What happened to the weekend effect?

Mary Cote

A STATISTICAL ANALYSIS OF THE WEEKEND EFFECT FOR THE VIX INDEX AND HOW IT HAS EVOLVED OVER THE LAST 20 YEARS IN COMPARISON TO OTHER VOLATILITY INDICES

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Title of Signature Project: What happened to the weekend effect?: A statistical analysis of the weekend effect for the VIX Index and how it has evolved over the last 20 years in comparison to other volatility indices.

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TABLE OF CONTENTS

Introduction to Implied Volatility ................................................................................................................. 5
  Historical Advancements Relative to Implied Volatility calculations .............................................................. 5
  Usage of Implied Volatility Index ...................................................................................................................... 7
Data Sources and Methodology of Analysis ........................................................................................................ 9
  VIX Weekend Effect .......................................................................................................................................... 9
  Other Volatility Indices Weekend Effect ........................................................................................................... 10
  Other Stock Index Properties Weekend Effect ................................................................................................ 11
Results and Discussion ...................................................................................................................................... 12
  HYPOTHESIS 1 .................................................................................................................................................. 12
    Changes between Closing Values of the VIX .................................................................................................... 12
    Changes between Closing Values and Opening Values of the VIX ............................................................... 14
  HYPOTHESIS 2 .................................................................................................................................................. 16
    Changes between Closing Values of other volatility indices ....................................................................... 16
  HYPOTHESIS 3 .................................................................................................................................................. 21
    The Introduction of Futures ............................................................................................................................ 21
  HYPOTHESIS 4 .................................................................................................................................................. 24
    Stock Index Volumes to VIX Index .................................................................................................................. 24
    Correlation of the Volume growth and Weekend Effect ................................................................................ 28
Summary Notes and Future Work ...................................................................................................................... 30
APPENDIX A – WEEKEND EFFECT T-TEST RESULTS OF OTHER VOLATILITY INDICES .............................................. 33
  RVX – Russell 200 Volatility index ..................................................................................................................... 33
  VXST – S&P500 Short Term Volatility index .................................................................................................... 34
  VXV – S&P500 3-Month Volatility Index .......................................................................................................... 35
  VXMT – S&P500 Medium Term Volatility Index .............................................................................................. 36
  VVIX – VIX of the VIX ..................................................................................................................................... 37
APPENDIX B – DETAILED DESCRIPTIONS OF EACH STOCK INDEX VOLATILITY MEASURES .................................. 38
  VIX → www.cboe.com/vix ................................................................................................................................. 38
  VXD → www.cboe.com/vxd ............................................................................................................................... 38
  VXX → www.cboe.com/vxn ............................................................................................................................... 39
  RVX → www.cboe.com/rvx ............................................................................................................................... 39
  VXST → www.cboe.com/vxst ............................................................................................................................. 39
What happened to the weekend effect?

VXV  →  www.cboe.com/vxv..............................................................39
VXT  →  www.cboe.com/vxt ..............................................................40
REFERENCES .................................................................................41
The weekend effect is a widely studied but incompletely understood financial phenomenon. An analysis of the previously reported weekend effect with the VIX index (a measure of implied volatility of the S&P 500) was completed. The analysis demonstrated that while there is an overall weekend effect with the VIX index, a closer look shows relatively long time periods (multiple consecutive years) when the weekend effect is not statistically significant for the VIX. Previous and new suggestions on the source(s) of transitions between these time periods are discussed in the context of the VIX index over the past twenty years along with its similarities to other Volatility Indices. The research was able to determine that the weekend effect is not isolated to the S&P500 volatility index (VIX) nor is the pattern of weekend effects being affected by the launch of the futures product. However, as volumes increase to levels significantly higher than experienced in early 2000, the weekend effect statistical significance disappears. However, the research was inconclusive in correlating this increase with the use of HFT’s for such stock indices.
INTRODUCTION TO IMPLIED VOLATILITY

Implied asset volatility, commonly based on option prices, is an expectation of future variation in the value of the underlying asset and is considered to be an indicator of market sentiment for that asset (Fleming 1998). Implied volatility is a subjective measure that takes a forward look, similar to a forecast, unlike from historical volatility which is based on the actual past return of an option and would not be necessarily a representation what is to come but only what has happened so far. Beyond being a measure of market sentiment, implied volatility projections are valuable for traders and are used by some as signals of when to buy or sell short-term stock investments or options themselves (Bollen and Whaley 2004; Hulbert 2011; Simon 2003). For example, when a particular product is trading with high implied volatility, buyers often consider selling them as the price of the option increases. Each particular option types has different sensitivity levels to implied volatility as short-term options would be less sensitive while long-term ones would be more sensitive.

HISTORICAL ADVANCEMENTS RELATIVE TO IMPLIED VOLATILITY CALCULATIONS

Initially, the formalization of the mathematics around the volatility of financial option pricing was introduced in 1973 in a paper by Fischer Black and Myron Scholes called “The Pricing Options and Corporate Liabilities” published in the Journal of Political Economy. This paper started to revolutionize how investors estimated the price of an option. The equation, seen below in Figure 1, was enhanced over time and provided additional justifications by Robert Merton and eventually became a staple in the world of stock hedging, leading to the 1997 Nobel Prize in Economics. Several other mathematicians have tried to replicate the success of Black-Scholes and in attempt to generate a name for themselves while creating and publishing their own volatility measurement but none of which established themselves as strongly as the Black-Scholes model.
What happened to the weekend effect?

The model is based on four main variables: time, price of the asset for which the option is reviewed, the risk-free interest rate and lastly the volatility of the asset. The Black-Scholes equation makes two key assumptions: volatility remains constant in the time period of interest; and logarithmic returns of the asset follow a normal distribution. Both of these assumptions have been noted as inconsistent with empirical evidence of financial markets (Hull and White 1987). The assumption around constant volatility of the asset remains “the same for the life of the option, which need not be correct” (Stewart, 2012). is commonly used in theoretical reviews but unfortunately often false in real markets. However, the Black-Scholes equation has been widely used and accepted - perhaps due to its computational and conceptual simplicity and its demonstrated accuracy for common analyses.

In relatively recent history, some estimations of volatility have moved to the use of market prices of relevant options over a range of expiration periods instead of using a purely theory-based model (such as Black-Scholes). In 1993, the Chicago Board of Options Exchange (CBOE) introduced a new volatility index called the VIX. On September 22, 2003, the CBOE changed their leading measure of implied volatility, to such a model-free approach, but also by introducing some improvements relating to using the S&P500 and introducing a weighted-average component. They renamed the previous measure VXO, back-dated all calculations based on historical data and re-introduced the VIX. The VIX estimates volatility of the S&P500 stock index over the next thirty days and has been referred to as the “fear index” in mainstream media (CBOE 2004). High values of VIX indicate high values of expected volatility of the S&P500 stock index in the next thirty days and therefore high uncertainty or fear. It quickly became the go-to index for stock volatility measurements.
What happened to the weekend effect?

Usage of Implied Volatility Index

Implied volatility metrics, such as VIX, change regularly as future expectations change. The changes have been studied previously and directional movement of implied volatility generally has been found to have some predictability (Harvey and Whaley 1992). The VIX, specifically, has been found to have directional movement dependent upon factors that include stock returns and day of week and information announcement day (Brooks and Oozeer 2002; Carr and Wu 2006; Kim and Kim 2003; Mixon 2002).

Regarding dependence on the day of the week, the VIX has been found to have a statistically different change in value on different days. The VIX has been found to be most likely to increase on Mondays, and fall on Tuesdays and Fridays (Ahoniemi and Lanne 2009). Weekday dependence of financial asset pricing or the “weekend effect” is consistent with some other statistical analyses of stock returns on different days of the week (French 1980; Abraham and Ikenberry 1994). Some empirical analyses have found that the weekend effect is present under certain conditions, such as the mean stock market index return on Mondays being lower than on Fridays during non-Bear markets (Boudreaux et al 2010). Another set of analyses suggests that the weekend effect for equity prices has been opposite in direction for small firms compared to large firms (Brusa et al 2000). Finally, another argument suggests that the correlation related to the day of the week is also dependent on the time of the month (or the particular week of the month) in which it happens and is more concentrated on the fourth week of the month (Sun & Tong 2002).

The theoretical rationale for a statistically significant weekend effect either broadly or under certain conditions is not clear. One theme of suggestions focus on actions of individual investors who might take time over the weekend to reflect on their needs and choose to reduce their level of investment or reduce their exposure to risk (Miller 1998) and during weekdays investors are likely to see recommendations from the brokerage community disproportionally optimistic and encouraging equity purchases (Brooks and Hongshil 1997). A second theme of suggestions focus on information released on different days of the week - for example, firms waiting to release negative information until after trading on Fridays (Abraham and Ikenberry 1994). Furthermore, Abraham and Ikenberry have established a relation between the investors selling behavior with the need for cash. Similar to the early week liquidity
What happened to the weekend effect?

argument by Ikenberry, it has been researched that the liquidity could also be the reason behind the “fourth week” effect, supported by some evidence of a “monthly cyclical selling force occurring around the fourth week of the month” driving a need for cash (Sun et al 2002).

The intent of this research is to empirically investigate the weekend effect over the past twenty years (from approximately 1992 to 2013) with particular focus on observations related to changes in patterns over time. The following hypotheses are reviewed in order to investigate the change in behavior of the weekend effect seen in the VIX and Table 1 below outlines the various volatility indices that were used to accomplish the research.

- **Hypothesis 1:**
  - If the weekend effect of the VIX is present then the change between the closing value on Friday and the opening value on Monday is different than the change between the close/open of any other day of the week.

- **Hypothesis 2:**
  - If the weekend effect patterns are seen in the VIX, then they should also be seen in other volatility index of stock indices.

- **Hypothesis 3:**
  - If a Volatility index has a related futures product, then its weekend effect pattern will become statistically insignificant.

- **Hypothesis 4:**
  - If the trading volumes of the S&P500 stock index experiences growth above their normal 2001 levels, then the weekend effect pattern will become statistically insignificant.
What happened to the weekend effect?

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>NAME</th>
<th>FUTURE VOLATILITY TYPE</th>
<th>BASE</th>
<th>AVAILABLE DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIX</td>
<td>CBOE Volatility Index</td>
<td>FV of Stock Index</td>
<td>S&amp;P 500 (SPX)</td>
<td>1990 to 2013</td>
</tr>
<tr>
<td>RVX</td>
<td>CBOE Russell 2000 Volatility Index</td>
<td>FV of Stock Index</td>
<td>Russell 2000 options (RUT)</td>
<td>2004 to 2013</td>
</tr>
<tr>
<td>VXD</td>
<td>CBOE DJIA Volatility Index</td>
<td>FV of Stock Index</td>
<td>DowJones Industrial Average (DJX)</td>
<td>1997 to 2013</td>
</tr>
<tr>
<td>VXN</td>
<td>CBOE Nasdaq Volatility index</td>
<td>FV of Stock Index</td>
<td>NASDAQ (NDX)</td>
<td>2001 to 2013</td>
</tr>
<tr>
<td>VXV</td>
<td>CBOE 3-month Volatility Index</td>
<td>FV of Stock Index</td>
<td>S&amp;P 500 (SPX)</td>
<td>2007 to 2013</td>
</tr>
<tr>
<td>VXST</td>
<td>CBOE Short Term Volatility Index (9 days)</td>
<td>FV of Stock Index</td>
<td>S&amp;P 500 (SPX)</td>
<td>2011 to 2013</td>
</tr>
<tr>
<td>VXMT</td>
<td>CBOE Mid-Term Volatility Index (Options 6-9 Months from Maturity)</td>
<td>FV of Stock Index</td>
<td>S&amp;P 500 (SPX)</td>
<td>2011 to 2013</td>
</tr>
<tr>
<td>VVIX</td>
<td>Volatility of the VIX</td>
<td>Other</td>
<td>VIX</td>
<td>2007 to 2013</td>
</tr>
</tbody>
</table>

TABLE 1 - LIST OF VOLATILITY INDICES USED TO COMPLETE RESEARCH

The specific metric to be used in this research is mainly the VIX and the S&P500 Stock Index as a representation of implied volatility broadly throughout the US stock market and its correlation with other volatility and stock indices.

**DATA SOURCES AND METHODOLOGY OF ANALYSIS**

**VIX WEEKEND EFFECT**

Historical VIX (not VXO) data of closing values based on the model-free approach for each trading day from January 1, 1990 through December 31, 2013 was downloaded from the CBOE webpage (CBOE 2012). The data beginning from January 1, 1992 also includes the opening value, high value, and low value for each trading day. The change in closing values between adjacent trading days was calculated for each trading day. Additionally, the change between closing value on a trading day and opening value on the following trading day was calculated for each of the trading days beginning in 1992.
What happened to the weekend effect?

The data points were then organized chronological and based on day of the week with the intent of analyzing the weekend effect relevant to the VIX. Trading days immediately after a public holiday (when the S&P500 index is not traded) were excluded from the analysis as the number of days since the prior trades for those trading days was abnormally longer than most of the weeks without a public holiday.

To assess statistical differences of populations across different days of the week, ANOVA and/or t-tests were performed using Microsoft Excel. When populations were considered over time, two year time periods were analyzed to provide a statistically sufficient number of data points for each weekday (two years corresponds to approximately 100 trading days for each day of the week) and to provide a sufficiently short time period of analysis such that separate time periods before, during, and after the bear market beginning in 2000 and the financial crisis that began in 2007 could be considered.

In the second portion of this analysis, each data point related to the weekend effect is quantified by determining its frequency over the span of the data of one stock index. In order to look at a narrower and more specific set of data, instances of the weekend effect have been qualified as being when both the Friday-Monday and Monday-Tuesday effect is found present. The data for each index has situations where the tests demonstrated statistical significance of Friday-Monday or Monday-Tuesday effects. It was established for the purpose of this research that the weekend effect would consist of seeing at least one of them not necessarily both at any given time.

**OTHER VOLATILITY INDICES WEEKEND EFFECT**

Once initial statistical findings were calculated with the VIX data, secondary information was also downloaded for the other Stock Indices from the CBOE webpage to further review the validity of the Weekend Effect. As with the analysis of the VIX index previously described, this method was also used for other Volatility Indices listed in the below Table 1. T-tests were performed exactly as they were for the VIX data for all seven (7) other Volatility Indices, for all of the available data for each index through December 31st, 2013. It is important to note that Volatility indices of single stocks (Amazon, Apple, Google, IBM, Goldman Sachs), although also available on the CBOE website, have been excluded from this analysis as they would did not represent comparable data points as all other indices accounted for a series of stocks rather than a single one.
OTHER STOCK INDEX PROPERTIES WEEKEND EFFECT

Additionally to further review the behavior of the weekend effect, the above described method was also used to better understand other properties of a stock such as close values and trading volumes. T-tests were performed exactly as they were for the close values and trading volumes of the stock indices as they were for the volatility values of its Volatility index.
RESULTS AND DISCUSSION

HYPOTHESIS 1

CHANGES BETWEEN CLOSING VALUES OF THE VIX
In considering the change in the closing values of the VIX between adjacent trading days for all of the available data, both the ANOVA and t-tests performed show a statistically significant difference for some of the five days of the trading week. A summary of which of the weekdays show statistically different mean daily change is shown in the below Table 2.

<table>
<thead>
<tr>
<th></th>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
<th>Thursday</th>
<th>Friday</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average:</strong></td>
<td>0.357</td>
<td>-0.239</td>
<td>-0.061</td>
<td>-0.013</td>
<td>-0.160</td>
</tr>
<tr>
<td>Monday</td>
<td>6.95E-17</td>
<td>2.51E-09</td>
<td>1.66E-07</td>
<td>4.00E-13</td>
<td></td>
</tr>
<tr>
<td>Tuesday</td>
<td></td>
<td>4.30E-03</td>
<td>3.60E-04</td>
<td>2.14E-01</td>
<td></td>
</tr>
<tr>
<td>Wednesday</td>
<td></td>
<td></td>
<td>4.43E-01</td>
<td>1.11E-01</td>
<td></td>
</tr>
<tr>
<td>Thursday</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.02E-02</td>
</tr>
</tbody>
</table>

The first row below the header row in contains the average daily change in the VIX for each of the weekdays. For example, the “Monday” column has an average of 0.357 meaning that between the close of the VIX on Friday and the close of the VIX on Monday, the VIX increases by an average of 35.7%. Of the five weekdays, only Monday, on average, closes at a value higher than the closing of the prior trading day. The overall average for the dates shown is negative 0.027.

The subsequent rows in Table 2 show the p-values for the t-tests to compare data for the different weekdays. Highlighted cells contain small p-values (all less than 0.05) indicating a high level of statistical confidence that those weekdays exhibit mean changes between closing values that are different from one another. Based on this analysis, Mondays are statistically different from all other days (increasing the VIX by more on average) while Tuesday and Friday are similar to each other but different from all...
other days (decreasing the VIX by more on average) both of which are consistent with the previous research which psychology hypotheses (Ahoniemi and Lanne 2009).

Although the statistically significant weekend effect is found for the full set of data as shown in Table 2, the weekend effect is not always of statistical significance for all subsets of the full set of data. Statistical significance can be determined when the p-values for either Friday-Monday or Monday-Tuesday is less than 0.05 (corresponding to 95% confidence), which is represented below in Figure 2 for over twenty (20) years.

![Figure 2: P-values from change in VIX closing values T-tests comparing weekend effect using prior two years of data for each date shown](image)

From the first quarter of 1994 through the second quarter of 2005, nearly all two year periods of the VIX values demonstrated a statistically significant weekend effect. Within that period of more than eleven
What happened to the weekend effect?

years, only during a relatively short-lived time in the second quarter of 2000 did the prior two years of VIX not demonstrate a weekend effect for both Friday-Monday and Monday-Tuesday. During some of the two year periods ending in the second quarter of 2000, the Monday-Tuesday weekend effect reduced in significance with p-values as high as 0.10 (corresponding to 90% confidence) while the Monday-Friday weekend effect continued to have lower p-values. The second quarter of 2000 contains the beginning of the “bear market” associated with the bursting of the dot-com bubble. During such period of low return and significant volatility the security prices are falling and investors tend to be gradually more pessimistic which triggers them to sell which compounds the behavior and can lead major downturn in the economy. Such phenomenon is usually associated with great volatility and the previously observed patterns could become statistically insignificant until markets adjust to the new reality after the trigger event such as the dot-com bubble. In total, this dot-com bubble bear market has been recorded as being between January 18, 2000 and September 13, 2002 (Boudreaux et al 2010).

Of additional note from Figure 2, between the second quarter of 2005 and the end of the data (last quarter of 2013) there are very few times when the weekend effect was significant (demonstrated by Friday-Monday and/or Monday-Tuesday being significant at the 0.05 p-value). The frequency of the weekend effect pre and post 2005 are quantified in a later section of this research. This is quite different from the prior eleven years shown in Figure 2. This second quarter of 2005 and its prior two years do not have any bear markets, suggesting that the source of change regarding the weekend effect is not directly correlated with a bear market. This suggests that in this case, at least, the application of the change to weekend effect is not dependent upon a bear market as suggested by some previous research (Bourdeaux et al 2010). However, as the financial crisis beginning in 2007 and the associated bear market starting in early 2008 start affecting the data, then the p-values associated with the weekend effect (as shown in Figure 2) are no longer significant and vary with greater frequency. Comparisons of other weekdays (not just Mondays) were completed for the time period since the financial crisis and there are no p-values of statistical significance (p-values not shown).

Changes between Closing Values and Opening Values of the VIX

In addition to analyzing the change between closing values, a comparison of change between close and open was undertaken as an attempt to understand whether trading of the VIX intraday and interday
What happened to the weekend effect?

differed between the two set of data previously described (1Q1994 to 2Q2005; 2Q2005 to 4Q2013). Specifically, a ratio comparing overnight (or over weekend for Friday to Monday) change in value of the VIX to change between closing values of the VIX was used in the analysis. The numerator of the ratio is the change in VIX value between close on a first trading day and open on the following trading day. The denominator of the ratio is the change in VIX value between closing values on those two trading days. It is possible to have a negative ratio because the direction of the overnight change may be opposite to the full change.

The summary of the analysis of the ratio for the first data series described (1Q1994 to 2Q2005) is presented in Table 3. For each trading weekday there are approximately 500 ratios within this range of dates. The average ratio for each weekday is shown in Table 6 as the row below the header row. The subsequent row displays the fraction of ratios that were found to be negative (the overnight change went in the direction opposite that the overall change went) for that weekday. The subsequent rows display the p-values for the t-tests of the ratios with statistically significant ones (p<0.05) highlighted. Friday in particular stands out from the other weekdays because the average is negative (all others are positive), the fraction of negative ratios is similar to the other weekdays, and the ratios associated with Friday are statistically different from those of most other days. Within the time period considered in Table 3, the Fridays appear to have some days in which the direction of the overnight change was reversed with relatively large magnitude during the trading during Friday in the day (creating an overall negative average despite most values being positive).

In other words, in the range of dates where the weekend effect was significant, trades in the day of Friday are unlike other trades in that they bucked the overnight trend with greater magnitude than average. This could be associated with greater investor responsiveness or anxiety on Fridays going into the weekend (during which time their portfolio positions are relatively locked) and/or greater release of information or rumours on Fridays (Abraham and Ikenberry 1994). It continues to support the concept of the weekend effect that shows increase volatility over the weekend than any other time when the stock market closes and opens.
What happened to the weekend effect?

In comparison, the same statistics are displayed for VIX trading between April 1, 2005 and December 1, 2013 in Table 4. For each trading weekday there are approximately 300 ratios within this range of dates. Compared to the ratios for the earlier dates shown in Table 8, Fridays continue to have the only negative average, similar fraction of negative ratios, but have no statistically significantly differences with any other weekdays. Consistent with the weekend effect analysis, the recent timeframe does not show significant differences across weekdays that had been seen in the earlier timeframe.

HYPOTHESIS 2

Changes between Closing Values of other volatility indices
In order to review the behavioral change of the weekend effect, the change between closing values test as indicated above for the VIX were conducted for other Volatility Index types in order to determine
What happened to the weekend effect?

whether or not this phenomenon is isolated to the VIX or not. Based on the CBOE website, Table 5 displays Volatility indices in five main groupings:

<table>
<thead>
<tr>
<th>STOCK INDEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBOE Volatility Index® (VIX) *</td>
</tr>
<tr>
<td>CBOE NASDAQ Volatility Index (VXN) *</td>
</tr>
<tr>
<td>CBOE S&amp;P 100 Volatility Index (VXO)</td>
</tr>
<tr>
<td>CBOE DJIA Volatility Index (VXD) *</td>
</tr>
<tr>
<td>CBOE Russell 2000 Volatility Index (RVX) *</td>
</tr>
<tr>
<td>CBOE Short-Term Volatility Index (VXST) *</td>
</tr>
<tr>
<td>CBOE 3-Month Volatility Index (VXV) *</td>
</tr>
<tr>
<td>CBOE Mid-Term Volatility Index (VXMT) *</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OTHER</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBOE VIX of VIX Index (VVIX) *</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ETF'S</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBOE Crude Oil ETF Volatility Index (OVX)</td>
</tr>
<tr>
<td>CBOE Gold ETF Volatility Index (GVX)</td>
</tr>
<tr>
<td>CBOE EuroCurrency ETF Volatility Index (EVX)</td>
</tr>
<tr>
<td>CBOE EFA ETF Volatility Index (VXEFA)</td>
</tr>
<tr>
<td>CBOE Emerging Markets ETF Volatility Index (VXEEM)</td>
</tr>
<tr>
<td>CBOE Silver ETF Volatility Index (VXSLV)</td>
</tr>
<tr>
<td>CBOE China ETF Volatility Index (VXFXI)</td>
</tr>
<tr>
<td>CBOE Gold Miners ETF Volatility Index (VXGDX)</td>
</tr>
<tr>
<td>CBOE Brazil ETF Volatility Index (VXEWZ)</td>
</tr>
<tr>
<td>CBOE Energy Sector ETF Volatility Index (VXXLE)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INTEREST RATES</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBOE/CBOT 10-year U.S. Treasury Note Volatility Index (VXTYN)</td>
</tr>
<tr>
<td>CBOE Interest Rate Swap Volatility Index (SRVX)</td>
</tr>
</tbody>
</table>

For the purpose of this research, the volatility indices used are all Stock Index ones and the VVIX (marked in Table 5 with an ‘*’ at the end of their name). The VVIX, although not based directly on a stock index, has been included due to its nature. The VVIX actually measures the volatility of the VIX itself. The detailed charts for each of the selected indices and the graphical representation of their weekend effect (based on the change in closing value between days t-test method used for the VIX above) can be seen in the below Figures 2 & Figure 3 for the VXD and VXN respectively, which
What happened to the weekend effect?

represents the two popular indices, while the others are not as vastly known. All others can be found in Appendix A and can be found summarized in Table 6 below.

This summary, sorted by magnitude of data points, along with the graphical representations in Figure 2, 3 and Appendix A show that all Stock Index Volatility measures have demonstrated signs of the weekend effects at some point in the data series with the exception of the S&P500 3-month and Medium Term, with minimal presence, 17% and 1% of their data points respectively. Those who had data prior to 2005 had a significant presence of the patter prior to 2005, ranging between 99-100% of the data points prior to that year.

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>BASE</th>
<th>AVAILABLE DATA</th>
<th>% DATA POINT with WEE</th>
<th>% DATA POINT with WEE up to 2005</th>
<th>% DATA POINT with WEE after 2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIX</td>
<td>S&amp;P 500 (SPX)</td>
<td>1990 to 2013</td>
<td>82% (4,455 out of 5,415)</td>
<td>99% (3,243 out of 3,278)</td>
<td>57% (1,212 out of 2,137)</td>
</tr>
<tr>
<td>VXD</td>
<td>DowJones Industrial Average (DJX)</td>
<td>1997 to 2013</td>
<td>75% (2,701 out of 3,578)</td>
<td>99% (1,296 out of 1,313)</td>
<td>62% (1,405 out of 2,265)</td>
</tr>
<tr>
<td>VXN</td>
<td>NASDAQ (NDX)</td>
<td>2001 to 2013</td>
<td>87% (2,389 out of 2,744)</td>
<td>100% (479 out of 479)</td>
<td>84% (1,910 out of 2,265)</td>
</tr>
<tr>
<td>RVX</td>
<td>Russell 2000 options (RUT)</td>
<td>2004 to 2013</td>
<td>75% (1,539 out of 2,057)</td>
<td>N/A</td>
<td>75% (1,539 out of 2,057)</td>
</tr>
<tr>
<td>VXV</td>
<td>S&amp;P 500 3-month</td>
<td>2007 to 2013</td>
<td>17% (184 out of 1,072)</td>
<td>N/A</td>
<td>17% (184 out of 1,072)</td>
</tr>
<tr>
<td>VXST</td>
<td>S&amp;P 500 Short Term</td>
<td>2011 to 2013</td>
<td>100% (296 out of 296)</td>
<td>N/A</td>
<td>100% (296 out of 296)</td>
</tr>
<tr>
<td>VXMT</td>
<td>S&amp;P 500 Medium Term</td>
<td>2008 to 2013</td>
<td>1% (9 out of 1,002)</td>
<td>N/A</td>
<td>1% (9 out of 1,002)</td>
</tr>
</tbody>
</table>
What happened to the weekend effect?

<table>
<thead>
<tr>
<th>VVIX (Appendix A)</th>
<th>VIX</th>
<th>2007 to 2013</th>
<th>46% (611 out of 1,317)</th>
<th>N/A</th>
<th>46% (611 out of 1,317)</th>
</tr>
</thead>
</table>

**TABLE 6 – FREQUENCY OF FRIDAY-MONDAY OR MONDAY-TUESDAY P-VALUE LESS THAN 0.05 FOR THE SPECIFIED VOLATILITY INDEX MEASURES**

**FIGURE 3** - P-VALUES FROM CHANGE BETWEEN CLOSING DAYS T-TESTS COMPARING VOLATILITY INDEX OF THE DOW JONES (VXD) WEEKEND EFFECT USING PRIOR TWO YEARS OF DATA FOR EACH DATE SHOWN
What happened to the weekend effect?

Based on the above analysis, we can conclude that the weekend effect, although significantly researched for the Volatility Index of the S&P500 Stock Index (VIX) over the last couple of decades is a phenomenon experienced by several volatility metrics, mainly related to Stock Indices. It is also visible that although the VIX experienced a drastic change in pattern around 2005, the same change is not consistent with other volatility indices. All other volatility measures, with the exception of the S&P500 Short-Term Volatility Index (VXST) which has only a few months of data, have experienced times where the weekend effect has statistical significance, but also all of them have had periods where its statistical significance was drastically impacted. The Dow Jones (VXD) appears to be around the same periods as the VIX while the Nasdaq (VXD) and Russell 2000 (RVX) seems to be later, around late 2008 and the S&P500 3-Month Volatility index (VXV) is even later in 2010. Interestingly, the Volatility of the VIX (VVIX) has a pattern of its own, when the weekend effect is only present for a short period of time around, 2009, early 2011 and 2013.
What happened to the weekend effect?

**HYPOTHESIS 3**

**THE INTRODUCTION OF FUTURES**

Based solely on the VIX weekend effect and not other volatility indices, there is an immediate event that appears to relate to the change in behavior of the effect. On March 26 2004, the VIX Futures were launched as a standalone derivatives product which could have impacted the VIX index values themselves (CBOE 2004). Consequently, a thorough review of the Volatility indices that have Future products was conducted to determine whether or not the introduction of the derivative on the market was the trigger for the weekend effect to be change for that particular Volatility index. Of the seven (7) indices that were reviewed in the previous section, four (4) of them have launched their own Futures: RVX, VXD, VXN and VIX.

The question remained: Did the launch of the VIX Future cause for eleven (11) years of the weekend effect to be no longer statistically significant? Figure 5-8 illustrate a variety of patterns for the VIX, VXN, VXD, and RVX and their weekend effect with a marker for the introduction of their Futures Derivatives. Initially at glance, there is an obvious pattern between 2005 and 2010 for all four (4) of the indices while their Future Launch varies over a decade span.

**FIGURE 5 - P-VALUES FROM T-TESTS COMPARING VIX WEEKEND EFFECT USING PRIOR TWO YEARS OF DATA FOR EACH DATE SHOWN & THE INTRODUCTION OF THE RELATED FUTURES**
What happened to the weekend effect?

FIGURE 6 - P-VALUES FROM T-TESTS COMPARING RVX WEEKEND EFFECT USING PRIOR TWO YEARS OF DATA FOR EACH DATE SHOWN & THE INTRODUCTION OF THE RELATED FUTURES

RVX Future Launch ➔ November 18, 2013

FIGURE 7 - P-VALUES FROM T-TESTS COMPARING VXD WEEKEND EFFECT USING PRIOR TWO YEARS OF DATA FOR EACH DATE SHOWN & THE INTRODUCTION OF THE RELATED FUTURES

VXD Future Launch ➔ April 25, 2005
Table 7 uses the same method as discussed for Table 5 and accounts for the number of instances of the weekend effect (Friday-Monday and/or Monday-Tuesday p-value < 0.05) along with the split pre and post launch of the derivative for each of the items. The VIX appears to be the only one that shows a drastic change in weekend effect Pre & Post launch where 99% of its data point pre-launch showing the effect while 60% post-launch. However, this split is not nearly as dramatic with the VXD, the only other one with a substantial amount of data points pre and post launch. With the case of the RVX and the VXN, the futures product is relatively new and therefore cannot be analyzed in detail yet. Predominantly in the case of the VXN, it is evident that something did affect the presence of the weekend effect between 2005 and 2009 and is not correlated to the launch of the future as it only took place in mid-2013. This information would suggest that the behavior of the weekend effect is not generally correlated the launch of the futures product.
What happened to the weekend effect?

<table>
<thead>
<tr>
<th>FUTURES LAUNCH DATE</th>
<th>AVAILABLE DATA</th>
<th>% DATA POINT with WEE</th>
<th>% DATA POINT with WEE Pre-Launch</th>
<th>% DATA POINT with WEE Post-Launch</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIX</td>
<td>Started on March 26 2004</td>
<td>1990 to 2013</td>
<td>82% (4,455 out of 5,415)</td>
<td>99% (3,053 out of 3,088)</td>
</tr>
<tr>
<td>RVX</td>
<td>Started on November 18 2013</td>
<td>2004 to 2013</td>
<td>75% (1,539 out of 2,057)</td>
<td>75% (1,518 out of 2,036)</td>
</tr>
<tr>
<td>VXD</td>
<td>Started on April 25 2005</td>
<td>1997 to 2013</td>
<td>75% (2,701 out of 3,578)</td>
<td>99% (1,296 out of 1,313)</td>
</tr>
<tr>
<td>VXN</td>
<td>Started on May 17 2013</td>
<td>2001 to 2013</td>
<td>87% (2,389 out of 2,744)</td>
<td>86% (2,241 out of 2,596)</td>
</tr>
</tbody>
</table>

TABLE 7 - SUMMARY OF WEE PRE & POST FUTURES LAUNCH FOR FOUR VOLATILITY INDICES WITH FUTURES

HYPOTHESIS 4

STOCK INDEX VOLUMES TO VIX INDEX

Based on the above observations where the weekend effect is not isolated to the VIX (S&P500) and is not correlated with the introduction of the futures product, we further examine another factor that would affect all Stock Indices independently of each other. Marko Kolanovic of the JP Morgan company, a leader in international financial services, published an article in October 2010 regarding the “correlation bubble” in which in uses the S&P500 to demonstrate how “High-Frequency Trading [HFT] activity has increased correlations” between stocks to a much higher level than experienced in the past. The US Security and Exchange Commission (SEC) chairman between January 2009 to December 2012, Mary Shapiro attempted to pass a ruling that HFT’s should be marked and easily identified in the stock market, but failed. At the present time, there are no direct measures to determine the HFT volume levels and can only be estimated based on the individual HFT’s companies daily volumes and the overall stock market volumes. In 2010, Kolanovic states that “60% of US turnover volume is due to HFT” and goes as far as predicting that this rise of HFT’s from 21% in 2005 to 61% in 2009 peaks then and then will be in a downwards trend and states volumes “are bound to decline”.

Several investing firms and market specialist have attempted to explain the impact of such trading methods like HFT’s but research remains inconclusive on this topic. Ian Stewart, a Mathematics professor at Warwick University said “The entire system is poorly understood and dangerously unstable”
What happened to the weekend effect? (Stewart, 2012). CBS’ 60-Minutes did a story called “The Speed Traders” (Available on Youtube.com, produced by Anderson & Cowan, 2012) where they have analyzed the poorly understood phenomenon of the HFT’s and super-computers. Chief Operating Office of NYSE Lawrence Liebowitz believes that the HFT’s, although perceived by a lot as an unfair advantage, only helps with the liquidity of the stock market.

As actual HFT volumes are not available, other indicators have been linked to HFT trading such as stock turn-over and plain trade volumes, in effort to link to the use of HFT’s for particular stock indices (Podobnik, Wang, Stanley 2012). The turnover ratio of a stock is a measure of sellers versus buyers of a particular stock. It is calculated by dividing the daily volume of a stock by the "float" of a stock, which is the number of shares available for sale by the general trading public. Although experts may have tied volatility measures to turnover ratios, this information is not readily available for all indices while trading volumes are (Podobnik et al, 2012). For that reason, trading volumes are used in this report to determine if the weekend effect behavior has a correlation to the stock index trading volumes, in hopes to link volumes to the increase and decline of HFT’s possibly in future research.

As earlier stated, we accessed the trading volumes of the S&P500, the base stock index of the VIX measures. If Kolanovic’s forecast is correct, HFT’s increased from 2005 to 2009 and then started to decline, we would like to see the trading volumes of the S&P500 behaving the same behavior and as the volume increases the statistical significance of the weekend effect would diminish. Figure 9 below shows the S&P500 daily volumes from 2001 and 2014, along with a 255day/1year moving average. The pattern expressed by Kolanovic is clearly visible and provides also a level of visibility regarding what happens after 2010, showing volumes stabilizing mid-2011 to 2014 at the average experienced in 2008.
What happened to the weekend effect?

Figure 9 illustrates the trade daily volumes of the S&P 500 over the last 13 years. Starting in 2005, there is a definite increasing slope in volumes, more clearly seen in the 255 days moving-average trend line (approximately one year of data averaged). Using a different visual, Figure 10 below displays the same daily S&P volumes normalized based on the 2001 average volumes. In 2008, volumes were three times as high as they were in 2001, peaked at 5 times between 2009 and 2010 and are stabilizing around 3 times over the recent months. This pattern is similar to the one exposed by JP Morgan and expressed in the 60 Minutes interview about HFT’s.
What happened to the weekend effect?

Furthermore, it was important to review that similar behavior can be seen with the trading volumes of other stock indices reviewed so far. Figure 11 shows the patterns of the S&P500, Russell 200 and NASDAQ monthly average volumes normalized based on their average monthly volumes of 2001. The SPX and RUT have a definite pattern commonality while the NDX (Nasdaq) is clearly not as effect in the year 2000’s in terms of volume change. Because of the electronic nature of the Nasdaq, it may relate to why it is not as affected by the gain in popularity in HFT’s and has not seen volume increases like the others. However, this remains inconclusive.
What happened to the weekend effect?

FIGURE 11 – NORMALIZED SPX, RUT & NDX DAILY VOLUME BASED ON 2001 AVERAGE VOLUMES

This paper can however not conclude that the trading volume variations for SPX, RUT & NDX vary because of their use of HFT’s. NDX does not seem to have the large increase in volumes between 2005 and 2010 but it may or may not be related to the use of HFT’s.

CORRELATION OF THE VOLUME GROWTH AND WEEKEND EFFECT
Below in Figure 12, the weekend effect p-values for both Friday-Monday and Monday-Tuesday are shown in parallel with the daily one year moving average of the SPX volumes. Although the statistical significance of the weekend effect appears to disappear when the volume slope becomes steeper, it is not clear whether or not they are indeed correlated.
What happened to the weekend effect?

FIGURE 12 – 12-MONTH MOVING AVERAGE OF DAILY SPX VOLUME WITH P-VALUES OF CHANGE BETWEEN DAYS T-TEST FOR JANUARY 1, 2001 TO DECEMBER 31, 2013
An analysis of the weekend effect for the implied volatility for the S&P 500 (VIX Index) over the last 20 years was completed. It shows that a statistically significant dependence of the change in the VIX index upon day of the week was found, consistent with prior research. When the daily VIX data was analyzed over two year periods instead of the full twenty year period, the weekend effect was found to be statistically significant for about 11 years beginning in the first quarter of 1994 and then not significant for the following 7 years beginning in the second quarter of 2005.

This transition from a statistically significant weekend effect to not significant corresponded with many potential changes in many financial markets such as the introduction of futures product as well as the increase use of algorithms and high-frequency trading (HFT) methods. Potential changes that were identified as being aligned with previously suggested reasons for the weekend effect or specific to the VIX index included:

- **Hypothesis 1:**
  - If the weekend effect of the VIX is present then the change between the closing value on Friday and the opening value on Monday is different than the change between the close/open of any other day of the week.
  - **CONCLUSION**
    - The significance in change between the open & close of Friday to Monday is statistically different from the ones for the rest of the week prior to 2005, when the weekend effect was present.
    - As the Weekend effect becomes statistically insignificant after 2005, so does the statistical significant of the open & close change between all days of the week

- **Hypothesis 2:**
  - If the weekend effect patterns are seen in the VIX, then they should also be seen in other volatility index of stock indices
  - **CONCLUSION**
    - The pattern has been visible in other Stock Index Volatility Indices, not just S&P500, such as Dow Jones, Nasdaq, Russell 2000 and variations in the volatility
What happened to the weekend effect?

window range of the S&P500. All Stock indices have shown the effect, a period of time where it disappears in the second half of 2000.

- Similar pattern, where the weekend effect has come and gone has been seen with the VIX of the VIX but the pattern has been intermittent all of 2000, unlike the other indices.

- **Hypothesis 3:**
  - If a Volatility index has a related futures product, then its weekend effect pattern will become statistically insignificant.

- **CONCLUSION**
  - The introduction of the Volatility Futures has not consistently impacted the presence of the weekend effect on the Volatility Indices that have futures

- **Hypothesis 4:**
  - If the trading volumes of the S&P500 stock index experiences growth above their normal 2001 levels, then the weekend effect pattern will become statistically insignificant.

- **CONCLUSION**
  - As the volume increases significantly above their 2001 average, the statistical significance of the weekend effect reduces for the S&P500. As the volume trends back towards the levels of 2001, the statistical significance of weekend effect increases but not to a sufficient significant level of confidence.

This research was able to determine that the weekend effect has lost statistical significance since the mid-2000’s for several stock index volatility measures and has been able to disconnect that change from the launch of the related futures product of the stock indices that have volatility futures. It was also able to determine that the change in the weekend effect pattern, in the case of the S&P500 and the Russell 2000 stock indices may be related to their increase in trading volumes. However, because the specific levels of volumes related to HFT are not captured and publicly available, the correlation between volumes and HFT levels cannot be measured and only assumed as directly tied to trading volumes.
What happened to the weekend effect? (Podobnik, 2012). Furthermore, although it may be explained by the fact that the Nasdaq was launch as an electronic trader, the volumes of that stock index has not been affected over the last decade by a significant increase but the statistical significance of its weekend effect remains similar to the other stock indices that have experienced significant volume increases. Consequently, research remains inconclusive about whether or not the volume increases seen in S&P500 and Russell 2000 are actually tied to the use of HFT’s and the cause for the weekend effect to change.

Planned future work related to a more complete understanding of the weekend effect will focus on identifying a more sound measure of HFT to the volumes numbers (Podobnik, 2012) and link it to the volatility of the stocks. Other topics relating to better understanding the weekend effect presence with the trading volumes of other indices may shed some light to the initial findings in this research. In order to remain consistent, the Dow Jones (DJX) volumes were not reviewed as they were not available from the CBOE webpage, like all other information for this research. Reviewing the behavior of the DJX trading volumes and its correlation to the change in weekend effect patterns should be reviewed. Understanding the properties of each of the different stock indices with volatility measures and reviewing the buyer profile of each index, whether more or less likely to be affected by HFT’s, may further explain why the weekend effect pattern shifts had different times for each of the stock indices. Furthermore, as the other CBOE index types (EFT’s and interest rates) with volatility measures gather more historical data, the weekend effect behaviors should also be reviewed for pattern changes. One other recent research suggests a similar correlation to volumes but with S&P500 returns rather and using those findings to review other volatility indices could be completed (Fernandes, Medeiros & Scharth, 2014).

Finally, as recent research suggests that HFT’s are here to stay (Easley, Lopez de Prado, & O’Hara, 2012) reviewing the methods used to build the algorithm for HFT’s and how they are modified to assure the user has an edge over others may be insightful (Phillips 2012) to explain their popularity. Reviewing the methods used to determine when the human factor remains necessary to benefit more than the competition (Anderson, et al, 2012) should be reviewed but understandably difficult to access as firms would keep confidential in order to profit. Although fear is a common concept, the mathematics of how it impacts the stock markets and may have ties to complex algorithm may remain an area difficult to research at a granular level with actual data.
APPENDIX A – WEEKEND EFFECT T-TEST RESULTS OF OTHER VOLATILITY INDICES

Figure 13-17 below are additional graphical representations of the t-test results in change between closing days for other volatility measures of stock indices.

RVX – RUSSELL 200 VOLATILITY INDEX

**FIGURE 17** - P-VALUES FROM CHANGE BETWEEN CLOSING DAYS T-TESTS COMPARING VOLATILITY INDEX OF THE RUSSELL 2000 (RVX) WEEKEND EFFECT USING PRIOR TWO YEARS OF DATA FOR EACH DATE SHOWN
What happened to the weekend effect?

**VXST – S&P500 Short Term Volatility Index**

![Graph showing p-values from change between closing days t-tests comparing volatility index of the S&P500 short term (VXST) weekend effect using prior two years of data for each date shown.](image)

**Figure 14** - P-values from change between closing days t-tests comparing volatility index of the S&P500 short term (VXST) weekend effect using prior two years of data for each date shown.
What happened to the weekend effect?

VXV – S&P500 3-Month Volatility Index

FIGURE 15 - P-VALUES FROM CHANGE BETWEEN CLOSING DAYS T-TESTS COMPARING VOLATILITY INDEX OF THE S&P500 3-MONTH (VXV) WEEKEND EFFECT USING PRIOR TWO YEARS OF DATA FOR EACH DATE SHOWN
What happened to the weekend effect?

**VXMT – S&P500 MEDIUM TERM VOLATILITY INDEX**

**FIGURE 16** - P-VALUES FROM CHANGE BETWEEN CLOSING DAYS T-TESTS COMPARING VOLATILITY INDEX OF THE S&P500 MEDIUM TERM (VXMT) WEEKEND EFFECT USING PRIOR TWO YEARS OF DATA FOR EACH DATE SHOWN
What happened to the weekend effect?

**VVIX – VIX OF THE VIX**

![Graph showing p-values from change between closing days t-tests comparing volatility index of the VIX (VVIX) weekend effect using prior two years of data for each date shown.](image)

**FIGURE 17 -** P-VALUES FROM CHANGE BETWEEN CLOSING DAYS T-TESTS COMPARING VOLATILITY INDEX OF THE VIX (VVIX) WEEKEND EFFECT USING PRIOR TWO YEARS OF DATA FOR EACH DATE SHOWN
APPENDIX B – DETAILED DESCRIPTIONS OF EACH STOCK INDEX VOLATILITY MEASURES

The following information was extracted directly from the CBOE Volatility Index webpage and microsites and describes the nature of each of the Stock Index volatility measures.


**VIX → WWW.CBOE.COM/VIX**

The CBOE Volatility Index® (VIX®) is a key measure of market expectations of near-term volatility conveyed by S&P 500 stock index option prices. Since its introduction in 1993, VIX has been considered by many to be the world's premier barometer of investor sentiment and market volatility.

**VXD → WWW.CBOE.COM/VXD**

The CBOE DJIA Volatility Index (VXD) is based on real-time prices of options on the Dow Jones Industrial AverageSM (DJIA, with an options ticker of DJX), and is designed to reflect investors' consensus view of future (30-day) expected stock market volatility.

**VXN → WWW.CBOE.COM/VXN**

The CBOE NASDAQ-100 Volatility IndexSM (VXNSM) is a key measure of market expectations of near-term volatility conveyed by NASDAQ-100 Index (NDX) option prices. It measures the market's expectation of 30-day volatility implicit in the prices of near-term NASDAQ-100 options. VXN is quoted in percentage points, just like the standard deviation of a rate of return, e.g. 19.36. CBOE disseminates the VXN index value continuously during trading hours. The VXN Index is a leading barometer of investor sentiment and market volatility relating to the NASDAQ-100 Index.
What happened to the weekend effect?

RVX → WWW.CBOE.COM/RVX

The CBOE Russell 2000 Volatility Index℠ (RVX℠) is a key measure of market expectations of near-term volatility conveyed by Russell 2000® stock index option prices. It measures the market's expectation of 30-day volatility implicit in the prices of near-term Russell 2000 options. RVX is quoted in percentage points, just like the standard deviation of a rate of return, e.g. 19.36. CBOE disseminates the RVX index value continuously during trading hours. The RVX Index is a leading barometer of investor sentiment and market volatility relating to the Russell 2000 Index.

VXST → WWW.CBOE.COM/VXST

The new CBOE Short-Term Volatility Index (VXST) and the popular CBOE Volatility Index® (VIX®) both reflect investors' consensus view of expected stock market volatility. While the VIX measures expectations of 30-day future volatility, the VXST provides a new market-based gauge of expectations of 9-day volatility, making it particularly responsive to changes in the S&P 500® Index. With its nine-day snapshot, VXST is a valuable tool for traders looking to target short-term moves with SPX Weeklys options. The VXST Index provides a market estimate of short-term expected (implied) volatility that is calculated by using real-time S&P 500® Index option bid/ask quotes. VXST uses nearby and second nearby options with at least 1 day left to expiration and then weights them to yield a constant, nine-day measure of the expected volatility of the S&P 500® Index.

On February 13, 2014, the CBOE Futures Exchange, LLC (CFE®) launched trading of futures with weekly expirations on the VXST Index, and the launch date for options on the VXST Index is April 10, 2014.

VXV → WWW.CBOE.COM/VXV

The CBOE 3-Month Volatility Index (VXVSM) is designed to be a constant measure of 3-month implied volatility of the S&P 500® (SPX) Index options.
What happened to the weekend effect?

The VXV Index has tended to be less volatile than the CBOE Volatility Index® (VIX®), which measures one-month implied volatility. Using the VXV and VIX indices together provides useful insight into the term structure of S&P 500 (SPX) option implied volatility.

VXT → WWW.CBOE.COM/VXT

The CBOE Mid-Term Volatility Index (Ticker: VXMT) is a measure of the expected volatility of the S&P 500 Index over a 6-month time horizon. It is calculated using the well-known VIX methodology applied to SPX options that expire 6-to-9 months in the future.

- As investors become more sophisticated in their understanding of volatility and their use of volatility products, VXMT offers a "macro" view of market risk, a view driven less by event risk and more by the perceived risk of broad economic factors. As a result, VXMT tends to move like VIX (0.91 correlation) but with lower volatility (55% vs. 116% since January 2008)

- VXMT joins CBOE’s other volatility benchmarks - VXST (9-day), VIX (30-day) and VXV (3-month) - to create a live, streaming representation of expected volatility at key points along the SPX option term structure.
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