

S&P U.S. Equity Momentum 40% VT 4% Decrement Autocall Index *Methodology*

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Table of Contents

Introduction	3
Index Objective and Highlights	3
Supporting Documents	3
Index Construction	4
Autocall Parameters	4
Index Calculation	4
Cash Calculation	4
Premium Calculation	5
Redemption Amount at Call Date Calculation	5
Cash Amount from Downsizing Calculation	5
Coupon Amount Calculation	6
Notional Amount Calculation	7
Mark-to-Market Value Calculation	7
Autocall Group Construction	7
Coupon Rate Determination	8
Index Maintenance	9
Additional Index Return Series	9
Base Date and History Availability	9
Index Data	10
Index Governance	11
Index Committee	11
Index Policy	12
Announcements	12
Holiday Schedule	12
Rebalancing	12
Unexpected Exchange Closures	12
Recalculation Policy	12
Real-Time Calculation	12
Contact Information	12
Index Dissemination	13
Tickers	13
Index Data	13

	Web Site	13
Appendix A		14
	Autocall Monte Carlo Pricing Method	14
Appendix B		17
	Generating the Simulated Returns Matrix	17
	Generating the Standard Normal Samples Matrix	17
	Random Number Generator Pseudocode	18
Appendix C		19
	Generating Discount Factors Using CME Three-Month SOFR Futures	19
Disclaimer		21

Introduction

Index Objective and Highlights

The S&P U.S. Equity Momentum 40% VT 4% Decrement Autocall Index measures the performance of a group of autocalls on the S&P U.S. Equity Momentum 40% VT 4% Decrement Index. The group is seeded with 24 autocalls issued over the first 24 weeks of the index’s life and is subsequently maintained near that size through a systematic weekly rolling mechanism. Each autocall is held until either it is called early as the redemption criteria is met or until it has been alive for three years and is closed out. Cash received from periodic coupon payments, early redemptions, and downsizes are reinvested into new autocalls periodically.

For more information on the S&P U.S. Equity Momentum 40% VT 4% Decrement Index, please refer to the S&P U.S. Equity Momentum 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 issued autocall (k):

Parameter	Variable	Value
Principal Amount	P	1.0
Autocall Strike	$Strike$	100%
Autocall Barrier	$BarrCall$	100%
Principal Barrier	$BarrPrin$	60%
Coupon Barrier	$BarrCpn$	60%
Number of Simulation Paths	$NumPaths$	50,000
Number of Calendar Days Simulated per Path	$NumDays$	1,875
Callable barrier asymmetry shift	Δ	0.15%
Coupon payment barrier call spread width	wc	2.50%

Index Calculation

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

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

where:

$Index_t$ = Closing level of the index for day t

$Cash_t$ = Value of the cash balance 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 base date, $t = 0$, the cash value initializes as:

$$Cash_0 = 100 - \frac{100}{24}$$

For every subsequent index calculation day t , the value of the cash balance calculates as:

$$Cash_t = Cash_{t-1} - PR_t + ER_t + DS_t + CP_t$$

where:

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

ER_t = The sum of the redemption amounts from all autocalls held by the index that were called prior to the autocall's maturity date on day t

DS_t = The sum of the cash received from all autocalls that were downsized by the index on day t

CP_t = The sum of the coupon amounts from all autocalls held by the index that paid a coupon on day t

Premium Calculation

If no new autocall initiated on day t :

$$PR_t = 0$$

If a new autocall initiated on day t :

$$PR_t = M_{k,t}$$

where:

$M_{k,t}$ = Mark-to-market value of k as of the end of day t

Redemption Amount at Call Date Calculation

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

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

where:

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

For each autocall 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:

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

If day t is a callable date:

$$E_{k,t} = \begin{cases} N_{k,t-1} & \text{if } \frac{RefIdx_t}{RefIdx_{t_k}} > BarrCall \\ 0 & \text{otherwise} \end{cases}$$

where:

$RefIdx_t$ = The closing level of the S&P U.S. Equity Momentum 40% VT 4% Decrement Index for day t rounded to two decimal places

t_k = The issuance date for autocall k

$BarrCall$ = The callable barrier value for autocall k

$N_{k,t-1}$ = The notional amount for autocall k as of the end of day $t - 1$

Cash Amount from Downsizing Calculation

The total cash received from all autocalls that were downsized by the index on day t calculates as:

$$DS_t = \sum_k CD_{k,t}$$

where:

$CD_{k,t}$ = The cash received from autocall k due to downsizing as of the end of day t

For each autocall k held by the index at the start of day t , the cash received from downsizing calculates as:

If day t is not a downsize date for autocall k :

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

If day t is a downsize date for autocall k :

$$CD_{k,t} = (N_{k,t-1} - N_{k,t}) \times (ACPriceMC_{k,t} - tcost)$$

where:

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

$tcost$ = The transaction cost for downsizing which is set to a fixed value of 0.025

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 :

$$C_{k,t} = \begin{cases} N_{k,t-1} \times MEM_{k,t-1} \times \frac{Cpn_k}{12} & \text{if } \frac{RefIdx_t}{RefIdx_{t_k}} > BarrCpn \\ 0 & \text{otherwise} \end{cases}$$

where:

Cpn_k = The annualized coupon rate for autocall k

$BarrCpn$ = The coupon barrier value for autocall k

$MEM_{k,t-1}$ = The memory coupon value for autocall k as of the end of day $t - 1$

The memory coupon value for autocall k as of the end of day t calculates as:

If day t is the issuance date for autocall k :

$$MEM_{k,t} = 1$$

If day t is a coupon payment date for autocall k :

$$MEM_{k,t} = \begin{cases} 1 & \text{if } \frac{RefIdx_t}{RefIdx_{t_k}} > BarrCpn \\ MEM_{k,t-1} + 1 & \text{otherwise} \end{cases}$$

For all other days:

$$MEM_{k,t} = MEM_{k,t-1}$$

Notional Amount Calculation

For each autocall k , the notional amount at the end of day t calculates as:

$$N_{k,t} = \begin{cases} M_{k,t} & \text{if day } t \text{ is the issuance date for autocall } k \\ 0.66 \times N_{k,t-1} & \text{if day } t \text{ is the 24th coupon payment date for autocall } k \text{ and } \frac{RefIdx_t}{RefIdx_{t_k}} \leq BarrCall \\ 0 & \text{if day } t \text{ is the 36th coupon payment date for autocall } k \text{ and } \frac{RefIdx_t}{RefIdx_{t_k}} \leq BarrCall \\ 0 & \text{if day } t \text{ is a callable date for autocall } k \text{ and } \frac{RefIdx_t}{RefIdx_{t_k}} > BarrCall \\ N_{k,t-1} & \text{otherwise} \end{cases}$$

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:

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

If day t is the issuance date for any of the first 24 autocalls, $k = 1, 2, 3, \dots, 24$, then the mark-to-market value for autocall k as of the end of day t calculates as:

$$M_{k,t} = \frac{100}{24}$$

If day t is the issuance date for any autocall that is after the initial 24, $k > 24$, then the mark-to-market value for autocall k as of the end of day t calculates as:

$$M_{k,t} = \min\left(\frac{Index_{t-1}}{6}, Cash_{t-1}\right)$$

For any other day t that is not the issuance date for autocall k , the mark-to-market value for autocall k as of the end of day t calculates as:

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

where:

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

For more information on the Monte Carlo-based method used to price a single autocall, please refer to Appendix A.

Autocall Group Construction

The autocall portfolio initializes by issuing a new autocall on each of the following index calculation dates:

09/05/2007	10/04/2007	11/02/2007	12/04/2007	01/04/2008	02/05/2008
09/12/2007	10/11/2007	11/09/2007	12/11/2007	01/11/2008	02/12/2008
09/19/2007	10/18/2007	11/16/2007	12/18/2007	01/18/2008	02/20/2008
09/26/2007	10/25/2007	11/26/2007	12/26/2007	01/28/2008	02/27/2008

Starting from 02/27/2008, eligible autocall issuance dates are generated by stepping forward through NYSE business days in a repeating cycle of six, five, five, five. That is, the first issuance date after 02/27/2008 falls six business days later, the next is five business days after that, the one after that another five business days later, and the one after that another five business days later — completing one cycle of 21 business days in total. This 6-5-5-5 cycle repeats ad infinitum, with each new cycle beginning six business days after the last date of the previous cycle.

For example, the first complete cycle from 02/27/2008 produces the issuance dates below:

Cycle Number	Step Number	Days After Previous	Issuance Date
1	0 (start)	—	02/27/2008
1	1	+6	03/06/2008
1	2	+5	03/13/2008
1	3	+5	03/20/2008
1	4	+5	03/28/2008
2	1	+6 (<i>next cycle begins</i>)	04/07/2008

For any date t after 02/27/2008 on which a new autocall could be issued, a new autocall is issued only when the following condition is met:

$$\min\left(\frac{Index_{t-1}}{6}, Cash_{t-1}\right) \geq \frac{Index_{t-1}}{24}$$

For each autocall k , the set of coupon payment dates calculate as:

- The first coupon payment date, $t_{k,1}$, is the date 20 business days after issuance date t_k
- The next coupon payment date, $t_{k,j}$, $j = 2,3,4, \dots, 60$ is the date 21 business days after the previous coupon date, $t_{k,j-1}$
- The last coupon payment date, $t_{k,60}$, is also the expiration date for the autocall

For each autocall k , there is a six-month no call period for the issuance date. Therefore, the set of callable dates for autocall k consists of all coupon payment dates after and including the sixth coupon payment date.

For each autocall k , the 24th and 36th coupon payment dates are downsizing dates on which the autocall can be downsized.

Coupon Rate Determination

- The coupon rate for a new autocall, k , that will be issued on day t is determined one business day prior by finding the coupon rate value that causes the Monte Carlo-based model price of the forward starting autocall to be near the target price.
- For each coupon rate C_j , starting from 0% to 30% inclusive in 5% increments, the price as of day $t - 1$, $P_{j,t-1}$, for the autocall, k , that will be issued on day t calculates.
- The coupon rate for autocall k calculates as:

$$Cpn_k = \max\left(0, C_{low} + \left(\frac{C_{high} - C_{low}}{P_{high,t-1} - P_{low,t-1}}\right) \times (TargetPx - P_{low,t-1})\right)$$

where:

C_{high} = The smallest coupon rate C_j that has price $P_{j,t-1} \geq TargetPx$

C_{low} = The largest coupon rate C_j that has price $P_{j,t-1} < TargetPx$

$P_{high,t-1}$ = The Monte Carlo-based model price for a coupon rate of C_{high} as of day $t - 1$

$P_{low,t-1}$ = The Monte Carlo-based model price for a coupon rate of C_{low} as of day $t - 1$

$TargetPx$ = The target price for the new autocall set by user

For all date determinations and references to business days, the index follows the NYSE trading calendar.

Index Maintenance

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 U.S. Equity Momentum 40% VT 4% Decrement Autocall Index	06/18/2026	09/05/2007	09/05/2007	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 U.S. Equity Momentum 40% VT 4% Decrement Autocall Index (USD) ER	SPUMPAC	.SPUMPAC

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

Autocall Monte Carlo Pricing Method

The price for an autocall calculates using a Monte Carlo simulation. The price calculates using a two-leg decomposition: the coupon leg, which captures all positive cash flows, and the put leg, which captures the downside exposure at expiration.

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 expiration 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
$BarrPrin$	= Principal protection barrier for the autocall
$BarrCall$	= Callable barrier for the autocall
$BarrCpn$	= Coupon payment barrier for the autocall
C	= Annualized coupon rate for the autocall
Δ	= Callable barrier asymmetry shift
wc	= Coupon payment barrier call spread width
$\delta_i^{cpn}(j)$	= A binary flag for path i that is 1 if the coupon leg has been called on or before time step j ; otherwise 0
$\delta_i^{put}(j)$	= A binary flag for path i that is 1 if the put leg has been called on or before time step j ; otherwise 0
$MEM_i(j)$	= Memory Coupon value for path i as of time step j

For more information on how to create the simulated returns for each path, please refer to Appendix B.

Calculation Steps for a Single Path i

Step 1: Compute 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: Update State Variables

$$\delta_i^{cpn}(0) = 0$$

$$\delta_i^{put}(0) = 0$$

$$MEM_i(0) = M_0$$

where:

$$M_0 = \text{The memory coupon value as of the pricing date } t_0$$

Step 4: Calculate cash flows at each coupon payment date prior to expiration date t_M

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, and strictly before expiration date t_M , the return, $R_i(j_c)$, calculates as:

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

If t_c is a callable date:

$$\delta_i^{cpn}(j_c) = \begin{cases} 1 & \text{if } R_i(j_c) \geq (BarrCall + \Delta) \\ \delta_i^{cpn}(j_c - 1) & \text{otherwise} \end{cases}$$

$$\delta_i^{put}(j_c) = \begin{cases} 1 & \text{if } R_i(j_c) \geq (BarrCall - \Delta) \\ \delta_i^{put}(j_c - 1) & \text{otherwise} \end{cases}$$

The cash flow received on coupon payment date, t_c , calculates as:

$$CF_i^{cpn}(j_c) = \begin{cases} P \times \left(1 + \frac{C}{12} \times MEM_i(j_c - 1)\right) & \text{if } \delta_i^{cpn}(j_c - 1) = 0 \text{ and } \delta_i^{cpn}(j_c) = 1 \\ P \times \frac{C}{12} \times MEM_i(j_c - 1) \times \min\left(1, \max\left(0, \frac{R_i(j_c) - (BarrCpn - wc)}{wc}\right)\right) & \text{if } \delta_i^{cpn}(j_c) = 0 \text{ and } R_i(j_c) > (BarrCpn - wc) \\ 0 & \text{if } \delta_i^{cpn}(j_c - 1) = 1 \text{ or } R_i(j_c) \leq (BarrCpn - wc) \end{cases}$$

$$CF_i^{put}(j_c) = 0$$

The memory coupon value as of date t_c calculates as:

$$MEM_i(j_c) = \begin{cases} 1 + MEM_i(j_c - 1) & \text{if } R_i(j_c) \leq BarrCpn - wc \\ 1 + MEM_i(j_c - 1) \times \left(1 - \min\left(1, \max\left(0, \frac{R_i(j_c) - (BarrCpn - wc)}{wc}\right)\right)\right) & \text{otherwise} \end{cases}$$

For every time step j that is not a coupon payment date, the state variables calculate as:

$$\delta_i^{cpn}(j) = \delta_i^{cpn}(j - 1)$$

$$\delta_i^{put}(j) = \delta_i^{put}(j - 1)$$

$$MEM_i(j) = MEM_i(j - 1)$$

Step 5: Calculate cash flow at expiration date

The return $R_i(j_M)$ at expiration date, t_M , with corresponding time step $j_M = (t_M - t_0)$ in calendar days, calculates as:

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

The cash flow received on expiration date, t_M , calculates as:

$$CF_i^{cpn}(j_M) = \begin{cases} P & \text{if } \delta_i^{cpn}(j_M - 1) = 0 \\ & \text{and } R_i(j_M) \leq (BarrCpn - wc) \\ P \times \left[1 + \frac{C}{12} \times MEM_i(j_M - 1) \times \min \left(1, \max \left(0, \frac{R_i(j_M) - (BarrCpn - wc)}{wc} \right) \right) \right] & \text{if } \delta_i^{cpn}(j_M - 1) = 0 \\ & \text{and } R_i(j_M) > (BarrCpn - wc) \\ 0 & \text{if } \delta_i^{cpn}(j_M - 1) = 1 \end{cases}$$

$$CF_i^{put}(j_M) = \begin{cases} -P \times \max(0, 1 - R_i(j_M)) & \text{if } \delta_i^{put}(j_M - 1) = 0 \text{ and } R_i(j_M) < BarrPrin \\ 0 & \text{otherwise} \end{cases}$$

Step 6: Discount cash flows back to pricing date

For each cash flow date t_j that is strictly after pricing date t_0 , the discounted value calculates as:

$$V_{cpn}(i) = \sum_{j=1}^M DF(j) \times CF_i^{cpn}(j)$$

$$V_{put}(i) = \sum_{j=1}^M DF(j) \times CF_i^{put}(j)$$

where:

$DF(j)$ = The discount factor value¹ used to discount the cash flows from date t_j back to the pricing date t_0

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

Calculation of Autocall Price

The final price of the autocall price calculates by averaging the prices calculated over all *NumPaths* simulation paths as:

$$V_{cpn} = \frac{1}{NumPaths} \times \sum_{i=1}^{NumPaths} V_{cpn}(i)$$

$$V_{put} = \frac{1}{NumPaths} \times \sum_{i=1}^{NumPaths} V_{put}(i)$$

$$ACPriceMC = V_{cpn} + V_{put}$$

¹ For history prior to 06/20/2018, U.S. Treasury yield curve rates were used to calculate the discount factors. The starting date of the reference period for the very first CME Three-Month SOFR Futures was 06/20/2018. Therefore, the bootstrapped discount factors were only available from this date forward. The source for the U.S. Treasury yield curve rates is the U.S. Department of the Treasury. The rates were captured at 18:00 New York Time every day and used for the following business day.

Appendix B

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 whereas each column represents one calendar day. Therefore, the matrix will have dimensions of $NumPaths \times (NumDays + 1)$.

The paths generate using Geometric Brownian Motion as follows:

$$x = \left(\mu - \frac{\sigma^2}{2} \right) \times \left(\frac{1}{365} \right)$$

where:

μ = The continuous drift rate used for simulation

σ = The 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):

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

where:

Z = A matrix, having 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 the SplitMix64² pseudo-random number generator algorithm and applying the Box-Muller transform to convert them into standard normal random numbers.

The Z matrix is constructed as follows:

- Initialize an empty matrix Z with dimensions of $NumPaths \times NumDays$
- Create an instance of SplitMix64Rng, rng with a specific seed value³
- For each path i from 1 to $NumPaths$ (inclusive):
 - For each day j from 0 to $NumDays - 1$ (inclusive):
 - Generate a random number: $Z_i(j) = rng.randn()$

² <https://prng.di.unimi.it/splitmix64.c>

³ The index uses a seed value of 3141592653.

Random Number Generator Pseudocode

```
CLASS SplitMix64Rng

  // Constants
  MASK64 = 2^64 - 1

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

  // Constructor
  CONSTRUCTOR(seedval)
    state ← seedval AND MASK64
    norm ← NULL
  END CONSTRUCTOR

  // 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 ← z
    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 C

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 settlement prices of the futures contracts in order of expiration date starting from the nearest expiring contract.

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

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

where:

- $\text{SettlePx}_{j,t}$ = The Settlement Price for futures contract j as of day t
- r_i = SOFR rate for business day i
- d_i = The number of calendar days for which SOFR rate r_i is applicable
- N = The number of business days in the reference quarter
- D = The number of calendar days in the reference quarter

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

$$\frac{100 - \text{SettlePx}_{1,t}}{100} \times \frac{\text{Act}(T_{S_1}, T_{e_1})}{360} = \left[\prod_{i=T_{S_1}}^{t-1} \left(1 + \text{SOFR}_i \times \frac{d_i}{360} \right) \right] \times \left(1 + f_{1,t} \times \frac{\text{Act}(t, T_{e_1})}{360} \right) - 1$$

Representing the above equation as:

$$A = B \times \left(1 + f_{1,t} \times \frac{\text{Act}(t, T_{e_1})}{360} \right) - 1$$

Yields the following formula:

$$f_{1,t} = \left[\frac{1 + A}{B} - 1 \right] \times \frac{360}{\text{Act}(t, T_{e_1})}$$

where:

- T_{S_1} = The start date of the reference quarter for futures contract $j = 1$
- T_{e_1} = The expiration date 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 T_{e_1}
- $\text{Act}(t, T)$ = The number of calendar days from and including day t to but excluding day T

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:

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

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

where:

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

Te_j = The expiration date for futures contract j

The discount factors convert 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 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 a day that is x days after day t calculates as:

$$rc_t[x] = \begin{cases} y_1 + \frac{y_2 - y_1}{x_2 - x_1} \times (x - x_1) & \text{if } x \leq x_1 \\ y_i + \frac{y_{i+1} - y_i}{x_{i+1} - x_i} \times (x - x_i) & \text{if } x_i < x < x_{i+1}, \quad i = 1, \dots, j - 1 \\ y_{j-1} + \frac{y_j - y_{j-1}}{x_j - x_{j-1}} \times (x - x_{j-1}) & \text{if } x \geq x_j \end{cases}$$

The discount factor calculates as:

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

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