
VIX®
CBOE VOLATILITY INDEX

CBOE would like to thank Sandy Rattray and Devesh Shah of Goldman, Sachs & Co. for their significant contributions to the development of the New VIX calculation.

THE NEW CBOE VOLATILITY INDEX® - VIX®

In 1993, the Chicago Board Options Exchange® (CBOE®) introduced the CBOE Volatility Index®, VIX®, and it quickly became the benchmark for stock market volatility. It is widely followed and has been cited in hundreds of news articles in the *Wall Street Journal*, *Barron's* and other leading financial publications. VIX measures market expectations of near term volatility conveyed by stock index option prices. Since volatility often signifies financial turmoil, VIX is often referred to as the "investor fear gauge".

In the ten years following the launch of VIX, theorists and practitioners alike have changed the way they think about volatility. It's time to update the VIX methodology to ensure that VIX remains the premier benchmark of U.S. stock market volatility. The changes reflect the latest advances in financial theory and what has become standard industry practice, and will provide a practical standard for trading and hedging volatility.

THE BASIC IDEA OF VIX HAS NOT CHANGED...

The fundamental features of VIX remain the same. VIX continues to provide a minute-by-minute snapshot of expected stock market volatility over the next 30 calendar days. This volatility is still calculated in real-time from stock index option prices and is continuously disseminated throughout each trading day.

...BUT THERE ARE IMPORTANT DIFFERENCES...

What is new? There are two important changes in the new VIX methodology.

- The most significant change is a new method of calculation. The new VIX estimates expected volatility from the prices of stock index options in a wide range of strike prices, not just at-the-money strikes as in the original VIX. Also, the new VIX is not calculated from the Black Scholes option pricing model; the calculation is independent of any model. The new VIX uses a newly developed formula to derive expected volatility by averaging the weighted prices of out-of-the money puts and calls. This simple and powerful derivation is based on theoretical results that have spurred the growth of a new market where risk managers and hedge funds can trade volatility, and market makers can hedge volatility trades with listed options.

- The second noteworthy change is that the new VIX calculation will use options on the S&P 500® index rather than the S&P 100. While the two indexes are well correlated, the S&P 500 is the primary U.S. stock market benchmark, and the reference point for the performance of many stock funds, with over $800 billion in indexed assets. In addition, the S&P 500 underlies the most active stock index derivatives, and it is the domestic index tracked by volatility and variance swaps.

...THAT RESULT IN A NUMBER OF IMPROVEMENTS AND BENEFITS...

With these changes, the new VIX measures expected volatility as financial theorists, risk managers and volatility traders have come to measure it. As such, the new VIX calculation more closely conforms to industry practice. It is simpler, yet it yields a more robust measure of expected volatility. The new VIX is more robust because it pools the information from option prices over the whole volatility skew, not just from at-the-money options.

The changes also increase the practical appeal of VIX. The new VIX is based on the S&P 500, the core index for U.S. equities, and the new calculation supplies a script for replicating VIX from a static strip of S&P 500 options. This will facilitate hedging and arbitrage of VIX derivative products.

...INCLUDING TRADABLE VOLATILITY PRODUCTS

In response to rising market demand, CBOE has developed a family of derivative products based on the new VIX methodology. The first to be listed will be futures and options on the new VIX.

FULL PRICE HISTORY FOR THE NEW VIX WILL BE AVAILABLE

Perhaps the most valuable feature of VIX is the existence of historical prices from 1986 to the present. This extensive data set provides investors with a useful perspective of how option prices have behaved in response to a variety of market conditions. CBOE has created an identical historical record for the new VIX dating back to 1986 so that investors can gain a better understanding of how the new VIX would have behaved in different markets and do their own side-by-side comparisons. In addition, CBOE will soon make available a historical file of intra-day VIX prices. Finally, realizing that some investors may want time to make the transition, CBOE plans to continue the calculation and dissemination of the original OEX VIX, but under the new ticker symbol - "VXO".

THE NEW VIX CALCULATION STEP-BY-STEP

Even though the basic concept remains the same, and the new VIX behaves in much the same way as its predecessor, the actual calculation has changed. In order to better understand these changes, the new VIX calculation is explained in detail in the following step-by-step example.

The generalized formula used in the new VIX calculation* is:

$$\sigma^2 = \frac{2}{T}\sum_i \frac{\Delta K_i}{K_i^2} e^{RT} Q(K_i) - \frac{1}{T}\left[\frac{F}{K_0} - 1\right]^2 \qquad \textbf{(1)}$$

Where…

σ is VIX/100 ⇨ VIX = σ x 100

T Time to expiration

F Forward index level derived from index option prices

K_i Strike price of i^{th} out-of-the-money option; a call if K_i>F and a put if K_i<F

ΔK_i Interval between strike prices - half the distance between the strike on either side of K_i:

$$\Delta K_i = \frac{K_{i+1} - K_{i-1}}{2}$$

(Note: ΔK for the lowest strike is simply the difference between the lowest strike and the next higher strike. Likewise, ΔK for the highest strike is the difference between the highest strike and the next lower strike.)

K_0 First strike below the forward index level, F

R Risk-free interest rate to expiration

$Q(K_i)$ The midpoint of the bid-ask spread for each option with strike K_i.

*Please see "More Than You Ever Wanted to Know About Volatility Swaps" by Kresimir Demeterfi, Emanuel Derman, Michael Kamal and Joseph Zou, Goldman Sachs Quantitative Strategies Research Notes, March 1999.

Getting Started

The options used in this hypothetical example have 16 days and 44 days to expiration, respectively. The new VIX generally uses put and call options in the two nearest-term expiration months in order to bracket a 30-day calendar period. However, with 8 days left to expiration, the new VIX "rolls" to the second and third contract months in order to minimize pricing anomalies that might occur close to expiration.

The time of the VIX calculation is assumed to be 8:30 a.m. (Chicago time). The new VIX calculation measures the time to expiration, T, in minutes rather than days in order to replicate the precision that is commonly used by professional option and volatility traders. The time to expiration is given by the following expression:

$$T = \{M_{\text{Current day}} + M_{\text{Settlement day}} + M_{\text{Other days}}\} / \text{Minutes in a year}$$

Where…

$M_{\text{Current day}}$ = # of minutes remaining until midnight of the current day
$M_{\text{Settlement day}}$ = # of minutes from midnight until 8:30 a.m. on SPX settlement day
$M_{\text{Other days}}$ = Total # of minutes in the days between current day and settlement day

Therefore, using 8:30 a.m. as the time of the calculation, the time to expiration for the near-term and next-term options, T_1 and T_2, respectively, is:

$T_1 = \{930 + 510 + 20{,}160) / 525{,}600 =$ **0.041095890**
$T_2 = \{930 + 510 + 60{,}480) / 525{,}600 =$ **0.117808219**

The risk-free interest rate is assumed to be 1.162%. For the sake of simplicity, the same number of options is used for each contract month and the interval between strike prices is uniform.[1]

Step 1 *- Select the options to be used in the new VIX calculation*

For **each** contract month:

- Determine the forward index level, F, based on at-the-money option prices. The at-the-money strike is the strike price at which the difference between the call and put prices is smallest. As shown in the following table, the difference between the call and put prices is smallest at the **900** strike in both the near and next term.

[1]In practice, there may be different options used in the near and next term, and the interval between strike prices may be different.

Near Term Options				Next Term Options			
Strike Price	Call	Put	Difference	Strike Price	Call	Put	Difference
775	125.48	0.11	125.37	775	128.78	2.72	126.06
800	100.79	0.41	100.38	800	105.85	4.76	101.09
825	76.70	1.30	75.39	825	84.14	8.01	76.13
850	54.01	3.60	50.41	850	64.13	12.97	51.16
875	34.05	8.64	25.42	875	46.38	20.18	26.20
900	***18.41***	***17.98***	***0.43***	***900***	***31.40***	***30.17***	***1.23***
925	8.07	32.63	24.56	925	19.57	43.31	23.73
950	2.68	52.23	49.55	950	11.00	59.70	48.70
975	0.62	75.16	74.53	975	5.43	79.10	73.67
1000	0.09	99.61	99.52	1000	2.28	100.91	98.63
1025	0.01	124.52	124.51	1025	0.78	124.38	123.60

The formula used to calculate the forward index level is:

$$F = \text{Strike Price} + e^{RT} \times (\text{Call Price} - \text{Put Price})$$

Using the 900 call and put in each contract month, the forward index prices, F_1 and F_2, for the near and next term options, respectively, are:

$$\mathbf{F_1} = 900 + e^{(0.01162 \times 0.041095890)} \times (18.41 - 17.98) = \mathbf{900.43}$$
$$\mathbf{F_2} = 900 + e^{(0.01162 \times 0.117808219)} \times (31.40 - 30.17) = \mathbf{901.23}$$

- Next, determine $\mathbf{K_0}$ - the strike price immediately below the forward index level, F. In this example, $\mathbf{K_0 = 900}$ for both expirations.

- Sort all of the options in ascending order by strike price. Select call options that have strike prices greater than K_0 and a **non-zero** bid price. After encountering two consecutive calls with a bid price of zero, do not select any other calls. Next, select put options that have strike prices less than K_0 and a **non-zero** bid price. After encountering two consecutive puts with a bid price of zero, do not select any other puts. Select **both** the put and call with strike price K_0. Then average the quoted bid-ask prices for each option.

  Notice that two options are selected at K_0, while a single option, either a put or a call, is used for every other strike price. This is done to center the strip of options around K_0. In order to avoid double counting, however, the put and call prices at K_0 are averaged to arrive at a single value. The price used for the 900 strike in the near term is, therefore, (18.41 + 17.98)/2 = 18.19; and the price used in the next term is (31.40 + 30.17)/2 = 30.78.

Following is a table that contains the options used to calculate the new VIX in this example:

Near term Strike	Option Type	Mid-quote Price		Next term Strike	Option Type	Mid-quote Price
775	Put	0.11		775	Put	2.72
800	Put	0.41		800	Put	4.76
825	Put	1.30		825	Put	8.01
850	Put	3.60		850	Put	12.97
875	Put	8.64		875	Put	20.18
900	Put/Call Average	***18.19***		***900***	Put/Call Average	***30.78***
925	Call	8.07		925	Call	19.57
950	Call	2.68		950	Call	11.00
975	Call	0.62		975	Call	5.43
1000	Call	0.09		1000	Call	2.28
1025	Call	0.01		1025	Call	0.78

Step 2 – *Calculate volatility for both near term and next term options*

Applying the formula (1) for calculating the new VIX to the near term and next term options with time to expiration of T_1 and T_2, respectively, yields:

$$\sigma^2_1 = \frac{2}{T_1}\sum_i \frac{\Delta K_i}{K_i^2} e^{RT_1} Q(K_i) - \frac{1}{T_1}\left[\frac{F_1}{K_0} - 1\right]^2$$

$$\sigma^2_2 = \frac{2}{T_2}\sum_i \frac{\Delta K_i}{K_i^2} e^{RT_2} Q(K_i) - \frac{1}{T_2}\left[\frac{F_2}{K_0} - 1\right]^2$$

The new VIX is an amalgam of the information reflected in the prices of all of the options used. The contribution of a single option to the new VIX value is proportional to the price of that option and inversely proportional to the option's strike price. For example, the contribution of the near term 775 Put is given by

$$\frac{\Delta K_{775\,Put}}{K^2_{775\,Put}} e^{RT_1} Q(775\,Put)$$

Generally, ΔK_i is half the distance between the strike on either side of K_i, but at the upper and lower edges of any given strip of options, ΔK_i is simply the difference between K_i and the adjacent strike price. In this case, 775 is the lowest strike in the strip of near term options and 800 happens to be the adjacent strike. Therefore, $\Delta K_{775\ Put} = 25$ (i.e., 800 – 775), and

$$\frac{\Delta K_{775\,Put}}{K_{775\,Put}^2} e^{RT_1} Q(775\,Put) = \frac{25}{775^2} e^{(0.01162 \times 0.041095890)} (0.11) = 0.000005$$

A similar calculation is performed for each option. The resulting values for the near term options are then summed and multiplied by $2/T_1$. Likewise, the resulting values for the next term options are summed and multiplied by $2/T_2$. The table below summarizes the results for each strip of options.

Near term Strike	Option Type	Mid-quote Price	Contribution by Strike		Next term Strike	Option Type	Mid-quote Price	Contribution by Strike
775	Put	0.11	0.000005		775	Put	2.72	0.000113
800	Put	0.41	0.000016		800	Put	4.76	0.000186
825	Put	1.30	0.000048		825	Put	8.01	0.000295
850	Put	3.60	0.000125		850	Put	12.97	0.000449
875	Put	8.64	0.000282		875	Put	20.18	0.000660
900	Put/Call Average	18.19	0.000562		900	Put/Call Average	30.78	0.000951
925	Call	8.07	0.000236		925	Call	19.57	0.000573
950	Call	2.68	0.000074		950	Call	11.00	0.000305
975	Call	0.62	0.000016		975	Call	5.43	0.000143
1000	Call	0.09	0.000002		1000	Call	2.28	0.000057
1025	Call	0.01	0.000000		1025	Call	0.78	0.000019
$\frac{2}{T} \sum_i \frac{\Delta K_i}{K_i^2} e^{RT} Q(K_i)$			**0.066478**					**0.063683**

Next, calculate $\frac{1}{T}\left[\frac{F}{K_0} - 1\right]^2$ for the near term (T_1) and next term (T_2):

$$\frac{1}{T_1}\left[\frac{F_1}{K_0} - 1\right]^2 = \frac{1}{0.041095890}\left[\frac{900.43}{900} - 1\right]^2 = 0.000006$$

$$\frac{1}{T_2}\left[\frac{F_2}{K_0} - 1\right]^2 = \frac{1}{0.117808219}\left[\frac{901.23}{900} - 1\right]^2 = 0.000016$$

Now calculate σ^2_1 and σ^2_2:

$$\sigma^2_1 = \frac{2}{T_1}\sum_i \frac{\Delta K_i}{K_i^2} e^{RT_1} Q(K_i) - \frac{1}{T_1}\left[\frac{F_1}{K_0} - 1\right]^2 = 0.066478 - 0.000006 = \mathbf{0.066472}$$

$$\sigma^2_2 = \frac{2}{T_2}\sum_i \frac{\Delta K_i}{K_i^2} e^{RT_2} Q(K_i) - \frac{1}{T_2}\left[\frac{F_2}{K_0} - 1\right]^2 = 0.063683 - 0.000016 = \mathbf{0.063667}$$

Step 3 *– Interpolate σ^2_1 and σ^2_2 to arrive at a single value with a constant maturity of 30 days to expiration. Then take the square root of that value and multiply by 100 to get VIX.*

$$\sigma = \sqrt{\left\{T_1\sigma_1^2\left[\frac{N_{T_2} - N_{30}}{N_{T_2} - N_{T_1}}\right] + T_2\sigma_2^2\left[\frac{N_{30} - N_{T_1}}{N_{T_2} - N_{T_1}}\right]\right\} \times \frac{N_{365}}{N_{30}}}$$

Where…

N_{T1} = number of minutes to expiration of the near term options (21,600)
N_{T2} = number of minutes to expiration of the next term options (61,920)
N_{30} = number of minutes in 30 days (30 x 1,440 = 43,200)
N_{365} = number of minutes in a 365-day year (365 x 1,440 = 525,600)

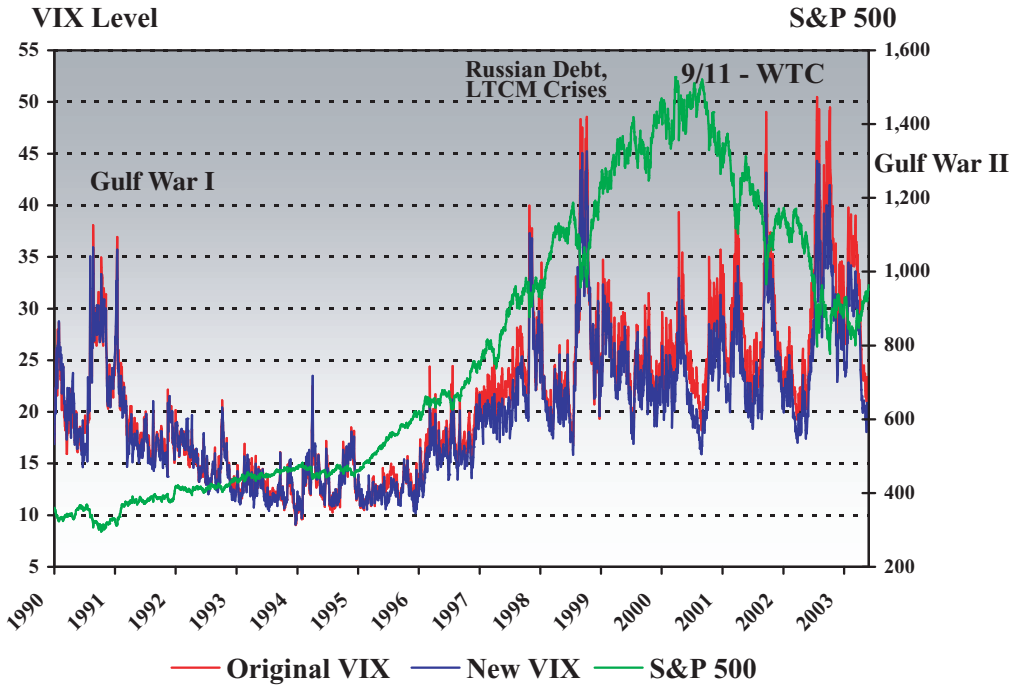
$$\sigma = \sqrt{\left\{\left(\frac{21{,}600}{525{,}600}\right) \times 0.066472 \times \left[\frac{61{,}920 - 43{,}200}{61{,}920 - 21{,}600}\right] + \left(\frac{61{,}920}{525{,}600}\right) \times 0.063667 \times \left[\frac{43{,}200 - 21{,}600}{61{,}920 - 21{,}600}\right]\right\} \times \frac{525{,}600}{43{,}200}}$$

$$\sigma = 0.253610$$

$$\boxed{\text{VIX} = 100 \times \sigma = 25.36}$$

HISTORICAL PERFORMANCE

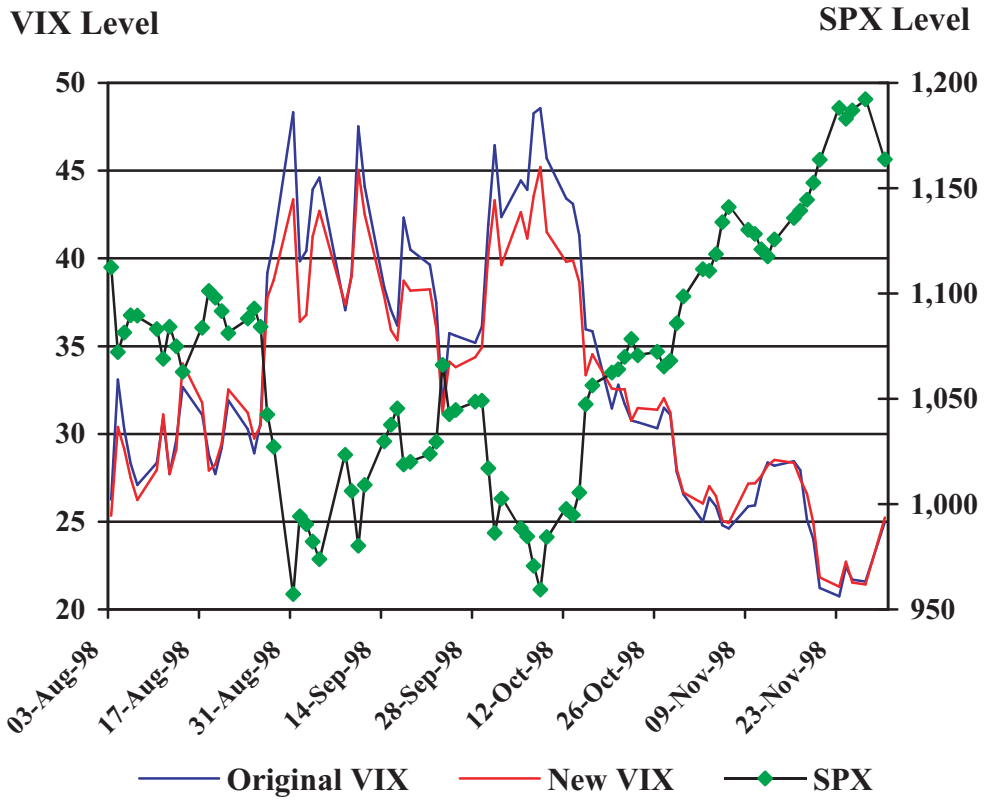
Despite changes in the methodology and calculation, the fundamental nature of VIX has remained unchanged. The new VIX still uses index option prices to measure the market's expectation of volatility. It still uses a weighted average of options with a constant maturity of 30 days to expiration. And, as shown in the chart below, the new VIX behaves much like the original introduced more than 10 years ago.



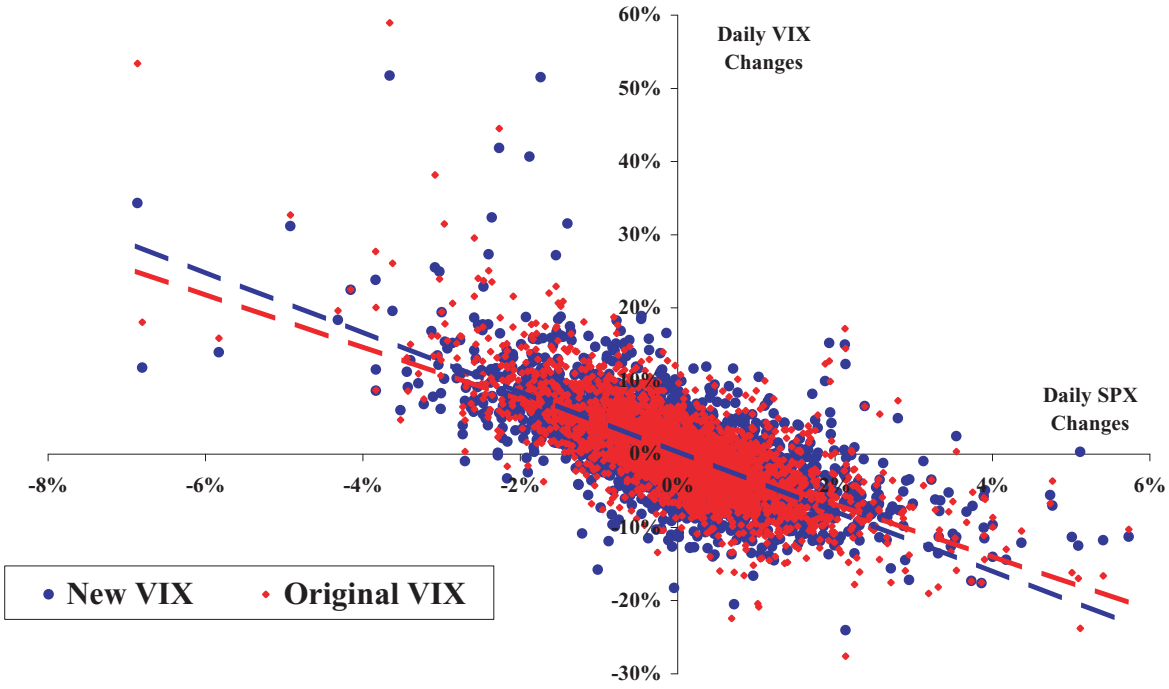
Notice that the new VIX tracks the movement of the original and that there is not much difference between the two values. The following table compares the annual highs and lows between new VIX and the original VIX from January 1990 through May 2003.

Year	Original VIX		New VIX	
	High	Low	High	Low
1990	38.07	15.92	36.47	14.72
1991	36.93	13.93	36.20	13.95
1992	21.12	11.98	20.51	11.51
1993	16.90	9.04	17.30	9.31
1994	22.50	9.59	23.87	9.94
1995	15.72	10.49	15.74	10.36
1996	24.43	12.74	21.99	12.00
1997	39.96	18.55	38.20	17.09
1998	48.56	16.88	45.74	16.23
1999	34.74	18.13	32.98	17.42
2000	39.33	18.23	33.49	16.53
2001	49.04	20.29	43.74	18.76
2002	50.48	19.25	45.08	17.40
2003 through August	39.77	19.23	34.69	17.75

One of the most interesting features of VIX, and the reason it has been called the "investor fear gauge," is that, historically, VIX hits its highest levels during times of financial turmoil and investor fear. As markets recover and investor fear subsides, VIX levels tend to drop. This effect can be seen in the VIX behavior isolated during the Long Term Capital Management and Russian Debt Crises in 1998. As the following chart illustrates, the new VIX mirrored the peaks and troughs of the original VIX as the market suffered through steep declines in August and October 1998, and then rallied through the end of November.



Another interesting aspect of VIX is that, historically, it tends to move opposite its underlying index. This tendency is illustrated in the following graph comparing daily changes in VIX with daily changes in the S&P 500 Index. Note first that the scatter diagram for the original VIX is almost identical to that for the new VIX. Also note that the negatively sloping trend line in both cases confirms the negative correlation between VIX and market movement.



A side-by-side comparison of the new VIX and the original VIX reveals that the new VIX, with its many enhancements, has retained the essential properties that made it the most popular and widely followed market volatility indicator for the past 10 years. It is still the "investor fear gauge", but made better by incorporating the latest advances in financial theory and practice. The new VIX paves the way for both listed and over-the-counter volatility contracts at a time of increased market demand for such products.

FREQUENTLY ASKED QUESTIONS ABOUT THE NEW VIX

1. What exactly is VIX?

In 1993, the Chicago Board Options Exchange® (CBOE®) introduced the CBOE Volatility Index®, VIX®, and it quickly became the benchmark for stock market volatility. It is widely followed and has been cited in hundreds of news articles in the Wall Street Journal, Barron's and other leading financial publications. Since volatility often signifies financial turmoil, VIX is often referred to as the "investor fear gauge".

VIX measures market expectation of near term volatility conveyed by stock index option prices. The original VIX was constructed using the implied volatilities of eight different OEX option series so that, at any given time, it represented the implied volatility of a hypothetical at-the-money OEX option with exactly 30 days to expiration.

The New VIX still measures the market's expectation of 30-day volatility, but in a way that conforms to the latest thinking and research among industry practitioners. The New VIX is based on S&P 500 index option prices and incorporates information from the volatility "skew" by using a wider range of strike prices rather than just at-the-money series.

2. Why is VIX called the "investor fear gauge"?

VIX is based on real-time option prices, which reflect investors' consensus view of future expected stock market volatility. Historically, during periods of financial stress, which are often accompanied by steep market declines, option prices - and VIX - tend to rise. The greater the fear, the higher the VIX level. As investor fear subsides, option prices tend to decline, which in turn causes VIX to decline. It is important to note, however, that past performance does not necessarily indicate future results.

3. How is VIX being changed?

Three important changes are being made to update and improve VIX:

1. *The New VIX is calculated using a wide range of strike prices in order to incorporate information from the volatility skew. The original VIX used only at-the-money options.*

2. *The New VIX uses a newly developed formula to derive expected volatility **directly** from the prices of a weighted strip of options. The original VIX extracted implied volatility from an option-pricing model.*

3. *The New VIX uses options on the S&P 500 Index, which is the primary U.S. stock market benchmark. The original VIX was based on S&P 100 Index (OEX) option prices.*

4. Why is the CBOE making changes to the VIX?

CBOE is changing VIX to provide a more precise and robust measure of expected market volatility and to create a viable underlying index for tradable volatility products.

- *The New VIX calculation reflects the way financial theorists, risk managers and volatility traders think about - and trade - volatility. As such, the New VIX calculation more closely conforms to industry practice than the original VIX methodology. It is simpler, yet it yields a more robust measure of expected volatility. The New VIX is more robust because it pools information from option prices over a wide range of strike prices thereby capturing the whole volatility skew, rather than just the volatility implied by at-the-money options. The New VIX is simpler because it uses a formula that derives the market expectation of volatility* ***directly*** *from index option prices rather than an algorithm that involves backing implied volatilities out of an option-pricing model.*

- *The changes also increase the practical appeal of VIX. As noted previously, the New VIX is calculated using options on the S&P 500 index, the widely recognized benchmark for U.S. equities, and the reference point for the performance of many stock funds, with over $800 billion in indexed assets. In addition, the S&P 500 is the domestic index most often used in over-the-counter volatility trading.*

- *This powerful calculation supplies a script for replicating the New VIX with a* ***static*** *portfolio of S&P 500 options. This critical fact lays the foundation for tradable products based on the New VIX, critical because it facilitates hedging and arbitrage of VIX derivatives. CBOE has announced plans to list VIX futures and options in Q4 2003, pending regulatory approval. These will be the first of an entire family of volatility products.*

5. What remains the same about VIX?

Despite the changes, the fundamental nature of VIX remains the same. The New VIX still uses index option prices to measure the market's expectation of near-term stock market volatility. The New VIX still uses a weighted average of options with a constant maturity of 30 days to expiration. Finally, the New VIX will still be calculated continuously in real-time throughout the trading day.

6. What impact will these changes have on VIX levels and the way the VIX responds to market moves?

As a result of the changes being made to the VIX methodology, the New VIX value will be different than the original VIX, although this difference should be small. The New VIX behaves very much like the original in that it tends to increase during stock market declines and decrease when the market advances. This historic tendency does not imply future results will be similar.

7. What will happen to the original VIX?

CBOE will continue to calculate and maintain the original VIX based on the S&P 100 (OEX) index option prices without interruption. However, the ticker symbol will change. Real-time OEX volatility values will continue to be disseminated under the new ticker symbol – "VXO".

8. Does this mean that all of the historical VIX prices are going to be discarded?

No. Perhaps the most valuable feature of VIX is the existence of historical prices from 1986 to the present. This extensive data set provides investors with a useful perspective of how option prices have behaved in response to a variety of market conditions. CBOE plans to preserve this valuable data, and add to it going forward, with VXO prices. The data will still be available on CBOE's website.

CBOE has created an identical historical record for the New VIX dating back to 1986 so that investors can gain a better understanding of how the new VIX would have behaved in different markets and do their own side-by-side comparisons. In addition, CBOE will soon make available a historical file of intra-day VIX prices.

9. I'm used to a range of VIX trading between 20 and 50. What is the new range?

The following table provides an annual comparison of the range of closing prices for the New VIX and the original VIX.

Year	Original VIX		New VIX	
	High	Low	High	Low
1990	38.07	15.92	36.47	14.72
1991	36.93	13.93	36.20	13.95
1992	21.12	11.98	20.51	11.51
1993	16.90	9.04	17.30	9.31
1994	22.50	9.59	23.87	9.94
1995	15.72	10.49	15.74	10.36
1996	24.43	12.74	21.99	12.00
1997	39.96	18.55	38.20	17.09
1998	48.56	16.88	45.74	16.23
1999	34.74	18.13	32.98	17.42
2000	39.33	18.23	33.49	16.53
2001	49.04	20.29	43.74	18.76
2002	50.48	19.25	45.08	17.40
2003 through August	39.77	19.23	34.69	17.75

10. How can I get historical data and other information on the New VIX?

Historical data, performance charts and other useful information can be found on the CBOE website at - www.cboe.com/vix.

11. Does this affect VXN (CBOE NASDAQ 100 Volatility Index)?

Yes. The same formula and methodology used to calculate the New VIX will be applied to VXN as well. Historical prices for VXN using the new calculation can be found on the CBOE website at - www.cboe.com/vxn. The New VXN calculation will continue to use Nasdaq-100 index option prices.

12. When did the changes to the VIX and VXN calculation take place?

CBOE began calculation and dissemination of the New VIX, and the New VXN, on Monday, September 22. At that same time, CBOE also began to disseminate the original OEX-based VIX under the new ticker symbol VXO.

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