UBS AG Trigger Autocallable Contingent Yield Notes linked to the common stock of MetLife, Inc. due January 9, 2026

Introduction

This report attempts to value the price of the UBS AG Trigger Autocallable Contingent Yield Notes linked to common stock of MetLife, Inc. due January 2026. We estimate the value of the note under consideration to be **$9.745**.

Some of the basic terms related to the Note are given below:

Key Dates	
Trade Date	January 6, 2023
Settlement Date	January 11, 2023
Observation Dates	Quarterly (callable after 6 months)
Final Valuation Date	January 6, 2026
Maturity Date	January 9, 2026

Underlying Asset	Bloomberg Ticker	Contingent Coupon Rate	Initial Level	Call Threshold Level	Coupon Barrier	Downside Threshold	CUSIP	ISIN
MetLife, Inc.	MET	8.60% p.a	$73.58	$73.58, which is 100.00% of the Initial Level	$39.62 (53.85% of the Initial Level)	$39.62, (53.85% of the Initial Level)	90289 W276	US90289W2769

Observation Dates	Coupon Payment Dates
April 6, 2023	April 10, 2023
July 6, 2023	July 10, 2023
October 6, 2023	October 11, 2023
January 8, 2024	January 10, 2024
April 8, 2024	April 10, 2024
July 8, 2024	July 10, 2024
October 7, 2024	October 9, 2024
January 6, 2025	January 8, 2025
April 7, 2025	April 9, 2025
July 7, 2025	July 9, 2025
October 6, 2025	October 8, 2025
Final Valuation Date	Maturity Date

The basic features of the note are:

1) The note has only one underlying asset. i.e., the common stock of MetLife, Inc.
2) On the observation dates, the notes will be autocalled by the issuer based on stock prices on the corresponding dates (discussed later)
3) There are contingent coupon payments on discrete dates, based on stock prices of the underlying asset i.e., MetLife Inc. on corresponding dates.

Approach:

We have used a 10960-step binomial model to ascertain the value of the note in our model. We are aware of the errors in valuation that crop up in a binomial model and therefore have taken the following steps:

1) Used a 10960-step binomial tree which is sufficiently large to reduce the error.
2) Utilized the **Cox, Ross, & Rubinstein (CRR)** method to value the note. This approach gives us the flexibility to incorporate complex features of notes. (*More models will be discussed in the later parts of the report*)

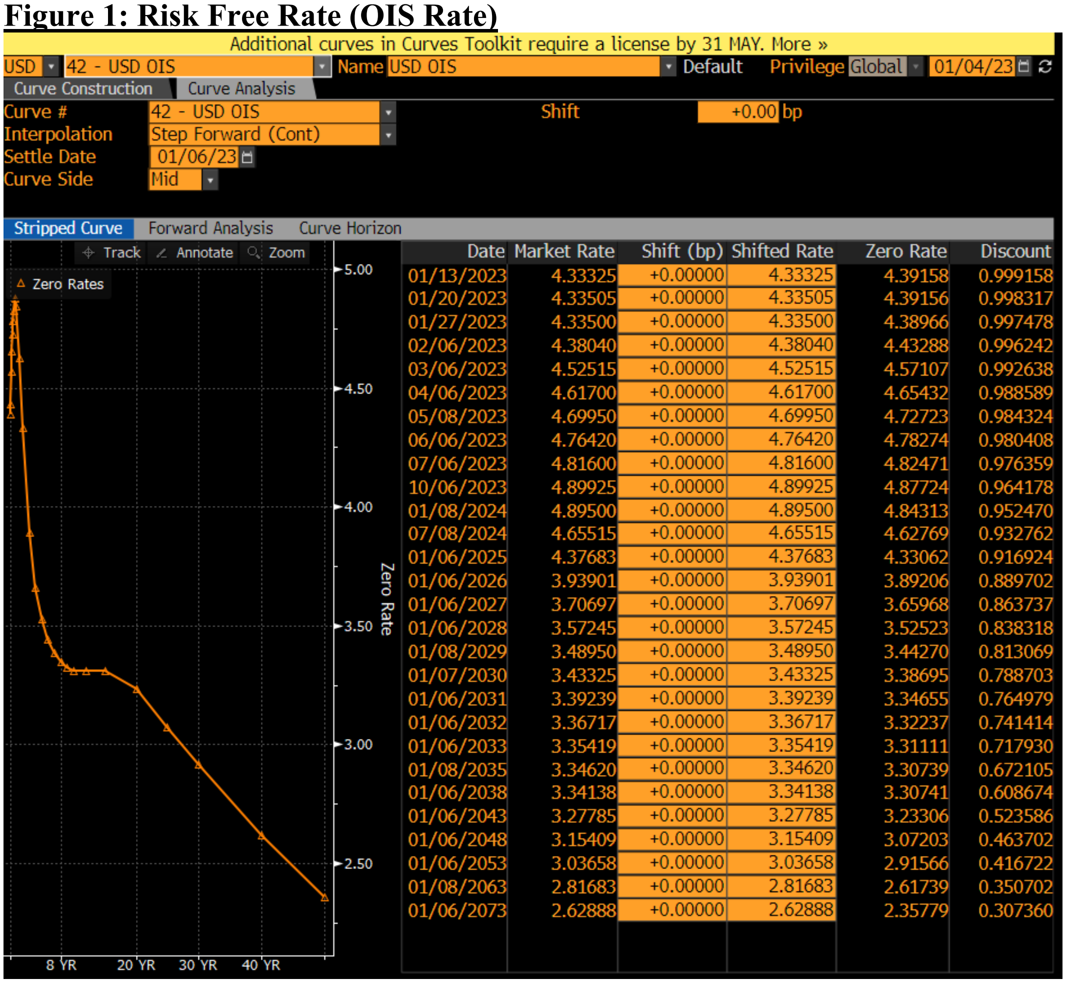
We are aware that despite these steps taken, there will be non-linearity errors in the value mainly due to payments related to discrete time points (*autocallable and contingent coupon feature of the note*). We will discuss the values derived from other models to make sure we are close to the values given by other and sometimes more sophisticated model of binomial method of option valuation.

For the dynamic components of our model, we have extracted data from a reliable source i.e., Bloomberg for precision of our values. The values we extracted from Bloomberg were OIS rate (in lieu of risk-free rate), dividend yields and implied volatilities. The screenshots have been provided below with the date ranges and moneyness visible for understanding.

Final Value:

Using the CRR method, we have concluded that the value of the note is **$9.745**. We will describe next what the CRR method entails and how does it help us to find the accurate values of options and notes of these nature. We have also conducted sensitivity analysis of the model using a reasonable range of volatilities and come up with a plausible set of values of the note, if some of the factors change or are interpreted in a different way.

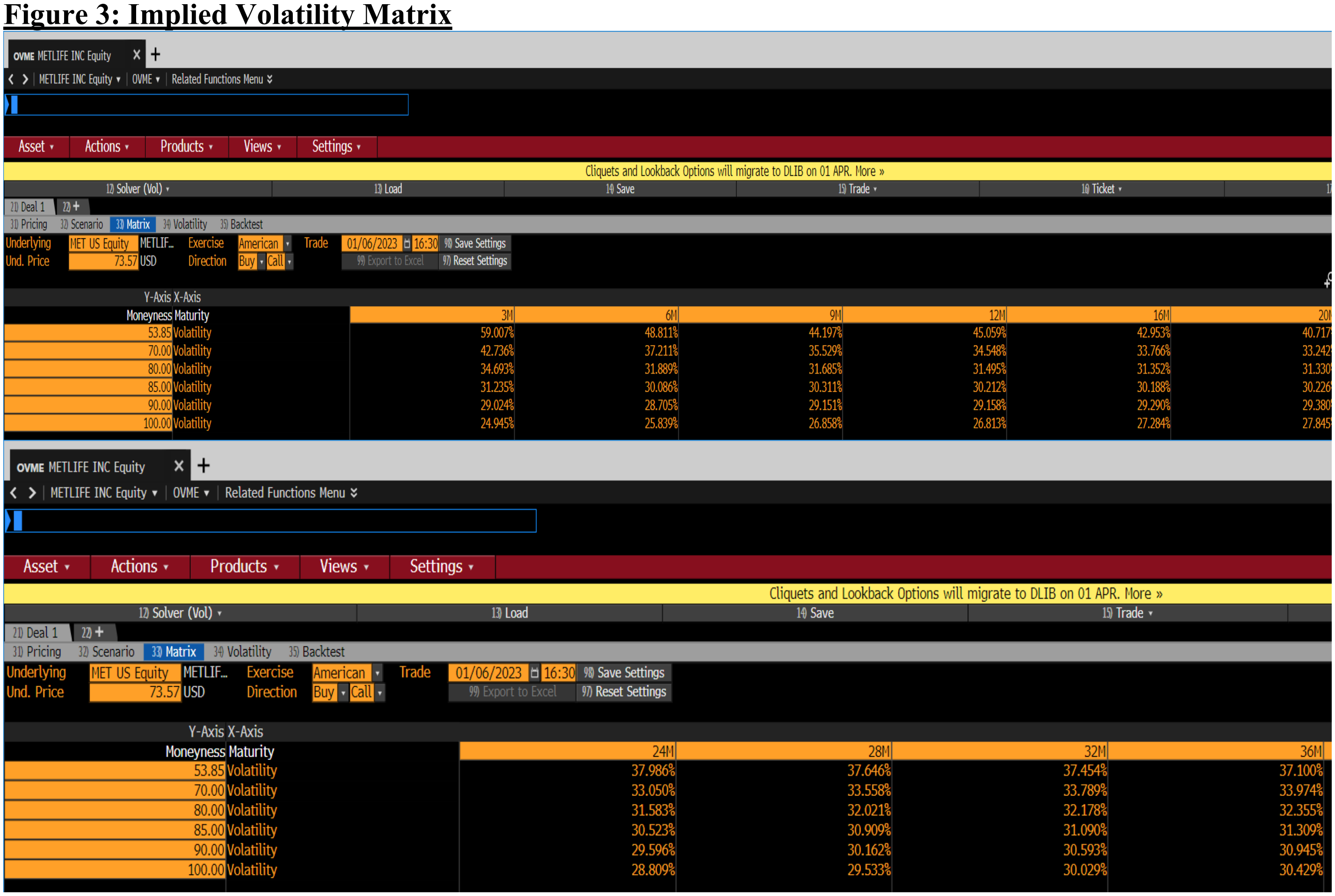
Figure 1: Risk Free Rate (OIS Rate)



Date	Market Rate	Shift (bp)	Shifted Rate	Zero Rate	Discount
01/13/2023	4.33325	+0.00000	4.33325	4.39158	0.999158
01/20/2023	4.33505	+0.00000	4.33505	4.39156	0.998317
01/27/2023	4.33500	+0.00000	4.33500	4.38966	0.997478
02/06/2023	4.38040	+0.00000	4.38040	4.43288	0.996242
03/06/2023	4.52515	+0.00000	4.52515	4.57107	0.992638
04/06/2023	4.61700	+0.00000	4.61700	4.65432	0.988589
05/08/2023	4.69950	+0.00000	4.69950	4.72723	0.984324
06/06/2023	4.76420	+0.00000	4.76420	4.78274	0.980408
07/06/2023	4.81600	+0.00000	4.81600	4.82471	0.976359
10/06/2023	4.89925	+0.00000	4.89925	4.87724	0.964178
01/08/2024	4.89500	+0.00000	4.89500	4.84313	0.952470
07/08/2024	4.65515	+0.00000	4.65515	4.62769	0.932762
01/06/2025	4.37683	+0.00000	4.37683	4.33062	0.916924
01/06/2026	3.93901	+0.00000	3.93901	3.89206	0.889702
01/06/2027	3.70697	+0.00000	3.70697	3.65968	0.863737
01/06/2028	3.57245	+0.00000	3.57245	3.52523	0.838318
01/08/2029	3.48950	+0.00000	3.48950	3.44270	0.813069
01/07/2030	3.43325	+0.00000	3.43325	3.38695	0.788703
01/06/2031	3.39239	+0.00000	3.39239	3.34655	0.764979
01/06/2032	3.36717	+0.00000	3.36717	3.32237	0.741414
01/06/2033	3.35419	+0.00000	3.35419	3.31111	0.717930
01/08/2035	3.34620	+0.00000	3.34620	3.30739	0.672105
01/06/2038	3.34138	+0.00000	3.34138	3.30741	0.608674
01/06/2043	3.27785	+0.00000	3.27785	3.23306	0.523586
01/06/2048	3.15409	+0.00000	3.15409	3.07203	0.463702
01/06/2053	3.03658	+0.00000	3.03658	2.91566	0.416722
01/08/2063	2.81683	+0.00000	2.81683	2.61739	0.350702
01/06/2073	2.62888	+0.00000	2.62888	2.35779	0.307360

Figure 2: Dividend Yields

Figure 3: Implied Volatility Matrix



Valuation Model

We have attempted to arrive at the value of this instrument using the binomial pricing model and input data obtained from Bloomberg, following the steps detailed below.

Estimating parameters (u, d and q) to construct of the binomial tree

Assuming no arbitrage, we estimate the value of the instrument using risk-neutral probabilities discounted at the risk-free rate. We have used the Cox, Ross and Rubenstein (CRR) model to determine the size of the up (u) and down (d) movements where:
$u = e^{\sigma\sqrt{\Delta t}}$ and $d = 1/u$

The risk-neutral probabilities (q and $1 - q$) are given by:
$q = \frac{e^{r\Delta t} - d}{u - d}$ and $1 - q = \frac{u - e^{r\Delta t}}{u - d}$

and r is the OIS rate and σ is the implied volatility (Figure 1 and 3 respectively).

Assumptions:
- In the risk-neutral world, all the assets have an expected return equal to the risk-free rate: $E[St] = S_0 e^{rt}$.
- Variance of returns = $\sigma^2 t$ over a period of time t.
- The underlying asset's returns are normally distributed over a period t with mean = $(r - ½\sigma^2)t$ and variance = $\sigma^2 t$: $r_t \sim N((r - ½\sigma^2)t, \sigma^2 t)$.

Constructing the stock price tree

We constructed the stock price tree with N = 10960 steps and τ = 3.0027 years or 1096 days which is the period between the Trade date and the Final Valuation date during which stock price movements are observed to determine the note payoff where:
- j denotes each time step ranging from 0 to N
- i is the number of up movements in the stock price at each time step (j) ranging from 0 to j.

For example, the stock price ($S_{j,i}$) at t = 0 or the current stock price will be denoted as $S_{0,0}$ to indicate that we are at time step (j) = 0 and that the number of up movements in the stock price (i) = 0.

We can now calculate the stock price at each node in the binomial tree with N = 10960 steps using the formula: $S_{j,i} = S_0 u^i d^{(j-i)}$.
For example,
- To obtain the stock price at the node $S_{1,1}$ (stock price after one time step ($j = 1$) that has moved up ($i = 1$)), we multiply $S_{0,0}$ with u (as $i = 1$) and 1 (as $j - i = 0$).
- At the top most node of the tree after N time steps, we have $S_{N,j}$ (where the stock price after N time steps ($j = N$) has only faced up movements ($i = j$)) equal to $S_{0,0}$ multiplied by u^j (as $i = j$ i.e. the stock price has gone up j times) and 1 (as $j - i = 0$) i.e. the stock price has not faced any down movements).

Additionally, we have factored in proportional discrete dividends using the dividend yield data obtained from Bloomberg (Figure 2) and the forecasted ex-dividend dates obtained from https://www.dividendmax.com/united-states/nyse/life-insurance/metlife-inc/dividends.
Dividends for MetLife US Equity are paid quarterly, and we have captured the drop in stock price from S_t to $S_t(1 - D)$ at the nodes on the time steps corresponding to the ex-dividend dates.

Constructing the valuation tree using backward induction

After we have the stock price tree, we constructed a new tree i.e., the valuation tree, where we start by specifying the note's value corresponding to each node of the stock price tree at maturity, which is equal to its payoff at maturity. The payoff of the UBS AG Trigger Autocallable Contingent Yield Notes at maturity is as follows:

$$Payoff = V_{\mathrm{T,i}} = \begin{cases} Principal\ Amount + Coupon_{\mathrm{T}} & \text{if } \mathrm{S_T} \geq \mathrm{B} \\ Principal\ Amount * (1 + \text{Underlying return}) & \text{if } \mathrm{S_T} < \mathrm{B} \end{cases}$$

where T = maturity date, $Principal\ Amount$ = \$10, $\mathrm{S_T}$ = Stock price at maturity and B = Downside threshold level or Coupon Barrier and $i = 0\ to\ N$.

In our valuation tree, since τ corresponds to the final valuation date, we discount the payoff at maturity as stated above by the risk-free rate $(r_{\tau,\mathrm{T}})$ between the maturity date (T) and the final valuation date (τ).
Thus,

$$V_{\tau,\mathrm{i}} = \begin{cases} (Principal\ Amount + Coupon_{\mathrm{T}}) * \mathrm{e}^{[r_{\tau,\mathrm{T}} * (\mathrm{T} - \tau)]} & \text{if } \mathrm{S_T} \geq \mathrm{B} \\ [Principal\ Amount * (1 + \text{Underlying return})] * \mathrm{e}^{[r_{\tau,\mathrm{T}} * (\mathrm{T} - \tau)]} & \text{if } \mathrm{S_T} < \mathrm{B} \end{cases}$$

Using backward induction and the binomial formula: $V_{j,i} = e^{-r\Delta \mathrm{t}}[qV_{j+1,i+1} + (1-q)V_{j+1,i}]$, we obtain the value of the instrument at all nodes in the binomial tree with N = 10960 steps. However, we need to adjust the payoff at the time steps corresponding to the observation dates to obtain the value of the note which incorporates the value of its complex features i.e., the contingent coupon and auto callable features.

- At each of the observation dates, for $\mathrm{B} \leq \mathrm{S_T} < \mathrm{K}$ (observed in the stock price tree at the time step corresponding to each observation date), on the corresponding nodes of the valuation tree, we adjust the payoff to $V_{j,i} = e^{-r\Delta \mathrm{t}}[qV_{j+1,i+1} + (1-q)V_{j+1,i}] + \text{Coupon}*\mathrm{e}^{-\mathrm{r}\delta}$.
- For $\mathrm{S_T} \geq \mathrm{K}$, the payoff is adjusted to $V_{j,i} = \text{Principal Amount} + \text{Coupon}*\mathrm{e}^{-\mathrm{r}\delta}$,

where $\delta = \text{number of days between the observation date and the coupon payment date}$ and $K = \text{Call Threshold Level}$

Finally, we obtain the values corresponding to the node $\mathrm{V_{0,0}}$ on the valuation tree and estimate the final value of the note after performing a sensitivity analysis of the model (discussed ahead).

Discussion/Analysis

Parameters used and Sensitivity Analysis

In this section, we discuss the accuracy of our input parameters and conduct a sensitivity analysis using a varying range of plausible volatilities.

Dividends:
We have used the proportional discrete dividends approach which results in an appropriate valuation for instruments with a single stock as its underlying asset as is our case. Using this approach ensures that the binomial tree recombines at each time step which maintains the simplicity of the model as opposed to the fixed size discrete dividends approach.
Although the continuous dividends approach is the easiest to model, this does not reflect real-world scenarios as dividends are almost always paid on discrete dates.

Implied Volatilities:
The risk-neutral volatilities or volatilities implied by option prices are good estimates of the real-world volatilities. Using volatilities for a varying range of moneyness from 53.85% of initial stock level to 100% of initial stock level for a period of 36 months (time to maturity), we have conducted a sensitivity analysis to calculate a set of values for the note as below:

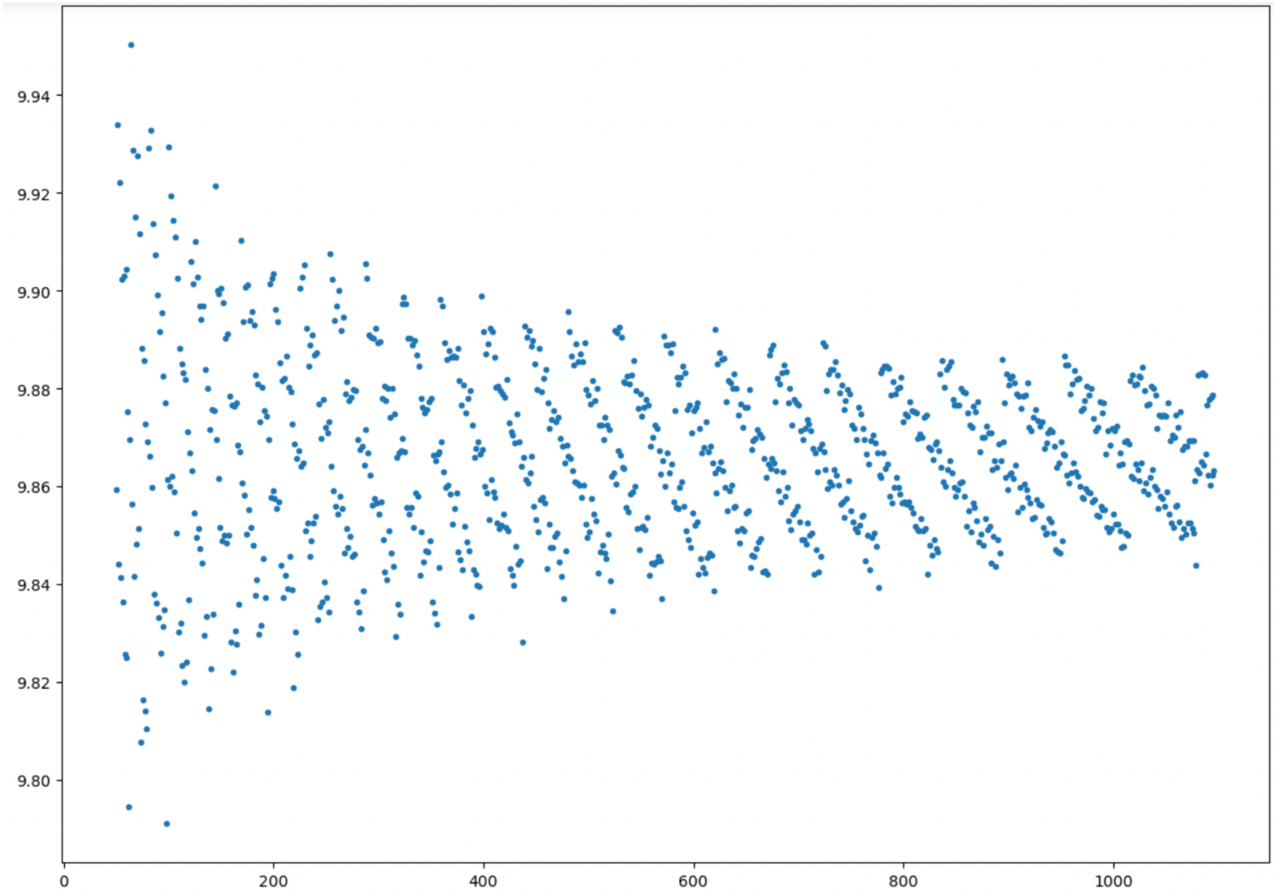
% of Initial Level	Implied Volatility (%)	Estimated Note value ($)
53.85	37.1	9.51
70	33.974	9.6778
80	32.355	9.7612
85	31.309	9.8225
90	30.945	9.8345
100	30.429	9.8636

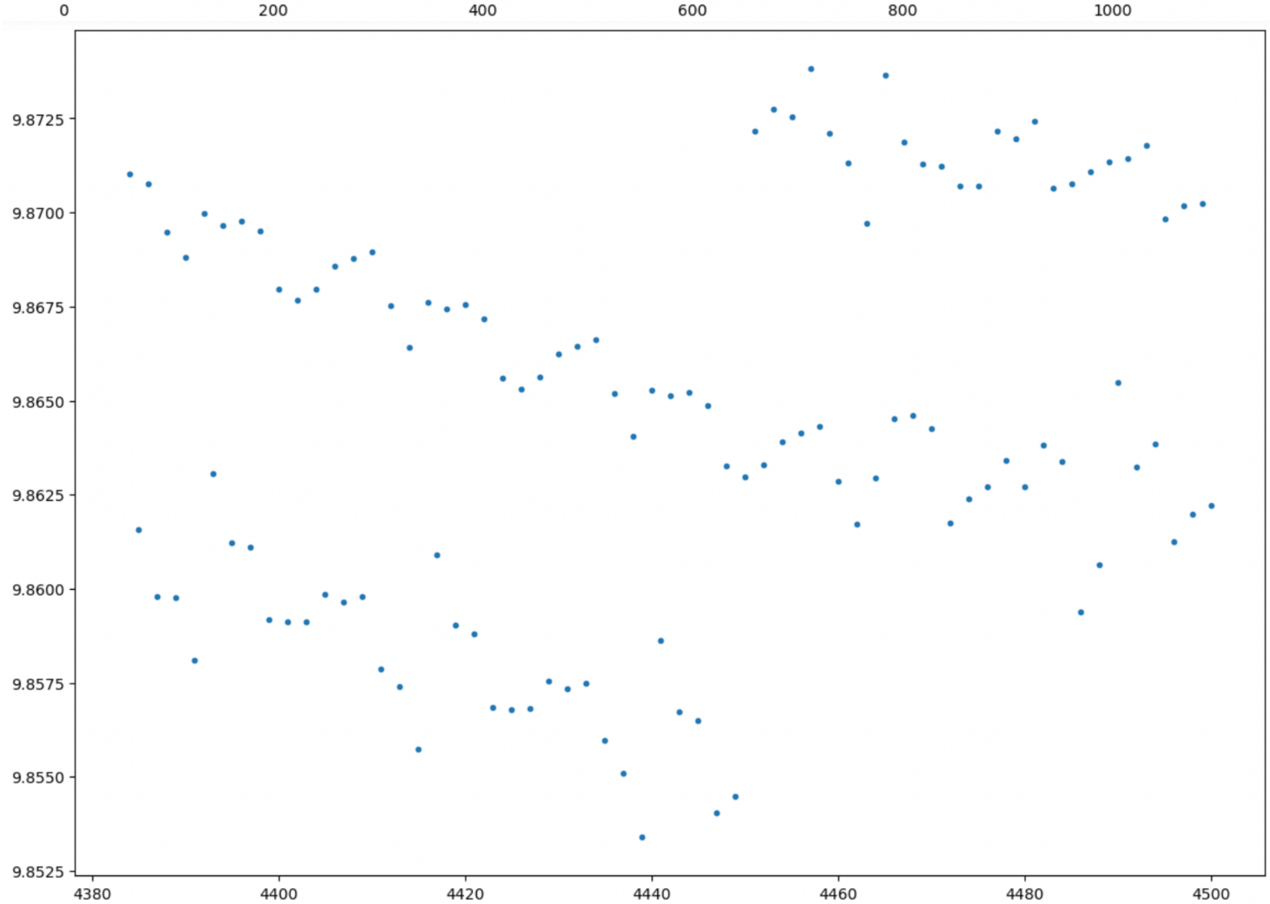
By considering the volatility at 100% of initial level, we are effectively over valuing the note by underestimating the probability of $S_t <$ B.
Inversely, considering the volatility at 53.85% of initial level, results in under valuing the note by overestimating the probability of $S_t <$ B.
Thus, we estimate the value of the note to be **$9.745** by averaging the calculated set of values above. This helps us reduce the possibility of under/overestimating the probabilities associated with S_t falling below the coupon barrier or above the call threshold level.

Errors associated with the binomial model

Using binomial methods to price instruments with complexities such as discrete coupon barriers and auto call features results in large errors. However, errors for discrete barrier instruments are smaller than that observed for continuous barrier options, as the non-linearity error (discussed ahead) arises only at discrete points in time.

Distribution error: In a binomial model, we assume that the underlying asset follows the binomial path i.e., the asset values take on the exact values at each node of the binomial tree (asset value moves discretely). This is an unrealistic assumption and arises due to the lack of continuity in the tree. We can overcome this problem by increasing the number of steps in the tree to ensure convergence to the true value or the value with the smallest possible error. We have presented the convergence of the note value in the graphs below which plots note values for varying time steps from 50 to 1096 and 4384 to 4500 and compared it to the value obtained from a 10960-step tree.





From the graphs above, we can see that the value converges to the value with the smallest possible error after 1096 steps.

Non-Linearity Error: When the exercise price or barrier does not exactly fall on one of the nodes in the binomial tree, the effective strike/barrier (the strike/barrier represented by the stock price node closest to the specified strike/barrier) tends to under/over-value the note. This error is relatively higher for discrete barrier options as the error arises at every observation date rather than just at maturity.

Estimation method for u and d parameters

We have used the **Cox, Ross and Rubenstein (CRR)** method to estimate u and d parameters for the binomial model which maintains the simplicity of the model and offers the flexibility to incorporate complex features of note. This flexibility is not available with the Leisen and Reimer (LR) method which is not easily adaptable to value instruments with various complexities. This method was specifically designed to value Vanilla options. The Broadie and Detemple (BD) method removes non-linearity errors at maturity using the Black-Scholes model to obtain values at $(\mathrm{T} - \Delta\mathrm{t})$ and the idea that between $(\mathrm{T} - \Delta\mathrm{t})$ and maturity (T), all options are European options. However, we cannot apply this method for the valuation of this note since the payoffs at maturity are not well behaved. Additionally, the BD method removes non-linearity error at maturity only and does not address the error arising at every observation date.