Toulouse School of Management
M2 Finance 2022 - VBA for Finance

Stock Option Pricing and P/L Visualization

Group: Thi Thanh Mai Bui - Soukaina Bouaouda - Dong Ding - Yan Jiang

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1. INTRODUCTION

1.1. Motivation/ aim of project

An Option is a contract in which the seller of the option grants the buyer of the option the right to purchase from or sell to a designated instrument at a specified price within a period. In compensation, the seller receives a premium. Call option is the right to buy, Put option is the right to sell the underlying assets.

Stock options are widely used in financial markets by different roles, estimating appropriate option price is crucial part in their daily activities. e.g.

- Retail investors: who buy and sell small scale options with their own money for personal profit.
- Institutional traders: professionals trading for large entities like mutual funds, hedge funds, … for hedging or trading as pure speculation.
- Broker-dealers: who facilitate trades that accept orders on behalf of clients and then ensure they are executed in the open market at the best available price.
- Market makers: who make bids and offers on the options traded on specific securities, thus, provide liquidity in the options marketplace.

According to financial theories, there are 4 main factors affect the price of an option:

- The level of the underlying (increase premium for a call)
- The strike (decrease premium for a call)
- The time to expiry (increase premium for call and put)
- The volatility of the underlying (increase premium for both)

Considering all the above factors, this assignment examines the option contract of a single stock paying regular dividend yield (defined by users). In addition to explaining above impacts, we propose an application which calculate option price – according to the Binomial Pricing Model. After the calculation, having a quick view of the option contract P/L, according to trader's position and type of options (call/ put) helps stakeholders quickly make decision on their investment/ management strategy.

1.2. Project questions

Our project answers following questions:

- How to estimate the option price (premium value) for each type of options (call/ put)? How does it different from European and American options?
- How to visualize the Payoff of above options in a readable graph?
- From technical point of view, develop an Excel VBA application to execute above processes and explain to users how to use the tool.

1.3. Key functions

1.3.1. Input required data with relevant validation rules

- Data elements are added via input boxes
- Within the "InputData"/ "Home"/ "Result", tables, buttons are visually formatted
- Available validation rules to limit wrong entries:

Data elements	Data validation rules
Option positions	- Can not blank - limited to Short/ Long
Option type	- Can not blank - limited to Put/ Call (Put: -1, Call:1)
Stock's purchasing price	- Can not blank - Numeric - >0
Strike price	- Can not blank - Numeric - >0
Maturity	- Can not blank - Integer - >0
Volatility	- Can not blank - % format - <100
Risk-free interest rate	- Cannot blank - % format - <100%
Steps	- Can not blank - Integer - >0
Dividend yield	- Can not blank - % format - >0 - <100

- In case any of above is not met, pop up an error and allow users to re-input

1.3.2. Calculate European and American Option Price
- From Binomial Pricing model, based on data inputted, develop a Binominal tree to calculate the current price of the option (as known as option premium)
- Above option premium is calculated separately for European and American option and distributed into the "Result"

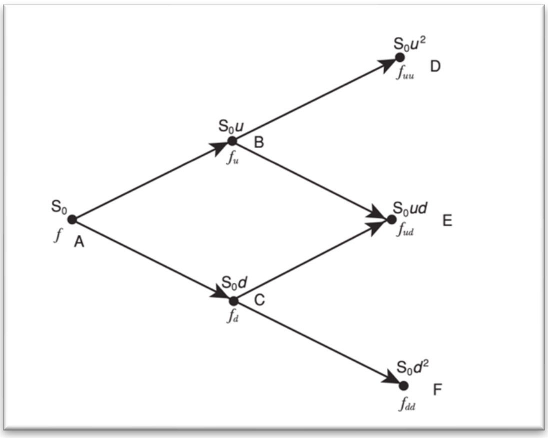
1.3.3. Visualize option payoff (P/L)
- From inputted strike price, create dummy data of stock price for P/L calculation. The range of dummy data is to be wide enough to cover all option situations (0.5*Strike_price;1.5*Strike_price)
- Calculate both European and American option style P/L based on following input:
  - Stock price (dummy)
  - Strike price (inputted)
  - Option premium (for both European and American option calculated in 1.3.2)
  - Option type (inputted)
  - Option position (inputted)
- For both European and American option style P/Ls, plot and format 2 line-charts.

2. METHODOLOGY

2.1. Binominal Option Pricing Model

The Binomial Option Pricing model is a risk-free method for estimating the value of path-dependent alternatives. Investors can determine how likely they are to buy or sell at a given price in the future. As such, an investor can be aware of the current stock price at any given time. If they are going to predict future changes in stock prices, they can divide the time until the option expires into equal parts under this scenario (weeks, months, quarters). The model uses an iterative process to effectively create a binomial distribution of stock prices for each period by determining how likely the movement will be up or down.

A binomial tree represents the different possible paths that the price of a stock or other security can follow over time. E.g. below is a two-step binomial tree, if the price of a stock is S_0, over a short interval of time (step 1) it can either move up to a new level S_0u or down to a new level S_0d as shown in below figure:



Graph 1: Binomial tree illustration

Here, u > 1 and d < 1 and u - 1 and 1 - d represent the proportional increase and decrease in the stock's price over the interval (for example, up 10% or down 8%). If the stock is assumed to always behave the same way, then at the end of the next interval (step 2), the stock can take on 3 possible values and it can take 4 possible paths to get to them. It may seem simplistic, but by choosing the values for *u* and *d* properly and making the steps smaller and smaller, a binomial tree can be made to closely approximate the paths a stock may follow over any period.

To calculate the probabilities of the up and down movements, we assume that we are living in a risk-free world, it means all cash flows can be discounted using the risk-free rate of return. This method of valuing derivatives assuming a risk-free world is called risk- neural valuation. It is important to understand that it is the proper choice of the probabilities of the up and down movements that makes the risk-neutral valuation possible. In Cox, Ross, and Rubinstein (CRR) formula, a known dividend yield can be incorporated in the up and down movement probabilities for risk-neutral valuation. With that adjustment, binomial trees can be used to value both European and American options on dividend-paying stocks the same way we discussed using them for valuing options on stocks that pay no dividend.

$$u = \exp\left(\sigma\sqrt{\delta t}\right)$$

$$d = \frac{1}{u}$$

$$p = \frac{a-d}{u-d}, \text{ where } a = \exp\left[(r-q)\delta t\right]$$

Graph 2: Binomial tree - Calculating up factor, down factor, and risk neutral probability

In which:

- dt is the length of each step, that is, it equals the time-length of the tree (for example, time to expiration for the option for a tree for option valuation) divided by the number of steps we choose for the tree, dt =T/n
- T is time to maturity of the option

- n is number of steps
- u is the up factor that led to stock price increased
- d is the down factor that led to stock price decreased
- sigma designates the magnitude, or standard deviation of the absolute change in the short-term volatility of the stock
- p is risk-neutral probability of up movement
- q is the constant dividend yield, for stocks that do not pay any dividend/ or bond that do not pay any coupon, q would be 0
- a is the discount factor per step

With above formula, if we choose the parameter for a binomial tree and probability of up movement, the Binominal tree will closely match the mean and variance of the stock/ bond's price over short time intervals, and we can use risk-neutral valuation. .

2.2. Binominal tree for Stock price

The first node of the tree is purchasing price inputted by users. Based on the up factor and down factors, we develop the following nodes as its up/ down movements.

The tree built is represented as a right-angled triangle in which its base and height are both equal to number of steps (n+1). Each node in the tree represents stock_price (i, j) with i, j ∈ (0; n).

Step		0	1	2	3	4	5	6	7	8	9
Time	up movement	0	0.055555556	0.111111111	0.16666667	0.22222222	0.27777778	0.33333333	0.38888889	0.44444444	0.5
Stock price		50	53.66353301	57.59549551	61.8155555	66.3448221	71.205951	76.423258	82.0228406	88.0327083	94.4829229
			46.58657117	50	53.663533	57.5954955	61.8155555	66.3448221	71.205951	76.423258	82.0228406
	down movement			43.40617227	46.5865712	50	53.663533	57.5954955	61.8155555	66.3448221	71.205951
					40.4428947	43.4061723	46.5865712	50	53.663533	57.5954955	61.8155555
						37.6819158	40.4428947	43.4061723	46.5865712	50	53.663533
							35.1094251	37.6819158	40.4428947	43.4061723	46.5865712
sample of stock price's Binomial tree:								32.7125546	35.1094251	37.6819158	40.4428947
- purchase price (s) = 50									30.4793151	32.7125546	35.1094251
- number of steps = 9										28.3985356	30.4793151
											26.459808

Graph 3: Sample of Binominal tree for stock price

2.3. Binominal tree for European option

A European option is a version of an options contract that limits execution to its expiration date. In other words, if the underlying security such as a stock has moved in price, an investor would not be able to exercise the option early and take delivery of or sell the shares. According to the American Style - investors have the right to exercise an option at any time during its life, including the maturity date. The purpose of separating European and American options is to allow users to see the differences in calculated option prices.

Building Binominal tree is to calculate the option price (as known as option premium) at t0. The option price (option premium) is calculated as the payoff for option holder at each node. Let us consider a call option with exercise price K and assume the stock price is S at the time of the call's expiration. If S is less than or equal to K, the call holder will let the call expire and the payoff of the call will be zero. If S is greater than K, the call holder will exercise the call for a payoff of S - K. By adding a variable of option Type (call, put) with values of 1 for calls and -1 for puts. We can then write one equation for option payoff as follows:

*Payoff to option holder = Max {0, optType * (stock_price - K)}*

For example, in Excel, considering each node position as Eur (i, j), we now build a tree for European option price with n nodes (the height of above triangle)

1st we start at final expiration nodes calculated by formula with j = n:

Eur (i, j) =Max (0, OptType * (Stock_price(i, j) - K)

2nd we calculate the option price for the earlier nodes - to build backwards from final nodes. For a European option, the value at any node is its expected value in the next step (calculated using the risk-neutral probabilities of up and down movements) discounted by the risk-free rate. We use the formula:

Eur (i, j) = p* *Eur (i, j+1)* +(1-p) * *Eur (i+1, j+1)* * emrdt

2.4. Binominal tree for American option

Considering each node position as Amer (i, j), we now build a tree for American option price with n nodes (similar to the base and height of above triangle).

1st we start at final expiration nodes calculated by formula with j = n:

Amer (i, j) = Max (0, OptType * (stock_price (i, j) - K)

2nd we calculate the option price for the earlier nodes - to build backwards from final nodes. For a American option, the value at any node is its expected value in the next step (calculated using the risk-neutral probabilities of up and down movements) discounted by the risk-free rate. But the differences between European option is the inner MAX function calculates the payoff from immediately exercising the model as the higher of zero and the difference between the stock price at the corresponding node and the exercise price.

We use below calculations:

Amer (i, j) = p* *Eur (i, j+1)* +(1-p) * *Eur (i+1, j+1)* * emrdt (1)

*exVal = Max (0, optType * (stock_price (i, j) - k))* *(2)*

Then, the final value of American option is the comparison between (1) and (2).

Amer(i, j) = Max (Amer(i, j), exVal) *(3)*

2.5. Calculate Option P&L

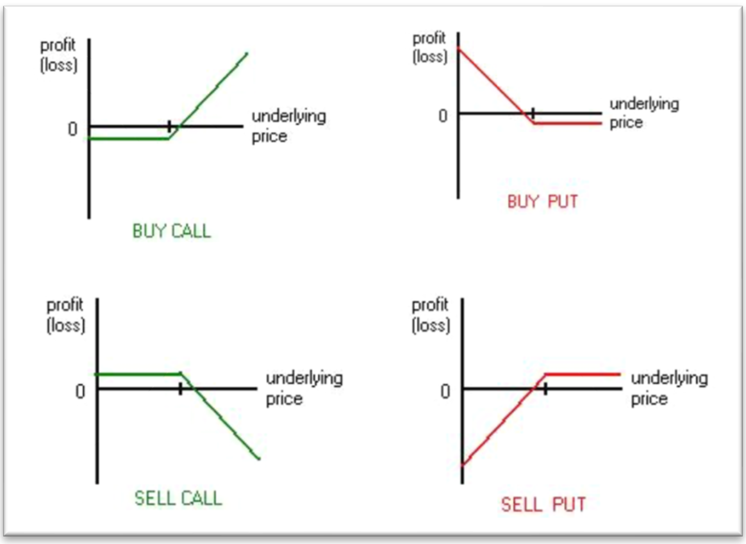
The option holder's profit (PL or Payoff per share) will be equal to the payoff minus the premium per share paid for the options (calculated by above Binomial tree). In general, we calculate Option P&L formula, similar to American and European style:

Long Call P/L = MAX(Stock Price – Strike Price - Premium, - Premium)

Short Call P/L = MIN(Strike Price – Stock Price + Premium, Premium)

Long Put P/L = MAX(Strike Price – Stock Price - Premium, - Premium)

Short Put P/L = MIN(Stock Price – Strike Price + Premium, Premium)

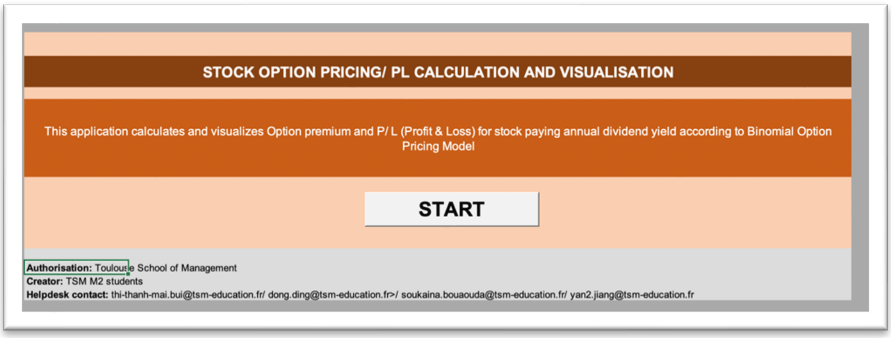


Graph 4: P/ L charts for different option types and positions

3. USER'S INSTRUCTION

3.1. Home page

After reading instructions, user clicks "START" button to use our tool:

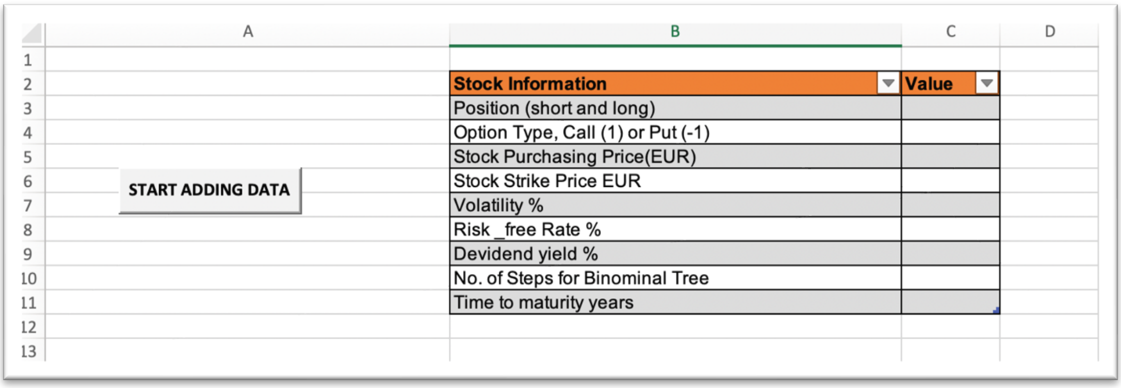


Graph 5: Home page

It leads you to the next page "InputData" where you start input our required data.

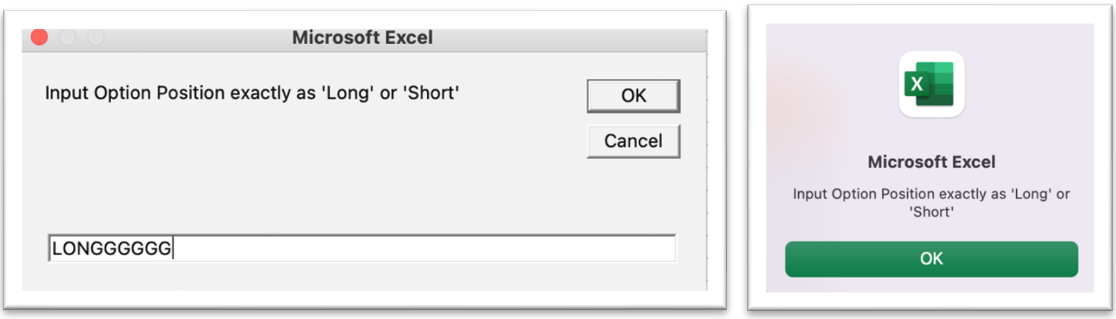
3.2. Input page

In the left side, users click the "START INPUTTING DATA BUTTON" to start insert data to "Stock Information" table:



Graph 6: InputData page

Then, user fills in input boxes appeared with our instructions, if the data entered is incorrect, you need to reinput until correct. (See section *1.3.1. Input required data with relevant validation rules* for the rules you need to follow)

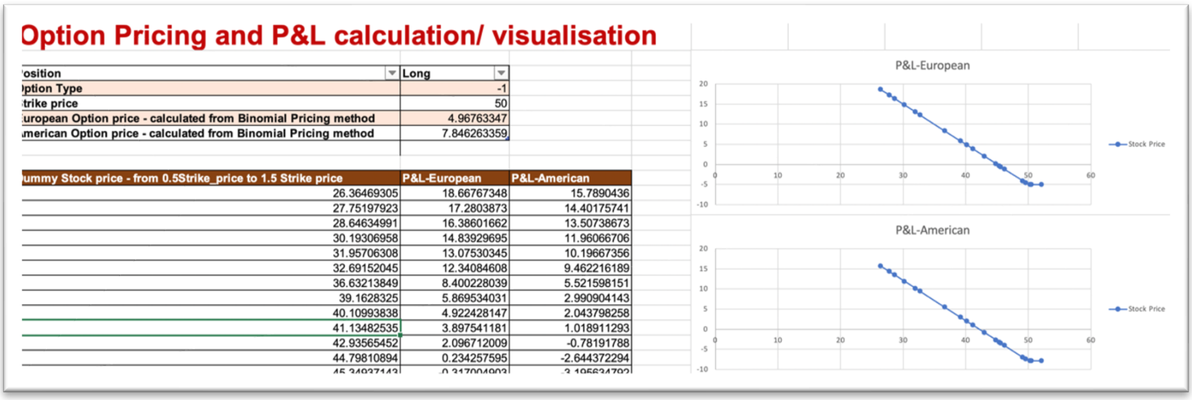


Graph 7: Any incorrect data input will be rejected

3.3. Result page

After all required data complete, it will lead you to Result page, where user can find below information:

- European and American option's price (calculated by Binomial tree)
- P/L calculation table (based on dummy data)
- Other stock information user inputted (strike price, Option Type/ Position)
- P/L graph with differences from European and American style


Option Pricing and P&L calculation/ visualisation

osition	Long
ption Type	-1
trike price	50
uropean Option price - calculated from Binomial Pricing method	4.96763347
merican Option price - calculated from Binomial Pricing method	7.846263359

ummy Stock price - from 0.5Strike_price to 1.5 Strike price	P&L-European	P&L-American
26.36469305	18.66767348	15.7890436
27.75197923	17.2803873	14.40175741
28.64634991	16.38601662	13.50738673
30.19306958	14.83929695	11.96066706
31.95706308	13.07530345	10.19667356
32.69152045	12.34084608	9.462216189
36.63213849	8.400228039	5.521598151
39.1628325	5.869534031	2.990904143
40.10993838	4.922428147	2.043798258
41.13482535	3.897541181	1.018911293
42.93565452	2.096712009	-0.78191788
44.79810894	0.234257595	-2.644372294

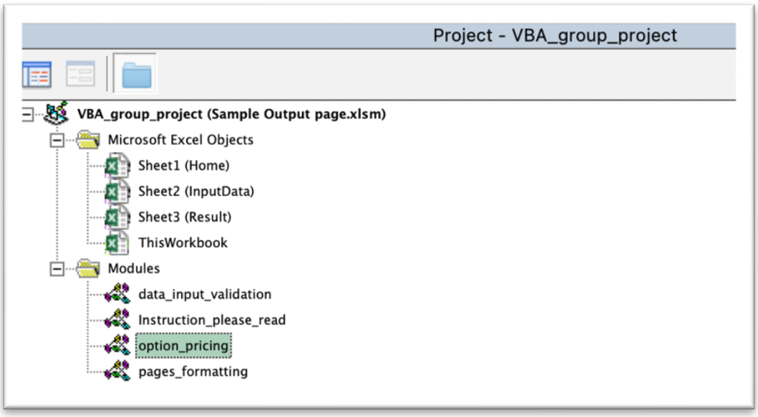
Graph 8: Sample Result page

4. CODE EXPLANATION

4.1. Code Setting and Structure

We populate codes in 3 modules and 2 sheets:

- Sheet(1) Home includes "START" button – to initiate the work/ and delete previous data
- Sheet(2) InputData includes "START inputting data" button – to lead to data entry and validation
- Module "data_input_validation" include variable's definition and to validate each entry with error handling
- Module "option_pricing" is to:
  - Calculate option prices based on Binomial method
  - Output those calculation to page "Result"
  - Calculate P/L based on dummy data
  - Plot the P/L charts
- Module "pages_formatting" focuses on setting up tables in different pages and formatting those (by Macro Recording)



Graph 9: Code structure

Now we will explain 2 key modules (Data_input_validation and option_pricing)

4.2. Module Data_input_validation

Step 1 - Set up all variable as Public, to allow using those in different modules.

```
Public Position As String           'option Position investors would like to enter - Long or Short
Public optType As Double            'Option type investor would like to trade - (1) for CALL and (-1) for PUT
Public S As Double                  'Stock current price or purchasing price
Public Strike_price As Double       'Stocks strike price (aka Excerciese Price)
Public sig As Double                'market volatility by %
Public q As Double                  'stock annual dividend yield %
Public T As Integer                 'option's time to maturity(years)
Public n As Integer                 'number of steps in binomial tree
Public ir As Double                 ' risk free interest rate%
```

Graph 10: Variables for input

Step 2 – Validate each data through input boxes and error handling

Next, each data field inputted will be added by input boxes with detailed descriptions for users on what they need to put into and its requirements. The validation rules are under the code with a message box popped up when the wrong entry appeared until being accepted (by Loop Until). Error handling is in place for all 9 sets of code (9 variables) to let us know which set contains bugs.

```
Sub Input3()
On Error GoTo R:

 Do
      Position = InputBox("Input Option Position exactly as 'Long' or 'Short'")
      If Position = "Long" Or Position = "Short" Then
         Range("C3").Value = Position
      Else
         MsgBox "Input Option Position exactly as 'Long' or 'Short'"
      End If
  Loop Until Position = "Long" Or Position = "Short"


Call Input4
Exit Sub

R: MsgBox "Please re-input Option Position as Long or Short"
   Resume
```

Graph 11: An example of variable “Position”, is limited by “Long” and “Short” in its dropdown.

After user added the last data field T – option’s time to maturity, we call the next step to the Module “option_pricing”.

4.3. Module “option_pricing”

Step1 - Compute relevant factor for BSM model

Calculate the transformed variable required.

```
Sub option_price_cal()

On Error GoTo R:
'Redimension the arrays based on number of steps specified
ReDim stock_price(1 To n + 1, 0 To n)
ReDim Euro(1 To n + 1, 0 To n)
ReDim Amer(1 To n + 1, 0 To n)

dt = T / n                                  'Stepsizeinyears
u = Exp(sig * Sqr(dt))                      'Up movement multiplier
d = 1 / u ' d = 1 / u                       'Down movement multiplier
emrdt = Exp(-ir * dt)                       'Discount factor per step
p = (Exp((ir - q) * dt) - d) / (u - d)      'p is risk neutral probability of up movement
stock_price(1, 0) = S                       'Initial value, at time 0
```

Graph 12: Calculate up/ down factor and Risk neutral probability

Step 2 - Generate stock price tree

- i+1, j are accordingly the base and height of the binomial tree
- with u and d (up and down factors), each node of the tree contains stock price projected from current price - Stock_price(1, 0) – until all nodes are filled.

```
'Generate stock price tree
For j = 1 To n                              'Count steps
   For i = 1 To j + 1
      If i = 1 Then
         stock_price(i, j) = stock_price(i, j - 1) * u
      Else
         stock_price(i, j) = stock_price(i - 1, j - 1) * d
      End If
   Next
Next
```

Graph 13: Create stock price tree by up and down factor

Step 3 - Option price is calculated backwards from the final price

```
' Generate option value tree  (P&L tree based on above stock price, almost similar to Sengupta Book)
For j = n To 0 Step -1
   For i = 1 To j + 1
      If j = n Then
         Amer(i, j) = Application.Max(optType * (stock_price(i, j) - Strike_price), 0)

         Euro(i, j) = Application.Max(optType * (stock_price(i, j) - Strike_price), 0)
      Else
         Amer(i, j) = (p * (Amer(i, j + 1)) + (1 - p) * (Amer(i + 1, j + 1)) * emrdt)

         Euro(i, j) = (p * Euro(i, j + 1) + (1 - p) * Euro(i + 1, j + 1) * emrdt)

         exval = Application.Max(0, optType * (stock_price(i, j) - Strike_price))

         Amer(i, j) = Application.Max(Amer(i, j), exval)

      End If
```

Graph 14: Create Option price tree with Risk neutral probability

Step 4 – Output calculated prices to Result page

```
Sub output()
On Error GoTo R:

Sheets("Result").Activate

'polpulate option informatin to Result sheet

Worksheets("Result").Range("B3").Value = Position          'Option Position - inputted by users
Worksheets("Result").Range("B4").Value = optType           'Option TYpe - inputted by users
Worksheets("Result").Range("B5").Value = Strike_price      'Strike - inputted by users
Worksheets("Result").Range("B6").Value = Euro(1, 0)        'Option price (premium)- calculated by BInomial tree
Worksheets("Result").Range("B7").Value = Amer(1, 0)
```

Graph 15: Show Euro and Amer Option price

Step 5 - To random the dummy stock price from Strike price, each value are in the range of (k * 0.5; k * 1.5)

```
'To random the dummy stock price from Strike  price in which each value are in  the range of (k * 0.5; k * 1.5)
Dim RndNumber, temp(30), g, h, k As Integer
Randomize (Timer)

k = 0
Do While k < 30

   RndNumber = 1 * Rnd + 0.5
   temp(k) = RndNumber
   Cells(k + 11, 1) = RndNumber * Strike_price
   For g = 0 To k - 1
      If temp(g) = RndNumber Then Exit For
   Next g
   If g = k Then k = g + 1

Loop
```

Graph 16: Create and Random for dummy price

Step 6 – Calculate P/L for each Option case based on its type and position (for both European and American style)

```
'According to each random number, calculate the PL base on value each case (4 cases based on Position - Long or Short and Option type - Call or Put)

If Position = "Long" And optType = "1" Then
h = 0
Do While h < 30
Cells(h + 11, 2) = Application.Max(Cells(h + 11, 1) - Strike_price - Euro(1, 0), -Euro(1, 0))
Cells(h + 11, 3) = Application.Max(Cells(h + 11, 1) - Strike_price - Amer(1, 0), -Amer(1, 0))

h = h + 1
Loop
```

Graph 17: Calculate P/L

Step 7 - Plot P/L charts and set the charts in the specific location of Result page

```
Sub plotting()

Dim Result As Worksheet
Dim Rg1, Rg2 As Range

    Set Rg1 = Range("$E$2:$I$12")
    Set Rg2 = Range("$E$13:$I$23")
    Dim Plot1, Plot2 As Shape
    Set Plot1 = Worksheets("Result").Shapes.AddChart2(240, xlXYScatterLines)
    Set Plot2 = Worksheets("Result").Shapes.AddChart2(240, xlXYScatterLines)
    Dim PLChart1, PLChart2 As Chart
    Set PLChart1 = Plot1.Chart
    Set PLChart2 = Plot2.Chart

    PLChart1.SetSourceData Source:=Range("$A$11:$B$30")
    PLChart1.HasTitle = True
    PLChart1.ChartTitle.Text = "P&L-European"
    PLChart1.SetElement (msoElementLegendRight)
    PLChart1.SeriesCollection(1).Name = "Stock Price"


    PLChart2.SetSourceData Source:=Union(Range("$A$11:$A$30"), Range("$C$11:$C$30"))
    PLChart2.HasTitle = True
    PLChart2.ChartTitle.Text = "P&L-American"
    PLChart2.SetElement (msoElementLegendRight)
    PLChart2.SeriesCollection(1).Name = "Stock Price"

'locate the chart in a fixed place
    Plot1.Top = Rg1.Top
    Plot1.Left = Rg1.Left
    Plot1.Width = Rg1.Width
    Plot1.Height = Rg1.Height
```

Graph 18: Plot P/L

5. LIMITS OF OUR MODEL

Our model are limited in following points:

(1) The methodology assumes that stock's dividend is in yield-base and is fixed years by years. But in fact, dividends often are paid by different amount of money. Our model need to be further enhanced to be flexible with different dividend policies.

(2) The P/L chart is developed based on dummy stock price data. As such:
- Chart length does not be able to go to infinity.
- In some situations, the chart's shape is non-linear, since the number of dummy data is not enough to cover the case of Strike price = Stock price.

6. REFERENCES

(1) Financial Modeling Using Excel and VBA - CHANDAN SENGUPTA – Chapter 13 Binomial Option Pricing

(2) Financial Modeling Using Excel and VBA - CHANDAN SENGUPTA – Chapter 24: Binomial Option Pricing (with modelling examples)