Model Documentation

Vanilla Equity Option Models

Model Documentation Change Log

Author	Reviewer	Date	Details of the Changes

Model Information

Model Name	
Model Version	
Model Owner	
Model Developers	
Model User Contacts	
Model Implementation Tester	
Production System Owner	
Production Deployment Lead	
User Acceptance Testers	

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1 Executive Summary

1.1 Background

A vanilla equity option is a contract that gives the buyer the right (without obligation) to buy (in case of call option) or sell (in case of put option) a certain quantity of the underlying asset at a set price (strike price), within a certain period, before or on the expiration date. The underlying assets for equity options are typically single stocks, baskets of stocks, equity indices, Exchange Traded Funds (ETFs) or combinations of these. This document describes the key aspects of methodology and implementation of vanilla Equity Option valuation and risk sensitivity models within the quantitative toolbox environment.

1.2 Model Business Purpose and Use

The models cover the valuation and risk sensitivity of the following product types and styles:

- Vanilla equity option
- Forward starting equity option

These options can be European or American.

1.3 Summary of the Model Methodology

Vanilla European options are valued analytically, using the standard Black-Scholes formula. Quanto and composite options models apply appropriate modifications to the Black-Scholes formula to account for the different yield curves. American options, which can be exercised at any time before and at maturity, are valued using backward induction on the Cox, Ross, and Rubinstein (CRR) binomial lattice.

Options with strikes/maturities that fall in-between the matrix (grid) points are priced with volatilities interpolated between neighbouring grid points. Linear interpolation in variance space is used for interpolation in time, while the strike dimension interpolation can be either linear or based on cubic splines. Implied volatilities for strikes or maturities that fall beyond the volatility grid are extrapolated ‘flat’, which means that the volatility of the closest point on the boundary of the grid is used.

1.4 Known Limitations on Model Use & Associated Mitigants

Model Weakness or Limitation	Associated Model Risk(s)	Model Risk Mitigants / Remediation
The current valuation framework for vanilla options makes the following key assumptions: • Interest rates are deterministic • Volatilities are deterministic	Risks associated with the valuations of long dated products and skew sensitive products such as forward start options may not be represented with complete accuracy.	The impact of the assumptions outlined is expected to be minimal for shorter duration trades (i.e., < 5Y). The impact of the assumptions should be monitored as part of the ongoing monitoring plan.
The CRR tree has potential to induce oscillations under certain scenarios (such as low volatility). This is a well-known limitation of the CRR tree.	This may result in valuation instabilities in the tree.	The general convergence properties of the trees should be monitored as part of the ongoing monitoring plan.

Table 1 Known limitations and mitigants

2 Model Development

2.1 Model Development Data

EQD vanilla Option model requires the following data for valuation:

- Trade/economic data (key fields provided in Table 2)
- Spot price
- Implied volatility
- Borrow cost (Repo rate)
- Forecasted dividend
- Yield curves (discount factors) for relevant currencies

2.1.1 Development Data Sources and Extraction

2.1.1.1 Data Sources

TBD

2.1.1.2 Data Relevance

The market data required for vanilla equity options rely on information from and calibration to appropriate market instruments, as well as the relevant historical data.

2.1.1.3 Data Extraction Process

TBD

Data type	**Description**
Spot Price	Current price of the underlying asset
Volatility	Implied volatilities
Borrow/Repo Rate	Equity repo rates
Dividend	Dividend schedules, amounts or yields
Yield Curves	Discount and Capitalization factors across different curves

Table 2: Model Development Data

2.1.2 Development Data Preparation

2.1.2.1 Data Quality Checks and Treatments

TBD

2.1.3 Data Limitations

At the time of writing there are no known limitations of the data used by the model.

2.2 Model Theory and Assumptions

2.2.1 Product Descriptions

Product	Description
Vanilla European Option	European call (put) option grants the holder the right (without the obligation) to buy (sell) the underlying asset at a pre-specified price (strike) at the expiration date of the contract. When the option is cash settled, the holder of a call (put) receives the equivalent cash payoff given by: $\max(S_T - K, 0)$, for European call $\max(K - S_T, 0)$, for European put S_T is the value of the underlying asset at expiration T; K is the strike price
Forward Start Option	A forward start option is an option that strikes at a specified date in the future and expires at a further future date. Quanto and composite features are available for this option too.
American Option	American option gives the holder the right to exercise that option 'early', i.e. at any time prior to or at the maturity of the trade.

Table 3 Products and description

2.2.2 European Style Options - Model Theory and Methodology

2.2.2.1 Vanilla European Options

The valuation of vanilla European options follows the standard Black-Scholes:

Notation	Description
S_t	Spot price at time t (valuation date); it is assumed to follow geometric Brownian motion
K	Strike price (price at which the derivative contract can be exercised)
σ	Annualized implied volatility linked to the returns of the underlying asset for the period between the valuation date and the expiry date; usually inferred from the market
T_e	Time to expiry in years (from valuation date to expiry date)
T_d	Time to settlement in years (from valuation date to delivery date)
r_d	Continuously compounded discount rate between valuation and settlement dates
r_c	Continuously compounded capitalization interest rate between valuation date and expiry date
r_{cs}	Continuously compounded capitalization spread rate between spot date and expiry date. This corresponds to (effective) dividend yields and repo rates for underlying equity asset
F_{T_e}	Forward price, $F_{T_e} = S_t \times \exp\left((r_c - r_{cs})T_e\right)$ with maturity T_e
$N(\,)$	Standard Normal Cumulative Distribution Function $$N(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x} e^{\frac{-z^2}{2}} dz$$
$N'(\,)$	Standard Normal Probability Density Function $$N'(x) = \frac{1}{\sqrt{2\pi}} e^{\frac{-x^2}{2}}$$

Table 4 Notations, descriptions and known formulas

The payoff of a European option at maturity is:

- $\max(S_T - K, 0)$, for a call option.
- $\max(K - S_T, 0)$, for a put option.

The value of a European call/ put is given by the Black-Scholes formula:

$$c = e^{-r_d T d}\left[F_{T_e} N(d_1) - K N(d_2)\right] \qquad \text{(call option)}$$

$$p = e^{-r_d T d}\left[F_{T_e}(N(d_1) - 1) - K(N(d_2) - 1)\right] \qquad \text{(put option).}$$

where

$$\boldsymbol{d_1} = \frac{\ln\frac{F_{T_e}}{K} + \frac{\sigma^2}{2} T_e}{\sigma\sqrt{T_e}},$$

$$d_2 = d_1 - \sigma\sqrt{T_e}.$$

It is evident that the put-call parity equation: $c - p = e^{-r_d T d}\left(F_{T_e} - K\right)$ holds, as required by no-arbitrage principle.

2.2.2.2 Forward start options

Forward start options is an option that strikes at a specified future date (forward start date) with an expiration date set further in the future, but the option is valued and settled on or around the valuation date. Specifically, at valuation, the strike is specified as a percentage of the spot price, where that spot price is determined on the forward start date.

The trade inputs are the same as inputs for the standard vanilla option except for the forward start date t_1 and the strike k which specified as percentage of the spot price S_{t_1} at strike time t_1.

There are two types of forward start options:

- Forward start options with a fixed number of share units Q. The payoff in this case is: $Q \times \left(S_T - k \times S_{t_1}\right)$.
- Forward start options with a fixed nominal N. The payoff in this case is: $N \times \frac{S_T - k \times S_{t_1}}{S_{t_1}}$.

The value of a vanilla forward start option that starts at time t_1 and matures at time T $(t_0 < t_1 < T)$, for which the strike is equal to $k \times S_{t_1}$ can be determined by replacing the corresponding quantities in vanilla pricers with the following:

- Strike: k times the forward price at t_1 (valued at t_0).
- Volatility: forward volatility of the underlying asset for the period $[t_1, T)$.

The forward volatility (between two dates $t_1 < T$) is computed from volatility σ_1 at a forward start date t_1 and volatility σ_2 at a maturity T. Each of those two volatilities are interpolated on the smile curve at the strike level of kS:

$$\sigma(k) = \sqrt{\frac{\sigma_2(k)^2 T - \sigma_1(k)^2 t_1}{T - t_1}}.$$

For discounting e.g. for a plain vanilla payoff style, the forward-forward zero rates are calculated at t_0, for the interval t1 to T, and used to calculate the forward price F_T at t1. The calculated option price is discounted from T to t_0.

Note that at the forward start date t_1, it is necessary to set a fixing in order to define the actual strike of the forward option.

2.2.3 American Style Options - Model Theory and Methodology

The Cox, Ross, and Rubinstein (CRR) model is a binomial tree-based model convenient for use of backward induction, a method for capturing of the value of the early exercise. This model is widely considered as the industry standard for valuation of American options.

Notations used:

K: Option strike;

σ: Annualized implied volatility linked to the returns of the underlying asset but inferred from the market

t_0: Valuation time ('today')

t_m: Option maturity;

$t_{ex.p}$: Ex-dividend date of p^{th} dividend. $t_{ex.L}$ represents last ex-dividend date before option maturity;

$t_{pay.p}$: Payment date of p^{th} dividend. $t_{pay.L}$ represents payment date of the last dividend before option maturity;

$t_{eq.spot}$: Underlying equity's spot date, it equals to $t_0 + equity\ payment\ lag$ which can be found in the equity's trading clause;

$t_{eq.expiry}$: Underlying equity's expiry date, it equals to $t_m + equity\ payment\ lag$ which can be found in the equity's trading clause;

$t_{op.spot}$: Option spot date, it equals to $t_0 + option\ payment\ lag$ which can be found in the option contract trading clause;

$t_{op.expiry}$: Option expiry date, it equals to $t_m + option\ payment\ lag$ which can be found in the option contract trading clause;

r: zero interest rate interpolated on the discounting curve between $t_{op.spot}$ and $t_{op.expiry}$;

F: $F_{i,j}$ represents j^{th} node in the forward tree at the time step i. All forward prices within this document correspond to forward at maturity.

S: Underlying spot. $S_{i,j}$ represents j^{th}node in the spot tree at time step i;

c: Option premium. $c_{i,j}$ represents j^{th} node in the premium tree at time step i;

T_e: time to option expiry in years between t_0 and t_m;

T_d: time to option delivery in years between $t_{op.spot}$ and $t_{op.expiry}$;

N: Number of iteration;

D_p: p^{th} dividend amount which goes ex at $t_{ex.p}$and is paid at $t_{pay.p}$;

$r_{p.q}$: Zero rate interpolated on the capitalization curve between ex-dividend date $t_{ex.p}$ and ex-dividend date $t_{ex.q}$;

r_p: Zero rate interpolated on the capitalization curve between $t_{eq.spot}$ and ex-dividend date $t_{ex.p}$. Then r_L represents the zero rate for period between $t_{eq.spot}$ and last ex-dividend date $t_{ex.L}$;

r'_p: Zero rate interpolated on the capitalization curve between $t_{ex.p}$ and $t_{eq.expiry}$. Then r'_L represents the zero rate for period between last ex-dividend date $t_{ex.L}$ and $t_{eq.expiry}$

CF_p: Capitalization factor from $t_{ex.p}$ to $t_{pay.P}$. P^{th} dividend discounted value at ex-dividend date is $\frac{D_p}{CF_p}$;

ϵ: 1 for call and -1 for put;

p^u: Probability that spot goes up from step i to step $i+1$ under risk-neutral measures. $p^d = 1 - p^u$ is the corresponding probability that spot goes down.

2.2.3.1 Principle

The CRR model initial input is the forward. There are three main steps to get the option premium:

- Diffuse the forward to get the forward tree;
- Based on the forward tree, deduce the spot tree;
- Starting from the last iteration of spot tree, apply backward induction to compute premium tree. At each step i , premiums are determined by premiums at step $i+1$ and spot at step i which is used to check if early exercise is optimal. That is, checking the option intrinsic value (immediate exercise) against the option price.

2.2.3.2 Forward diffusion

The forward is first diffused (Nsteps) in a tree with the following characteristics (Figure 1 below)

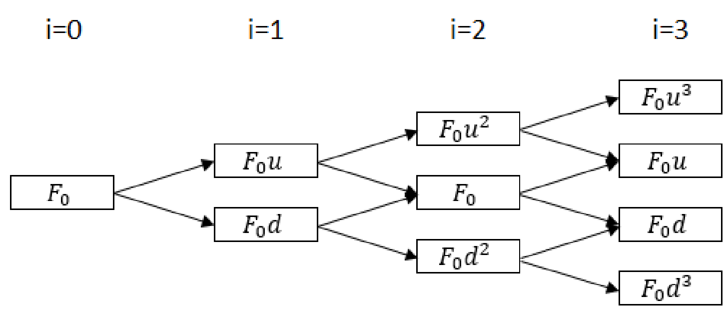

Figure 1: Forward diffusion process

$$\boldsymbol{u} = \mathbf{exp}\left(\boldsymbol{\sigma} \times \sqrt{\frac{\boldsymbol{T_e}}{\boldsymbol{N}}}\right), \quad (1)$$

$$\boldsymbol{d} = \frac{\mathbf{1}}{\boldsymbol{u}}. \quad (2)$$

2.2.3.3 Spot tree computation

Spot tree is deducted from the forward tree (Figure 2 below).

The rates used for discounting forward prices are computed differently for cases where a dividend schedule is present or not.

This section presents the rate conventions for both cases and explains how to convert the forward tree to the spot tree.

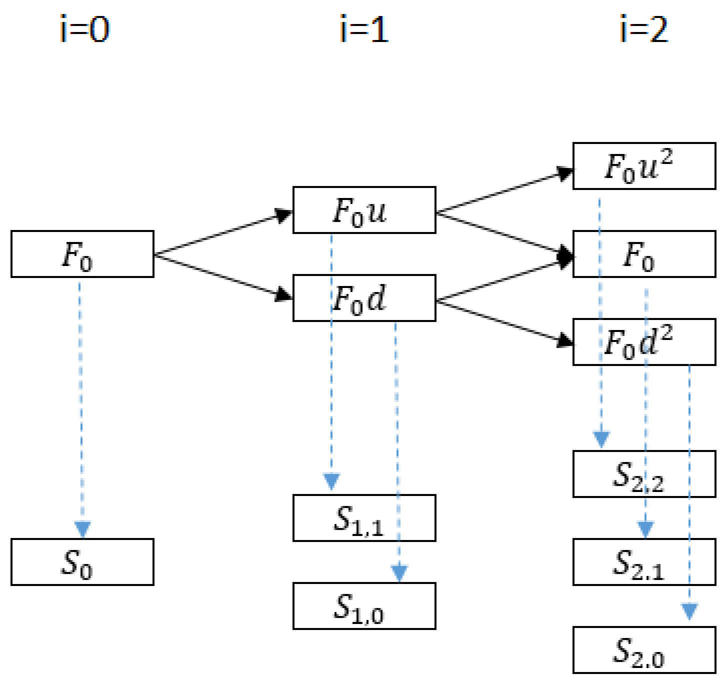

Figure 2: Deduce spot free from forward tree

2.2.3.4 Backward computation of premium

This section describes how to compute the premium. There are two sub-steps:

- Initialization: applying the Black-Scholes formula to compute the premiums at $N-1$ step.
- Starting from $N-1$ step, compute premiums backward. At each step, spot prices are used to examine if it is optimal to early exercise the option (Figure 3 below).

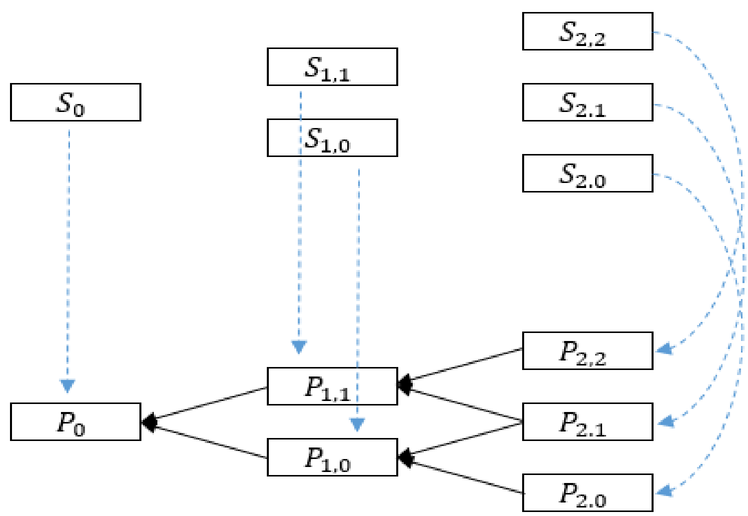

Figure 3: Backward computation of premium

2.2.3.5 Initialization with Black-Scholes

At the last iteration, premium is first computed for each branch applying Black-Scholes formula between the step $N-1$ and N.

For $j \in [0, N-1]$,

$$\boldsymbol{C_{N-1,j}} = \mathbf{max}\left[\boldsymbol{Black\&Sholes}\left(\boldsymbol{K}, \boldsymbol{F_{N-1,j}}, \boldsymbol{\sigma}, \frac{\boldsymbol{T_e}}{\boldsymbol{N}}, \boldsymbol{r}, \frac{\boldsymbol{T_d}}{\boldsymbol{N}}\right);\ \boldsymbol{\epsilon}\left(\boldsymbol{S_{N-1,j}} - \boldsymbol{K}\right)\right]. \tag{3}$$

For a call option,

$$\boldsymbol{Black\&Scholes}\left(\boldsymbol{K}, \boldsymbol{F_{N-1,j}}, \boldsymbol{\sigma}, \frac{\boldsymbol{T_e}}{\boldsymbol{N}}, \boldsymbol{r}, \frac{\boldsymbol{T_d}}{\boldsymbol{N}}\right) = \boldsymbol{e}^{-r\frac{\boldsymbol{T_d}}{N}} \times \left[\boldsymbol{Normal}(\boldsymbol{d_1})\boldsymbol{F_{N-1,j}} - \boldsymbol{Normal}(\boldsymbol{d_2})\boldsymbol{K}\right]. \tag{4}$$

For a put option,

$$\boldsymbol{Black\&Scholes}\left(\boldsymbol{K}, \boldsymbol{F_{N-1,j}}, \boldsymbol{\sigma}, \frac{\boldsymbol{T_e}}{\boldsymbol{N}}, \boldsymbol{r}, \frac{\boldsymbol{T_d}}{\boldsymbol{N}}\right) = \boldsymbol{e}^{-r\frac{\boldsymbol{T_d}}{N}} \times \left[\boldsymbol{Normal}(-\boldsymbol{d_2})\boldsymbol{K} - \boldsymbol{Normal}(-\boldsymbol{d_1})\boldsymbol{F_{N-1,j}}\right], \tag{5}$$

where, $d_1 = \frac{1}{\sigma\sqrt{\frac{T_e}{N}}}\left[\ln\left(\frac{F_{N-1,j}}{N}\right) + \frac{1}{2}\sigma^2\frac{T_e}{N}\right]$ and $d_2 = d_1 - \sigma\sqrt{\frac{T_e}{N}}$. (6)

$Normal(.)$ stands for the cumulative distribution function of the standard normal distribution.

The CRR model enables exercise only at each iteration step so the option is locally European and cannot be exercised with in the period between two neighbouring iteration steps.

Initializing the premium tree using the Black-Scholes formula at step $N-1$ instead of using intrinsic values at step N gives a better convergence result.

2.2.3.6 Backward Computation payoffs

From the initial evaluation of the premium at step $N-1$in the premium tree and from the spots tree, premiums are then computed backward. Before giving the premium formula, the probabilities that spot goes up and down under risk-neutral measure are:

$$\boldsymbol{P^u} = \frac{\boldsymbol{e}^{\left(\frac{rT_d}{N}\right)} - \boldsymbol{d}}{\boldsymbol{u} - \boldsymbol{d}},\ \boldsymbol{P^d} = \mathbf{1} - \boldsymbol{P^u}. \tag{7}$$

With u and d as defined above.

- In the case of a European option:

For $i \in [0; N-2], \in [0; i]$, $c_{i,j} = \max\left[\left(p^u \times c_{i+1,j+1} + P^d \times c_{i+1,j}\right) \times e^{\left(\frac{rT_d}{N}\right)}, 0\right]$.

- In case of an American option with no dividend:

For $i \in [0; N-2], \in [0; i]$, $c_{i,j} = \max\left[\left(p^u \times c_{i+1,j+1} + P^d \times c_{i+1,j}\right) \times e^{\left(\frac{rT_d}{N}\right)}, \epsilon\left(S_{i,j} - K\right), 0\right]$.

- If a dividend D_p goes ex between i and $i+1$ at time $t_{ex.p}$, an additional step is added:

For $i \in [0; N-2], \in [0; i]$, $\widetilde{C_{i,j}} = \max\left[\left(p^u \times c_{i+1,j+1} + P^d \times c_{i+1,j}\right) \times e^{\left(r\frac{T_d}{N}\right)},\ \epsilon\left(\widetilde{S_{i-j}} - K\right)e^{r\frac{T_d}{N}(t_{ex.p}-t_i)}, \epsilon\left(\widetilde{S_{i+j}} - K\right)e^{r\frac{T_d}{N}(t_{ex.p}-t_i)}, 0\right]$, where,

$$\widetilde{S_{\iota-J}} = S_{i,j} \times \exp\{r_{p-1,p}(t_{ex.p} - t_i)\}, \text{ and} \quad (8)$$

$$\widetilde{S_{\iota+J}} = S_{i,j} \times \exp\{r_{p-1,p}(t_{ex.p} - t_i)\} - \frac{D_p}{CF_p}. \quad (9)$$

2.2.4 Dividends

TBD

2.2.5 Risk Sensitivities

Greeks for vanilla options can be computed either ‘analytically’ or as a difference between ‘bumped’ values of the option (‘finite difference method’). When the risk numbers are returned by the valuation model the method is called analytical, and when the numbers are returned by the risk engine that bumps the underlying risk factor and repeatedly calls the model to compute the sensitivity, the method is referred to as ‘finite difference’. Generally, the risks are computed by ‘bumping’, except in the case of CRR method where delta and gamma can be read from the same binomial tree that is used to compute the option price.

2.2.5.1 Analytic

If sensitivities are computed with analytic method than computations depend on the underlying model, i.e. CRR binomial lattice for American or Black-Scholes model for European payoffs.

2.2.5.1.1 Black-Scholes model:

The following notation will be used to describe the Greeks:

- P: Premium of the equity product computed using the analytical method.
- S: Spot of the underlying asset as of the pricing date.
- F: Forward price of the underlying asset on the pricing date (at maturity).
- σ : Volatility used in the pricing
- r: Risk neutral rate.
- r_m: Repo rate.
- ϵ: Bump value in the finite difference calculation of spot Greeks. It is expressed in percentage of the spot.
- η: Bump value in the finite difference calculation of volatility Greeks. It is expressed in basis points
- Δ: Delta value
- Γ: Gamma value
- ν: Vega value
- ρ: Rho value.
- θ: Theta value.

Delta:

$$\boldsymbol{\Delta} = \frac{P(F(S+\epsilon S)) - P(F)}{\epsilon S}, \text{ with } \boldsymbol{\epsilon} = \mathbf{10^{-5}}.$$

Gamma:

$$\boldsymbol{\Gamma} = \frac{P(F(S+\epsilon S)) - 2P(F(S)) + P(F(S-\varepsilon S))}{(\epsilon S)^2}, \text{ with } \boldsymbol{\epsilon} = \mathbf{10^{-5}}.$$

Vega:

$$\boldsymbol{\nu} = \frac{P(\sigma+\eta) - P(\sigma)}{\eta}, \text{ with } \boldsymbol{\eta} = \mathbf{10^{-3}}.$$

Vanna:

$$\boldsymbol{Vanna} = \frac{\nu(F(S+\epsilon S)) - \nu(F(S))}{\epsilon S}, \text{ with } \boldsymbol{\epsilon} = \mathbf{10^{-4}}.$$

Volga:

$$\boldsymbol{Volga} = \frac{\nu(\sigma+\eta) - \nu(\sigma)}{\eta}, \text{ with } \boldsymbol{\eta} = \mathbf{10^{-3}}.$$

Rho:

$$\boldsymbol{\rho} = \frac{\partial P}{\partial r}|\boldsymbol{F} + \frac{\partial F}{\partial r} * \frac{\partial P}{\partial F}|\boldsymbol{r}.$$

Theta:

$$\boldsymbol{\theta} = \frac{\partial P}{\partial t}\Big|\boldsymbol{F} + \frac{\partial F}{\partial t} \times \frac{\partial P}{\partial F}|\boldsymbol{t}.$$

2.2.5.1.2 CRR model:

Analytic Delta and Gamma under the CRR model need to use nodes in the premium tree and spot tree:

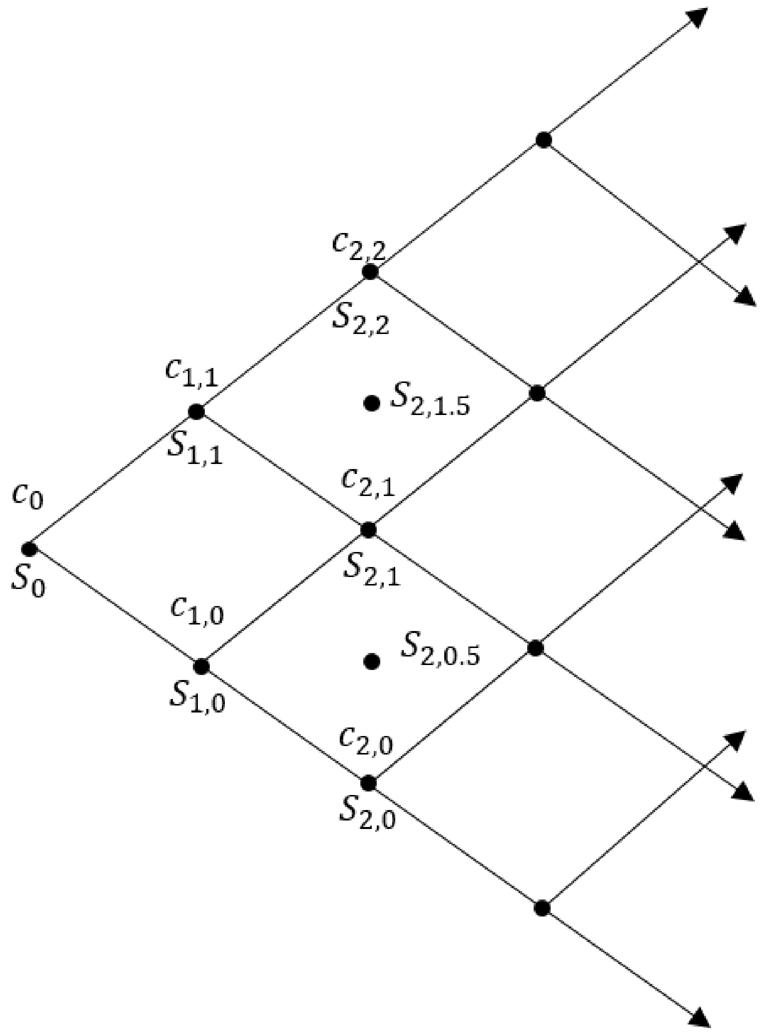

Figure 4: Premium and spot tree in the CRR model

2.2.5.2 Finite difference

If sensitivities are evaluated with finite difference method, then Greeks are computed by parameters with the shift defined in securities evaluation settings.

$$\boldsymbol{Greek} = \frac{\boldsymbol{premium(marketparameter+\epsilon)-premium(marketparameter)}}{\boldsymbol{\epsilon}},$$

where ϵ being the shift defined in securities evaluation settings, except for theta.

2.2.6 Model Assumptions

The following are the key assumptions behind the valuation and risk computation framework employed for the vanilla option models:

1. The underlying asset is assumed to follow a lognormal diffusion process. In the case of Quanto and composite options, the FX rate of the rate is also assumed to follow a lognormal diffusion process that is correlated with the underlying asset process.
2. Interest rates are assumed to be deterministic.

3. The volatilities (diffusion coefficients) of the underlying asset and the FX rate processes are assumed to be deterministic.

2.2.7 Model Settings

This section describes the different configuration settings for determination of the spot price, and for calculation of volatility using various types of interpolation, as well as the configurations for the Cox, Ross and Rubinstein binomial tree used for the vanilla products with American (early exercise) feature.

2.3 Model Parameter Calibration

The model parameter calibration settings are not required for equity option pricing using Black-Scholes Model or in the Cox, Ross & Rubinstein (CRR) model.

2.4 Model Development Testing

This section provides a series of tests aimed at assessing that the implemented vanilla equity models are fit for purpose. The following sets of tests are carried out for the products in scope.

- **Model Implementation Tests** – The objective of these tests is to verify that the key features in the model framework have been implemented properly.
- **Life Cycle Tests** – The objective of these tests is to verify if the PVs and sensitivities reported at various points during the life of a set of trades are broadly in line with the economics of the trades.
- **Sensitivity Analysis** – The objective of this test is to evaluate the response of the model(s) to shifts in the various inputs to the model(s) i.e. spot bumps, volatility bumps, and interest rate bumps.
- **P&L Attribution** – The objective of this test is to evaluate if key sensitivities computed by the model(s) reasonably predict the observed P&L of representative portfolio(s) of trades on a day-to-day basis.

2.4.1 Model Implementation Tests

Implementation of methodology is tested in this section by creating test trades and performing analysis of the produced toolbox results.

2.4.1.1 Independent Replication of Option Premium

The objective of this test is to compare the prices for different vanilla options obtained from the toolbox with the independent replication of the computational logic in Microsoft Excel/VBA on the other.

The relative difference is computed as a

$$\text{relative percentage} = \frac{PV\ from\ replication - PV\ reported\ by\ Murex}{PV\ reported\ by\ Murex}.$$

2.4.1.2 Put- Call Parity Test

$$c - p = e^{-r_d T_d}(F - K) \tag{10}$$

Equation (10) represents the no-arbitrage condition of put-call parity applicable for European options. Put-call parity is a model independent result and should hold across all strikes independent of model assumptions.

Test Case: TBD

2.4.1.3 American vs European exercise style

In this test we have examined a set of call options by pricing American Vanilla contracts using the Cox, Ross, and Rubinstein (CRR) model and European contacts using the Black-Scholes model.

2.4.1.4 Convergence Analysis for American Options

In this test we will vary the geometry of the binomial tree (number of time steps = 10, 20, 30, 100… 1000).

From the results we have observed for the number of steps ≥ 150, that the Premium and Greeks converge to a stable value; it is recommended using the number of steps greater than or equal to 150 per year.

2.4.1.5 Risk Sensitivities: Independent Replication Using 'Bump and Reprice'

In this section, the sensitivities reported by the toolbox are compared against the values obtained by the bump and reprice method. The sensitivities of various EQ derivatives are computed by bumping the spot rates by 1 basis point, calculating the difference in PV and then obtaining the Greeks.

$$Delta = \frac{PL\ (S^{+}) - PL}{S^{+} - \ S},$$

$$Gamma = \frac{PL\ (S^{2+}) + PL - 2PL(S^{+})}{(S^{+} - S)^{2}} S,$$

where $S^{+} = S * \ (1 + 0.0001)$ and $S^{2+} = S * \ (1 + 0.0002)$.

$$Vega = \frac{PL\ (\sigma^{+}) - PL}{\sigma^{+} - \ \sigma},$$

where $\sigma^{+} = \sigma + 0.001$.

The relative error in percent terms is found to be within a limit of 1% for all the cases considered.

2.4.2 Trade Life Cycle Test

In life cycle testing we evaluate contracts at expiry (T), to see how the PV and Greeks behaves at one day prior to expiry $(T - 1)$, at expiry T and after the expiry $(T + 1)$.

2.4.3 P&L Attribution

The objective of the P&L attribution test is to ensure that the key sensitivities computed by the model reasonably predict the observed P&L of a representative set of trades on a day-to-day basis.

The following approach is taken for the P&L attribution tests in this section:

- Instead of considering P&L attribution for separate business days, a particular business day is chosen, and the underlying spot and volatilities are shocked by a pre-specified bump amount, to compute the P&L impact arising due to the bumps.
- Due to the relatively small magnitude of the interest rate and dividend sensitivities for the contracts considered, their contribution in the risk-based P&L attribution is excluded. Therefore, the P&L tests considered below include only the impact of Delta, Gamma and Vega.

3 Model Implementation

This section includes details on the procedures and information related to the model implementation within the Quantitative Toolbox.

3.1 Production Application Testing

3.1.1 User Acceptance Testing Approach and Results

TBD

3.2 Model Production Specifications

3.2.1 Model Platform

TBD

3.2.2 Data Flow diagram

TBD

3.2.3 Input Data Specifications

3.2.3.1 Market Data Specifications

TBD

3.2.3.2 Model Parameter Specifications

The model parameter calibration settings are not required for equity option pricing using Black-Scholes Model or in the Cox, Ross & Rubinstein (CRR) model. Key model parameters are those of the volatility for the underlying asset and FX, σ_A and σ_{FX}, respectively as well as the cross asset correlation coefficient ρ where applicable.

3.2.4 Model Parameter Values

TBD

3.2.5 Model Outputs

TBD

The following are the list of main outputs from the model

- PV of the trade

Risks/Sensitivities:

- Delta
- Gamma
- Vega
- Rho
- Theta

3.2.6 Reports

TBD

3.3 Operational Controls

3.3.1 Model Access and Security

TBD

3.3.2 Access Level Review

TBD

3.3.3 Production Deployment

TBD

3.3.4 Model Usage Controls

TBD

3.3.5 Model Backup

TBD

3.4 Contingency Plans

3.4.1 Disaster Recovery Plan

TBD

3.4.2 Business Continuity Plan

TBD

4 Ongoing Model Governance

4.1 Ongoing Monitoring Plan

The table shows the list of tests intended to be run for monitoring the model on a periodic basis.

S. No	Test Name	Test Description	Acceptance criteria
1.	Risk Based P&L predict Analysis	For a set of benchmark trades across different currencies, the daily P&L is compared with the P&L predicted using the sensitivities reported by the model.	It is expected that the residual/ unexplained P&L, defined as $\text{Actual PnL} - \text{Predicted P\&L}$, is small. Cases with material unexplained P&L are marked for further analysis. The materiality is judged, based on: • absolute value of the unexplained P&L • percentage of the unexplained P&L relative to the realized P&L At present, no quantitative thresholds are set; they will be set after onset of trading.
2.	American Options- CRR Tree stability/ convergence Analyses	For a set of benchmark American options, the convergence of the PVs and Greeks on CRR tree is analyzed by varying the number of steps in the tree under both normal and stressed market conditions.	This test is mainly for diagnostic purposes. At present, no quantitative performance thresholds are set. Further decisions on quantitative thresholds may be taken at a later stage, based on going model use.
3.	Sensitivity Analyses with respect to key variables	For a set of benchmark trades, sensitivity analyses of PV and Greeks with respect to key model input are carried out. These include: • Spot/Volatility scenarios	This test is mainly for diagnostic purposes and as a result no quantitative thresholds are set.

Table 5. Ongoing Monitoring plan

4.2 Assumptions Management Plan

The underlying pricing models are, in principle, sensitive to the following inputs

1. Volatilities and correlation coefficients relevant to the underlying diffusion.
2. Forward values calculation and relevant discount factors.

Discount factors are dependent on the yield curve methodology.

4.3 Model Approval and Change Management Process

TBD

Preapproved Model Changes

There are no preapproved model changes for this version of the model.

Change Log

This is the first version of the model to go live in production. As a result, there are no change logs for this model.

5 References