Cboe® NASDAQ-100 Volatility Index℠

This document details the calculation methodology of the titled index/benchmark. This document, in conjunction with the Cboe Index Rules and Governance document (available on Cboe’s Governance website), provides a transparent and easily accessible view of the methodology used to calculate the Cboe® NASDAQ-100 Volatility Index℠ (“VXN’ Index”), ticker symbol ‘VXN’.

Description of the Market or Economic Reality Measure

Cboe Global Markets Inc., in its capacity as a reporting authority, calculates and disseminates the Cboe® NASDAQ-100 Volatility Index℠ commonly known as the "VXN Index" (ticker: VXN). The VXN Index is a financial benchmark designed to be an up-to-the-minute market estimate of the expected volatility of the NASDAQ-100 and is calculated by using the midpoint of real-time NASDAQ-100 Index (NDX) option bid/ask quotes. More specifically, the VXN Index is intended to provide a measure of how much the market expects the NASDAQ-100 Index will fluctuate in the next 30 days from the time of each tick of the VXN Index.

Intraday VXN Index values are based on snapshots of NDX option bid/ask quotes every 15 seconds and are intended to provide an indication of the fair market price of expected volatility at particular points in time. As such, these VXN Index values are often referred to as “indicative” or “spot” values. Cboe currently calculates VXN Index spot values between 8:30 a.m. CT and 3:15 p.m. CT.

The VXN Index does not use contributed input data, and all of the input data is readily available via public sources. The VXN Index is non-significant, as defined by EU Regulation 2016/1011 (“EU Benchmark Regulation” or “EU BMR”).

Index Calculations

The following describes the methodology for calculating the VXN Index, including applicable formulas and input data.

The generalized formula used in the VXN Index calculation¹ is:

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

(1)

where:

- \( \sigma \): Volatility of \( \frac{VXN}{100} \) \( \Rightarrow \) \( VXN = \sigma \times 100 \)
- \( T \): Time to expiration
- \( F \): Forward index level derived from index option prices
- \( K_0 \): First strike below the forward index level, \( F \)
- \( K_i \): Strike price of \( i^{th} \) out-of-the-money option; a call if \( K_i > K_0 \) and a put if \( K_i < K_0 \); both put and call if \( K_i = K_0 \).
- \( \Delta K_i \): Interval between strike prices – half the difference between the strike on either side of \( K_i \):

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

(Note: \( \Delta K \) for the lowest strike is the difference between the lowest strike and the next higher strike. Likewise, \( \Delta K \) for the highest strike is the difference between the highest strike and the next lower strike.)

- \( R \): Risk-free interest rates to expiration
- \( Q(K_i) \): The average of the bid quote and ask quote for each option with strike \( K_i \).

**Time to Expiration for Constituent Options**

The VXN Index measures the 30-day expected volatility of the NASDAQ-100 Index. The components of the VXN Index are generally at- and out-of-the-money 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, VXN "rolls" to the second and third contract months in order to minimize pricing anomalies that might occur close to expiration.

The VXN Index calculation measures time-to-expiration in calendar days and divides each day into minutes in order to replicate the precision that is commonly used by professional option and volatility
traders. N represents time-to-expiration in minutes and T represents time-to-expiration in years. The time-to-expiration is given by the following expressions:

\[
N = M_{\text{Current day}} + M_{\text{Settlement day}} + M_{\text{Other days}}
\]

\[
T = N / \text{Minutes in a year}
\]

where:

- \(M_{\text{Current Day}}\): minutes remaining until midnight of the current day
- \(M_{\text{Settlement day}}\): minutes from midnight until 8:30 a.m. for “standard” AM-settled NDX expirations
- \(M_{\text{Other days}}\): total minutes in the days between current day and expiration day

### Risk-Free Interest Rates

The risk-free interest rates, \(R_1\) and \(R_2\), are yields based on U.S. Treasury yield curve rates (commonly referred to as “Constant Maturity Treasury” rates) to which a cubic spline is applied to derive yields on the expiration dates of relevant NDX options. As such, the VXN Index value calculation may use different risk-free interest rates for near- and next-term options.

### Selecting the options to be used in the VXN Index calculation

The selected options are out-of-the-money NDX calls and out-of-the-money NDX puts centered around an at-the-money strike price, \(K_0\). \(K_0\) is defined as the strike price that equals or is immediately below the forward index level, \(F\), for the near- and next-term options:

\[
F_j = \text{Strike Price}_j + e^{R_j T_j} \times (\text{Call Price}_j - \text{Put Price}_j)
\]

where:

- \(F_j\): Forward NDX level (\(j=1\) for near-term maturity, \(j=2\) for next-term maturity)
- \(\text{Strike Price}_j\): The strike price at which the absolute difference between the Call Price\(_j\) and Put Price\(_j\) is smallest.
- \(R_j\): Risk-Free Interest Rate for \(j^{th}\) maturity
• $T_j$  
  Time to expiration for $j^{th}$ maturity

• Call Price$_j$  
  Average of Call bid quote and Call ask quote for $j^{th}$ maturity

• Put Price$_j$  
  Average of Put bid quote and Put ask quote for $j^{th}$ maturity

The near-term and next-term NDX options used in each VXN Index value calculation are selected using the following steps:

**Out-of-the-money put options with strike prices $< K_0$**

Start with the put strike immediately lower than $K_0$ and move to successively lower strike prices. Exclude any put option that has a bid price equal to zero (i.e., no bid). As shown below, once two puts with consecutive strike prices are found to have zero bid prices, no puts with lower strikes are considered for inclusion. (Note that the 7010 and 7020 put options are not included despite having non-zero bid prices.)

<table>
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<tr>
<th>Put Strike</th>
<th>Bid</th>
<th>Ask</th>
<th>Include?</th>
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<td>0.15</td>
<td>Not considered following two zero bids</td>
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<tr>
<td>7010</td>
<td>0.05</td>
<td>0.15</td>
<td></td>
</tr>
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</tr>
<tr>
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<td>0.35</td>
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<td>Yes</td>
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|          |     |     |         |

**Out-of-the-money call options with strike prices $> K_0$**

Start with the call strike immediately higher than $K_0$ and move to successively higher strike prices, excluding call options that have a bid price of zero. As with the puts, once two consecutive call options are found to have zero bid prices, no calls with higher strikes are considered. (Note that the 8075 call option is not included despite having a non-zero bid price.)
<table>
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<tr>
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<td><strong>0.05</strong></td>
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**At-the-money call and put options with strike price = K₀**

Select both the put and call with strike price K₀. Notice that two options are selected at K₀, while a single option, either a put or a call, is used for every other strike price.

**Determining prices for the selected options**

The price of each put option with a strike price < K₀ and each call option with a strike price > K₀ is the average of that option’s bid quote and ask quote. For the purpose of the VXN Index calculation, the bid/ask quotes of the put and call with strike price equal to K₀ are combined into a single price.

\[
Q(K_{ij}=K₀) = \frac{(\text{Put Bid}_{ij} + \text{Put Ask}_{ij})}{2} \\
Q(K_{ij}>K₀) = \frac{(\text{Call Bid}_{ij} + \text{Call Ask}_{ij})}{2} \\
Q(K_{ij}=K₀_j) = \frac{(\text{Put Bid}_{ij} + \text{Put Ask}_{ij} + \text{Call Bid}_{ij} + \text{Call Ask}_{ij})}{4}
\]
Determining the contribution of both near-term and next-term options

Applying the generalized VXN Index formula, set forth earlier, to the near-term and next-term options with time-to-expiration of \( T_1 \) and \( T_2 \), respectively, yields:

\[
\sigma_1^2 = \frac{2}{T_1} \sum_i \frac{\Delta K_i}{K_i^2} e^{r T_i} Q(K_i) - \frac{1}{T_1} \left[ \frac{F_1}{K_0} - 1 \right]^2
\]

\[
\sigma_2^2 = \frac{2}{T_2} \sum_i \frac{\Delta K_i}{K_i^2} e^{r T_i} Q(K_i) - \frac{1}{T_2} \left[ \frac{F_2}{K_0} - 1 \right]^2
\]

Generally, \( \Delta K \) is half the difference between the strike prices on either side of \( K_i \). For example, the \( \Delta K \) for a NDX put option with a strike price of 8070 that is bracketed by a NDX 8060 put and a NDX 8075 put is 7.5: \( \Delta K_{8070\text{ Put}} = (8075 - 8060)/2 \).

The \( \Delta K \) for the options with the highest and lowest strike prices with the same maturity is the difference between that option’s strike price and the strike price of the adjacent option. For example, if the lowest strike price was 8060 and the adjacent strike price was 8065, then \( \Delta K_{8060\text{ Put}} \) would be 5 (i.e., 8065 – 8060).

Combining \( \sigma_1^2 \) and \( \sigma_2^2 \) into a 30-day weighted average and calculating the VXN Index value:

\[
\text{VXN Index} = 100 \times \sqrt{\left( T_1 \sigma_1^2 \left[ \frac{N_{T_2} - N_{30}}{N_{T_2} - N_{T_1}} \right] + T_2 \sigma_2^2 \left[ \frac{N_{30} - N_{T_1}}{N_{T_2} - N_{T_1}} \right] \right)} \times \frac{N_{365}}{N_{30}}
\]

\( N_{11} = \) number of minutes to expiration of the near-term options
\( N_{12} = \) number of minutes to expiration of the next-term options
\( N_{30} = \) 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)

VXN Index Filtering Algorithm

As described above, “spot” VXN Index values are based on the average of NDX option bid/ask quotes (“mid-quote” prices), and only options that have a non-zero bid price are included. The bid-ask spread is generally accepted as a current indication of market price, and the average of the bid and
ask quotes can be thought of as an indication of “fair” value. Spot VXN Index values are calculated using mid-quote option prices that are assumed to reflect these option fair values.

From time to time, option price quotations widen due to changing market conditions, technology failures or other reasons. When this occurs, options that were previously included in a VXN Index value calculation might be excluded due to them now having a zero-bid price. In other instances, the mid-quote prices of one or more NDX options might materially change. This can result in a VXN Index value that, while accurately reflecting NDX option quotes at the time, does not reflect the expected volatility of the NASDAQ Index.

The VXN Index Filtering Algorithm operates as follows

1. The first VXN Index spot value calculated during the Cboe trading session is deemed to be the “baseline” VXN Index spot value.

2. Any VXN Index spot value calculated after and within two (2) minutes of the baseline that is higher than the baseline value or lower than the baseline value by .49 volatility points or less becomes the new baseline value.²

3. If VXN Index spot values calculated after and within two (2) minutes of a baseline are lower than the baseline by 0.50 volatility points or more, then the baseline VXN Index spot value will be republished as the VXN Index spot value.

4. If the published VXN Index spot values remain the same for a period of two (2) minutes because the calculated values are 0.50 or more volatility points lower than the baseline, the first VXN Index spot value calculated after the two-minute period becomes the new baseline VXN Index spot value.

The filtering algorithm does not apply to the first VXN Index spot value calculated during the Cboe trading session (approximately 8:30 a.m. CT). All other VXN Index spot values calculated during Cboe trading hours are subject to the filtering process.

**Historical VXN Index Prices**


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² Threshold parameters used in the VXN Index Filtering algorithm are subject to change at any time in response to changing levels of volatility or other market conditions. Cboe will provide notice to market participants for all such parameter changes.
Calculation and Dissemination

Cboe compiles, calculates, maintains, and disseminates all VXN Index values. The VXN Index is calculated and disseminated every 15 seconds between 8:30 a.m. CT and 3:15 p.m. CT.

Judgement and Potential Limitations in Calculation

No expert judgement or discretion is used by Cboe in performing the calculation of the VXN Index. Potential limitations for this index (i.e., situations where the index may not reflect the above described market or economic reality) include:

- where underlying index input data is unavailable, the VXN Index value will not be able to be calculated, and
- where the underlying option contract data is not available, the VXN Index value will not be able to be calculated.

Document Information <DO NOT EDIT>

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