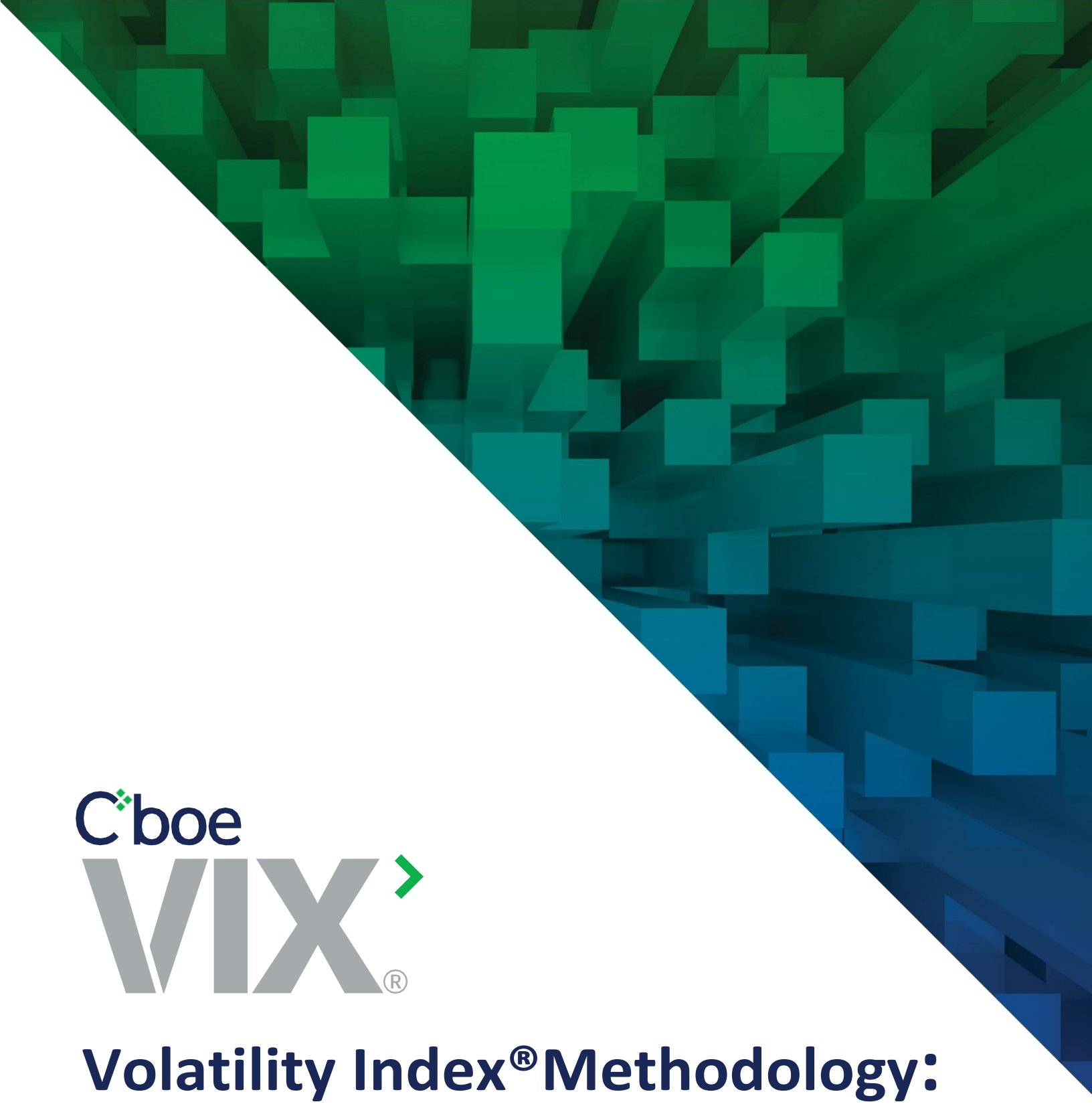

Volatility Index®Methodology: Cboe 1-Day Volatility Index®

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Contents

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Introduction

In 1993, Cboe Global Markets, Incorporated® (Cboe®) introduced the Cboe Volatility Index® (VIX® Index). Originally designed to measure the market's expectation of 30-day volatility implied by at-the-money S&P 100® Index (OEX® Index) option prices, the VIX Index soon became the premier benchmark for U.S. stock market volatility. It is regularly featured in the Wall Street Journal, Barron's, and other leading financial publications, as well as business news shows on CNBC, Bloomberg TV, and CNN/Money, where the VIX Index is often referred to as the "fear gauge."

Ten years later in 2003, Cboe collaborated with Goldman Sachs to update the VIX Index. The changes reflected a new way to measure expected volatility, a methodology that continues to be widely used by financial theorists, risk managers, and volatility traders alike. The new VIX Index is based on the S&P 500® Index, the core index for U.S. equities, and estimates expected volatility by aggregating the weighted prices of S&P 500 Index puts and calls (SPX™ options) over a wide range of strike prices. By supplying a script for replicating volatility exposure with a portfolio of SPX options, this new methodology transformed the VIX Index from an abstract concept into a practical standard for trading and hedging volatility.

Similar to the VIX Index, the Cboe 1-Day Volatility Index® (VIX1D Index) estimates expected volatility by aggregating the weighted prices of P.M.-settled S&P 500 Index (SPX℠) puts and calls over a wide range of strike prices. The prices used to calculate VIX1D Index values are midpoints of real-time, P.M.-settled SPX (SPXW) option bid/ask price quotations. Because the period of expected volatility being measured is a single day, the P.M.-settled SPX option series that are used during the majority of the day that the VIX1D Index is calculated and disseminated include those where the expiry date is equal to the current day of the calculation (near-term expiration) and those with an expiry date closest to and after the near-term expiration (next term expiration). For example, during a business week with no holiday closures, the VIX1D Index calculated on a Tuesday, would use that Tuesday's expiration as the near-term option and that Wednesday's expiration (next term) expiration occurring during that week as the next-term option.

The VIX1D Index has been designed to account for the compressed measurement of expected volatility over a single day and differs from the VIX Index in ways to account for this. These differences include:

<u>Time Decay of Near-Term (Current Day Expiry) Options Used to Calculate the VIX1D Index</u>
Through a given day, the time to expiration of the near-term (current day expiry) declines to zero when these option contracts expire, typically at 4:00 p.m. ET, which impacts the calculation of near-term volatility due to the 1/T factor in the generalized formula used in the VIX1D Index calculation. As a result, when the time to expiration for the near-term (current day expiry) is less than 60 business minutes (at approximately 3:00 p.m. ET), the single-term volatility of the near term will be the last valid value and persisted until the near-term expiration time. During this period, the VIX1D Index will be the interpolation between the persisted near-term volatility and the next-term volatility, where the weights are heavily concentrated on the next-term. At the near-term expiration time, the VIX1D Index will fully converge to the volatility of the next term.

<u>Calculation of the VIX1D Index After Near-Term Expired</u>
After the near-term contracts expired, at approximately 4:00 p.m. ET, the near-term leg (current day expiry) will no longer exist and the VIX1D Index will be calculated from 4:00 p.m. ET to 4:15 p.m. ET using only a single expiration – the next-term expiry. The formerly persisted near-term volatility will not be used in the calculation after 4:00 p.m ET.

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Use of Business Year and Minutes vs. Calendar Year and Minutes

The calculation of the VIX1D Index uses business years and business minutes during the Regular Trading Hours (RTH) session. As a result, the time component for the VIX1D Index is measured in a different increment than the VIX Index, which uses calendar years and calendar minutes.

The Volatility of the VIX1D Index

By its nature, the VIX1D Index is expected to generally behave in a more volatile manner than indexes that measure a longer period of expected volatility. One reason for this is that the news events that affect the S&P 500 Index on a given day are expected to have a larger impact on the short-dated SPX options than on longer dated options when market participants have more time to react to the news event.

Supporting Documents

This Methodology references and should be read in conjunction with the following document:

Cboe Volatility Index Mathematics Methodology

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The VIX1D Index Attributes

In this section, some of the configurations used for the Cboe 1-Day Volatility Index® (VIX1D Index) are provided.

Contracts Used for the Near and Next Terms and Their Selection Method

The table below provides the attributes used for the near and next term selection for the VIX1D Index.

Index	Constant Maturity	Set of Contracts Used for Constituent Series Selection	Selection Method
VIX1D	1 day	PM-settled SPXW option contracts	**Nearest Term Method**

Table Key

- Constant Maturity: reflects the target expected volatility term
- Set of Contracts Used for Constituent Series Selection: provides the initial set of series that are candidates for the near and next term selection

Market Data

The table below provides the source of the market data for all options series used in the VIX1D Index calculation. The market data used can be sourced from a specific exchange, from a subset of exchanges or from among all available exchanges or trading venues reflecting the (National) Best Bid/Offer ((N)BBO) quotes.

Index	Market data source
VIX1D	Cboe Options Exchange (C1) data via OPRA

Calculation and Dissemination

The calculation and dissemination of volatility index values is determined by trading session, e.g., regular trading hours (RTH), global trading hours (GTH) or both. The trading session(s) and approximate dissemination and calculation time periods are listed below. These times may be modified due to shortened trading sessions, e.g., shortened holiday trading hours. Calculation and dissemination occur approximately four times per minute. A Business Day is defined as a day when the Cboe Options Exchange is open for the Cboe Regular Trading Hours (RTH) session. The Index follows the Cboe Options Exchange holiday schedule.

Index	Trading Session(s)	Approximate Calculation and Dissemination Time Period
VIX1D	RTH	Between 9:31 a.m. and 4:15 p.m. ET

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The VIX1D Index Calculation: Step-by-Step

Stock indexes, such as the S&P 500 Index, are calculated using the prices of their component stocks. Each index employs rulesthat govern the selection of component securities and a formula to calculate index values.

The VIX1D Index is a volatility index comprised of options rather than stocks, with the price of each option reflecting the market's expectation of future volatility. Like conventional indexes, the VIX1D Index calculation employs rules for selecting component options and a formula to calculate index values.

The generalized formula used in the VIX1D Index calculation[§] is:

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

where

σ $VIX1D\ index = \sigma \times 100$

T Time to expiration (in business years)

F Option-implied forward price

K_0 First strike equal to or otherwise immediately below the forward index level, F

K_i Strike price of the 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 $K_i = K_0$.

ΔK_i Interval between strike prices – half the difference between the strike on either side of K_i:

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

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.

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The VIX1D Index measures 1-day expected volatility of the S&P 500 Index. The calculation takes as input the market prices of SPXW options and U.S. Treasury yield curve rates. The VIX1D Index value can be obtained by following the four steps below:

Step 1. Select the Near- and Next-Term

The universe of options that can be selected as components of the VIX1D Index are all PM-settled SPXW option contracts. The "near-term" options are defined to be the options where expiry date is equal to current day of calculation. The "next-term" options are defined to be the options within the remaining set expiring closest to and after the "near-term" options expiration date. Details can be found in section 1(b) Nearest Term Method of the Cboe Volatility Index Mathematics Methodology document. Contracts originally set to expire on unplanned closures will not be selected as near- or next-term contracts.

Step 2. Calculate the Interest Rates

The risk-free interest rates, R1 and R2, are based on U.S. Treasury yield curve rates (commonly referred to as "Constant Maturity Treasury" rates, or CMTs), to which a cubic spline is applied to derive yields on the expiration dates of relevant SPXW options. As such, the VIX1D Index calculation may use different risk-free interest rates for near- and next-term options. The rules for calculating the interest rates for the near- and next-terms can be found in section 2(a) Interest Rate Calculation – Bounded Cubic Spline Interpolation of the Cboe Volatility Index Mathematics Methodology.

Step 3. Calculate the Near- and Next-Term Variances

The inputs for calculating the variances for both terms σ_1^2 and σ_2^2 are based on the options series defined in Step 1 above. These include the corresponding bid, ask, and options price for each options series, where options price is defined as the midpoint of the bid / ask quotes, and the corresponding interest rates defined in Step 2 above. Given these inputs, the variances for the near- and next-terms can be calculated by following the steps outlined in section 3(a) Volatility Index Calculation – Single Term of the Cboe Volatility Index Mathematics Methodology.

Unlike other volatility indexes, the VIX1D Index calculation measures time to expiration of a constituent option series, *T*, in business years and business minutes (vs. calendar years and calendar minutes). This step is described in Step 3(a)(i) Time to Expiration of the Cboe Volatility Index Mathematics Methodology and is applied as set forth below in business years / business minutes. The time to expiration, T, is given by the following:

$$T = \left(M_{Time\ to\ Expiry}\right)/M_{year}$$

where

$M_{Time\ to\ Expiry}$	Number of business minutes during RTH session from time of calculation until expiration
M_{year}	Number of business minutes during RTH session in a year (252 x 6.75 x 60 = 102,060)

The value of σ_1^2 is calculated based on the method described above when $M_{Time\ to\ Expiry} \geq 60$. If $M_{Time\ to\ Expiry} < 60$, σ_1^2 will be the last valid σ_1^2 calculated when $M_{Time\ to\ Expiry} \geq 60$.

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Step 4. Calculate the VIX1D Index

- The inputs for calculating the VIX1D Index are based on the near- and next-term expiration dates defined in Step 1 above and the variances for each term calculated in Step 3 above. Given these inputs, the VIX1D Index is calculated as follows:

$$\textbf{VIX1D} = 100 \times \sqrt{\left\{T_1\sigma_1^2\left[\frac{M_{T_2}-M_{\text{CM}}}{M_{T_2}-M_{T_1}}\right] + T_2\sigma_2^2\left[\frac{M_{\text{CM}}-M_{T_1}}{M_{T_2}-M_{T_1}}\right]\right\} \times \frac{M_{year}}{M_{\text{CM}}}}$$

where

M_{T_1}	The number of business minutes until expiration of the near-term options
M_{T_2}	The number of business minutes until expiration of the next-term options
M_{CM}	The number of business minutes during RTH session (6.75 x 60 = 405)
M_{year}	The number of business minutes in one year (252 x 6.75 x 60 = 102,060)
T_i	$M_{T_i} \,/\, M_{year}$
σ_i^2	Variance of the ith term calculated on Step 3

In order to avoid extrapolations in this calculation, when $M_{T_2} < M_{\text{CM}}$, VIX1D should be calculated based on the next term only: $\textbf{VIX1D} = 100 \times \sqrt{\sigma_2^2}$.

Sample Calculation for the VIX1D Index

In this section, we implement a sample calculation for the VIX1D Index using the process outlined above.

- **Select the Near- and Next-Term Constituent Series**
  In this hypothetical example, assume that the calculation is performed on trade date of September 27, 2022 at 11:00:00 a.m. ET. Given the inputs described in the Step 1 above, and the methodology in section 1(b) of the Cboe Volatility Index Mathematics Methodology, the selected terms for this calculation are the SPXW options expiring on Tuesday, September 27, 2022 for the near term and the SPXW options expiring on the following day (Wednesday, September 28, 2022) for the next term.

- **Calculate the Interest Rates**
  Assume that the yield curve rates provided below are available on Monday, September 26, 2022 at the end of the day.

Date	1 Mo	2 Mo	3 Mo	6 Mo	1 Yr	2 Yr	3 Yr	5 Yr	7 Yr	10 Yr	20 Yr	30 Yr
9/26/2022	0.03	0.02	0.04	0.05	0.08	0.11	0.22	0.59	1	1.37	2.03	2.21

  Given these yield curve rates, and the rules outlined in the section 2(a) of the Cboe Volatility Index Mathematics Methodology, the results are R_1 = 0.0393% for the near-term options and R_2 = 0.0390% for the next-term options.

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- **Calculate the Single Term Variances**

Time to Expiration

Following the steps described on Step 3 of the section "The VIX1D Index Calculation: Step-by-Step" for calculating time to expiration in business minutes and applying 11:00:00 a.m. ET as the time of the calculation, the time to expiration for the near-term and next-term options, T_1 and T_2, respectively, are:

$$T_1 = 300 \,/\, 102{,}060 = \; 0.00293945$$

$$T_2 = 705 \,/\, 102{,}060 = \; 0.00690770$$

Forward Price and K_0

Using the call and put prices for the near-term and next-term options below and following the steps in Forward Price and K_0 in section 3(a)(ii) Volatility Index Calculation – Single Term of the Cboe Volatility Index Mathematics Methodology, we can calculate the forward price and K_0.

Near Term Options			
Strike Price	**Call**	**Put**	**Difference**
3980	25.7	2.73	22.975
3985	21.65	3.60	18.05
3990	17.75	4.70	13.05
3995	14.2	6.15	8.05
4000	11	8.00	3
4005	**8.3**	**10.3**	**-2**
4010	6.1	13.00	-6.9
4015	4.25	16.30	-12.05
4020	2.8	19.80	-17

Next Term Options			
Strike Price	**Call**	**Put**	**Difference**
3980	33.2	9.1	24.1
3985	29.7	10.6	19.05
3990	26.3	12.3	14.05
3995	23.2	14.1	9.1
4000	20.2	16.0	4.15
4005	**17.3**	**18.25**	**-0.95**
4010	14.8	20.7	-5.9
4015	12.4	23.3	-10.9
4020	10.2	26.2	-15.95

The ATM strike for the near-term options is **4005** and the ATM strike for the next-term options is **4005**. Applying their respective call and put prices to the formula

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

gives that the forward index prices, F_1 and F_2, for the near- and next-term options, respectively, are:

$$F_1 = 4005 + e^{(0.000393 \times 0.00293945)} \times (8.3 - 10.3) = 4002.999998$$

$$F_2 = 4005 + e^{(0.000390 \times 0.00690770)} \times (17.3 - 18.25) = 4004.049997$$

We have then that K_0, the strike price equal to or immediately below the forward index level F, is **4000** for the near-term options and **4000** for the next-term options.

Strike Selection

To determine the strikes to be included in this calculation, refer to the steps in Strike Selection of section 3(a)(iii) Volatility Index Calculation – Single Term in the Cboe Volatility Index Mathematics Methodology.

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First, for each term, select out-of-the-money put options with strike prices less than 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, exclude the observed put(s) and consider no puts with lower strikes for inclusion.

Put Strike	Bid	Ask	Include?
3845	0.00	0.05	Not considered following two zero bids
3850	0.00	0.05	
3855	0.00	0.05	
3860	0.00	0.05	No
3865	0.00	0.05	No
3870	0.05	0.10	Yes
3875	0.05	0.10	Yes
3880	0.00	0.10	No
3885	0.05	0.10	Yes

Next, select out-of-the-money call options with strike prices greater than 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 (i.e., no bid). As with the puts, once two call options with consecutive strike prices are found to have zero bid prices, exclude the observed call(s) and consider no calls with higher strikes for inclusion.

Call Strike	Bid	Ask	Include?
4060	0.05	0.10	Yes
4065	0.05	0.10	Yes
4070	0.00	0.10	No
4075	0.05	0.10	Yes
4080	0.00	0.05	No
4085	0.00	0.05	No
4090	0.00	0.05	Not considered following two zero bids
4095	0.00	0.05	
4100	0.00	0.05	

Finally, select **both** the put and call with strike price K_0. 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.

The following tables contain the options used to calculate the VIX1D Index in this example. This calculation uses the midpoint of quoted bid and ask prices for each option selected. The K_0 put and call prices are averaged to produce a single value. The price used for the 4000 strike in the near-term is, therefore, (11.00 + 8.00) / 2 = 9.5. The price used for the 4000 strike in the next term is (20.15 + 16.0) / 2 = 18.075.

Near-Term Strike	Option Type	Midpoint Price
3870	Put	0.075
3875	Put	0.075
3885	Put	0.075
.	.	.
3990	Put	4.7
3995	Put	6.15
4000	Put/Call Average	9.5
4005	Call	8.3

Next-Term Strike	Option Type	Midpoint Price
3650	Put	0.075
3660	Put	0.075
3670	Put	0.075
.	.	.
3990	Put	12.25
3995	Put	14.05
4000	Put/Call Average	18.075
4005	Call	17.3

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4010	Call	6.1
.	.	.
4060	Call	0.075
4065	Call	0.075
4075	Call	0.075

4010	Call	14.75
.	.	.
4120	Call	0.1
4125	Call	0.075
4130	Call	0.075

Calculating Volatility

The VIX1D Index is an amalgam of the information reflected in the prices of all of the selected options. The contribution of a single option to the VIX1D Index value is proportional to ΔK and the price of that option, and inversely proportional to the square of the option's strike price.

Referring to Calculating Volatility of section 3(a)(iv) Volatility Index Calculation – Single Term of the Cboe Volatility Index Mathematics Methodology, we generally have that ΔK_i is half the difference between the strike prices on either side of K_i. For example, the ΔK for the near-term 3875 Put is 7.5: $\Delta K_{3875\ \text{Put}}$ = (3885 – 3870) / 2. 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 example, the 3870 Put is the lowest strike in the strip of near-term options and 3875 is the adjacent strike. Therefore, $\Delta K_{3870\ \text{Put}}$ = 5 (i.e., 1375 – 1370).

The contribution of the near-term 1370 Put is given by: $\frac{\Delta K_{3870\ Put}}{K^2_{3870\ Put}}\ e^{R_1T_1}Q(3870\ Put)$

$$\frac{\Delta K_{3870\ Put}}{K^2_{3870\ Put}}\ e^{R_1T_1}Q(3870\ Put) = \frac{5}{(3870)^2}\ e^{(0.000393\ x\ 0.00293945)}\ (0.075) = \ 0.000000025$$

A similar calculation is performed for each option. The resulting values for the near-term options are then summed and multiplied by 2/T1. Likewise, the resulting values for the next-term options are summed and multiplied by 2/T2. The tables below summarize the results for each set of options.

Near-Term Strike	Option Type	Midpoint Price	Contribution by Strike
3870	Put	0.075	0.000000025
3875	Put	0.075	0.000000037
3885	Put	0.075	0.000000037
.	.	.	.
3990	Put	4.7	0.000001476
3995	Put	6.15	0.000001927
4000	**Put/Call Average**	**9.500**	**0.000002969**
4005	Call	8.3	0.000002587
4010	Call	6.1	0.000001897
.	.	.	.
4060	Call	0.075	0.000000023
4065	Call	0.075	0.000000034
4075	Call	0.075	0.000000045
$\frac{2}{T_1}\sum_i \frac{\Delta K_i}{K_i^2}\ e^{R_1T_1}Q(K_i)$			**0.013281**

Next-Term Strike	Option Type	Midpoint Price	Contribution by Strike
3650	Put	0.075	0.000000056
3660	Put	0.075	0.000000056
3670	Put	0.075	0.000000042
.	.	.	.
3990	Put	12.25	0.000003847
3995	Put	14.05	0.000004402
4000	**Put/Call Average**	**18.075**	**0.000005648**
4005	Call	17.3	0.000005393
4010	Call	14.75	0.000004586
.	.	.	.
4120	Call	0.1	0.000000044
4125	Call	0.075	0.000000022
4130	Call	0.075	0.000000022
$\frac{2}{T_2}\sum_i \frac{\Delta K_i}{K_i^2}\ e^{R_2T_2}Q(K_i)$			**0.019303**

Next calculate $^1/_T\left[^F/_{K_0} - 1\right]^2$ for the near-term (T1) and next-term (T2):

$$\frac{1}{T_1}\left[\frac{F_1}{K_{0,1}} - 1\right]^2 = \frac{1}{0.00293945}\left[\frac{4002.999998}{4000} - 1\right]^2 = 0.00019136$$

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$$\frac{1}{T_2}\left[\frac{F_2}{K_{0,2}}-1\right]^2=\frac{1}{0.0069077}\left[\frac{4004.049997}{4000}-1\right]^2=0.00014841$$

Now calculate σ^2_1 and σ^2_2:

$$\sigma_1^2=\frac{2}{T_1}\sum_i\frac{\Delta K_i}{K_i^2}\,e^{R_1T_1}Q(K_i)-\frac{1}{T_1}\left[\frac{F_1}{K_{0,1}}-1\right]^2=0.01328108-0.00019136=0.01308972$$

$$\sigma_2^2=\frac{2}{T_2}\sum_i\frac{\Delta K_i}{K_i^2}\,e^{R_2T_2}Q(K_i)-\frac{1}{T_2}\left[\frac{F_2}{K_{0,2}}-1\right]^2=0.01930298-0.00014841=0.01915457$$

- **Calculate the VIX1D Index**

  The VIX1D Index value is now calculated by following Step 4 of the section "The VIX1D Index Calculation: Step-by-Step". First, calculate the 1-day weighted average of σ_1^2 and σ_2^2. Then take the square root of that value and multiply by 100:

$$\boldsymbol{VIX1D=100\times\sqrt{\left\{0.00293945\times0.01308972\times\left[\frac{705-405}{705-300}\right]+0.0069077\times0.01915457\times\left[\frac{405-300}{705-300}\right]\right\}\times\frac{102{,}060}{405}}}$$

VIX1D = 100 × 0.1258046 = 12.58

Volatility Index Filtering Algorithm

From time to time, options price quotations widen due to changing market conditions, technology failures, or other reasons. When this occurs, options that were previously included in a VIX1D Index value calculation might be excluded due to them now having a zero bid price. This can result in a VIX1D Index value that, while accurately reflecting SPXW options quotes at the time, may not reflect the one day expected volatility of the S&P 500 Index. Cboe uses a filtering algorithm to address these circumstances.

For the rules that guide this filtering process, refer to the details given in section "Index Level Filtering Algorithm" of the Cboe Volatility Index Mathematics Methodology. At a minimum annually, we review the thresholds used in the Index Level Filtering Algorithm to consider their reflection of market conditions, and may, in our discretion, change these thresholds as a result, by notice to clients from time to time. The inputs itemized below apply to the VIX1D Index:

Index	Session	Threshold Level (x)	Threshold Period
VIX1D	RTH	1.00 volatility points	1 minute

Exception When VIX1D Index Cannot be Calculated

In the event the VIX1D Index cannot be calculated, the last calculated and disseminated spot VIX1D Index value is republished until a new valid spot VIX1D Index can be calculated. The conditions that would prevent the VIX1D Index from being calculated can be found in sections 3(a) (ii) and (iii) Volatility Index Calculation – Single Term of the Cboe Volatility Index Mathematics Methodology. A summary can also be found in the section 4(b) Volatility Index Cannot be Calculated of the Cboe Volatility Index Mathematics Methodology.

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Appendix 1: Complete SPXW Option Data Used in Sample VIX1D Index Calculation

Option series included in the VIX1D Index calculation are

Near-Term Options				
Strike	Calls		Puts	
	Bid	Ask	Bid	Ask
3625	377.4	378.5	0	0.05
3630	372.4	373.5	0	0.05
3640	362.4	363.5	0	0.05
3650	352.4	353.5	0	0.05
3660	342.4	343.5	0	0.05
3670	332.4	333.5	0	0.05
3675	327.4	328.5	0	0.05
3680	322.4	323.5	0	0.05
3690	312.4	313.5	0	0.05
3695	307.4	308.5	0	0.05
3700	302.4	303.5	0	0.05
3705	297.4	298.5	0	0.05
3710	292.4	293.5	0	0.05
3715	287.4	288.5	0	0.05
3720	282.4	283.5	0	0.05
3725	277.4	278.5	0	0.05
3730	272.4	273.5	0	0.05
3735	267.4	268.5	0	0.05
3740	262.4	263.5	0	0.05
3745	257.4	258.5	0	0.05
3750	252.4	253.5	0	0.05
3755	247.4	248.5	0	0.05
3760	242.4	243.5	0	0.05
3765	237.4	238.5	0	0.05
3770	232.4	233.5	0	0.05
3775	227.4	228.5	0	0.05
3780	222.4	223.5	0	0.05
3785	217.4	218.5	0	0.05
3790	212.4	213.5	0	0.05
3795	207.4	208.5	0	0.05
3800	202.4	203.5	0	0.05
3805	197.4	198.5	0	0.05
3810	192.4	193.5	0	0.05
3815	187.4	188.5	0	0.05
3820	182.4	183.5	0	0.05
3825	177.4	178.5	0	0.05
3830	172.4	173.5	0	0.05
3835	167.4	168.5	0	0.05

Next-Term Options				
Strike	Calls		Puts	
	Bid	Ask	Bid	Ask
3550	453.4	454.5	0	0.05
3575	428.4	429.5	0.05	0.1
3600	403.4	404.5	0.05	0.1
3620	383.4	384.6	0.05	0.1
3625	378.4	379.6	0.05	0.1
3630	373.4	374.6	0	0.1
3640	363.4	364.6	0	0.1
3650	353.4	354.6	0.05	0.1
3660	343.4	344.6	0.05	0.1
3670	333.4	334.6	0.05	0.1
3675	328.4	329.6	0.05	0.1
3680	323.4	324.6	0.05	0.1
3690	313.4	314.6	0.05	0.1
3695	308.4	309.6	0.05	0.1
3700	303.4	304.6	0.05	0.1
3705	298.4	299.6	0.05	0.1
3710	293.5	294.6	0.05	0.1
3715	288.5	289.6	0.05	0.1
3720	283.5	284.6	0.05	0.1
3725	278.5	279.6	0.05	0.1
3730	273.5	274.6	0.05	0.15
3735	268.5	269.6	0.05	0.15
3740	263.5	264.6	0.1	0.15
3745	258.5	259.6	0.05	0.15
3750	253.5	254.6	0.05	0.15
3755	248.5	249.6	0.05	0.15
3760	243.5	244.6	0.05	0.15
3765	238.5	239.6	0.1	0.15
3770	233.5	234.6	0.1	0.15
3775	228.5	229.6	0.1	0.15
3780	223.5	224.7	0.1	0.15
3785	218.5	219.7	0.1	0.15
3790	213.5	214.7	0.1	0.15
3795	208.5	209.7	0.1	0.15
3800	203.5	204.7	0.1	0.2
3805	198.5	199.7	0.1	0.15
3810	193.5	194.7	0.1	0.2
3815	188.5	189.7	0.15	0.2

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Near-Term Options (cont.)				
Strike	Calls		Puts	
	Bid	Ask	Bid	Ask
3840	162.4	163.5	0	0.05
3845	157.4	158.5	0	0.05
3850	152.4	153.5	0	0.05
3855	147.4	148.6	0	0.05
3860	142.4	143.6	0	0.05
3865	137.4	138.6	0	0.05
3870	132.4	133.6	0.05	0.1
3875	127.4	128.6	0.05	0.1
3880	122.4	123.6	0	0.1
3885	117.4	118.6	0.05	0.1
3890	112.4	113.6	0.05	0.1
3895	107.5	108.5	0.05	0.1
3900	102.5	103.5	0.05	0.1
3905	97.5	98.4	0.05	0.1
3910	92.5	93.5	0.1	0.15
3915	87.5	88.5	0.1	0.15
3920	82.5	83.6	0.1	0.2
3925	77.6	78.6	0.15	0.2
3930	72.6	73.6	0.2	0.25
3935	67.7	68.6	0.25	0.3
3940	62.8	63.8	0.3	0.4
3945	57.8	58.9	0.4	0.5
3950	53.1	53.9	0.5	0.6
3955	48.1	49	0.7	0.75
3960	43.5	44.3	0.9	0.95
3965	38.7	39.6	1.15	1.25
3970	34.2	34.9	1.55	1.65
3975	29.7	30.3	2.05	2.1
3980	25.3	26.1	2.7	2.75
3985	21.4	21.9	3.5	3.7
3990	17.5	18	4.6	4.8
3995	14.1	14.3	6.1	6.2
4000	10.9	11.1	7.9	8.1
4005	8.2	8.4	10.2	10.4
4010	6	6.2	12.9	13.1
4015	4.2	4.3	16.1	16.5
4020	2.75	2.85	19.5	20.1
4025	1.7	1.8	23.4	24.1
4030	1	1.1	27.7	28.4
4035	0.6	0.65	32.3	33.2
4040	0.35	0.4	36.9	37.8
4045	0.2	0.25	41.9	42.8

Next-Term Options (cont.)				
Strike	Calls		Puts	
	Bid	Ask	Bid	Ask
3820	183.6	184.7	0.15	0.2
3825	178.6	179.7	0.15	0.2
3830	173.6	174.7	0.15	0.25
3835	168.6	169.7	0.15	0.25
3840	163.6	164.7	0.2	0.25
3845	158.6	159.8	0.2	0.25
3850	153.6	154.8	0.2	0.3
3855	148.7	149.8	0.25	0.3
3860	143.7	144.8	0.25	0.35
3865	138.7	139.8	0.3	0.35
3870	133.7	134.9	0.3	0.4
3875	128.8	129.9	0.35	0.4
3880	123.8	125	0.4	0.45
3885	118.9	120	0.45	0.5
3890	113.9	115.1	0.5	0.55
3895	109.1	110.1	0.55	0.65
3900	104.1	105.2	0.65	0.7
3905	99.3	100.2	0.75	0.8
3910	94.3	95.4	0.85	0.95
3915	89.5	90.5	1	1.1
3920	84.7	85.6	1.2	1.25
3925	79.9	80.8	1.4	1.45
3930	75.2	76.1	1.65	1.75
3935	70.5	71.5	1.95	2.05
3940	65.9	66.7	2.3	2.4
3945	61.3	62.2	2.8	2.85
3950	56.9	57.8	3.3	3.5
3955	52.6	53.4	3.9	4.1
3960	48.3	49.2	4.7	4.9
3965	44.2	45	5.6	5.7
3970	40.3	41	6.6	6.8
3975	36.4	37.2	7.7	7.9
3980	32.8	33.6	9	9.2
3985	29.4	29.9	10.5	10.7
3990	26.2	26.4	12.2	12.3
3995	23	23.3	14	14.1
4000	20	20.3	15.9	16.1
4005	17.2	17.4	18.1	18.4
4010	14.6	14.9	20.5	20.8
4015	12.3	12.5	23.2	23.4
4020	10.1	10.3	26	26.3
4025	8.2	8.4	29.1	29.4

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4050	0.15	0.2	46.8	47.7

Near-Term Options (cont.)				
Strike	Calls		Puts	
	Bid	Ask	Bid	Ask
4055	0.1	0.15	51.8	52.6
4060	0.05	0.1	56.6	57.7
4065	0.05	0.1	61.6	62.7
4070	0	0.1	66.6	67.7
4075	0.05	0.1	71.7	72.5
4080	0	0.05	76.7	77.5
4085	0	0.05	81.7	82.6
4090	0	0.05	86.7	87.6
4095	0	0.05	91.7	92.6
4100	0	0.05	96.7	97.6
4105	0	0.05	101.7	102.6
4110	0	0.05	106.7	107.6
4115	0	0.05	111.7	112.5
4120	0	0.05	116.5	117.6
4125	0	0.05	121.5	122.6
4130	0	0.05	126.5	127.6
4140	0	0.05	136.5	137.6
4150	0	0.05	146.5	147.6
4160	0	0.05	156.5	157.6
4175	0	0.05	171.5	172.6

4030	6.6	6.8	32.3	33.1

Next-Term Options (cont.)				
Strike	Calls		Puts	
	Bid	Ask	Bid	Ask
4035	5.2	5.4	35.8	36.7
4040	4	4.2	39.6	40.6
4045	3	3.2	43.7	44.6
4050	2.3	2.4	47.9	48.8
4055	1.75	1.85	52.4	53.3
4060	1.35	1.4	56.9	57.9
4065	0.95	1.05	61.6	62.5
4070	0.75	0.8	66.3	67.3
4075	0.55	0.65	71.1	72.1
4080	0.45	0.5	76	77
4085	0.35	0.4	80.9	81.9
4090	0.25	0.35	85.8	86.8
4100	0.15	0.25	95.8	96.8
4110	0.1	0.15	105.7	106.7
4120	0.05	0.15	115.5	116.6
4125	0.05	0.1	120.5	121.6
4130	0.05	0.1	125.5	126.6
4150	0	0.1	145.4	146.6
4175	0	0.05	170.4	171.6
4200	0	0.05	195.4	196.6

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Appendix 2: Individual Contributions

Near-Term Strike	Option Type	Midpoint Price	Delta-K	Contribution by Strike
3870	Put	0.075	5	0.0000000250
3875	Put	0.075	7.5	0.0000000375
3885	Put	0.075	7.5	0.0000000373
3890	Put	0.075	5	0.0000000248
3895	Put	0.075	5	0.0000000247
3900	Put	0.075	5	0.0000000247
3905	Put	0.075	5	0.0000000246
3910	Put	0.125	5	0.0000000409
3915	Put	0.125	5	0.0000000408
3920	Put	0.15	5	0.0000000488
3925	Put	0.175	5	0.0000000568
3930	Put	0.225	5	0.0000000728
3935	Put	0.275	5	0.0000000888
3940	Put	0.35	5	0.0000001127
3945	Put	0.45	5	0.0000001446
3950	Put	0.55	5	0.0000001763
3955	Put	0.725	5	0.0000002317
3960	Put	0.925	5	0.0000002949
3965	Put	1.2	5	0.0000003817
3970	Put	1.6	5	0.0000005076
3975	Put	2.075	5	0.0000006566
3980	Put	2.725	5	0.0000008601
3985	Put	3.6	5	0.0000011335
3990	Put	4.7	5	0.0000014761
3995	Put	6.15	5	0.0000019267
4000	Put/Call Average	9.5	5	0.0000029688
4005	Call	8.3	5	0.0000025873
4010	Call	6.1	5	0.0000018968
4015	Call	4.25	5	0.0000013182
4020	Call	2.8	5	0.0000008663
4025	Call	1.75	5	0.0000005401
4030	Call	1.05	5	0.0000003233
4035	Call	0.625	5	0.0000001919
4040	Call	0.375	5	0.0000001149
4045	Call	0.225	5	0.0000000688
4050	Call	0.175	5	0.0000000533
4055	Call	0.125	5	0.0000000380
4060	Call	0.075	5	0.0000000227
4065	Call	0.075	7.5	0.0000000340
4075	Call	0.075	10	0.0000000452

Next-Term Strike	Option Type	Midpoint Price	Delta-K	Contribution by Strike
3650	Put	0.075	10	0.0000000563
3660	Put	0.075	10	0.0000000560
3670	Put	0.075	7.5	0.0000000418
3675	Put	0.075	5	0.0000000278
3680	Put	0.075	7.5	0.0000000415
3690	Put	0.075	7.5	0.0000000413
3695	Put	0.075	5	0.0000000275
3700	Put	0.075	5	0.0000000274
3705	Put	0.075	5	0.0000000273
3710	Put	0.075	5	0.0000000272
3715	Put	0.075	5	0.0000000272
3720	Put	0.075	5	0.0000000271
3725	Put	0.075	5	0.0000000270
3730	Put	0.1	5	0.0000000359
3735	Put	0.1	5	0.0000000358
3740	Put	0.125	5	0.0000000447
3745	Put	0.1	5	0.0000000357
3750	Put	0.1	5	0.0000000356
3755	Put	0.1	5	0.0000000355
3760	Put	0.1	5	0.0000000354
3765	Put	0.125	5	0.0000000441
3770	Put	0.125	5	0.0000000440
3775	Put	0.125	5	0.0000000439
3780	Put	0.125	5	0.0000000437
3785	Put	0.125	5	0.0000000436
3790	Put	0.125	5	0.0000000435
3795	Put	0.125	5	0.0000000434
3800	Put	0.15	5	0.0000000519
3805	Put	0.125	5	0.0000000432
3810	Put	0.15	5	0.0000000517
3815	Put	0.175	5	0.0000000601
3820	Put	0.175	5	0.0000000600
3825	Put	0.175	5	0.0000000598
3830	Put	0.2	5	0.0000000682
3835	Put	0.2	5	0.0000000680
3840	Put	0.225	5	0.0000000763
3845	Put	0.225	5	0.0000000761
3850	Put	0.25	5	0.0000000843
3855	Put	0.275	5	0.0000000925
3860	Put	0.3	5	0.0000001007

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Individual Contributions (Cont.)				
Next-Term Strike	Option Type	Midpoint Price	Delta-K	Contribution by Strike
3865	Put	0.325	5	0.0000001088
3870	Put	0.35	5	0.0000001168
3875	Put	0.375	5	0.0000001249
3880	Put	0.425	5	0.0000001412
3885	Put	0.475	5	0.0000001574
3890	Put	0.525	5	0.0000001735
3895	Put	0.6	5	0.0000001977
3900	Put	0.675	5	0.0000002219
3905	Put	0.775	5	0.0000002541
3910	Put	0.9	5	0.0000002943
3915	Put	1.05	5	0.0000003425
3920	Put	1.225	5	0.0000003986
3925	Put	1.425	5	0.0000004625
3930	Put	1.7	5	0.0000005503
3935	Put	2	5	0.0000006458
3940	Put	2.35	5	0.0000007569
3945	Put	2.825	5	0.0000009076
3950	Put	3.4	5	0.0000010896
3955	Put	4	5	0.0000012786
3960	Put	4.8	5	0.0000015305
3965	Put	5.65	5	0.0000017969
3970	Put	6.7	5	0.0000021255
3975	Put	7.8	5	0.0000024683
3980	Put	9.1	5	0.0000028724
3985	Put	10.6	5	0.0000033375
3990	Put	12.25	5	0.0000038473
3995	Put	14.05	5	0.0000044016
4000	Put/Call Average	18.075	5	0.0000056485
4005	Call	17.3	5	0.0000053928
4010	Call	14.75	5	0.0000045864
4015	Call	12.4	5	0.0000038461
4020	Call	10.2	5	0.0000031559
4025	Call	8.3	5	0.0000025616
4030	Call	6.7	5	0.0000020627
4035	Call	5.3	5	0.0000016276
4040	Call	4.1	5	0.0000012560
4045	Call	3.1	5	0.0000009473
4050	Call	2.35	5	0.0000007164
4055	Call	1.8	5	0.0000005473
4060	Call	1.375	5	0.0000004171
4065	Call	1	5	0.0000003026
4070	Call	0.775	5	0.0000002339

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Individual Contributions (Cont.)				
Next-Term Strike	Option Type	Midpoint Price	Delta-K	Contribution by Strike
4075	Call	0.6	5	0.0000001807
4080	Call	0.475	5	0.0000001427
4085	Call	0.375	5	0.0000001124
4090	Call	0.3	7.5	0.0000001345
4100	Call	0.2	10	0.0000001190
4110	Call	0.125	10	0.0000000740
4120	Call	0.1	7.5	0.0000000442
4125	Call	0.075	5	0.0000000220
4130	Call	0.075	5	0.0000000220

Sum of Individual Contributions for near term: 0.0000195195

$$\frac{2}{T_1}\sum_i \frac{\Delta K_i}{K_i^2}\, e^{R_1 T_1} Q(K_i) = \ 0.0132811$$

Sum of Individual Contributions for next term: 0.0000666696

$$\frac{2}{T_2}\sum_i \frac{\Delta K_i}{K_i^2}\, e^{R_2 T_2} Q(K_i) = \ 0.0193030$$

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