



Cboe Global Indices

Cboe American and European-Style Theoretical Options Calculation METHODOLOGY

Contents

1	Introduction.....	2
1.1	Supporting Documentation	2
2	Theoretical Pricing Determinations	2
3	Implied Volatility Calculations	3
3.1	Implied Volatility for American-Style Options.....	3
3.1.1	Discrete Dividends	3
3.1.2	Interest Rates	3
3.1.3.	Implied Volatility Calculation	4
3.2	Implied Volatility for European-Style Options	4
3.2.1	Implied Discount Factor and Forward Price.....	4
3.2.2	Implied Volatility Calculation	5
3.3	Implied Volatility for Non-Listed Options	6
3.3.1	Spline Interpolation	6
3.3.2	SABR Model.....	6
	Appendix 1 – Changes	8
	Appendix 2 – Document Information.....	8

1 Introduction

Cboe Global Indices' ("CGI") Theoretical Options Pricing Service ("TOPS") utilizes theoretical prices from Cboe Options Analytics¹ as a primary source². In limited circumstances, the calculation methodology as described in this document is used in lieu of the Cboe Options Analytics prices. This document details the proprietary model used by CGI to calculate theoretical pricing for listed and non-listed American and European settlement style options.

1.1 Supporting Documentation

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

[Cboe_TPS_Policies_Practices](#)

2 Theoretical Pricing Determinations

CGI utilizes the Black-Scholes³ options pricing model to determine an estimated valuation for an option. The Black-Scholes model requires the following five input variables which are sourced and/or calculated as illustrated below.

		Listed American-Style Options (Stocks & ETFs)	Listed European-Style Options (Indices)	Non-listed European-Style & American-Style Options
Input Variables	Price of the Underlying	National Best Bid and Offer (NBBO) option quotes are sourced from the Options Price Reporting Authority (OPRA) at 4:00 PM and 4:15 PM ET (12:00 PM and 12:15 PM on half trading days).		
	Strike Price	The strike price is an inherent feature specific to the option contract being priced.		
	Expiration	The expiration is an inherent feature specific to the option contract being priced.		
	Interest Rates	The risk-free rate is derived from U.S. Constant Maturity Treasury (CMT) rates. A cubic spline is applied to interpolate yields to each option expiration date.		
	Implied Volatility	Calculated as described in Section 3.1 (Cox-Ross-Rubinstein Binomial Options Pricing Model)	Calculated as described in Section 3.2 (Black-Scholes)	Calculated as described in Section 3.3 (Spline & SABR models)

¹ Cboe Options Analytics is a service offered as part of Cboe Data Vantage. Learn more at: [Options Risk Analytics Product](#)

² Refer to [Cboe TPS Policies & Practices](#) for additional details on the usage of Cboe Options Analytics.

³ Black, Fischer; Scholes, Myron (1973). "The Pricing of Options and Corporate Liabilities". Journal of Political Economy.

3 Implied Volatility Calculations

This section describes how CGI derives certain data inputs required to construct a volatility surface⁴ of American or European settlement style options. This volatility surface can be used to support the determination of intra-day (at 10-minute intervals) or end-of-day theoretical prices for existing or hypothetical option series.

In addition to the derived data inputs described in this section, the volatility surface utilizes National Best Bid and Offer (NBBO) listed option quotes sourced from the Options Price Reporting Authority (OPRA).

3.1 Implied Volatility for American-Style Options

Discrete dividends and interest rates are required to construct the volatility surface to calculate implied volatility for American-style options.

3.1.1 Discrete Dividends

The discrete dividend is determined by applying a hybrid analyst and algorithm system to predict future dividend payments and dates associated with an array of securities. Cboe maintains a database of corporate actions to track dividend payment patterns, identify changes in shares in issue (due to rights issues, consolidations, bonus issues, subdivisions, etc.), and to record various types of disbursements.

The algorithmic calculation process follows a series of rules and involves:

- inspecting dividend history;
- incorporating changes to the issued share capital;
- identifying patterns⁵; and
- calculating individual forward amounts and dates two fiscal years ahead.

Analysts maintain and monitor the historical accuracy of forecasts vs. actual outcomes to control and improve forecast quality.

3.1.2 Interest Rates

The risk-free interest rate used is based on the 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.

The forward price is calculated as:

⁴ A volatility surface is a three-dimensional plot where the x-axis is the time to maturity, the z-axis is the strike price, and the y-axis is the implied volatility.

⁵ Where a clear pattern cannot be identified (e.g., due to a recent change in the fiscal year-end date, a resumption or cut of dividend, or alteration in the dividend payment pattern), the security is flagged to the analysts who perform individual market research to forecast the data.

$$F_T(\text{Divs to Expiry } T) = \sum_{i, t_i=1}^{t_i \leq T} D_i e^{r_i(T-t_i)}$$

where:

$F_T()$ = Forward Value at time t ;

D_i = Dividend payment of value D_i at time t ; and

r_i = risk free rate for period t_i to T ;

3.1.3. Implied Volatility Calculation

The implied volatility (IV) for each maturity and strike level is calculated using the Cox-Ross-Rubinstein Binomial Options Pricing Model, using the dividends and interest rates referenced in Sections 3.1.1 and 3.1.2:

For each maturity,

$$|Model Price_i - Option Price_i| < Tolerance$$

3.2 Implied Volatility for European-Style Options

Discount factors and forward prices are required to construct the volatility surface and calculate implied volatility for European-style options.

3.2.1 Implied Discount Factor and Forward Price

In order to calculate the implied volatility for European-style options, the implied discount factor and forward price need to be determined. For each maturity, we calculate the discount factor (DF) and the forward (F) by the following methodology:

- Using put-call parity, we calculate the implied forward price from the European-style call and put prices around the at-the-money (ATM) strike. For each maturity, we select the strikes satisfying the following criteria: ATM – 8% to ATM + 8% and perform Linear Regression.
- For each maturity and each selected strike K_i $i \in \{1, 2, \dots, n\}$, we define $\text{call}(K_i)$ and $\text{put}(K_i)$ as the mid-price of the call and put options with strike K_i , respectively.

Put-call parity states that for call and put options with the same strike and maturity:

$$\text{call} - \text{put} = S - DF \times K - Div$$

where:

- S is the underlying index value;
- Div is the discrete dividend amount;

Using the put-call parity formula for each selected strike, we have the following linear model:

$$Y_i = \alpha + \beta X_i$$

$$Y_i = \text{put}(K_i) - \text{call}(K_i) + S$$

$$X_i = K_i$$

We perform linear regression to fit this model. The ordinary least squares estimation gives us:

$$\beta = \frac{\Sigma(X_i - \bar{X})(Y_i - \bar{Y})}{(X_i - \bar{X})^2}$$

$$\alpha = \bar{Y} - \beta \bar{X}$$

$$\text{where: } \bar{X} = \frac{\Sigma X_i}{n}, \bar{Y} = \frac{\Sigma Y_i}{n}$$

Given:

$$DF = \beta$$

$$Div = \alpha$$

$$\text{Forward Price} = F = \frac{S - Div}{DF}$$

As the maturity of the option, T, will not generally be a listed maturity, we must now interpolate the discount factor and forward. We select T₁ and T₂ as the closest maturity less or equal to T and the closest maturity greater to T, respectively.

$$DF_T = DF_1 + \frac{DF_2 - DF_1}{T_2 - T_1} \times (T - T_1)$$

$$F_T = F_1 + \frac{F_2 - F_1}{T_2 - T_1} \times (T - T_1)$$

3.2.2 Implied Volatility Calculation

The implied volatility (V) for each maturity and strike level is calculated by equating the Black-Scholes formula to the observed option price from the market and the implied forward price calculated in section 3.2.1.

For each maturity,

$$|Model Price_i - Option Price_i| < Tolerance$$

For the call,

$$Model Price(F, DF, T, K, V)_i = DF_i \times (F_i \times Norm(d_1) - K_i \times Norm(d_2))$$

For the put,

$$Model Price(F, DF, T, K, V)_i = DF_i \times (K_i \times Norm(-d_2) - F_i \times Norm(-d_1))$$

where:

$$d_1 = \frac{LN\left(\frac{F}{K}\right) + \frac{V^2}{2} \times (T - t)}{T_2 - T_1}$$

$$d_2 = d_1 - V \times \sqrt{T - t}$$

And:

$$Norm(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^x e^{-\frac{u^2}{2}} du$$

3.3 Implied Volatility for Non-Listed Options

To calculate the implied volatility for a non-listed strike and a non-listed maturity of American-Style or European-Style options, we utilize two different techniques for smile interpolation and extrapolation: (i) the spline interpolation for smile interpolation and (ii) the classical SABR model for smile extrapolation.

The spline interpolation output is used when the interpolated implied volatility and price are valid and positive, and the spline and SABR outputs are in reasonable agreement. Where these conditions are not met, for example, in low-liquidity or far out-of-the-money scenarios, the SABR model output is used instead.

3.3.1 Spline Interpolation

The spline interpolation is used for the strike range $K- \leq K \leq K+$, and the expiration range $T- \leq T \leq T+$. We use a cubic spline interpolation in total implied variance space. This is a method to interpolate unknown values between given points using piecewise third order polynomials. The idea is to fit a piecewise function of the form:

$$f(x) = \begin{cases} f_1(x) & x_1 \leq x < x_2 \\ f_2(x) & x_2 \leq x < x_3 \\ \dots & \dots \\ f_{n-1}(x) & x_{n-1} \leq x < x_n \end{cases}$$

$$x = K$$

$$f(x) = V(K)$$

For each f_i is a third-order polynomial defined by:

$$f_i(x) = \alpha_i x^3 + \beta_i x^2 + \gamma_i x + \delta_i$$

$$f_i(x_i) = \alpha_i x_i^3 + \beta_i x_i^2 + \gamma_i x_i + \delta_i = f_{i-1}(x_i)$$

Next, we make the first and second derivatives agree at each adjacent points.

$$f'_i(x) = 3\alpha_i(x - x_i)^2 + 2\beta_i(x - x_i) + \gamma_i = f'_{i-1}(x)$$

$$f''_i(x) = 6\alpha_i(x - x_i) + 2\beta_i = f''_{i-1}(x)$$

Now, we have $4(n-1)$ coefficients and $4(n-1)$ equations, therefore, from basic algebra, we could derive the coefficients, and the volatility between known implied volatility.

3.3.2 SABR Model

The SABR model extrapolates the smile for $0 \leq K(T) \leq K(T) -$ (left extrapolation) and $K(T) + < K(T)$ (right extrapolation).

The SABR model was introduced as a simple class of stochastic volatility processes for the underlying. Given traded and liquid options, we fit the SABR model on the observed smile and estimate the parameters. Using these parameters, we can estimate implied volatility to price at various points on the volatility surface.

The SABR model assumes that the forward rate and the instantaneous volatility are driven by two correlated Brownian motions:

$$\begin{aligned}df_t &= \alpha_t F_t^\beta dW_t^1 \\d\alpha_t &= v\alpha_t dW_t^2 \\E[dW_t^1 dW_t^2] &= \rho dt\end{aligned}$$

where:

- α is the instantaneous vol;
- v is the vol of vol;
- ρ is the correlation between the Brownian motions driving the F and the v ;
- β is the leverage effect;

The formula that the implied volatility must satisfy is:

$$|SABR\ Implied\ Vol - Observed\ Implied\ Vol| < Tolerance$$

$$\begin{aligned}SABR\ Implied\ Vol(T, F, K, \alpha, \beta, v, \rho) \\&= \frac{\alpha z}{\chi(z) F K^{(1-\beta)/2}} \left(1 + \frac{(1-\beta)^2 (LnF/K)^2}{24} + \frac{(1-\beta)^4 (LnF/K)^4}{1920} \right)^{-1} \\&\times \left(1 + \left(\frac{(1-\beta)^2 (\alpha)^2}{24(FK)^{1-\beta}} + \frac{\alpha\beta v\rho}{4(FK)^{(1-\beta)/2}} + \frac{(2-3\rho^2)v^2}{24} \right) T \right),\end{aligned}$$

where:

$$z = \frac{v \ln F}{\alpha} (FK)^{\frac{1-\beta}{2}}, \chi(z) = \ln \left(\frac{\sqrt{1-2\rho z + z^2} + z - \rho}{1-\rho} \right)$$

Given the initial value of the forward, F , the model is governed by 4 parameters, α , β , v , ρ .

Appendix 1 – Changes

Major changes described in this document since June 30, 2026 are as follows:

Change Summary	Effective Date	Previous Language	Updated Language
-	-	-	-

Appendix 2 – Document Information

Version Number ⁶	1.0
Last Revised Date	June 30, 2026

⁶ Prior to June 30, 2026, the Cboe American-Style and European-Style Options Implied Volatility Calculation methodologies were separately maintained in a legacy format.

Disclosures and Disclaimers Related to Cboe Indices

Cboe Global Indices, LLC and Cboe Europe Indices, B.V. (collectively, the “Cboe Index Providers”, and individually a “Cboe Index Provider”), are both subsidiaries of Cboe Global Markets, Inc. (Cboe Global Markets, Inc., the Cboe Index Providers, and the other subsidiaries and affiliates of Cboe Global Markets, Inc. are collectively referred to herein as the “Cboe Companies” and those entities are individually referred to as a “Cboe Company”).

The Cboe Index Providers are each an index provider that administers, calculates and distributes indices and other values (as applicable) (collectively, “Cboe Indices” and individually a “Cboe Index”). Additional information regarding the Cboe Index Providers and their operations is available at www.cboe.com/indices/.

Nothing herein constitutes an offer of services. The information herein is provided solely for informational purposes. Cboe Indices are calculated and administered (as described in relevant methodologies, rules and other information) without regard to the needs of any particular person, entity, or group of persons, using market information, including, without limitation, market data from exchanges owned and operated by other Cboe Companies.

Index and benchmark values for dates or time periods prior to an index launch date, if any, are calculated using a theoretical approach involving back-testing historical data in accordance with the methodology in place on the launch date (unless otherwise stated). Back-testing involves the theoretical application of the index methodology in hindsight and therefore does not involve actual performance and may not produce performance commensurate with prospective application of the methodology. No back-tested approach can completely account for the impact of decisions that might have been made if calculations were made at the same time as certain underlying market conditions occurred. Supporting documentation for statements, comparisons, statistics or other technical data provided in this document is available by request at www.cboe.com/contact/.

Past performance of an index or financial product is not indicative of future results. Indices are not financial products that can be invested in directly, but they can be used as the basis for financial products (for example, without limitation, options, futures, mutual funds or exchange-traded funds) or to help manage portfolios.

The Cboe Index Providers are not investment advisers or tax advisers. No decision to buy, hold, or sell any financial product should be made in reliance on any of the information provided herein, and no representation is made regarding the advisability or tax consequences of any investment, whether based on an index or not. Nothing herein should be construed as investment advice. No representation or assurance is made that any financial product will accurately track the performance of an underlying index or provide positive investment returns. Index values and returns are theoretical, and do not reflect the results of actual trading of financial products, nor the value of an actual portfolio, and may not reflect the fees, taxes or other expenses associated with buying, holding or selling investments or the effect of actual market conditions or events. The Cboe Index Providers are not broker-dealers, intermediaries, investment firms or securities exchanges and they do not manage actual financial products. None of the Cboe Companies sponsor, endorse, promote, manage, sell or administer any financial product that is created, sponsored, issued or sold by a third-party, whether based on any Cboe Index or not.

No data, values, or other content contained herein (“Content”) may be copied, modified, reverse-engineered, reproduced, distributed, or stored in a database or retrieval system, in any form or by any means, nor may any Content be used to create a derivative work (e.g., a financial product, service or index) or used to verify or correct other data or information, without the Cboe Index Provider’s prior written consent. Without derogating from the aforementioned, Content shall not be used for any unlawful or unauthorized purposes.

The Cboe Companies, their third-party service or data providers, or any party from whom they have licensed trademarks or indices (collectively, the “Cboe Parties”) do not guarantee the accuracy, completeness, or timeliness of the Content, trademarks, strategies or values, or the methodologies or input data used to calculate index values. The Cboe Parties are not responsible for any errors or omissions, regardless of the cause, or for the results obtained from the use of the Content, index strategies or values, methodologies or input data. THE CONTENT, INDICES AND RELATED STRATEGIES AND METHODOLOGIES ARE PROVIDED “AS IS” WITHOUT WARRANTY OF ANY KIND, EITHER EXPRESS OR IMPLIED, INCLUDING, WITHOUT LIMITATION, ANY WARRANTY WITH RESPECT TO MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE OR USE. USERS OF CONTENT AND/OR THE CBOE INDICES BEAR ALL RISKS OF LOSS.

WITHOUT LIMITING THE FOREGOING AND TO THE MAXIMUM EXTENT PERMITTED BY APPLICABLE LAW, IN NO EVENT SHALL THE CBOE PARTIES BE RESPONSIBLE OR LIABLE TO ANY PERSON OR ENTITY FOR ANY DAMAGES OF ANY KIND, INCLUDING, BUT NOT LIMITED TO, DIRECT, INDIRECT, SPECIAL, INCIDENTAL, CONSEQUENTIAL, PUNITIVE, LOST PROFITS OR LOST OPPORTUNITIES, WHETHER OR NOT A CBOE PARTY HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES. THE FOREGOING LIMITATIONS SHALL APPLY REGARDLESS OF WHETHER A CLAIM ARISES IN CONTRACT, TORT, NEGLIGENCE, STRICT LIABILITY, OR OTHERWISE.

The Cboe Index Providers receive compensation in connection with licensing Cboe Indices to third parties and providing calculation services to third parties. Some Cboe Companies operate markets for the trading of financial products and provide services to many organizations, including issuers of securities, investment advisers, broker-dealers, investment banks, other financial institutions and financial intermediaries, and accordingly may provide or receive fees or other economic benefits to or from those organizations. These organizations may also be Cboe Index Provider licensees or customers, and the Cboe Index Providers may include securities of or relating to such organizations in Cboe Indices.

Cboe®, C2SM, Cboe ClearSM, Cboe Closing Cross®, Cboe DigitalSM, Cboe LIS®, Cboe Futures ExchangeSM, Cboe Global IndicesSM, Cboe Global Markets®, Cboe Options Institute®, Cboe Volatility Index®, Cboe Magnificent 10 IndexSM, Bats®, BIDS Trading®, Buffer ProtectSM, BuyWriteSM, BYX®, BZX®, CFE®, EDGA®, EDGX®, Eris Exchange®, ErisX®, f(t)optionsSM, FLEX®, FLEXible EXchange®, HanweckSM, Hybrid®, LiveVol®, MGTNSM, NANO®, Options Institute®, PutWriteSM, Silexx®, SRVIXSM, Trade AlertSM, VIX® and XSPSM and are trademarks and service marks of the Cboe Companies. Trademarks of the Cboe Companies may only be used with written permission, subject to applicable Cboe Company trademark usage guidelines as published from time to time. Select third-party trademarks and service marks which may be used in this document are described below. All other trademarks and service marks are the property of their respective owners, and their use to describe index constituents does not imply an affiliation with or endorsement by the trademark owner. The values and methodologies for indices branded with the “Cboe” trademark are the property of the relevant Cboe Index Provider.

The Cboe Companies have licensed several trademarks from third parties from whom they have also licensed indices which may be included in this document or in other materials related to Cboe Indices, as follows:

- Dow Jones®, Dow Jones Industrial Average® and DJIA® are trademarks or service marks of Dow Jones Trademark Holdings LLC (“Dow Jones”), have been licensed for use for certain purposes by the Cboe Companies. Derivative indices created, used and distributed by Cboe Companies and any investment products based thereon are not sponsored, endorsed, sold or promoted by Dow Jones, and Dow Jones makes no representation regarding the advisability of investing in any investment product that is based on any such derivative indices.
- FTSE® and the FTSE indices are trademarks and service marks of FTSE International Limited, used under license.
- IHS, IHS Markit, CDX, iBoxx, and iTraxx are trademarks of IHS Markit Limited and its affiliates (“IHS”) and have been licensed for use by the Cboe Companies. Any IHS Markit index referenced herein is the property of IHS Markit and is used under license. Any products that have an IHS Markit index as their underlying interest are not sponsored, endorsed, or promoted by IHS Markit.
- MSCI and the MSCI index names are service marks of MSCI Inc. (“MSCI”) or its affiliates and have been licensed for use by the Cboe Companies. Any derivative indexes and any financial products based on the derivative indexes (“Products”) are not sponsored, guaranteed or endorsed by MSCI, its affiliates or any other party involved in, or related to, making or compiling such MSCI index. Neither MSCI, its affiliates nor any other party involved in, or related to, making or compiling any MSCI index makes any representations regarding the advisability of investing in such Products; or any warranty, express or implied; or bears any liability as to the results to be obtained by any person or any entity from the use of any such MSCI index or any data included therein. No purchaser, seller or holder of any Product, or any other person or entity, should use or refer to any MSCI trade name, trademark or service mark to sponsor, endorse, market or promote Products without first contacting MSCI to determine whether MSCI’s permission is required.
- Nasdaq®, Nasdaq-100®, and Nasdaq-100 Index®, are trademarks of Nasdaq, Inc. (together with its affiliates, the “Corporations”) and are licensed for use by Cboe Exchange, Inc. The CBOE Nasdaq-100 Volatility Index (the “Volatility Index”) and CBOE Nasdaq-100 BuyWrite Index (the “BuyWrite Index”) are not derived, maintained, published, calculated or disseminated by the Corporations. Neither the Volatility Index, the BuyWrite Index nor any product based on such indexes have been passed on by the Corporations as to their legality or suitability. Such products are not issued, endorsed, sold, or promoted by the Corporations. THE CORPORATIONS MAKE NO WARRANTIES AND BEAR NO LIABILITY WITH RESPECT TO THE VOLATILITY INDEX OR BUYWRITE INDEX.
- Russell, Russell 1000®, Russell 2000®, Russell 3000® and Russell MidCap® are registered trademarks of the Frank Russell Company, used under license.
- S&P, S&P 500, US500, 500, THE 500, SPDR, SPX, and DSPX are trade names or trademarks of S&P Dow Jones Indices, LLC or its affiliates (“S&P”). Any products that have an S&P index as their underlying interest are not sponsored, endorsed, sold or promoted by S&P and S&P makes no representation regarding the advisability of investing in any investment product that is based on any such indices.

© 2026 Cboe Exchange, Inc. and its affiliates. All Rights Reserved.

v20251022



Cboe Global Indices

CONTACT US

IndexSupport@cboe.com
www.cboe.com/indices