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MONTE CARLO SIMULATION

In continuation of our series, where in the past we have discussed the (i) Black Scholes model and the (ii) Binomial option pricing model, we present the Monto Carlo simulation model to conclude our series on option pricing models.

The footnote provides the link to those two newsletters[1].

INTRODUCTION

Monte Carlo Simulation (referred to as "Monte Carlo" or "the model") is a model used to simulate multiple outcomes for a scenario based on pre-defined inputs. The Monte Carlo model has multiple real-life applications in virtually every field such as finance, engineering, supply chain, science etc.

Monte Carlo requires the specification of the variable to be simulated and assign a probability distribution to the same based on its features. Probability distribution can be understood as a statistical representation of the possible values a variable can assume. In its practical applications, Monte Carlo simulation, acts as a decision-making tool. For example, it can be used to analyze the feasibility of a project by simulating potential NPVs and making a decision.

This newsletter discusses the application of the Monte Carlo simulation for option pricing analysis.

MONTE CARLO IN OPTION PRICING ANALYSIS

Monte Carlo simulation also finds applications in option pricing analysis. In the context of an option pricing analysis, the model simulates the price of the underlying asset and computes the option payoff for each of the possibility. The option value can then be concluded as an average payoff at all potential levels of prices.

There are certain assumptions that underlie a Monte Carlo simulation for option pricing. One of the foremost assumptions of a Monte Carlo model is that the underlying stock's price follows a Geometric Brownian Motion ("GBM") stochastic process. The GBM assumes that stock price of a company follows a random walk. The formula for a GBM is as follows:

$$\frac{\Delta S}{S} = \mu \Delta t + \sigma \varepsilon \sqrt{\Delta t}$$

Where;

S = underlying stock price
μ = the expected return
σ = Volatility
t = time period
ε = random variable

In layman terms, the GBM forecasts a constant drift in the stock price captured by the volatility input and a "shock" which is accounted by the random number.

[1]Inputs to the Black Scholes Option Pricing Model – A Primer on ASC 718 valuation
Binomial Lattice Model – ASC 718 valuation

INPUTS TO THE MONTE CARLO MODEL

The inputs to the Monte Carlo simulation model are in line with the inputs required for other option pricing models such as:

- Stock price
- Exercise price
- Volatility
- Expected term
- Risk free rate
- Dividend yield

A key differentiator in Monte Carlo simulation is an additional input in the form of probability distribution that the variables to be simulated must follow. Commonly used probability distributions include normal, lognormal, uniform, triangular etc.

For option pricing analysis, a lognormal distribution is preferred. As the lognormal distribution is positively skewed, it is apt for representing values that don't go below zero and have unlimited potential upside. Given that share prices of companies have a floor value of zero, a lognormal distribution is the preferred choice.

APPLICATIONS IN FINANCIAL REPORTING FOR VALUING OPTIONS

Monte Carlo simulations are the preferred option pricing models when valuing employee stock options ("ESOPs") with complex market vesting conditions as well as performance conditions. Following features of ESOPs can be modelled using a Monte Carlo simulation:

- **Multiple conditions**: Monte Carlo simulations are useful when valuing ESOPs with multiple complex conditions. For example, an ESOP with graded vesting, and a market condition of the company's share price crossing a pre-determined level can be best valued using Monte Carlo simulation.
- **ESOPs issued by listed companies**: Share prices of listed companies are more volatile than those of their unlisted counterparts. While a binomial option pricing model captures an upward and downward movement in the stock price, the Monte Carlo Model introduces a random factor which takes into account the impact of market shocks that are likely to be faced by listed companies.
- **Incorporating early exercise:** ESOPs which incorporate an early exercise factor can also be valued using a Monte Carlo Model.
- **Maximum payout:** Conditions imposing a cap on the payout (in case of Stock Appreciation Rights) can be modelled in a Monte Carlo Model. While computing the option payoff at each simulation, a condition can be imposed that limits the payoff at the pre-determined cap.
- **Performance conditions:** There are certain ESOPs which are issued with performance vesting conditions. For example, an ESOP may vest when the revenue of the company crosses a certain threshold. Performance metrics like revenue, operating profits etc. can be best modelled using a Monte Carlo simulation.
- **Multiple probability distributions:** A Monte Carlo model allows the user to specify multiple probability distributions for multiples variables that are being simulated. For example, an ESOP may be issued with a market condition i.e. the stock price must cross a pre-decided level for the ESOP to vest. An additional performance condition may also be imposed i.e. the operating profit must exceed a pre-decided threshold. An ESOP with these dual conditions can be valued using Monte Carlo simulation as follows:
    - Simulate the stock price: Along with the other inputs to an option pricing model, a probability distribution must be specified. Since the stock price has a floor value of zero and cannot take negative form, a lognormal distribution is specified which is skewed positively.
    - Simulate operating profit: The operating profit of a company may be negative and is not bound to 0. For simulating the profit, a normal distribution can be specified based on which the profit can take values symmetrically on either side of the bell curve.

LIMITATIONS

Following are the limitations of the Monte Carlo simulation model:

- **Complex model:** One of the most cited limitations of the Monte Carlo simulation is the complexity involved in building the model. It is a data intensive exercise and though it can be manually designed, it may lead to human errors**.**
- **Expensive software needed:** While a simple Monte Carlo model with a limited number of simulations can be structured manually, complex simulations require the use of expensive simulation software. A cost benefit analysis of using a Monte Carlo model must be performed before applying the same.
- **Inputs driven**: Like every complex model, results produced by a Monte Carlo simulation are driven by the inputs to the model. The level of subjectivity is increased in a Monte Carlo simulation as one needs to specify the probability distribution that the underlying variable is expected to follow. Thus, the number of assumptions required to run a Monte Carlo simulation creates a garbage in garbage out situation.

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