta	0.97	1.00	0.01	0.21	0.22
Period Alpha	-0.33%		-0.91%	-2.56%	-3.69%
Alpha P-Value	0.538		0.370	0.565	0.466

Source: Bloomberg, CFE, Cboe Options Exchange

Exhibit 30: *This exhibit illustrates the performance of the VXTH index as well four traditional benchmark indexes over the month of February 2018. It is clear that the February 5, 2018 spike in the VIX index did not benefit the VXTH index in this case as the VXTH index tracks the S&P 500 index through the first half of the month. This is illustrative of one of the limits of market expectation-based dynamic allocation strategies in which unanticipated events such as the February 5, 2018 spike in the VIX index might not be captured since they are not expected.*

Exhibit 30 illustrates the performance of the VXTH index as well four traditional benchmark indexes over the month of February 2018. It is clear that the February 5, 2018 spike in the VIX index did not benefit the VXTH index in this case as the VXTH index exactly tracks the S&P 500 index through the first half of the month. This is illustrative of one of the limits of market expectation-based dynamic allocation strategies in which unanticipated events such as the February 5, 2018 spike in the VIX index may not be captured since they are not expected. While

the VXTH index may provide a more efficient exposure to the diversification benefits of long VIX calls due to its dynamic allocation methodology, it cannot be expected to anticipate all volatility movements and will at time underperform a continuous VIX exposure or a portfolio with no VIX exposure.

7.0 Diversification Benefits – Expansion of the Efficient Frontier

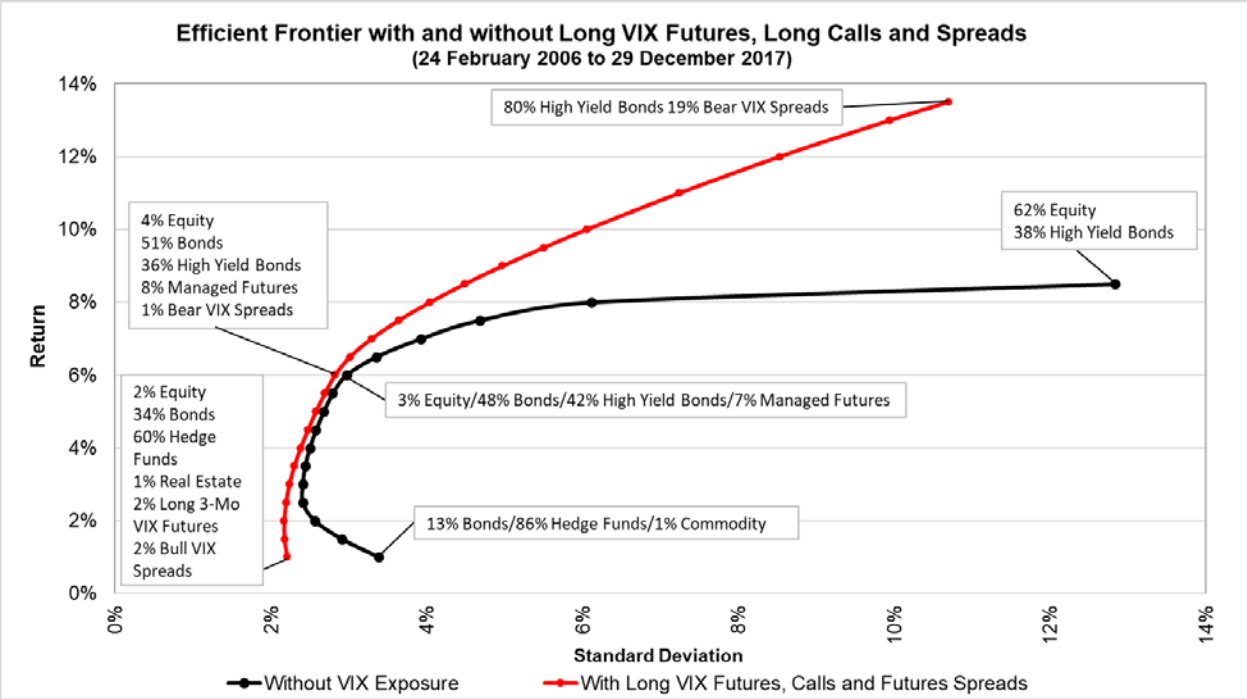
Much of the discussion in the previous sections focused on the diversification benefits of long VIX futures and VIX call options, particularly in 2008. This section approaches the analysis from a slightly different perspective by considering impacts on an efficient frontier over the entire 10+ year period since the inception of VIX options. Exhibit 31 provides an efficient frontier with and without the inclusion of long exposures to VIX futures, call options and futures spreads (for additional discussion of the performance of VIX futures spreads see Szado [2018b]). The efficient frontiers are constructed by considering long-only exposure to the following ten total return indexes representing a wide range of asset classes: S&P 500 (Equity), Barclays U.S. Aggregate (Bonds), Barclays High Yield U.S. Corporate (High-Yield Bonds), HFR Global Hedge Fund Index (Hedge Funds), SG CTA Index, (formerly Newedge CTA Index) (Managed Futures), S&P GSCI (Commodity), S&P Listed Private Equity Index (Private Equity), Dow Jones Equity REIT Index (Real Estate), MSCI EAFE Index USD (EAFE), and MSCI EEM Index USD (Emerging Markets). The exhibit presents two efficient frontiers; one calculated by considering inclusion of the ten indexes listed above and the second calculated by considering inclusion of the ten indexes plus long exposures to long one-month and long three-month VIX futures, long one-month VIX ATM and 25% OTM call options and bull or bear VIX one-month/three-month futures spreads.

It is clear that the addition of long VIX futures, long VIX call option and VIX futures spread exposure expanded the efficient frontier across the full range of returns and standard deviations, illustrating possible risk reduction abilities of long VIX exposures. Labels are provided on the efficient frontiers to indicate the approximate asset allocations at three points on each frontier. For the sake of clarity, any allocations below 1% are not noted in the labels but are included in the calculations. The bull VIX futures spread consists of a long one-month VIX futures position and a short three-month VIX futures position, while a bear VIX Futures Spread is short one-month VIX futures and long three-month VIX futures. The terms “bull” and “bear” do not refer to bull or bear equity exposure, but rather to the exposure to volatility through VIX futures. A bull spread in VIX futures might be considered in some way comparable to a bear spread in S&P 500 futures since one would expect VIX futures to rise as S&P 500 futures fall.

The red efficient frontier in Exhibit 31 suggests that the addition of long VIX futures, long VIX calls and/or VIX futures spreads may provide risk reduction and/or return enhancement benefits, shifting the efficient frontier up and to the left. The red efficient frontier (which includes long VIX exposure) dominates the black frontier (without VIX) throughout its length. It is worth noting that the addition of bull and bear VIX futures spreads to the efficient frontier calculations effectively allows the inclusion of inverse VIX futures exposures through the

spreads thus expanding the efficient frontier beyond the frontiers that only allow long VIX exposure.

Exhibit 31: Efficient Frontier with and without Long VIX Futures, Long VIX Calls, and Bull and Bear VIX Futures Spreads



Source: Bloomberg, CFE, Cboe Options Exchange, Optionmetrics

Exhibit 31: *This exhibit illustrates the diversification benefits of including long VIX exposure to a sample universe of diversified investments in the construction of an efficient frontier. The black efficient frontier illustrates an efficient frontier optimized across ten asset classes (Equity, Bonds, High Yield Bonds, Hedge Funds, Managed Futures, Commodities, Private Equity, Real Estate, EAFE, Emerging Markets) without considering the inclusion of VIX exposure and without allowing short positions. The red efficient frontiers optimizes the portfolio allocations across the ten asset classes as above plus 1-month and 3-month long VIX futures, long VIX ATM and OTM calls, and bull and bear 1-month/3-month VIX futures spreads. The efficient frontier depicts the ex post optimum portfolios that are constructed to maximize returns for each level of standard deviation and minimize standard deviation for each level of returns. The addition of long VIX exposure expands the upper end and lower end of the efficient frontier. The approximate allocations are provided in the labels in the exhibit. Any allocations below 1% are not reported in the labels, but are included in the calculations. For a target portfolio return of 1%, the addition of long VIX exposure reduced standard deviation by about one percentage point. Similarly, at a target portfolio return of 8%, the addition of inverse VIX exposure reduced standard deviation by about two percentage points. It is worth noting that the efficient frontier depicts optimal portfolios that are constructed with perfect hindsight considering only return and standard deviation, with no consideration of the appropriateness of these portfolios. For example, a 3% Equity, 48% Bonds, 42% High Yield Bonds, 7% Managed Futures portfolio generated a 6% return at a standard deviation of 2.97%. Of all possible portfolios that could have been constructed using the 10 indexes considered in the black efficient frontier, no portfolio could have generated a 6% return at a standard deviation below 2.97%. It is worth noting that it would be unrealistic to assume that any individual would have the foresight to have chosen one of the portfolios on the frontier ex ante.*

One should bear in mind that an ex post efficient frontier is, by its very nature, more of an academic exercise than a realistic representation of the performance that could have been expected of any particular portfolio manager. Efficient frontiers are created with perfect hindsight, utilizing optimization techniques, and thus represent the best possible return/standard deviation combinations that were possible over the time period, based on the investments included in the optimization procedure. For example, at a 1% target return, the optimal portfolio consisted of approximately 2% Equity, 34% Bonds, 60% Hedge Funds, 2% 3-month VIX futures, and 2% bull VIX futures spreads. It questionable whether a typical portfolio manager would have expected this portfolio to be an optimum portfolio (at that return level), or that they would have considered this an appropriate portfolio for their clients.

Exhibit 32: Efficient Frontier Asset Allocation without Long VIX Exposure

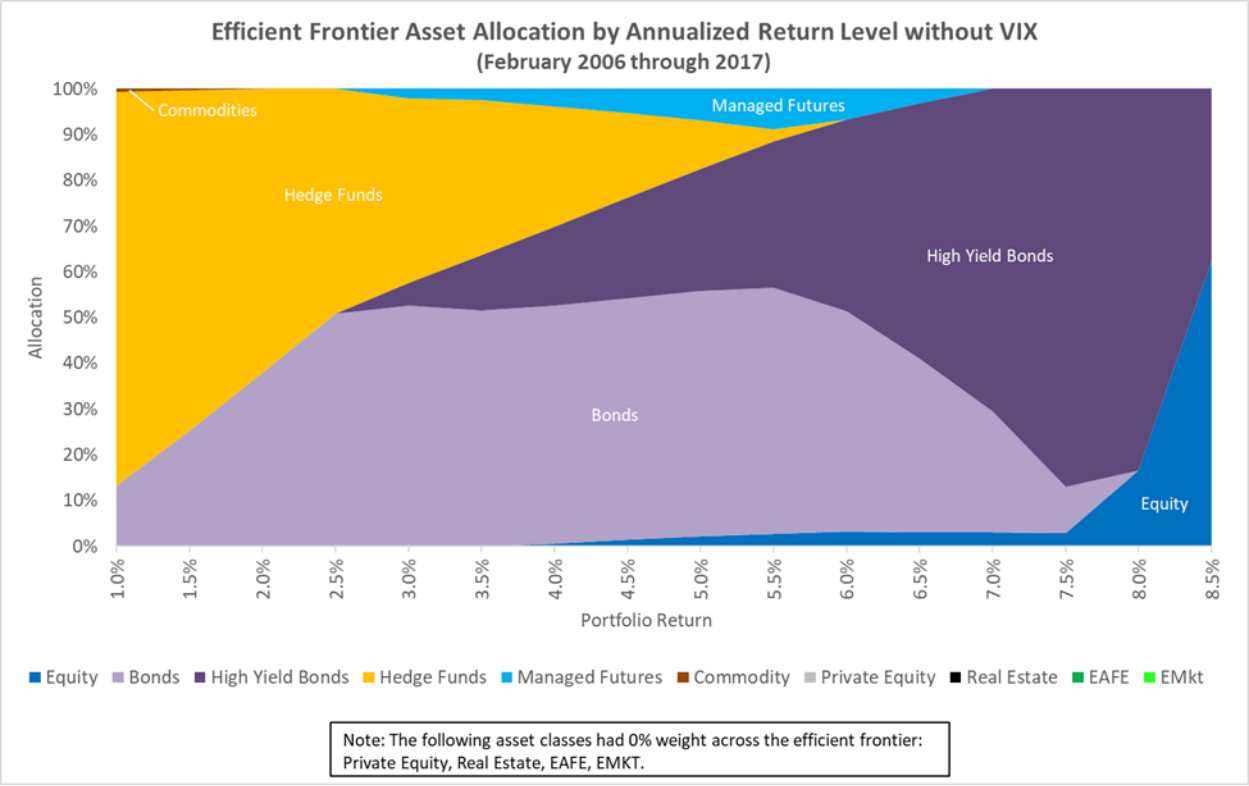


Exhibit 32: *This exhibit illustrates the asset allocations at each target return level represented in the black efficient frontier in Exhibit 31 (without VIX exposure). An efficient frontier depicts the ex post optimum portfolios that are constructed to maximize returns for each level of standard deviation and minimize standard deviation for each level of returns. For example, of all possible portfolios, the portfolio with a 6% return that had the lowest standard deviation was approximately 3% Equity, 48% Bonds, 42% High Yield Bonds, and 7% Managed Futures. All ten indexes which comprise the sample theoretical endowment portfolio were considered in the optimization and short positions were not allowed. It is worth noting that the following asset classes had zero weights across the entire frontier: Private Equity, Real Estate, EAFE, and Emerging Markets.*

Exhibit 33: Efficient Frontier Asset Allocation with Long VIX Futures, VIX Calls, and Bull and Bear VIX Futures Spreads

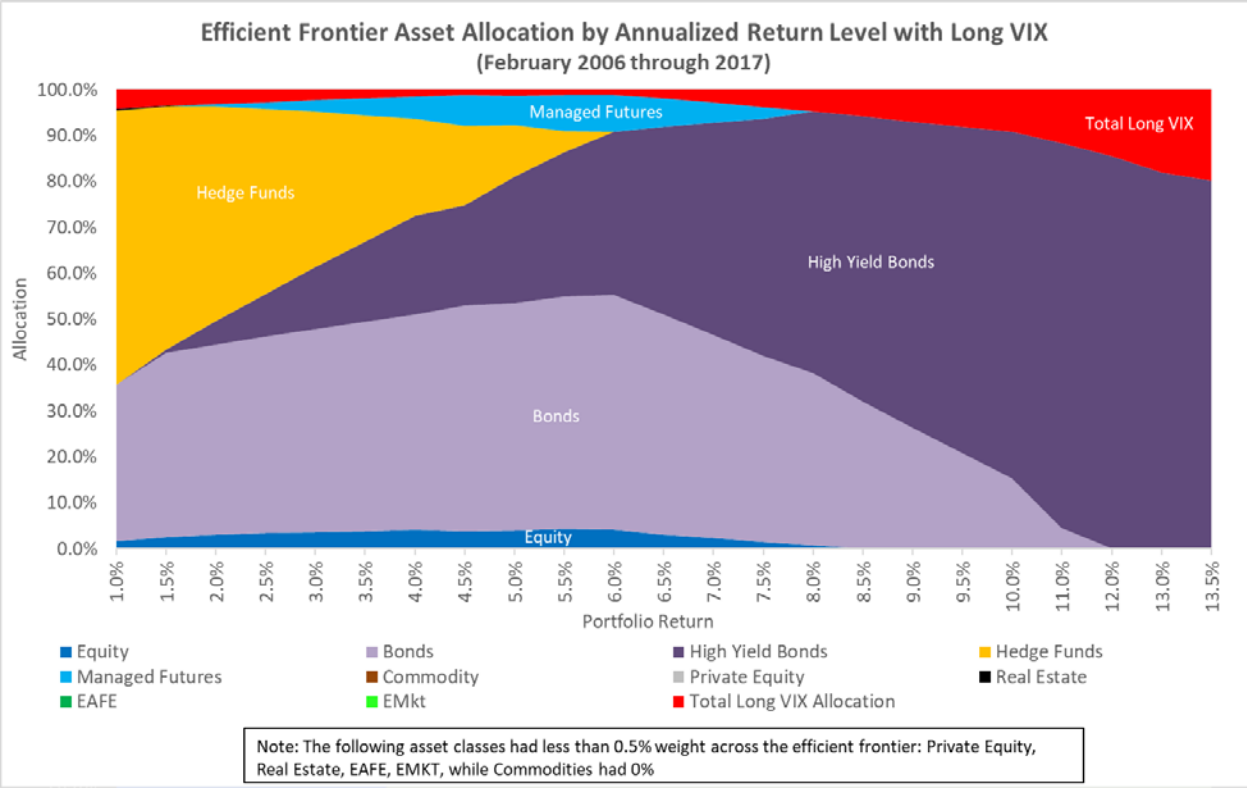


Exhibit 33: *This exhibit illustrates the asset allocations at each target return level represented in the red efficient frontier in Exhibit 31 (with long VIX exposure). An efficient frontier depicts the ex post optimum portfolios that are constructed to maximize returns for each level of standard deviation and minimize standard deviation for each level of returns. For example, of all possible portfolios, the portfolio with a 6% return that had the lowest standard deviation was approximately 4% Equity, 51% Bonds, 36% High Yield Bonds, 8% Managed Futures, and 1% Bear VIX Spreads. All ten indexes which comprise the sample theoretical endowment portfolio were considered in the optimization as well as the long VIX future, long VIX call and VIX futures spread strategies used previously in the paper, and short index positions were not permitted. It is worth noting that the following asset classes had allocations below 0.5% across the entire frontier: Private Equity, Real Estate, EAFE, and Emerging Markets, while Commodities had 0% allocations across the frontier.*

8.0 Conclusions

The goal of this study is to detail some important characteristics of investment in VIX-related instruments and investigate the potential effectiveness of long VIX futures or calls as a diversifier over short periods of equity market distress and consider the impact of such allocations in periods that do not experience significant market distress. While the results indicate that small allocations to long VIX allocations may effectively provide diversification benefits over particular time periods, the potentially substantial portfolio drag imposed by contango in VIX futures warrants significant consideration.

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