Title:

Options Fundamentals through Data Visualization: Pricing Methods, Relationship between Measures, and Common Trading Strategies

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Abstract

This project aims at providing information on how options are used as the investment and risk hedging tools by means of various data visualizations. First, the project talks about the pricing method of options like BSM model and Monte Carlo method. Next, the paper aims at exploring the following measures of options across its maturity and strikes: implied volatility (option value), the Greeks (sensitivity measures), volume and open interest (trading activities), and Bid-Ask spread (transaction costs). Then, common trading strategies are discussed using several examples. The data were obtained mainly from the quotes dashboard in the Cboe Global Markets database. This project deploys various techniques to generate 2D and 3D financial data visualizations. The output of this visualization forms a better understand about options as both investment hedging and trading instrument.

1. Introduction

Options contracts are financial instruments that give the holder the right, but not the obligation, to buy or sell an underlying security at a predetermined price, known as the strike price or exercise price, at some point in the future. The value of an option is determined by the difference between the strike price and the market price of the underlying security, called the option's moneyness. For call options, the strike price must be lower than the market price for the option to be considered in-the-money (ITM), meaning the holder can buy the security at a lower price and immediately sell it at a higher market price. For put options, the strike price must be higher than the market price for the option to be ITM, allowing the holder to sell the security above the current market price. Options that have strikes that are higher than the market price for calls or lower than the market price for puts are out-of-the-money (OTM) and only have extrinsic value, also known as time value.

Option Pricing Models are mathematical models that use certain variables to calculate the theoretical value of an option. The theoretical value of an option is an estimate of what an option should be worth using all known inputs. In other words, option pricing models provide us a fair value of an option. Knowing the estimate of the fair value of an option, finance professionals could adjust their trading strategies and portfolios. Therefore, option pricing models are powerful tools for finance professionals involved in options trading.

Options prices can be impacted by a range of factors that can affect traders depending on their positions. Experienced traders are aware of the factors, including implied volatility, the Greeks, trading activities, and transaction costs. In addition, algorithmic trading allows the use of common option strategies to observe relationships between profit, underlying stock and spreads. Options trading strategies are strategies employed by traders, by combining options with underlying, or options with futures, or by combining more than options of same or different types and/or same or different strikes/maturity. The strategies can be adopted based on the views of the trader on the following two fronts, with regard to the price of the underlying, i.e. a) Bullish Option Strategies b) Bearish Option Strategies c) Range bound Option Strategies d) Volatile Option Strategies.

2. Data Source

Data are obtained from the Cboe Global Markets website. Three indices are used. The first is Cboe's SPX® and XEO® options which underlaying is the Standard & Poor's 500 Index, a capitalization-weighted index of 500 stocks from a broad range of industries. The second index is NDX options which is an index composed of securities issued by 100 of the largest non-financial companies listed on the Nasdaq Stock Market (Nasdaq). Hypothetical data are used to illustrate the pricing options models and trading strategies.

3. Findings

3.1. Valuation of Options

3.1.1. Stochastics process

A stochastic process in finance is a mathematical model that describes the evolution of a financial time series over time. It is a statistical model that describes how the future value of a financial asset or portfolio is uncertain, and how it is influenced by random events or factors. A stochastic process is used to model financial time series because financial markets are highly complex and dynamic, and the future value of an asset or portfolio is influenced by many random factors such as economic conditions, market trends, investor sentiment, and so on. By modelling these random factors as a stochastic process, analysts and investors can better understand the uncertainty and risk associated with financial assets and make more informed investment decisions. There are many different types of stochastic processes that are used in finance, including the geometric Brownian motion model, the Vasicek model, and the Hull-White model, among others. These models are used to describe the behaviour of different types of financial assets, such as stocks, bonds, and derivatives, and are often used to price financial instruments, calculate risk measures such as value at risk, and perform other types of financial analysis.

3.1.1. Monte Carlo simulation

Monte Carlo simulation is a method that is often used to calculate the value of financial instruments called "contingent claims," which include options, derivatives, and other hybrid instruments. In finance, the value of a contingent claim is determined by the expected payoff that can be obtained from the instrument, adjusted for the time value of money using a risk-neutral measure. A risk-neutral measure is a probability calculation that assumes that the underlying assets, such as stocks or indices, will grow at a fixed, risk-free rate. The absence of arbitrage opportunities, as described by the Fundamental Theorem of Asset Pricing, is equivalent to the existence of a risk-neutral measure. European options are financial instruments that give the holder the right to buy or sell a specific asset at a specific price, known as the strike price, at a specific point in the future. American options are similar, but they can be exercised at any time during a specified period. The process of valuing European options is simpler than valuing American options. Figure 1 shows the analytical option value compared to Monte Carlo estimators for static and dynamic simulation, respectively. While there are both negative and positive value differences, all valuation differences are smaller than 1%. The European value of an option represents a lower bound to the American option's value. The difference is generally called the early exercise premium. What follows compares European and American option values for the same range of strikes as before to estimate the early exercise premium, this time with puts. Figure 3 shows that shows that for the range of strikes chosen the early exercise premium can rise to up to 10%.

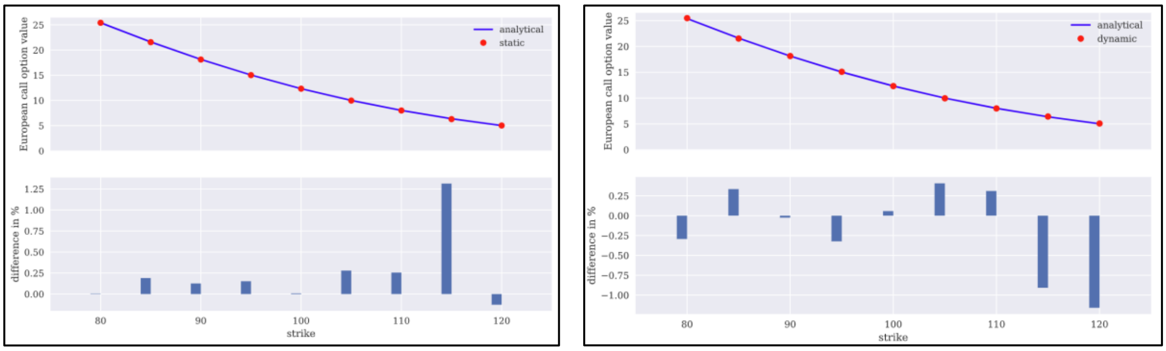


Fig. 1. Analytical option values vs. Monte Carlo estimators: static (left) and dynamic (right)simulation.

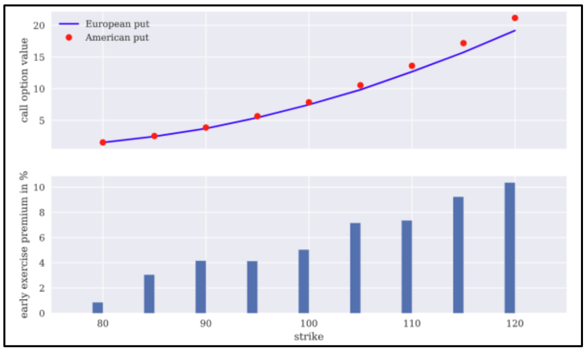


Fig.2. European vs. American Monte Carlo estimators.

3.1.3. Black-Scholes-Merton

The following presents a class definition for a European call option in the Black-Scholes-Merton (1973) model. The option class can also be used to visualize, for example, the value and vega of the option for different strikes and maturities. It is, in the end, one of the major advantages of having an analytical option pricing formula available.

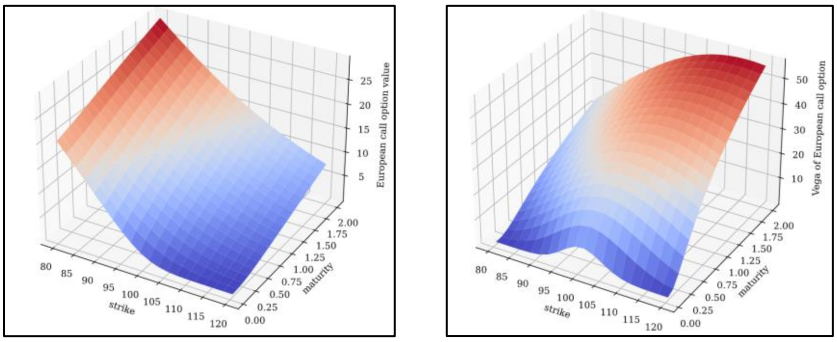


Fig. 3. Value surface (lef) and Vega surface (right) for European call option.

3.2. Relationship between Measures of Options

3.2.1. Introduction

Given a call or a put, it is uniquely defined by its strike price and maturity. Therefore, in this section the paper want to explore the following across strikes and maturities: (1) The option value—implied volatility; (2) The sensitivity measures—the Greeks; (3) Trading activities—Volume and Open Interest, and (4) Transaction costs—Bid-Ask spread. Furthermore, whether the above quantities differ by calls/puts are also examined.

3.2.2. The option value – implied volatility

Options contracts allow the holder to purchase or sell an asset at a predetermined price for a specified period of time. The value of an option is influenced by several factors, including implied volatility, which is an estimate of the future volatility of the underlying asset. Options with higher implied volatility tend to have higher premiums, while those with lower implied volatility have lower premiums. The volatility surface is a three-dimensional plot that shows the implied volatilities of various options on the same stock. Implied volatility is one of the factors taken into account when using the Black-Scholes model to price options. The data reveal that SPX, NDX, and NDX show similar surface across the maturity and strike price. However, the volatility surface is not always flat and can change over time, indicating that the assumptions of the Black-Scholes model may not always hold true.

As shown in Figure 4, like the market as a whole, implied volatility can be subject to unpredictable changes. Two major factors that can affect implied volatility are supply and demand for the underlying asset. When an asset is in high demand, its price may increase, which can also lead to an increase in implied volatility and a higher option premium due to the increased risk. The time value of the option, or the amount of time until the option expires, can also influence implied volatility. Options with shorter expiration dates tend to have lower implied volatility, while options with longer expiration dates may have higher implied volatility. Moreover, as the time to maturity approaches infinity, volatilities across strike prices tend to converge to a constant level. However, the volatility surface is often observed to have an inverted volatility smile. Options with a shorter time to maturity have multiple times the volatility compared to options with longer maturities. This observation is seen to be even more pronounced in periods of high market stress. It should be noted that every option chain is different, and the shape of the volatility surface can be wavy across strike price and time. Also, put and call options usually have different volatility surfaces.

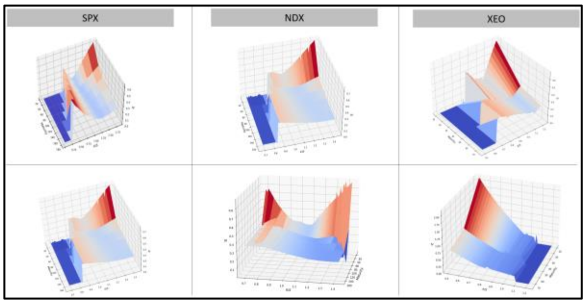


Fig. 4. Implied surface volatilities across maturity and moneyness for calls (top) and put (bottom).

<u>*3.2.3. The sensitivity measure: Delta*</u>

Delta, gamma, vega, and theta are known as the "Greeks" and are used to measure the sensitivity of an option's price to different factors. Delta measures the sensitivity of an option's premium to a change in the price of the underlying asset, while theta measures how the option's price will change as time passes. The Greeks can be used to understand the risk exposures associated with an option or a portfolio of options. Delta is a measure of how the price (premium) of an option change in response to a change in the price of the underlying security. As shown in Figure 5, the value of delta ranges from -100 for puts to 0 for puts and from 0 for calls to 100 for calls (-1.00 and 1.00 without the decimal shift, respectively). Puts have a negative relationship with the underlying security, meaning that their premiums decrease when the underlying security's price increases and vice versa. On the other hand, calls have a positive relationship with the price of the underlying asset. If the price of the underlying asset increases, the premium of the call option will also increase, provided that other variables such as implied volatility and time remaining until expiration remain unchanged. If the price of the underlying asset decreases, the call premium will also decline, again provided that other variables remain constant. Delta changes as the options become more profitable or in-the-money. In-the-money means that a profit exists due to the option's strike price being more favorable to the underlying's price.

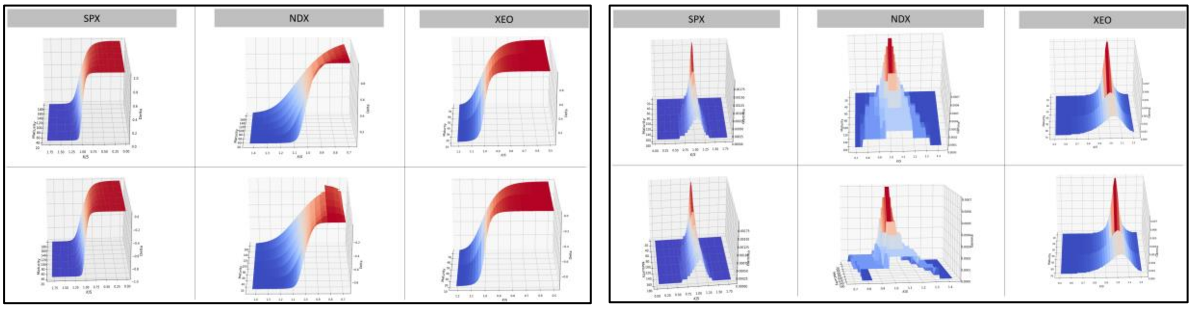


Fig. 5. Delta (left) and Gamma (right) across maturity and moneyness for calls (top) and put (bottom).

3.2.4. The sensitivity measure: Gamma

Gamma is a measure of the rate of change in delta over time. Delta values are constantly changing as the price of the underlying asset changes, so gamma is used to measure these changes and give traders an idea of what to expect in the future. Gamma values are typically highest for options that are at the money and lowest for options that are deep in or out of the money. As shown in Figure 5, Gamma is smallest for options that are deep out of the money or deep in the money. It is highest for options that are near the money. In addition, gamma is positive for long options and negative for short options.

3.2.5. Trading activities: Volume

Volume refers to the number of options contracts that are traded on a given day. It is shown for each strike price for both call and put options and is a measure of investor demand and liquidity for the options contract. As volume increases, the difference between the bid price and the ask price (bid-ask spread) tends to decrease, resulting in more efficient pricing. Higher volume means higher liquidity. The more options volume there is for a contract, the more liquidity exists. These contracts are much easier to enter and exit because more market participants are transacting in the contract.

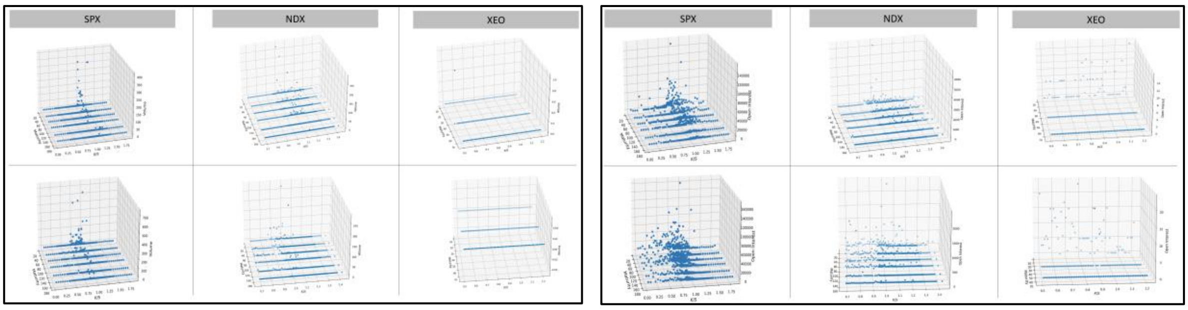


Fig. 6. Volume (left) and open interest (right) across maturity and moneyness for calls (top) and put (bottom).

3.2.6 Trading activities: Open interest

Open interest is the total number of contracts outstanding. Open interest represents the active number of options contracts for a particular class, strike price, and expiration date that are open and have not been closed or exercised. Open interest is updated daily and is typically displayed beside volume on an options chain. Open interest starts at 0 for every option contract. Open interest rises and falls throughout the the contract's trading life. Options open interest is the number of open contracts that remain for an expiration. This includes contracts that have not been exercised, offset, or expired.

3.2.7. Transaction costs: Bid-Ask spread

The bid-ask spread is the difference between the highest price that a buyer is willing to pay for an option and the lowest price that a seller is willing to accept. It is the amount by which the ask price exceeds the bid price in the market. When an individual wants to sell an asset, they will receive the bid price, while someone looking to buy the asset will pay the ask price. The spread is the cost of a transaction. Price takers buy at the ask price and sell at the bid price, while market makers buy at the bid price and sell at the ask price. Furthermore, bid-ask spreads tend to widen during times of higher volatility because price changes in the stock are more drastic on the option contract. Investors and market makers tend to take advantage of higher volatility which results in wider spreads and in some cases an unfavorable order fill. n general, more liquid assets will have smaller bid-ask spreads because there are more buyers and sellers willing to trade at any given time. On the other hand, less liquid assets may have wider bid-ask spreads because there are fewer buyers and sellers, which can make it more difficult to find a matching trade. The bid-ask spread can also be influenced by the market maker's perceived risk in offering a trade, as well as the potential for price changes. For example, options or futures contracts may have larger bid-ask spreads compared to other assets because they are more complex and have more inherent risks.

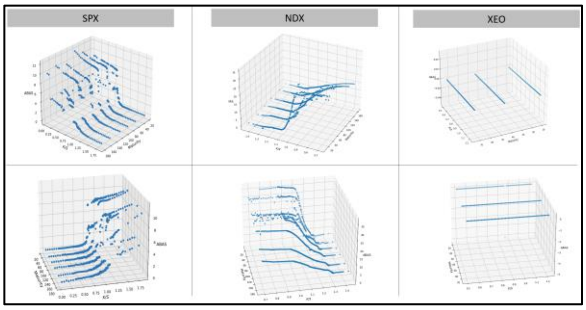


Fig. 7. Absolute Bid-Ask Spread across maturity and moneyness for calls (top) and put (bottom).

3.3. Options Trading Strategies

3.3.1. Covered call

A Covered Call is an options strategy that involves both the underlying stock and an options contract. The trader buys (or already owns) a stock, then sells call options for the same amount of stock. The aim of the Covered Call is to profits from the option premium by selling calls written on the stock traders already owned. The risk of a Covered Call also comes from the long stock position whose price could drop. Figure 8 illustrates the pay-off diagram for this strategy. In this scenario, strike, option premium, and stock price range are 160, 7.5, and 110-230, respectively. Back testing of the model shows small drawdown. This implies that the Covered Call strategy performs better than a simple buy-and-hold strategy of underlying stock in a bearish market. In a bullish market, however, traders miss out on any gains if the underlying stock price breaches the strike price.

3.3.2. Bull call spread

A Bull Call Spread is a trading strategy that involves purchasing one call option with a lower strike price and selling another call option with a higher strike price, both with the same expiration date. The goal of this strategy is to reduce the cost of a long call option by selling a call option with a higher strike price, while also creating a profit ceiling and floor. The trader benefits from a potential increase in the price of the underlying stock, but the potential profit is limited by the difference between the strike prices of the two call options. The strategy also limits the potential loss if the price of the underlying stock drops, as the trader has already received premium income from selling the higher strike call option. As shown in Figure 9, if the price of a stock is $950 at the time the strategy is initiated and the premium for an in-the-money call option with a strike price of $900 is $20, while the premium for an out-of-the-money call option with a strike price of $1000 is $2, the potential payoff for a Bull Call Spread strategy would be as shown in Fig. 8.

3.3.3. Long straddle

Long Straddle is an options trading strategy involving the going long in both a call and a put option, where both options have the same underlying asset, strike price and expiration date. This strategy aims to profit from volatile movements in the underlying stock, either positive or negative. Given the plot shown in Figure 9, if the stock price moves significantly away from the strike price in either direction, the Long Straddle will profit. The potential profit is unlimited on the upside because the stock price can rise indefinitely. On the downside, the potential profit is substantial but limited since the stock price can't fall below zero. The potential loss is limited to the premium of both call and put options. The maximum loss will be realized if the stock price is exactly equal to the strike price at expiration, and both options will expire worthless.

3.3.4. Long strangle

A Long Strangle is an options trading strategy that involves the simultaneous buying of an out-of-the-money put and an out-of-the-money call with the same underlying stock and expiration date. Similar to a Long Straddle, the Long Strangle has unlimited profit and limited risk, and can be applied if traders think the underlying asset will become volatile and move significantly in either direction. It differs from Long Straddle, however, in that the call strike is above the put strike.

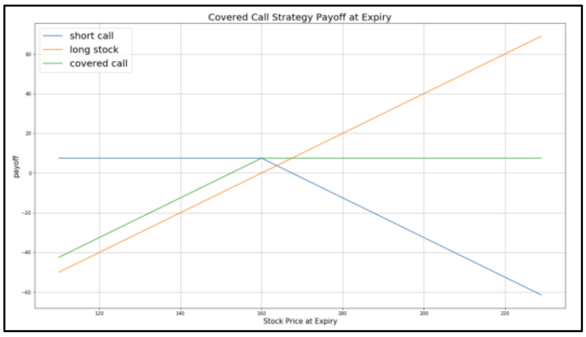


Fig. 8. Covered call payoff diagram.

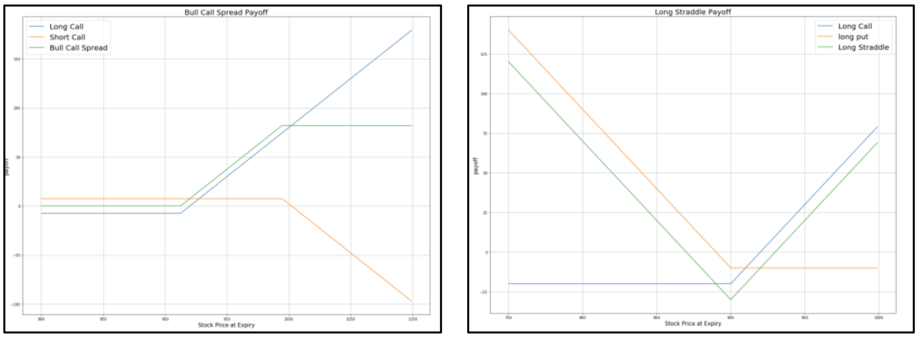
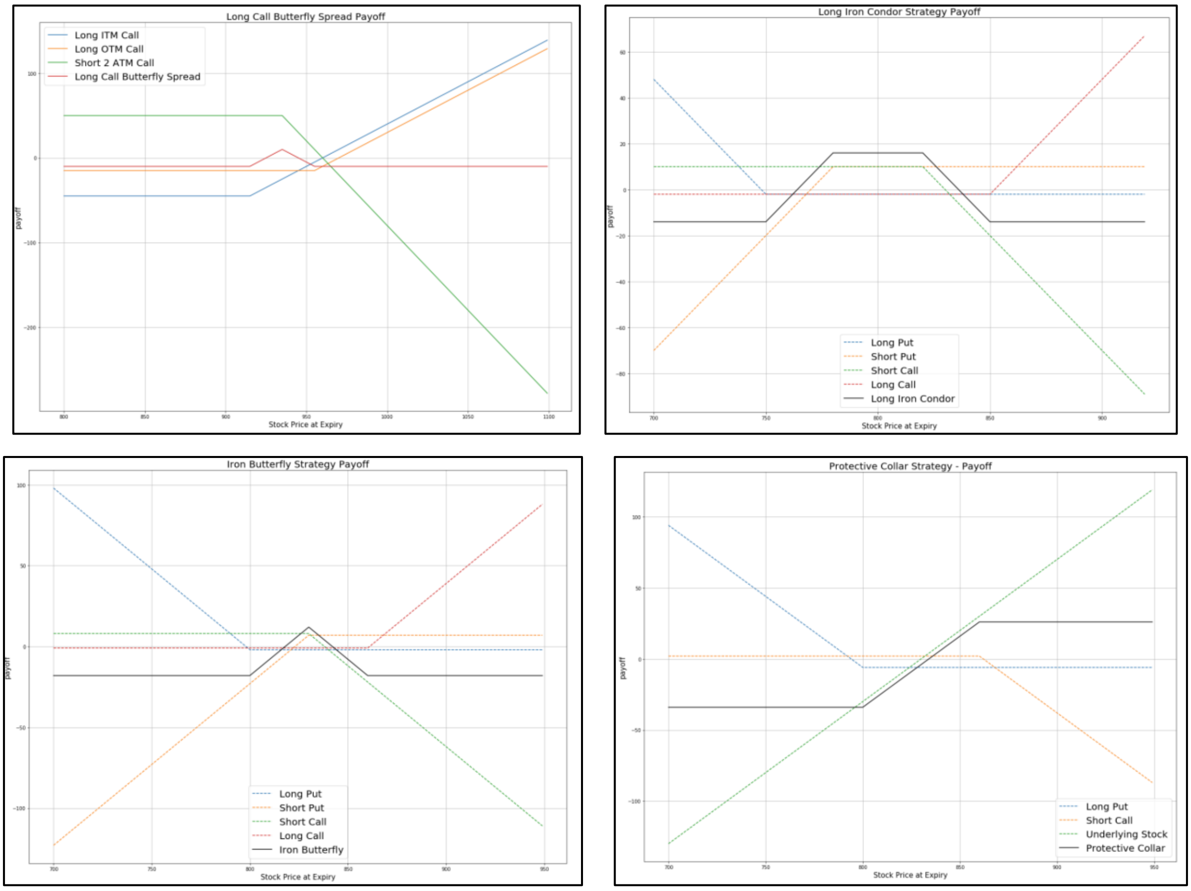


Fig. 9. Long straddle (left) and long strangle (right) payoff diagram.

3.3.5. Others trading strategies

The following plots, shown in Figure 10, show the pay-off diagram for other trading strategies. The long call butterfly consists of three legs with a total of four options: long one ITM call, short two ATM calls and long one OTM call. All the calls have the same expiration. On the other hand, the middle strike is halfway between the lower and the higher strikes. As seen in the payoff plot of long iron condor, the maximum profit comes from the options premium because the deeper OTM options are cheaper than the shallower ones. From the iron butterfly payoff, the maximum gain is simply the net credit you received when traders buy and sell 4 options. This occurs if the stock price is exactly the same as the strike price of the ATM options. According to the payoff plot of protective collar strategy, the maximum profit is the strike price of short call minus the purchase price of the underlying asset plus the net credit from the premium.



Fig, 10. Payoff diagrams for other trading strategies.

4. Conclusion

From the findings above, some conclusion can be made. In terms of theory, Monte Carlo Simulation (MCS) relies on risk neutral valuation. This approach, although relatively straightforward, allows for increasing complexity. There are some similarities and differences among options measures when analyzed across maturity and moneyness. This is true for all indices used in this project. There are many options strategies that both limit risk and maximize return. Traders can learn how to take advantage of the flexibility and power that stock options can provide. However, some literature argues that MCS are computationally inefficient due to the generated high variances. Also, the BMS's assumption of constant market volatility and no options returns are unrealistic. Use of other methods, such as binomial pricing options, are recommended for improvement. Trading strategies payoff must be examined in a sideways market, and also together with algorithmic trading to allow for back testing.