

S&P 500 Futures 40% Defined Volatility Autocall Index *Methodology*

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Introduction

Index Objective and Highlights

The S&P 500 Futures 40% Defined Volatility Autocall Index measures the performance of a portfolio of autocalls on the S&P 500 Futures 40% Defined Volatility TCA 6% Decrement Index II issued on a rolling weekly basis. Each autocall is held until maturity or an early redemption call. Cash received from periodic coupon payments, early redemptions, and redemption at maturity are reinvested into new autocalls periodically.

For more information on the S&P 500 Futures 40% Defined Volatility TCA 6% Decrement Index II, please refer to the S&P Defined Volatility Indices Methodology, available at www.spglobal.com/spdji.

Supporting Documents

This methodology is meant to be read in conjunction with supporting documents providing greater detail with respect to the policies, procedures and calculations described herein. References throughout the methodology direct the reader to the relevant supporting document for further information on a specific topic. The list of the main supplemental documents for this methodology and the hyperlinks to those documents is as follows:

Supporting Document	URL
S&P Dow Jones Indices' Commodities Indices Policies & Practices Methodology	Commodities Indices Policies & Practices
S&P Dow Jones Indices' Commodity Index Mathematics Methodology	Commodity Index Mathematics Methodology
S&P Dow Jones Indices' Index Mathematics Methodology	Index Mathematics Methodology
S&P Dow Jones Indices' Equity Indices Policies & Practices Methodology	Equity Indices Policies & Practices

This methodology was created by S&P Dow Jones Indices to achieve the aforementioned objective of measuring the underlying interest of each index governed by this methodology document. Any changes to or deviations from this methodology are made in the sole judgment and discretion of S&P Dow Jones Indices so that the index continues to achieve its objective.

Index Construction

Autocall Parameters

The index uses the following common parameters for each autocall k issued:

Parameter	Variable	Value
Principal Amount	P	1.0
Autocall Strike	$Strike$	100%
Autocall Barrier	$BarrCall$	100%
Principal Barrier	$BarrPrin$	60%
Coupon Barrier	$BarrCpn$	60%
Annualized Rate for Simulation	r	-6%
Annualized Volatility for Simulation	σ	38.5%
Smoothing Parameter	ϵ	3%
Number of Simulation Paths	$NumPaths$	200000
Number of Calendar Days Simulated per Path	$NumDays$	2240

Index Calculation

For each index calculation day t , the end of day index level calculates as:

$$Index_t = \max(Cash_t + MV_t, 0)$$

where:

$Index_t$ = Index closing level for day t

$Cash_t$ = Cash balance value at the end of day t

MV_t = Sum of the mark-to-market value (calculated as of the end of day t) of all autocalls held by the index at the end of day t

Cash Calculation

On the index initialization date, $t = 0$, the cash value is set to 100. For every subsequent index calculation day t , the value of the cash balance calculates as:

$$Cash_t = Cash_{t-1} \times \left[1 + SOFR_{t-1} \times \frac{Act(t-1, t)}{360} \right] - PR_t + FR_t + ER_t + CP_t - RC_{t-1}$$

where:

$SOFR_{t-1}$ = Secured Overnight Financing Rate value as of the end of day $t - 1$

$Act(t-1, t)$ = Number of calendar days between day $t - 1$ and day t

PR_t = Premium of the autocall that was newly issued on day t

FR_t = Sum of the redemption amounts from all autocalls held by the index that matured on day t

ER_t = Sum of the redemption amounts from all autocalls held by the index that were called prior to their maturity date on day t

- CP_t = Sum of the coupon amounts from all autocalls held by the index that paid a coupon on day t
- RC_{t-1} = Replication cost for the index calculated as of the end of day $t - 1$

Premium Calculation

If day t is not an autocall issuance date

$$PR_t = 0$$

If day t is an autocall issuance date

$$PR_t = N_t$$

$$N_t = \max(0, \min(0.05 \times Index_{t-2}, Cash_{t-2}))$$

where:

N_t = Notional amount of the autocall that was issued on day t

Redemption Amount at Maturity Calculation

The total redemption amount at maturity as of the end of day t from all autocalls held by the index as of the start of day t calculates as:

$$FR_t = \sum_k F_{k,t}$$

where:

$F_{k,t}$ = Redemption amount at maturity for autocall k as of the end of day t

For each autocall k held by the index at the start of day t , the redemption amount at maturity calculates as:

If day t is not the maturity date for autocall k

$$F_{k,t} = 0$$

If day t is the maturity date for autocall k

$$F_{k,t} = \begin{cases} N_{t_k} \times \left[1 + 0.5 \times \max\left(0, \frac{RefIdx_t}{RefIdx_{t_k}} - 1\right) \right] & \text{if } \frac{RefIdx_t}{RefIdx_{t_k}} \geq BarrPrin \\ \frac{RefIdx_t}{RefIdx_{t_k}} \times N_{t_k} & \text{otherwise} \end{cases}$$

where:

$RefIdx_t$ = Closing index level of the S&P 500 Futures 40% Defined Volatility TCA 6% Decrement Index II as of the end of day t ¹

t_k = Issuance date for autocall k

$BarrPrin$ = Principal barrier value for autocall k

Redemption Amount at Call Date Calculation

The total redemption amount at call date as of the end of day t from all autocalls held by the index as of the start of day t calculates as:

¹ The reference index level values round to five decimal places prior to use in calculations.

$$ER_t = \sum_k E_{k,t}$$

where:

$E_{k,t}$ = The redemption amount at call date for autocall k as of the end of day t

For each autocall k held by the index at the start of day t , the redemption amount at call date calculates as:

If day t is not a callable date for autocall k

$$E_{k,t} = 0$$

If day t is a callable date for autocall k

$$E_{k,t} = \begin{cases} N_{t_k} \times \left[1 + 0.5 \times \max\left(0, \frac{RefIdx_t}{RefIdx_{t_k}} - 1\right) \right] & \text{if } \frac{RefIdx_t}{RefIdx_{t_k}} \geq BarrCall \\ 0 & \text{otherwise} \end{cases}$$

where:

$BarrCall$ = The callable barrier value for autocall k

Coupon Amount Calculation

The total coupon amount from all autocalls held by the index that paid a coupon on day t calculates as:

$$CP_t = \sum_k C_{k,t}$$

where:

$C_{k,t}$ = The coupon amount for autocall k as of the end of day t

For each autocall k held by the index at the start of day t , the coupon amount calculates as:

If day t is not a coupon payment date for autocall k

$$C_{k,t} = 0$$

If day t is a coupon payment date for autocall k

$$C_{k,t} = \begin{cases} N_{t_k} \times Cpn_k & \text{if } \frac{RefIdx_t}{RefIdx_{t_k}} \geq BarrCpn \\ 0 & \text{otherwise} \end{cases}$$

where:

Cpn_k = The per period coupon rate for autocall k

$BarrCpn$ = The coupon barrier value for autocall k

Replication Cost Calculation

On the index initialization date, $t = 0$, the replication cost initializes to 0. On each subsequent day, the replication cost as of the end of day t calculates as:

$$RC_t = 0.14 \times \max(0, RC_t^{\text{up}} + RC_t^{\text{down}})$$

$$RC_t^{\text{up}} = \sum_k N_{t_k} \times (ACPriceMC_{k,t}^{\text{up}} - ACPriceMC_{k,t}) \times Act(t, t + 1)$$

$$RC_t^{\text{down}} = \sum_k N_{t_k} \times (ACPriceMC_{k,t}^{\text{down}} - ACPriceMC_{k,t}) \times Act(t, t + 1)$$

where:

$ACPriceMC_{k,t}$ = The Monte Carlo-based model price for autocall k as of the end of day t

$ACPriceMC_{k,t}^{\text{up}}$ = The Monte Carlo-based model price for autocall k with the underlying reference index value scaled up by 2% while keeping all other parameters the same as of the end of day t

$ACPriceMC_{k,t}^{\text{down}}$ = The Monte Carlo-based model price for autocall k with the underlying reference index value scaled down by 2% while keeping all other parameters the same as of the end of day t

Mark-to-Market Value Calculation

The total mark-to-market-value as of the end of day t of all autocalls held by the index as of the end of day t calculates as:

$$MV_t = \sum_k M_{k,t}$$

$$M_{k,t} = N_{t_k} \times ACPriceMC_{k,t}$$

where:

$ACPriceMC_{k,t}$ = The Monte Carlo-based model price for autocall k as of the end of day t

For details on the Monte Carlo-based method used for single autocall pricing, please refer to Appendix A.

Autocall Portfolio Construction

- A new autocall is added to the autocall portfolio weekly on Fridays.^{2 3}
- The autocall maturity date is set to the Friday 312 weeks after the autocall issuance date.
- The autocall coupon payment dates occur every four weeks on Fridays starting strictly after the issuance date and ending strictly on and including the maturity date.
- The first date that is a callable date of an autocall is the coupon payment date 52 weeks after the issuance date. All subsequent coupon payment dates (excluding the maturity date) are also callable dates for the autocall.

² If the new autocall date, maturity date, or coupon payment date is a scheduled NYSE holiday, the date is set to the prior business day.

³ The new autocall is only issued if the notional amount is greater than zero.

- The autocall coupon rate is determined two business days prior to the autocall issuance date.
 - The coupon rate is determined by applying a root-finding algorithm to iteratively solve for the value where the Monte Carlo-based model price of the forward starting autocall equals the target price, $TargetPx_{k,t}$, which calculates as:

$$TargetPx_{k,t} = 0.965 \times DF(t, t_k)$$

where:

$DF(t, t_k)$ = The discount factor used to discount cashflows from date t_k back to the coupon determination date t

For details on the coupon determination process, please refer to Appendix B.

For details on discount factor calculations, please refer to Appendix D.

- An autocall is held in the portfolio until maturity or until it is redeemed early due to the redemption criteria being met on a callable date.

Index Maintenance

Currency of Calculation and Additional Index Return Series

In addition to the indices detailed in this methodology, additional return series versions of the indices may be available, including, but not limited to the following: currency, currency hedged, decrement, fair value, inverse, leveraged, and risk control versions. For a list of available indices, please refer to the [S&P DJI Methodology & Regulatory Status Database](#).

For information on index calculation, please refer to S&P Dow Jones Indices' Index Mathematics Methodology.

For the inputs necessary to calculate certain types of indices, including decrement, dynamic hedged, fair value, and risk control indices, please refer to the Parameters documents available at www.spglobal.com/spdji.

Base Date and History Availability

The index history availability, base dates, and base values are shown in the table below:

Index	Launch Date	First Value Date	Base Date	Base Value
S&P 500 Futures 40% Defined Volatility Autocall Index (USD) TR	05/29/2026	06/20/2018	06/20/2018	100

Index Data

Calculation Return Types

S&P Dow Jones Indices calculates multiple return types which vary based on the treatment of regular cash dividends. The classification of regular cash dividends is determined by S&P Dow Jones Indices.

- Price Return (PR) versions are calculated without adjustments for regular cash dividends.
- Gross Total Return (TR) versions reinvest regular cash dividends at the close on the ex-date without consideration for withholding taxes.
- Net Total Return (NTR) versions, if available, reinvest regular cash dividends at the close on the ex-date after the deduction of applicable withholding taxes.

In the event there are no regular cash dividends on the ex-date, the daily performance of all three indices will be identical.

For a complete list of indices available, please refer to the daily index levels file (“.SDL”).

For more information on the classification of regular versus special cash dividends as well as the tax rates used in the calculation of net return, please refer to S&P Dow Jones Indices' Equity Indices Policies & Practices Methodology.

For more information on the calculation of return types, please refer to S&P Dow Jones Indices' Index Mathematics Methodology.

Index Governance

Index Committee

An index committee maintains the index. All committee members are full-time professional members of S&P Dow Jones Indices' staff. The Index Committee meets regularly. At each meeting, the Committee reviews pending corporate actions that may affect index constituents, statistics comparing the composition of the indices to the market, companies that are being considered as candidates for addition to the indices, and any significant market events. In addition, the Index Committee may revise index policy covering rules for selecting companies, treatment of dividends, share counts or other matters.

S&P Dow Jones Indices considers information about changes to its indices and related matters to be potentially market moving and material. Therefore, all Index Committee discussions are confidential.

S&P Dow Jones Indices' Index Committees reserve the right to make exceptions when applying the methodology if the need arises. In any scenario where the treatment differs from the general rules stated in this document or supplemental documents, clients will receive sufficient notice, whenever possible.

In addition to the daily governance of indices and maintenance of index methodologies, at least once within any 12-month period, the Index Committee reviews the methodology to ensure the indices continue to achieve the stated objectives, and that the data and methodology remain effective. In certain instances, S&P Dow Jones Indices may publish a consultation inviting comments from external parties.

For information on Quality Assurance and Internal Reviews of Methodology, please refer to S&P Equity Indices Policies & Practices Methodology.

Index Policy

Announcements

Announcements of the daily index values are made after the market close each day.

For more information, please refer to the Announcements section of S&P Commodities Indices Policies & Practices Methodology.

Holiday Schedule

The index calculates daily, throughout the calendar year, when the U.S. equity markets are open.

For a complete holiday schedule, please refer to S&P Dow Jones Indices' site at www.spglobal.com/spdji.

Rebalancing

The Index Committee may change the date of a given rebalancing for reasons including market holidays occurring on or around the scheduled rebalancing date. Any such change will be announced with proper advance notice where possible.

Unexpected Exchange Closures

For information on Unexpected Exchange Closures, please refer to S&P Commodities Indices Policies & Practices Methodology.

Recalculation Policy

Intraday index calculations are executed for some index versions whenever the index's primary exchanges are open. In case an issue arises during calculation, the index is restated, based on feasibility assessment by the index committee, for every reported intraday index level period following the issue.

Real-Time Calculation

Real-time, intraday, index calculations are executed for some versions of the index, whenever the index's primary exchanges are open. Real-time indices are not restated.

For information on Calculations and Pricing Disruptions, Expert Judgment and Data Hierarchy, please refer to S&P Commodities Indices Policies & Practices Methodology.

Contact Information

For questions regarding an index, please contact: index_services@spglobal.com.

Index Dissemination

Index levels are available through S&P Dow Jones Indices' Web site at www.spglobal.com/spdji, major quote vendors (see codes below), numerous investment-oriented Web sites, and various print and electronic media.

Tickers

The table below lists headline indices covered by this document. All versions of the below indices that may exist are also covered by this document. Please refer to the [S&P DJI Methodology & Regulatory Status Database](#) for a complete list of indices covered by this document.

Index	BBG	RIC
S&P 500 Futures 40% Defined Volatility Autocall Index (USD) TR	SPDV40AC	.SPDV40AC

Index Data

Daily constituent and index level data are available via subscription.

For product information, please contact S&P Dow Jones Indices, www.spglobal.com/spdji/en/contact-us.

Web Site

For further information, please refer to S&P Dow Jones Indices' Web site at www.spglobal.com/spdji.

Appendix A

Monte Carlo Pricing Method for an Autocall

Each autocall price calculates using a Monte Carlo simulation with a backward induction approach and smoothing applied to the barrier payoffs.

Notation

i	= Path index ($i \in \{1, 2, \dots, NumPaths\}$ where $NumPaths$ is the total number of paths)
j	= Time step index in calendar days from pricing date
t_0	= Pricing date
t_{init}	= Autocall issuance date
t_M	= Autocall maturity date
P	= Autocall principal amount
$S_i(j)$	= Simulated return for path i at time step index j
$I_i(j)$	= Simulated reference index level for path i at time step index j
<i>Strike</i>	= Autocall strike represented as a percentage of reference index level
<i>BarrPrin</i>	= Principal protection barrier for the autocall
<i>BarrCall</i>	= Callable barrier for the autocall
<i>BarrCpn</i>	= Coupon payment barrier for the autocall
C	= Per period coupon rate for the autocall
ϵ	= Smoothing parameter

For more information on creating simulated returns for each path, please refer to Appendix C.

Calculation Steps for a Single Path i

Step 1: Calculate simulated reference index levels

$$I_i(j) = RefIdx_{t_0} \times S_i(j)$$

where:

$$RefIdx_{t_0} = \text{The closing level of the reference index as of pricing date } t_0$$

Step 2: Determine reference index level as of autocall issuance date

$$RefInit_i = \begin{cases} I_i(j_{init}) & \text{if } t_{init} > t_0 \\ RefIdx_{t_{init}} & \text{otherwise} \end{cases}$$

where:

$$j_{init} = (t_{init} - t_0) \text{ in calendar days}$$

$$RefIdx_{t_{init}} = \text{The closing level of the reference index as of autocall issuance date } t_{init}$$

Step 3: Calculate Maturity Payoff

$$R_i(j_M) = \frac{I_i(j_M)}{RefInit_i}$$

$j_M = (t_M - t_0)$ in calendar days

$$V_{prelim,i}(j_M) = \begin{cases} 1 & \text{if } R_i(j_M) > BarrPrin \\ 1 - \max[0, Strike - R_i(j_M)] & \text{if } R_i(j_M) < BarrPrin - \epsilon \\ 1 - \max[0, Strike - (BarrPrin - \epsilon)] \cdot (1 - \phi_{i,1}) & \text{if } BarrPrin - \epsilon \leq R_i(j_M) \leq BarrPrin \end{cases}$$

$$\phi_{i,1} = \text{smooth_indicator}(R_i(j_M) - BarrPrin, \epsilon, \text{True})$$

$$\text{smooth_indicator}(x, \epsilon, \text{form1}) = \begin{cases} \max\left[0, \min\left(1, \frac{x + \epsilon}{\epsilon}\right)\right] & \text{if form1 is True} \\ \max\left[0, \min\left(1, \frac{x}{\epsilon}\right)\right] & \text{if form1 is False} \end{cases}$$

$$\text{gap}_i = 1 + 0.5 \cdot \max[0, R_i(j_M) - 1] - V_{prelim,i}(j_M)$$

$$\phi_{i,2} = \text{smooth_indicator}(R_i(j_M) - BarrCall, \epsilon, \text{gap}_i > 0)$$

$$V_i(j_M) = V_{prelim,i}(j_M) + \phi_{i,2} \times \text{gap}_i$$

Step 4: Calculate Coupon Cashflows at all coupon payment dates

For each coupon payment date, t_C , that is strictly after pricing date, t_0 , with corresponding time step $j_C = (t_C - t_0)$ in calendar days, the coupon cashflow, $CPN_i(j_C)$, calculates as:

$$R_i(j_C) = \frac{I_i(j_C)}{RefInit_i}$$

$$\phi_{i,3} = \text{smooth_indicator}(R_i(j_C) - BarrCpn, \epsilon, \text{True})$$

$$CPN_i(j_C) = C \times \phi_{i,3}$$

Step 5: Add the Coupon Cashflow received at maturity date to the maturity payoff

$$V_i(j_M) = V_i(j_M) + CPN_i(j_M)$$

Step 6: Backward Induction through all Cash Flow Dates

Starting from the second-to-last cash flow date, t_{M-1} , corresponding to time step $j_x = j_{M-1}$, and working backwards to the first cash flow date, t_1 , corresponding to time step $j_x = j_1$ that is strictly after the pricing date, t_0 :

6a. Discount Cash flow from Next Date

$$V_i(j_x) = V_i(j_{x+1}) \times \frac{DF(j_{x+1})}{DF(j_x)}$$

where:

$$DF(j_x) = \text{The discount factor value used to discount the cash flows from date } t_x \text{ back to the pricing date } t_0$$

For more information on how the discount factors are calculated, please refer to Appendix D.

6b. Check for early redemption on Callable Dates

If j_x is a callable date:

$$R_i(j_x) = \frac{I_i(j_x)}{RefInit_i}$$

$$gap_i = 1 + 0.5 \cdot \max[0, R_i(j_x) - 1] - V_i(j_x)$$

$$\phi_{i,4} = \text{smooth_indicator}(R_i(j_x) - BarrCall, \epsilon, gap_i > 0)$$

$$V_i(j_x) = V_i(j_x) + \phi_{i,4} \times gap_i$$

6c. Add coupon cashflow on coupon payment dates

If j_x is a coupon payment date:

$$V_i(j_x) = V_i(j_x) + CPN_i(j_x)$$

Step 7: Final Discounting to Pricing Date

The cash flow at the first cash flow date, $V_i(j_1)$, is discounted back to the pricing date, t_0 , as:

$$V_i(j_0) = DF(j_1) \times V_i(j_1)$$

Computation of Autocall Price

The final price of the autocall price is calculated by averaging the prices from all N simulation paths and multiplying by the principal amount as:

$$ACPriceMC_{t_0} = P \times \frac{1}{NumPaths} \times \sum_{i=1}^{NumPaths} V_i(j_0)$$

Appendix B

Coupon Determination Method for an Autocall

Each autocall coupon is determined by using a Newton-Raphson root-finding algorithm to iteratively solve for the coupon rate where the autocall price produced by the Monte Carlo pricing method is equal to the target price.

The Newton-Raphson method is an iterative root-finding algorithm that solves equations of the form:

$$f(x) = target$$

by rearranging to find the root of:

$$g(x) = f(x) - target = 0$$

The method uses the derivative (gradient) to iteratively refine the estimate:

$$x_{n+1} = x_n - \frac{g(x_n)}{g'(x_n)}$$

which can be rewritten as:

$$x_{n+1} = x_n + \frac{target - f(x_n)}{f'(x_n)}$$

In this context:

x = The coupon rate being solved for

$f(x)$ = The Monte Carlo-based autocall pricing function

$target$ = The target price of the autocall

$f'(x)$ = Derivative of autocall price with respect to the coupon rate that will be estimated numerically

To estimate the derivative $f'(x)$, a forward difference approximation is used as follows:

$$f'(x) \approx \frac{f(x+h) - f(x)}{h}$$

where:

h = A small step size, set to 0.00001

The algorithm stops when either of the following two conditions are met:

1. Tolerance met: $|x_{n+1} - x_n| \leq tol$
2. Maximum iterations reached: $IterCount > n_{max}$

where:

tol = The tolerance level, set to 0.000000001

$IterCount$ = A variable tracking the number of completed algorithm iterations

n_{max} = Maximum number of iterations, set to 10

Newton-Raphson Solver Pseudocode

To derive the final autocall coupon, a Newton-Raphson root-finding algorithm calculates a coupon rate, provided in pseudocode below:

```
FUNCTION newton_solve(target_price, initial_coupon, pricing_function, pricing_args, step_size,
tolerance, max_iterations):

    # Initialize
    coupon = initial_coupon
    iteration = 0

    # Iterative refinement loop
    WHILE True:
        # Calculate current price at current coupon rate
        current_price = pricing_function(coupon, pricing_args...)

        # Estimate derivative numerically
        price_plus = pricing_function(coupon + step_size, pricing_args...)
        derivative = (price_plus - current_price) / step_size

        # Update coupon estimate using Newton-Raphson formula
        IF derivative != 0:
            new_coupon = coupon + (target_price - current_price) / derivative
        ELSE:
            new_coupon = coupon # No change if derivative is zero
        END IF

        # Increment iteration counter
        iteration = iteration + 1

        # Check convergence criteria
        IF iteration > max_iterations OR |new_coupon - coupon| <= tolerance:
            BREAK
        END IF

        # Update for next iteration
        coupon = new_coupon
    END WHILE

    RETURN coupon
END FUNCTION
```

The final coupon rate for the autocall is the coupon value from the solver rounded to seven decimal places:

$$Cpn = \text{round}(\text{coupon}, 7)$$

$$\text{round}(x, nd) = \frac{\text{floor}(x \times 10^{nd} + 0.5)}{10^{nd}}$$

where:

$$\text{floor}(y) = \text{A function that returns the largest integer } z, \text{ such that } z \leq y$$

Appendix C

Generating the Simulated Returns Matrix

The Simulated Returns Matrix, S , represents the set of cumulative returns for each path as of each calendar day from the start. Each row of the matrix represents one simulation path and each column represents one calendar day. Therefore, the matrix has dimensions of $NumPaths \times (NumDays + 1)$.

The paths generate using Geometric Brownian Motion as follows:

$$drift = \left(\mu - \frac{\sigma^2}{2} \right) \times \left(\frac{1}{365} \right)$$
$$\mu = \begin{cases} \ln(1 + r) & \text{if } r \geq 0 \\ -\ln(1 + |r|) & \text{if } r < 0 \end{cases}$$

where:

r = Annualized rate used for simulation

σ = Annualized volatility used for simulation

Initialize an empty matrix S with dimensions of $NumPaths \times (NumDays + 1)$.

For each path i :

- Initial return: $S_i(0) = 1.0$
- For each day j from 1 to $NumDays$ (inclusive):

$$S_i(j) = S_i(j - 1) \times \exp \left(drift + \sigma \times \sqrt{\frac{1}{365}} \times Z_i(j - 1) \right)$$

where:

Z = A matrix, with dimensions $NumPaths \times NumDays$, of independent samples taken from the standard normal distribution

Generating the Standard Normal Samples Matrix

The Standard Normal Samples Matrix, Z , consists of $NumPaths \times NumDays$ independent samples taken from the standard normal distribution. The samples are generated by producing uniform random numbers using a modified variant of the SplitMix64⁴ pseudo-random number generator algorithm and applying the Box-Muller transform method to convert the numbers into standard normal random numbers.

The Z matrix is constructed as follows:

- Initialize an empty matrix Z with dimensions of $NumPaths \times NumDays$
- For each path i from 1 to $NumPaths$ (inclusive):
 - Calculate the seed: $seed = (i - 1) \times NumDays + 1$
 - Initialize random number generator with the calculated seed: `rng.reset_state(seed)`
 - Generate one throwaway value: $throwaway = rng.randn()$ (do not store this value)

⁴ <https://prng.di.unimi.it/splitmix64.c>

- For each day j from 0 to $NumDays - 1$ (inclusive):
 - Generate a random number: $Z_i(j) = rng.randn()$

where:

rng = An instance of the SplitMix64ModifiedRng

Random Number Generator Pseudocode

```

CLASS SplitMix64ModifiedRng

  // Constants
  MASK64 = 2^64 - 1

  // Member variables
  state: unsigned 64-bit integer
  norm: nullable float

  // Constructor
  CONSTRUCTOR()
    state ← 0
    norm ← NULL
  END CONSTRUCTOR

  // Reset the internal state
  METHOD reset_state(stateval)
    state ← stateval
    norm ← NULL
  END METHOD

  // Generate next pseudo-random integer
  METHOD next_int() → unsigned 64-bit integer
    z ← (state × 0x9E3779B97F4A7C15) AND MASK64
    z ← ((z XOR (z >> 30)) × 0xBF58476D1CE4E5B9) AND MASK64
    z ← ((z XOR (z >> 27)) × 0x94D049BB133111EB) AND MASK64
    z ← z XOR (z >> 31)
    state ← state + 1
    RETURN z
  END METHOD

  // Generate uniform random number in [0, 1)
  METHOD rand() → float
    RETURN (next_int() >> 11) / 2^53
  END METHOD

  // Generate standard normal random variable using Box-Muller transform
  METHOD randn() → float
    IF norm = NULL THEN
      u1 ← rand()
      u2 ← rand()
      y1 ← sqrt(-2 × ln(u1))
      y2 ← 2 × pi × u2
      res ← y1 × cos(y2)
      norm ← y1 × sin(y2) // Cache for next call
    ELSE
      res ← norm
      norm ← NULL // Clear cached value
    END IF
    RETURN res
  END METHOD

END CLASS

```

Appendix D

Generating Discount Factors using CME Three-Month SOFR Futures

The discount factors used on a given index calculation day t are constructed from the calendar chain of contracts of the CME Three-Month SOFR Futures available on that day. Only the quarterly contracts – March (H), June (M), September (U) and December (Z) – are considered and all other contract months are ignored. The discount factors are generated iteratively using futures contracts' settlement prices in order of expiration date starting from the nearest expiring contract. The futures contracts' settlement prices are adjusted for convexity prior to the bootstrapping process.

For each futures contract j , the adjusted settlement price calculates as:

$$F_{j,t}^{adj} = SettlePx_{j,t} + round\left(\frac{cvxty_{j,t}}{100}, 4\right)$$

where:

- $SettlePx_{j,t}$ = Settlement Price for futures contract j as of day t
- $cvxty_{j,t}$ = Convexity adjustment value for futures contract j as of day t
- $round(x, nd)$ = A function that rounds the value x to nd number of decimals

The convexity adjustment for futures contract j as of day t calculates as:

$$cvxty_{j,t} = 10000 \times \sigma_{j,t}^2 \times 4 \times teq_{j,t} \times \frac{1}{1 + \frac{R_{j,t}}{4}}$$

$$teq_{j,t} = \max\left(0, \frac{1}{8} \times \left(\frac{Act(t, Te_j)}{365} - \frac{1}{4}\right) \times \left(\frac{Act(t, Te_j)}{365} + \frac{1}{4}\right) + 0.005\right)$$

$$R_{j,t} = \frac{100 - SettlePx_{j,t}}{100}$$

$$\sigma_{j,t}^2 = 252 \times \frac{62}{61} \times \left[\frac{1}{62} \times \sum_{i=t-61}^t (R_{j,i-1} - R_{j,i-2})^2 - \left(\frac{1}{62} \times \sum_{i=t-61}^t (R_{j,i-1} - R_{j,i-2}) \right)^2 \right]$$

where:

- Te_j = The expiration date for futures contract j
- $Act(t, T_j)$ = The number of calendar days from and including day t to but excluding day T_j

Since the calculation of volatility requires the futures contract to be active for at least 63 business days prior to day t , only futures contracts that have at least that history length are used in the bootstrapping process.⁵

⁵ For the back test period starting from 6/20/2018 until and including 8/2/2018 there were no futures contracts that satisfied the 63 business days active criteria. Therefore, the volatility for these dates were calculated using as much data that was available as of each calculation date.

The adjusted settlement price relates to the periodic SOFR rates as follows:

$$\frac{100 - F_{j,t}^{adj}}{100} = \left(\left[\prod_{i=1}^N \left(1 + r_i \times \frac{d_i}{360} \right) \right] - 1 \right) \times \frac{360}{D}$$

where:

- r_i = SOFR rate for business day i
- d_i = Number of calendar days for which SOFR rate r_i is applicable
- N = Number of business days in the reference quarter
- D = Number of calendar days in the reference quarter

For the very first active futures contract, $j = 1$, as of day t :

$$\frac{100 - F_{1,t}^{adj}}{100} \times \frac{Act(Ts_1, Te_1)}{360} = \left[\prod_{i=Ts_1}^{t-1} \left(1 + SOFR_i \times \frac{d_i}{360} \right) \right] \times \left(1 + f_{1,t} \times \frac{Act(t, Te_1)}{360} \right) - 1$$

Representing the above equation as:

$$A = B \times \left(1 + f_{1,t} \times \frac{Act(t, Te_1)}{360} \right) - 1$$

Yields the following formula:

$$f_{1,t} = \left[\frac{1 + A}{B} - 1 \right] \times \frac{360}{Act(t, Te_1)}$$

where:

- Ts_1 = The start date of the reference quarter for futures contract $j = 1$
- $SOFR_i$ = The SOFR rate as of the end of day i
- d_i = The number of calendar days for which $SOFR_i$ is applicable
- $f_{1,t}$ = The rate as of day t applicable from day t to futures expiry date Te_1

The discount factor used to discount cash flows occurring in $Act(t, Te_1)$ days calculates as:

$$DF[Act(t, Te_1)] = \frac{1}{1 + f_{1,t} \times \frac{Act(t, Te_1)}{360}}$$

For all subsequent futures contracts, $j > 1$, the discount factors calculate as:

$$f_{j,t} = \frac{100 - F_{j,t}^{adj}}{100}$$

$$DF[Act(t, Te_j)] = \frac{DF[Act(t, Te_{j-1})]}{1 + f_{j,t} \times \frac{Act(Ts_j, Te_j)}{360}}$$

where:

- Ts_j = The start date of the reference quarter for futures contract j

The discount factors are converted to continuously compounded rates as:

$$rc_t[Act(t, Te_j)] = \frac{365}{Act(t, Te_j)} \times \ln \left(\frac{1}{DF[Act(t, Te_j)]} \right)$$

To calculate the discount factor used to discount cash flows occurring in any x days after day t , piecewise linear interpolation with flat extrapolation is applied to the continuously compounded rates.

The set of known data points $(x_1, y_1), (x_2, y_2), \dots, (x_j, y_j)$ are constructed from the j bootstrapped continuously compounded rates as:

$$(Act(t, Te_1), rc_t[Act(t, Te_1)]), (Act(t, Te_2), rc_t[Act(t, Te_2)]), \dots, (Act(t, Te_j), rc_t[Act(t, Te_j)])$$

The rate for an arbitrary day that is x days after day t calculates as:

$$rc_t[x] = \begin{cases} y_1 & \text{if } x \leq x_1 \\ y_i + \frac{y_{i+1} - y_i}{x_{i+1} - x_i} \times (x - x_i) & \text{if } x_i < x < x_{i+1}, \quad i = 1, \dots, j - 1 \\ y_j & \text{if } x \geq x_j \end{cases}$$

The discount factor calculates as:

$$DF[Act(t, t + x)] = \exp\left(-rc_t[x] \times \frac{x}{365}\right)$$

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