UCD Michael Smurfit Graduate Business School

Derivative Securities (FIN42020)

Cisco Systems, Inc.

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Introduction

The purpose of this report is to apply the knowledge gained throughout the Derivatives Securities course to the practical analysis of options. Our group did so by analysing call and swap options on the stock of Cisco Systems, Inc. (Nasdaq: CSCO), an IT company which "designs and sells a broad range of technologies that power the Internet". CSCO's main product offerings are grouped into six categories: Secure, Agile Networks; Internet for the Future; Collaboration; End-to-End Security; Optimized Application Experiences; and Other Products. (CSCO, 2023, p. 1)

The layout of the report is structured in line with the five overarching questions to be answered. Each question begins with a brief description of our approach to addressing the problem at hand, before leading into a discussion of the results developed throughout the process.

- **Question 1**: definition and sourcing of appropriate sets of data, based upon which the Black-Scholes implied volatility of selected options was determined.
- **Question 2**: analysis of the sensitivity of at-the-money call and put options to changes in various input variables to the Black-Scholes formula.
- **Question 3**: exploration of the differences between the intrinsic value and the Black-Scholes prices of our call and put options for different spot prices.
- **Question 4**: volatility forecasting and development of a trade in volatility.
- **Question 5**: simulation of a real-life delta hedging strategy for two distinct volatility assumptions: first, using our calculated implied volatility from Question 1, and in a second step using our volatility forecast from Question 4.

For the most comprehensive understanding of this report's contents, it is recommended to simultaneously consult the accompanying Excel file containing the various calculations, as well as the MATLAB codes used for Questions 4 and 5.

Question 1: Implied Volatility

1.1 Data Definition and Gathering

The first task at hand was to determine and obtain all data which would be required in subsequent calculations.

- CSCO options data, including the **strike price**, **last price** and **implied volatility** for a range of call and put options on CSCO with expiry on 24 November 2023 were retrieved from Yahoo! Finance (Yahoo) on 31 October 2023.
- CSCO's **spot price** at the same time was retrieved from CNBC. It had a value of \$52.13.
- The applicable **time to maturity** could easily be calculated from the trade and the expiry dates of the options.
- The yield on 1-month US treasury bills on the same date was deemed to be the appropriate **risk-free interest rate**, as it matched both the maturity and currency of the securities being analysed. Its value was retrieved from the Federal Reserve's database, and found to be 5.56%.
- Lastly, we calculated the appropriate **dividend yield**. As CSCO had just announced its fourth consecutive quarterly dividend payment of \$0.39 per share, we calculated the appropriate dividend yield using Equation 1:

$$g = \frac{4 * quarterly\ dividend\ payment}{S} = \frac{4 * \$0.39}{\$52.13} \approx 2.9925\%$$

Equation 1: Dividend Yield

1.2 Black-Scholes Implied Volatility

Having gathered all necessary raw data, we computed the Black-Scholes implied volatility for selected options by instructing the Microsoft Excel add-in program "Solver" to find the volatility for which the result of the Black-Scholes formula corresponds exactly to the market price for each respective option.

This was done for both the call and the put option which was as close as possible to being at-the-money. For our data specifically, the options with the strike prices closest to the spot price were identified as those with a strike price of \$52.00.

The computations yielded an implied volatility of **27.28%** based on the call option price, which is notably lower than the implied volatility of **30.08%** published by Yahoo. On the other hand, the implied volatility of **28.55%** which we determined based on the put option prices higher than the value of **26.56%** published by Yahoo.

There are several possible reasons why these discrepancies between our calculated implied volatilities and those published by Yahoo exist.

- As the implied volatility is calculated based on the Black-Scholes formula, its input variables and the assumptions underlying them are a reasonable place to start the analysis. It is entirely possible that the implied volatility published by Yahoo relied on assumptions about the input variables which deviated from our own, such as:
    - A different proxy for the risk-free rate;
    - An alternative method to determine an appropriate dividend yield;
    - An alternative daycount convention when calculating the time to maturity.
- Furthermore, the implied volatility is not a static figure, but much rather constantly evolves, adapting to changing circumstances. While an effort was made to ensure all data had the same timestamp, it is naturally impossible to guarantee this with absolute precision. Such minor time disparities could be a further explanation of the diverging implied volatility figures.

Question 2: Sensitivity Analysis

2.1 Sensitivity of Option Price to Changes in the Volatility σ

Graphical Illustrations:

- Figures 1 and 2 illustrate the implied prices for the call and put options respectively, for varying levels of volatility.

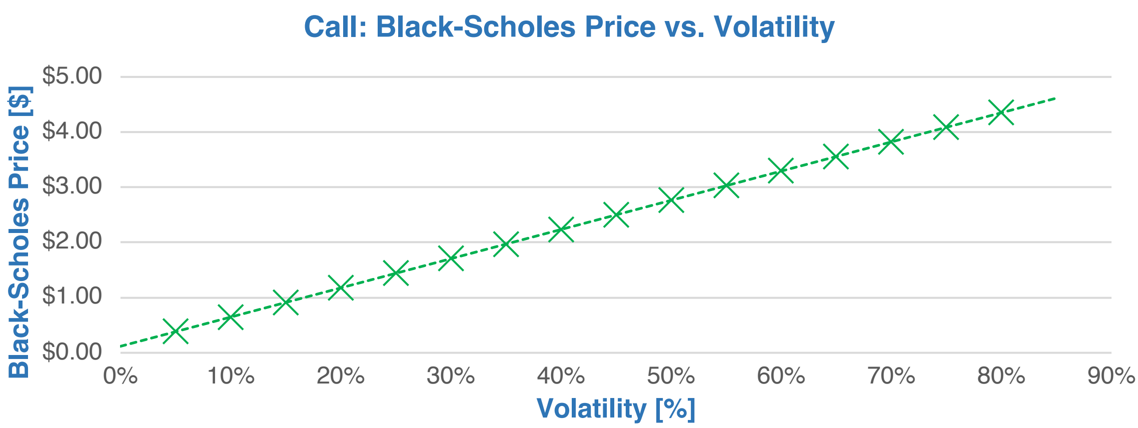

Figure 1: Call: Black-Scholes Price vs. Volatility

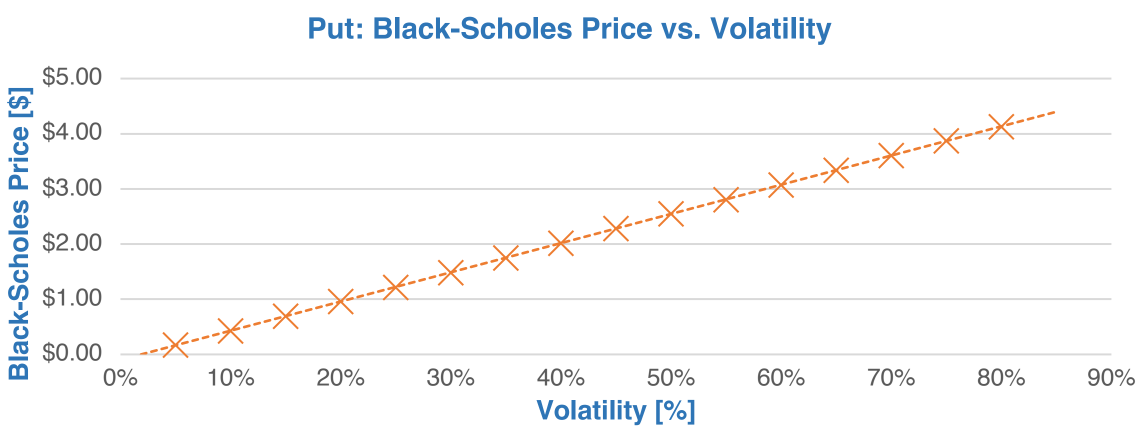

Figure 2: Call: Black-Scholes Price vs. Volatility

Discussion of Results:

A clear, positive, linear trend emerges for both options. This positive relationship is to be expected, as option pricing theory states that both calls and puts typically have positive Vegas, with Vega being defined as the rate of change of the value of an option's price with respect to volatility (McGee, 2023, p. 50).

- The idea behind this observation is that a higher volatility implies a higher probability of larger price movements, which increases the value of both call and put options. This arises from the fact that an option holder can take full advantage of the higher chance of favourable price developments, while his losses are capped by the possibility of simply not exercising the option.

- Therefore, all holders of long positions in options, both of calls and puts, benefit from a higher volatility, justifying the positive relationship between the two variables seen in Figures 1 and 2.

2.2 Sensitivity of Option Price to Changes in the Time to Maturity T

Graphical Illustrations:

- The implied prices for the call and put options respectively for varying times to maturity are illustrated in Figures 3 and 4.

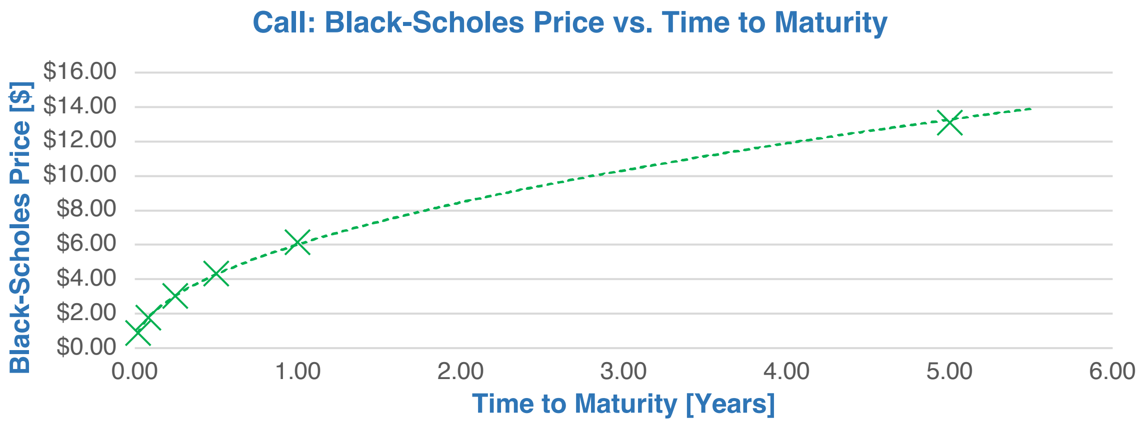

Figure 3: Call: Black-Scholes Price vs. Time to Maturity

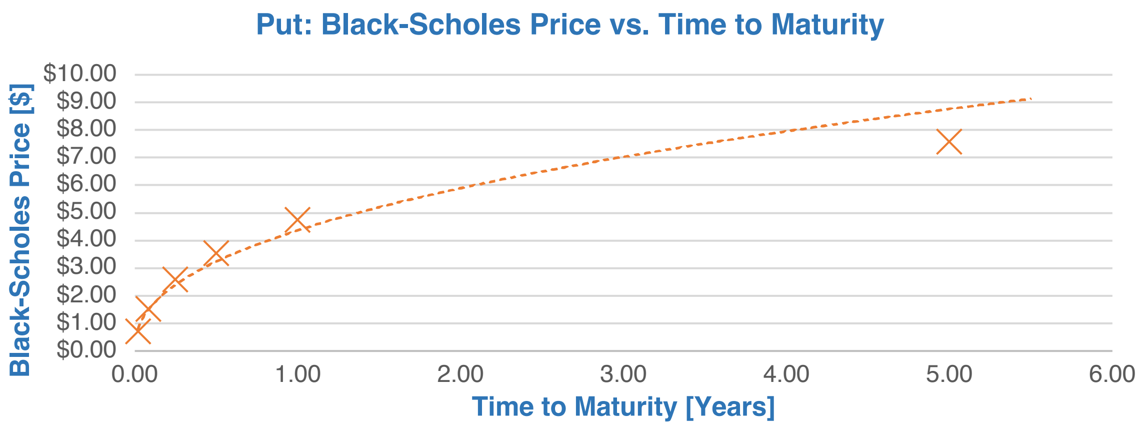

Figure 4: Put: Black-Scholes Price vs. Time to Maturity

Discussion of Results:

For time to maturity, the trend does not take a linear form as was the case with volatility. Much rather, the relationship can be approximated by a function which increases in T, but at a decreasing rate of increase.

- Again, this structure conforms with option pricing theory, which states that the theta of an option is generally negative, implying that option prices generally decrease as we move closer to the expiry date (McGee, 2023, p. 45).
- A part of an option's value stems from its time value. In a similar argument to the one seen in the context of volatility, a higher time to maturity leaves more time – and therefore increases the probability – that the option will become in-the-money. Again, if the movements turn out to be disadvantageous, the option is simply not exercised. This argument holds for both call and put options. As we move closer to the expiry date, the option's time value therefore decreases in a process known as time decay. (Investopedia, 2022)
- This time decay, however, does not follow a linear trend, but increases the closer we get to the expiry date (approximately 1/3 of the value is lost in the first half of the lifespan, 2/3 in the second half). This explains the trends in Figures 3 and 4. (IG, n.d.; Investopedia, 2022)

2.3 Sensitivity of Option Price to Changes in the Interest Rate r

Graphical Illustrations:

- Figures 5 and 6 illustrate the implied prices for the call and put options respectively for varying interest rates.

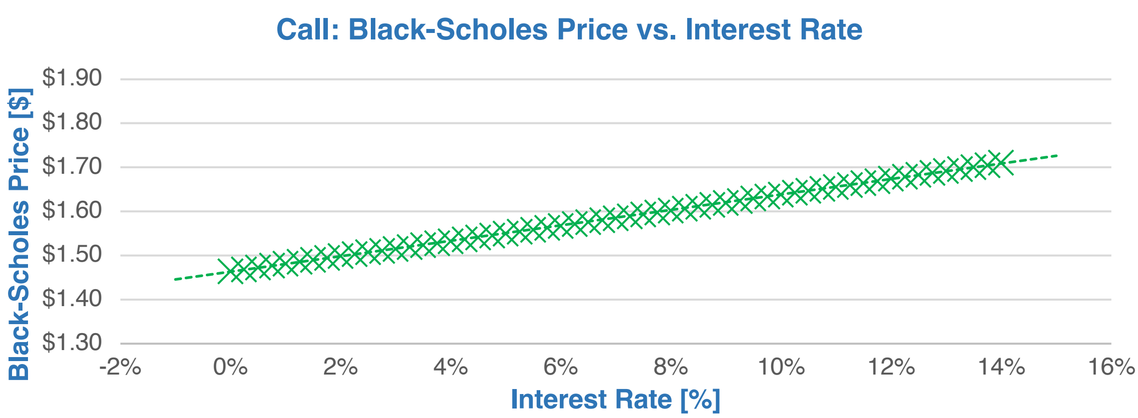

Figure 5: Call: Black-Scholes Price vs. Interest Rate

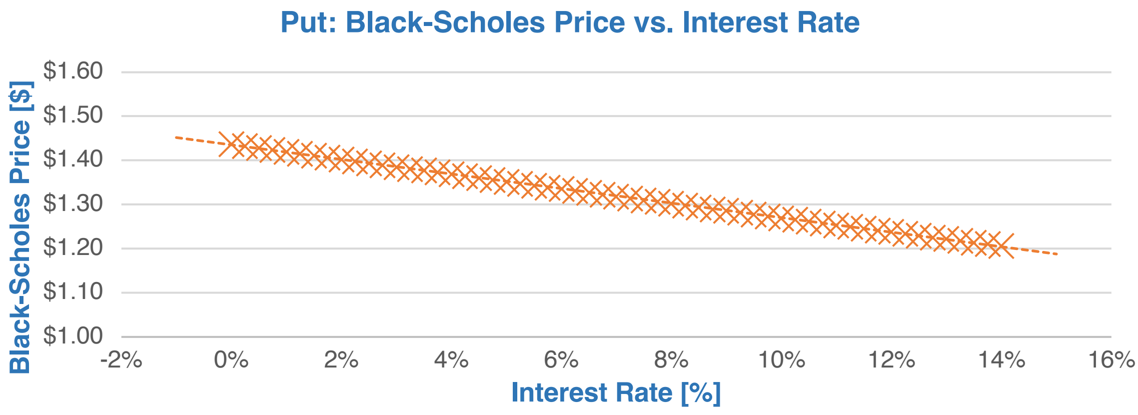

Figure 6: Call: Black-Scholes Price vs. Interest Rate

Discussion of Results:

Both option prices have a linear relationship with the interest rate. While this is a positive relationship for the call option, it is negative for the put option. These relationships between the option prices and interest rates are unsurprising when recalling the simple economic principle that higher interest rates benefit savers and punish borrowers.

Comparing the choice of buying a stock or buying a call option, as well as comparing the choice of shorting a stock or buying a put option illustrates the underlying phenomenon behind this concept well (these two sets of trades are utilised as they have similar structures and payouts).

- When buying a call option rather than taking a long position in the spot market for the underlying asset, the funds saved as a result of the option price being lower than the spot price can be invested in an interest-bearing deposit account until maturity of the option. This generates interest income, which increases for rising interest rates. In other words, the cost of carrying the underlying stock increases for rising interest rates, making call options more attractive and leading to higher call option prices. (Investopedia, 2022)
- The opposite is true when observing the case of buying a put option compared to shorting a stock. When shorting a stock, the trader receives cash which can be invested in an interest-bearing account, thus generating interest income. As a result, buying puts becomes less attractive in higher interest rate environments, causing the inverse relationship observable in Figure 6. (Investopedia, 2022)

Question 3: Misvaluations

3.1 Call Option

Graphical Illustrations:

- While Figure 7 shows the intrinsic value of the call option for a range of spot prices, Figure 8 does the same for its Black-Scholes price.
- To better illustrate the mismatch between the Black-Scholes price and the intrinsic value, Figure 9 depicts the difference between the two values for the same range of spot prices.

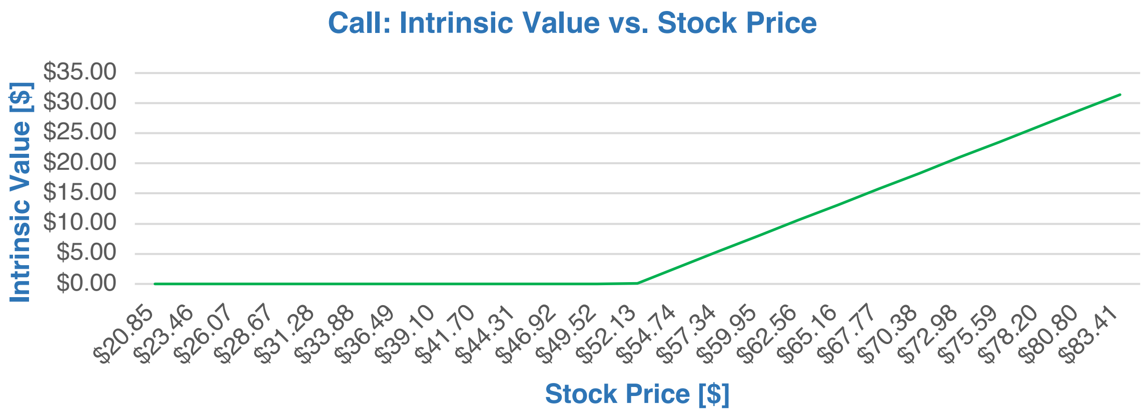

Figure 7: Call: Intrinsic Value vs. Stock Price

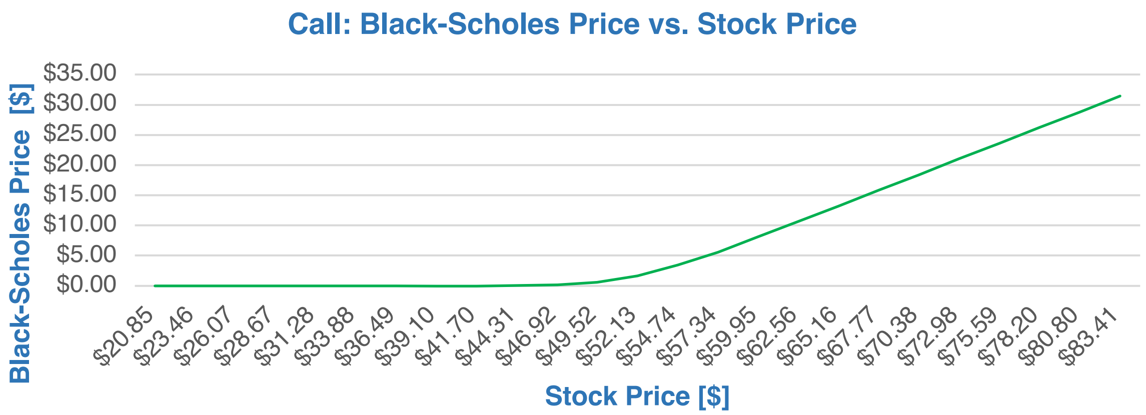

Figure 8: Call: Black-Scholes Price vs. Stock Price

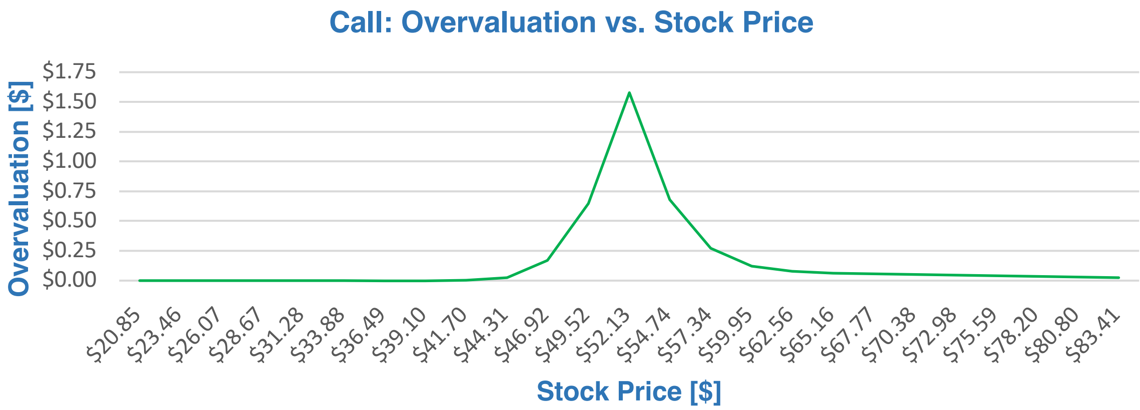

Figure 9: Call: Under- and Overvaluation vs. Stock Price

Discussion of Results:

Figures 7 and 8 show the expected linear characteristics of the call option's intrinsic value and the similar, but curved features of its Black-Scholes price.

- Arising from its formula, the intrinsic value is the maximum out of either 0, or the difference between the spot price and strike price if the former rises above the latter. The constant value of 0 followed by a positive linear function beginning where the stock price equals the strike price is therefore fully expected.
- The Black-Scholes price on the other hand, as a theoretical approximation of what an option's price should be, follows a similar, though not quite identical path to the intrinsic value.
- Observing Figure 9, we can see that while the Black-Scholes price is almost equal to the option's intrinsic value when we are either are either far in-the-money or far out-of-the-money, the real significant differences arise when finding ourselves close to at-the-money. This is where the optionality feature of an option matters the most and where probabilities play a key role.

Figure 9 allows us to make an optimal decision on whether to exercise the call option and benefit from its intrinsic value or to sell it on to another trader at the Black-Scholes price.

- Assuming the market prices options using the Black-Scholes formula, and that the market is overpricing an option, it is optimal behaviour to sell said option at the Black-Scholes price, as the resulting profit will exceed the intrinsic value held in the option. Contrarily, in cases of undervaluation, it is financially sounder to exercise the option rather than sell it at a discount, as the trader can then benefit from the option's intrinsic value, which is worth more than the market price.
- Applying this understanding to our data represented in Figure 9, the first important observation is that there seems to be an overvaluation across the entire data series. Moreover, this overvaluation increases the closer the spot price is to the strike price.
- As a result of this pervasive overvaluation of the call option, it would be best to sell it to another market participant for the Black-Scholes price. This recommendation

has all the more weight in a scenario at or close to at-the-money, as this is when the overvaluation and subsequently the trader's benefit would be largest.

3.2 Put Option

Graphical Illustrations:

- Mirroring the approach applied for the call option, Figure 10 shows the intrinsic value of the put option for a range of spot prices, while Figure 11 does the same for its Black-Scholes price.
- Figure 12 illustrates the mismatch between the Black-Scholes price and the intrinsic value, displaying the difference between the two values across the range of spot prices.

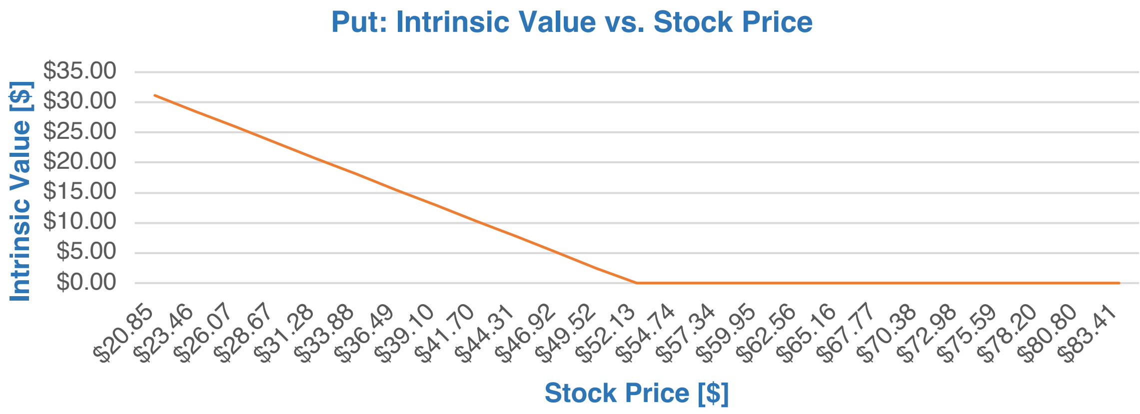

Figure 10: Put: Intrinsic Value vs. Stock Price

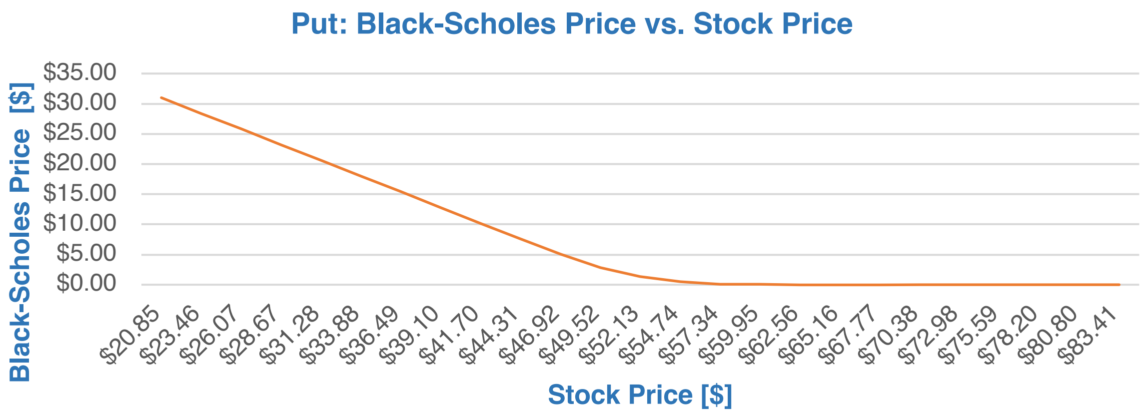

Figure 11: Put: Black-Scholes Price vs. Stock Price

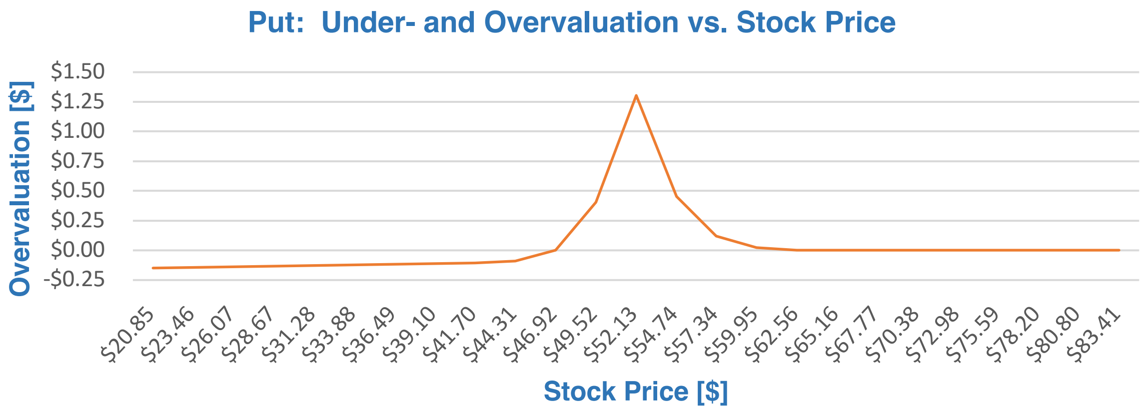

Figure 12: Put: Under- and Overvaluation vs. Stock Price

Discussion of Results:

The initial observations regarding the development of the intrinsic value and Black-Scholes price made for the call option are also valid for the put option. They are simply mirrored, as puts, in contrast to calls, have value when the spot price is lower than the strike price.

- Arising from its formula, the intrinsic value is the maximum out of either 0, or the difference between the spot price and strike price if the former falls below the latter. The negative linear function intercepting the x-axis at the strike price followed by a constant value of 0 is therefore fully expected.
- Again, the Black-Scholes price, as a theoretical approximation of what an option's price should be, follows a similar, though not quite identical path to the intrinsic value.
- While the price is almost equal to the option's intrinsic value when we are either far in-the-money or far out-of-the-money, the real significant differences arise when finding ourselves close to at-the-money. This is where the optionality feature of an option matters the most and where probabilities play a key role.

A trader with a long position in this put option, trying to decide on whether or not to sell the option, can once again make an optimal trading decision by relying on the information illustrated in Figure 12.

- The first observation is a strikingly similar development of misvaluation of the put option as we had seen for the call option in Figure 9.
- Similar to the case with the call option, the overvaluation of the put option increases the closer the spot price is to the strike price. However, a noteworthy difference to what we had observed with the call option is that there is a slight undervaluation of the put option when the spot price falls beneath $46.92. This will have an impact on our trading strategy.
- The above observations indicate that in scenarios where the spot price finds itself above $46.92, it is optimal to sell the put option to another trader at the Black-Scholes price and benefit from the overvaluation.

- Should the spot price however fall below a value of $46.92, the optimal strategy is to exercise the put option, as we can access its intrinsic value this way and avoid selling it at an undervalued price.

Question 4: Volatility Forecasting

4.1 Estimation of Volatility Metrics

Graphical Illustrations:

- Figure 13 shows the output generated by the GARCH(1,1) model we fit in order to estimate a forecast volatility for the lifetime of the option.
- Combining the above with various additional approaches, Table 1 subsequently summarises all the different volatility figures established throughout this report so far.
- To comprehensively interpret the figures in Table 1, Figure 14 shows the development of CSCO's spot price over the lifetime of the option to provide necessary context.

```
Fitting GARCH Model:

    GARCH(1,1) Conditional Variance Model (Gaussian Distribution):

                    Value       StandardError    TStatistic      PValue
                 ___________    _____________    __________    __________

    Constant      4.8886e-05     6.0952e-06        8.0204       1.054e-15
    GARCH{1}         0.63398       0.030253        20.956      1.6639e-97
    ARCH{1}          0.21344       0.017243        12.378      3.4455e-35

*************************************************************
GARCH(1,1) forecast Vol: 26.21
*************************************************************
VIX: 18.14
*************************************************************
Realised Vol: 43.54
*************************************************************
```

Figure 13: MATLAB Output

Metric	Value
Annualised Volatility Forecast (GARCH)	26.21%
Annualised Realised Volatility (over lifetime of option)	43.54%
VIX (on trade date of 31 October 2023)	18.14%
Implied Volatility (calculated from Black-Scholes formula in Q1)	27.28%

Table 1: Volatility Metrics

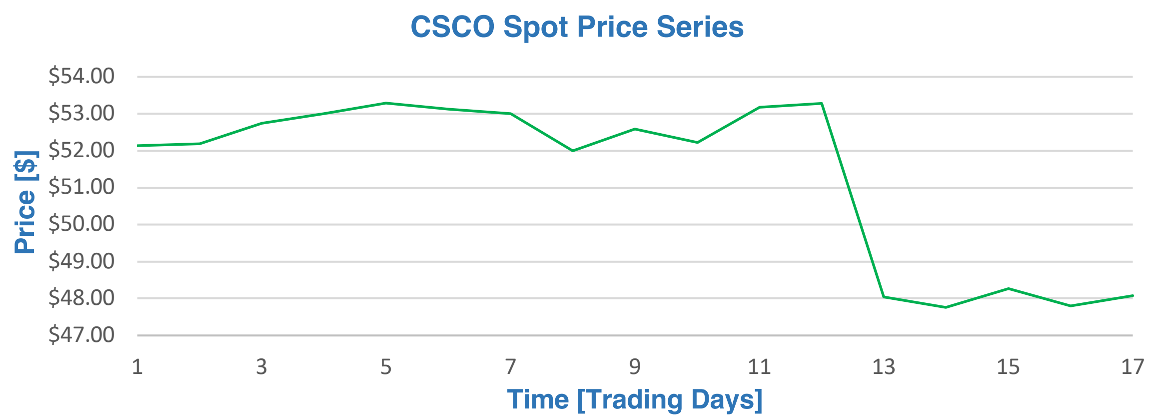

Figure 14: CSCO Spot Price Series

Discussion of Results:

Taking a closer look at the volatility forecast of the GARCH(1,1) model (26.32%) as well as the implied volatility (27.28%) confirms that both estimates are within a relatively close range of each other, boosting confidence in the accuracy of both values. Comparing these to the VIX value (18.14%) on our trade date, it becomes evident that in CSCO we are dealing with a relatively volatile stock compared to the market.

Furthermore, Table 1 clearly indicates that the realised volatility (43.54%) over the lifetime of the option exceeded all indicators predictions by a significant amount, approaching and even surpassing double the values of other metrics.

Figure 14 provides some insight into why this may be the case.

- On 15 November 2023, CSCO announced it was cutting its full-year revenue and profit forecasts, causing the share price to plummet from $53.28 to $48.04 (a drop of over 9.8%) (Reuters, 2023).
- Such drastic jumps in share price levels will naturally have an adverse effect on volatility. Compounded by the relatively short time span being observed provides a good explanation for the realised volatility metric exceeding the predictions so significantly.

4.2 Trading Strategy: Option Spread to Trade Volatility

Option Trading Strategy:

Based on our outputs above, we developed a suitable options strategy for a trader looking to trade volatility. This was done from the vantage point of and based on a knowledge base available on our trading day. Two main considerations which lead us to our suggested strategy are:

- Both the GARCH(1,1) model forecast volatility and the implied volatility calculations indicate high volatility is to be expected from CSCO.

- While the trader would not be aware of what CSCO was going to announce, it would have been public knowledge that an earnings report could be expected within lifespan of the option. Such reports typically lead to far from insignificant stock price movements, irrespective of whether or not the update is positive.

As both of these facts indicate a relatively high probability of large price movements, the trader will want to protect himself against and possible even gain from these developments. Therefore, it is our conclusion that a **long straddle** strategy would be the best approach for the trader to trade in volatility, as they benefit from higher volatility and enable traders to take a position in volatility without taking a view on the particular direction of the underlying asset.

A long straddle strategy involves taking a long position in two at-the-money options, one call and one put. To this end, we made the following trades:

- 1x long position in a call option at strike price $52.00.
- 1x long position in a put option at strike price $52.00

For further illustration purposes, the payoff function of the above constructed long straddle strategy is plotted in Figure 16. It clearly demonstrates the key characteristic of the long straddle of profiting from higher volatility.

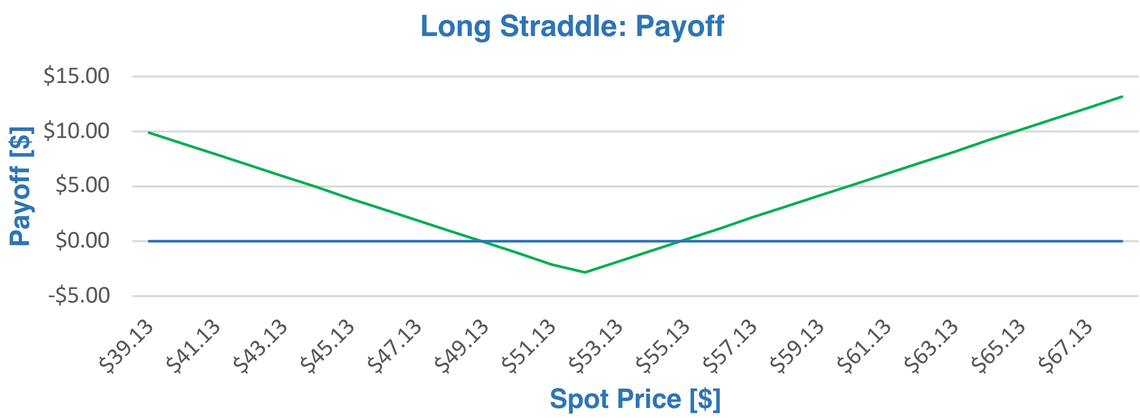

Figure 15: Long Straddle: Payoff

Results of the Long Straddle:

Table 2 presents an overview of the success of our long straddle strategy.

Metric	Value
Spot Price (24 November 2023)	$48.36
Strike Price(s)	$52.00
Premium Paid (Call)	-$1.56
Payoff (Call)	$0.00
Total Payoff from Long Position in Call Option	**-$1.56**
Premium Paid (Put)	-$1.41
Payoff (Put)	$3.64
Total Payoff from Long Position in Put Option	**$2.23**
Total Payoff from Long Straddle Strategy	**$0.67**

Table 2: Long Straddle: P&L

Through a combination of being well aware of the macro-environment in which our underlying found itself and perhaps a little bit of good fortune, our proposed long straddle managed to secure a profit of $0.67.

Question 5: Delta Hedging

5.1 Delta Hedge Using the Option Implied Volatility

Graphical Illustrations:

The processes underlying the delta hedge strategy are best understood when considering the following graphical illustrations:

- Figure 16 shows the development of CSCO's spot price over the lifetime of the call option.
- Figure 17 indicates how our delta position changed throughout this period, based on regular correctional trades.
- Figure 18 illustrates the P&L in our bank account resulting from the delta hedge.

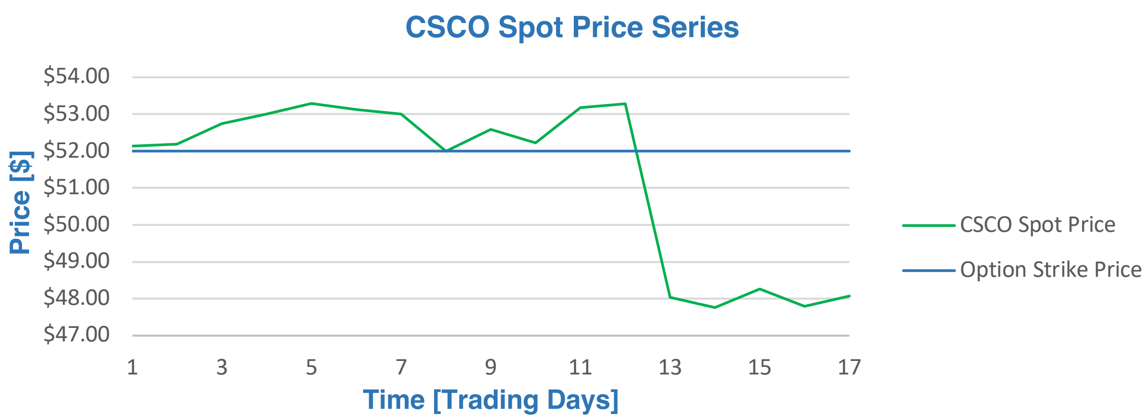

Figure 16: CSCO Spot Price Series

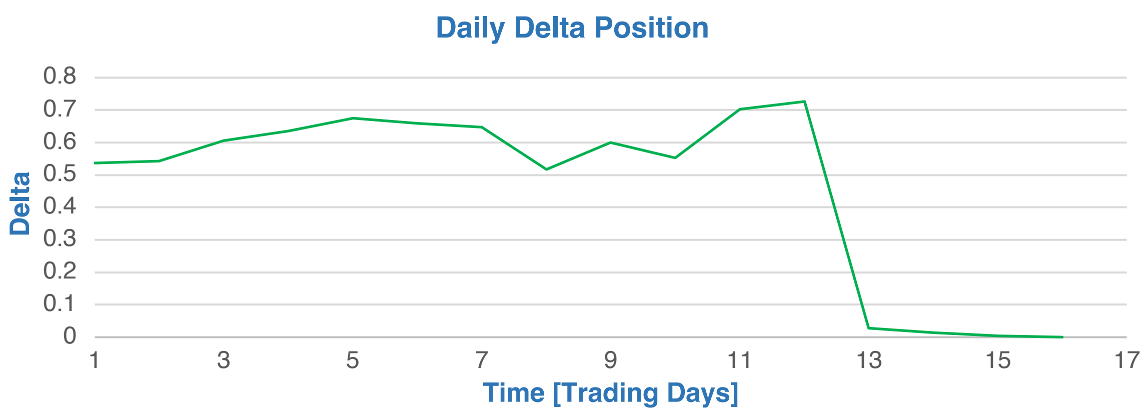

Figure 17: Implied Volatility: Daily Delta Position

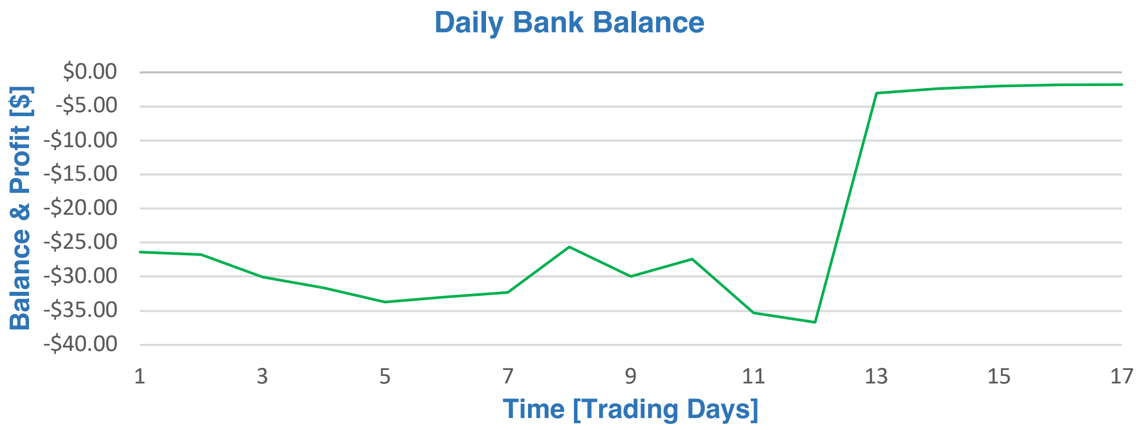

Figure 18: Implied Volatility: Daily Bank Balance and Final Hedge Profit

Discussion of Results:

An important observation is that CSCO's spot price takes a significant hit at $t = 12$, most likely as a reaction to its announcement that it was cutting its full-year revenue and profit forecasts. This drop in CSCO's spot price lead to a reduction of our delta position.

The reasoning behind this can be inferred from the theory illustrated in Figure 20.

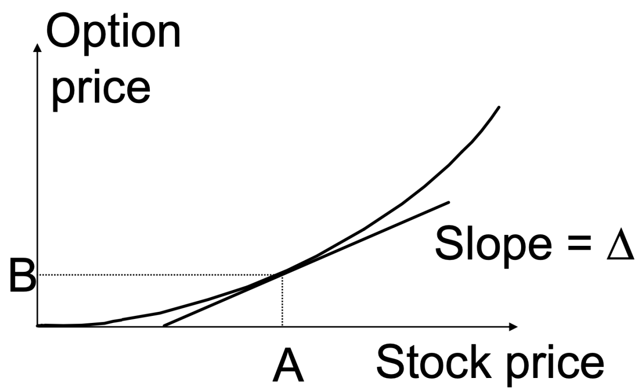

Figure 19: Delta Theory (McGee, 2023, p. 38)

As Figure 19 shows, the delta value is determined by the slope of the function of the option price for a given stock price. The value of delta will therefore always be between 0 and 1, as these are the natural limits of the slope of the curve.

The sudden drop in stock price moved us to a position which was so far out of the money, that we almost entirely eliminated our delta position from one day to the next.

- Graphically, we moved so far to the left along the x-axis that the slope of the curve – and hence the delta – reached a value close to zero.
- Logically, there was not much need for a delta position any longer, as we were far out of the money and the trader to whom we sold the call option was highly unlikely to ever exercise the option.

- This movement nicely illustrates how delta hedging relies on a linear approximation of the function shown in Figure 16, and is not accurate for big stock price movements.

The sale of the majority of our delta position lead to an inflow of cash into our bank account, subsequently significantly improving the overall P&L of the hedging strategy.

Despite this, the bottom line of our delta hedging strategy is negative, as we end up making a slightly negative delta hedge profit of -$1.80.

- This is, however, to be expected for a short position in a call option. In such a situation, we namely buy at higher spot prices and sell at lower prices, leading to expected losses for such a delta hedge strategy.
- While selling our delta position may have garnered a positive cash inflow, the drops in the stock price resulted in this being a lower value in absolute terms compared to the cash we had to invest in the first place to acquire the shares.

5.2 Delta Hedge Using the Volatility Forecast

Graphical Illustrations:

The following two graphics aim to enable the most insightful comparison of the effect of the two different volatility values by plotting the respective values both based on the implied volatility assumption as well as the volatility forecast assumption:

- Figure 20 plots the value of our delta position throughout the lifetime of the option, based on regular correctional trades.
- Figure 21 illustrates the P&L in our bank account resulting from the delta hedge.

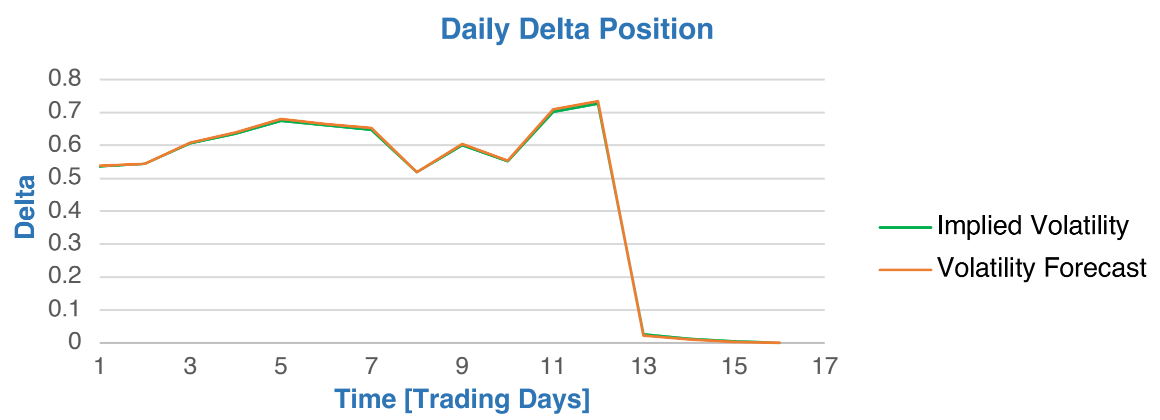

Figure 20: Implied Volatility vs. Volatility Forecast: Daily Delta Position

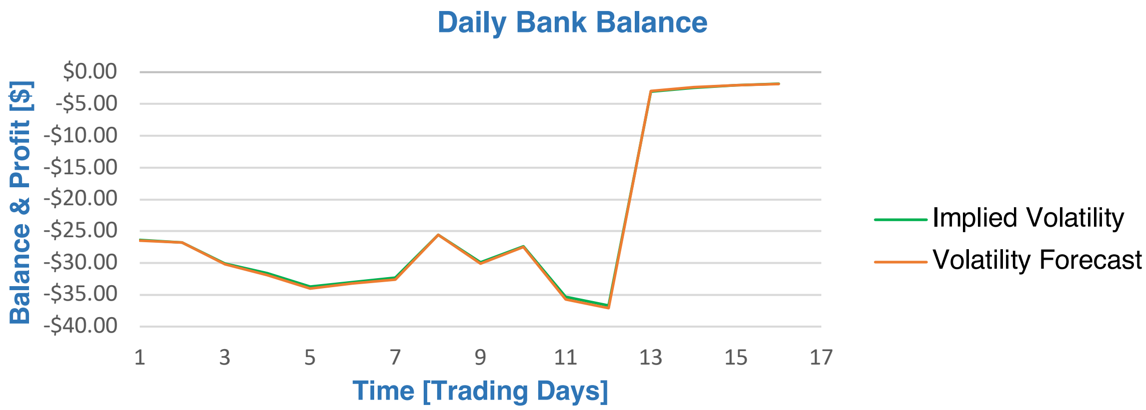

Figure 21: Implied Volatility vs. Volatility Forecast: Daily Bank Balance

Discussion of Results:

The figures show that inputting our volatility forecast of 26.41% in place of our implied volatility 27.28% does not have a significant effect on the daily delta positions for the hedging strategy, nor on the daily bank balance. The final hedge profit also remains nigh on unchanged at a value of -$1.84 compared to the previous -$1.80 previously.

A change in volatility can affect the outcome of such a delta hedge strategy in several different ways, which are worthwhile considering.

- Higher volatility implies larger price swings. This provides both the opportunity to profit from delta adjustments, while also increasing the risk of incurring losses.
- In a high-volatility environment, the timing of the delta adjustments gain in importance, as this will be a compounding factor of the profits and losses made as a result of dynamic price movements in the underlying.
- A more volatile underlying will typically necessitate more frequent delta adjustments. This can have a notable impact on your profits as a result of the increased incurring of transaction costs.

It is evident that a higher volatility has both pros and cons for a trader exercising a delta hedge strategy such as ours. It is clear, though, that the risk is more pronounced.

In our case, the difference in the final delta hedge profit for the two scenarios is very low. This is unsurprising, as the difference in the values of volatility as an input variable is also not large, making the two scenarios nearly identical. Nonetheless, the outcome is slightly better in the case of higher volatility (implied volatility), as the final loss of -$1.80 is smaller compared the loss of -$1.84 when inputting the forecast volatility. This indicates that, perhaps by chance, the pros of the higher volatility outweighed the cons.

Appendices

Appendix A: Assessment Submission Form

Project Number	Student Name	Student Number (id card)	Total Peer Mark (/30)
1.	Agarwal, Prerit	23206258	20
2.	Bhatt, Ayush	23200078	25
3.	Fernando, Sharon Jesuretnam	23200178	25.2
4.	Kharbanda, Pranjal	23200194	26
5.	Peppard, Eric	19741195	29

STUDENTS SHOULD KEEP A COPY OF ALL WORK SUBMITTED.
Procedures for Submission and Late Submission
Ensure that you have checked the School's procedures for the submission of assessments.
Note: There are penalties for the late submission of assessments. For further information please see the University's ***Policy on Late Submission of Coursework***, (http://www.ucd.ie/registrar/)

Plagiarism: the unacknowledged inclusion of another person's writings or ideas or works, in any formally presented work (including essays, examinations, projects, laboratory reports or presentations). The penalties associated with plagiarism designed to impose sanctions that reflect the seriousness of University's commitment to academic integrity. Ensure that you have read the University's ***Briefing for Students on Academic Integrity and Plagiarism*** and the UCD ***Plagiarism Statement, Plagiarism Policy and Procedures***, (http://www.ucd.ie/registrar/)

e-Signatures:

Signed Prerit Date …………………1 December 2023……………………

Signed Ayush Date …………………1 December 2023……………………

Signed Fernando Date …………………1 December 2023……………………

Signed Pranjal Date …………………1 December 2023……………………

Signed Eric Peppard Date …………………1 December 2023……………………

Number to Name Key Table

Student #	Name
1.	Agarwal, Prerit
2.	Bhatt, Ayush
3.	Fernando, Sharon Jesuretnam
4.	Kharbanda, Pranjal
5.	Peppard, Eric

Grids for Peer marking

Evaluator	**Evaluatee**	Peer Mark Effort (/10)	Peer Attitude (/10)	Peer Contribution (/10)	Total Peer Mark (/30)
1.	1.	8	8	8	24
2.	1.	7	8	7	22
3.	1.	7	7	7	21
4.	1.	7	7	7	21
5.	1.	5	5	4	12
				Total Average:	**20**
1.	2.	9	9	9	27
2.	2.	9	8	8	25
3.	2.	9	9	9	27
4.	2.	8	9	9	26
5.	2.	7	8	6	20
				Total Average:	**25**
1.	3.	9	9	9	27
2.	3.	8	9	9	26
3.	3.	9	9	9	27
4.	3.	8	9	9	26
5.	3.	7	8	6	20
				Total Average:	**25.2**
1.	4.	9	9	9	27
2.	4.	9	8	9	26
3.	4.	9	9	9	27
4.	4.	9	9	9	27
5.	4.	7	8	6	23
				Total Average:	**26**
1.	5.	10	9	10	29
2.	5.	10	9	9	28
3.	5.	10	10	10	30
4.	5.	10	10	9	29
5.	5.	10	9	10	29
				Total Average:	**29**

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