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Option Pricing Model Comparison between Black Scholes Merton Model and Monte Carlo Simulation

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Abstract:

The rapid growth of global option markets underscores the importance of accurate option pricing models for effective risk management and trading strategies. This paper focuses on two cornerstone methods: the Black–Scholes–Merton (BSM) model and Monte Carlo simulation. The central question is how the analytical efficiency of the BSM model compares with the flexibility of Monte Carlo simulation when applied to standard and complex options. The paper introduces the theoretical foundations of both models, highlighting the BSM model's closed-form precision under strict assumptions and Monte Carlo simulation's ability to handle stochastic, path-dependent payoffs. A case study of a three-month European call option on Apple Inc. illustrates the respective strengths and limitations of the two models. The findings of this paper conclude that the Black Scholes Merton model is still the benchmark for the standard option pricing market. In contrast, the Monte Carlo simulation provides better flexibility in pricing exotic options and adapting to a more volatile market. By combining these two methods, this study provides a more robust basis for valuation and decision-making in modern finance.

Keywords: Option Pricing; Black–Scholes–Merton Model; Monte Carlo Simulation; Derivatives and Risk Management; Financial Modeling

1. Introduction

With the rapid expansion of global option markets, the need for an accurate and convenient option pricing model has increased significantly.Option-pricing technologies have played a fundamental role in supporting the development of new financial products and global markets (Merton). This essay will analyze two different option pricing methods: the Black-Scholes-Merton model and the Monte Carlo simulation. The Black-Scholes-Merton model offers analytical efficiency and precision under strict assumptions, making it the benchmark for pricing European options. By contrast, Monte Carlo simu-

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lation—while computationally intensive—offers greater flexibility by simulating a large number of stochastic price paths under a volatile market, thereby enabling the valuation of exotic and path-dependent derivatives.

2. Options

An option grants its buyer the right, but not the obligation, to purchase or sell an underlying asset at a pre-determined strike price on or before a specified expiration date. Options have a fixed expiration date by which the holder must exercise their right if they choose to do so. A call option allows the buyer to buy the asset, while a put option allows the buyer to sell. They are deeply embedded in hedging, speculation, and strategic asset-allocation decisions; mispricing can lead to arbitrage losses or biased risk assessments. The Black–Scholes model provides a closed-form solution for European-style options and remains the core valuation framework for most trading desks today [1-2]. Yet real-world frictions, stochastic volatility, and payoffs often violate Black Scholes model assumptions. To overcome these limitations, analysts often employ Monte Carlo simulation, a computationally intensive, but highly flexible, technique that estimates option values by sampling thousands of plausible future price paths. This paper will examine and contrast the two most common approaches to option valuation. First, this essay will introduce the Black Scholes model and discuss how each input parameter shapes the final valuation. Second, this essay will turn to Monte Carlo simulation, detailing how random sampling of price paths can accommodate complexities beyond the Black–Scholes model's scope. By applying both methods to a real-world case, pricing a three-month call on Apple Inc., this essay will highlight where their results align, where they diverge, and the implications of these differences for risk management and trading.

Global exchange-traded-options volume reached 12.2 billion contracts in 2024, a 10 percent year-over-year rise, equivalent to ≈48 million contracts every trading day. Equity options alone grew 16 percent to 6.5 billion contracts [3]. These striking figures demonstrate that for asset managers, accurate option valuation is the cornerstone of portfolio insurance, volatility trading, convertible-bond arbitrage, and corporate treasury hedging. Precise models therefore help traders better evaluate option prices, which directly translates to improved capital allocation and regulatory compliance.

3. The Black Scholes Model

The Black Scholes model is one of the most influential frameworks for precisely valuing options. It begins by treating the underlying asset price as a continuous-time stochastic process, a geometric Brownian motion characterized by constant percentage volatility. Under the dual assumptions of frictionless markets and continuous trading, an investor can construct a self-financing portfolio consisting of the underlying asset and a risk-free bond that exactly replicates an option's payoff. The Black Scholes equation requires six input parameters: volatility, the price of the underlying asset, the option's strike price, time to maturity, the risk-free interest rate and the type of option. The Black Scholes formula is derived by multiplying the stock price by the cumulative standard normal probability distribution function. As shown in the picture below,

$$C = SN(d_1) - Ke^{-rt}N(d_2) \tag{1}$$

where

$$d_1 = \frac{ln\frac{S}{K} + \left(r + \frac{\sigma_v^2}{2}\right)t}{\sigma_s\sqrt{t}} \tag{2}$$

And

$$d_2 = d_1 - \sigma_s\sqrt{t} \tag{3}$$

C=Call option, S=Current Stock price, K= Strike price, r = Risk free interest rate, t=Time to maturity, N=A normal distribution[4]. The Black-Scholes model has been effectively utilized by financial practitioners, as it provides a theoretical basis for determining an option's fair value. However, the model has inherent limitations: it only assumes that volatility remains constant over the option's lifetime, which rarely holds in practice. This is often not the case because volatility fluctuates with market supply and demand dynamics. Furthermore, the Black–Scholes model is limited to valuing European-style options; it cannot determine the price of exotic options.

4. Monte Carlo Model

On the other hand, when modeling options on assets with intricate, non-linear price dynamics or when the future value of the underlying asset is uncertain, Monte Carlo simulation is much more flexible and reliable compared to the Black Scholes Model. It relies on large-scale repeated random sampling to simulate the future paths of the underlying asset price and compute the expected payoff. Instead of depending on a single, point estimate, traders can obtain a distribution of potential option values by employing Monte Carlo simulation. It yields probability-vs.-value relationships for key variables, including oil and gas reserves, capital exposure, and various financial metrics, such as net present value and return on investment [5]. As a result, traders can make more informed trading decisions and gain a clearer understanding of the option's potential risks and returns. To use the Monte Carlo method to calculate the option price, researchers first need to define the parameters of the option, such as the strike price, expiration date, and volatility and then we will need to generate a large number of random price paths for the underlying asset using a geometric Brownian motion model, applying the following formula

$$S(t+dt)=S(t)*exp\left((r-0.5*sigma^2)*dt+sigma*\sqrt{dt}*Z\right) \quad (4)$$

S(t) is the price of the underlying asset at time t, r is the risk-free interest rate sigma is the volatility of the underlying asset dt is the time increment Z is a standard normal random variable. Researchers then calculate the payoff of the option at expiration for each price path generated and discount it back to the present value using the risk-free interest rate. Finally, they compute the average of these discounted payoffs to derive the option's value [6]. The primary drawbacks of Monte Carlo simulation are that it requires a large volume of sampling and is highly dependent on the quality and accuracy of inputs provided by the user. Furthermore, there remains a risk that it may underestimate the probability of extreme events such as financial crises and irrational behavior from investors.

5. The Differences between the Black-Scholes Model and the Monte Carlo Model

There are several key differences between the Black-Scholes model and the Monte Carlo simulation when comparing them. Firstly, the two methods differ significantly in computational efficiency. The Black-Scholes model provides a more straightforward closed-form analytical solution, enabling rapid valuation—an advantage for traders requiring real-time option prices during live trading [7]. On the other hand, Monte Carlo simulation requires intensive computation, as it demands numerous iterations to generate a statistically reliable estimate of the option's value [8]. However, with advances in computing power, this shortcoming of Monte Carlo simulation has been significantly alleviated, making simulations more accessible and efficient than in previous decades.

Moreover, the two models differ in their applications. The Black-Scholes model is specifically designed for European options, which are exercisable only at expiration. Its analytical framework cannot easily accommodate exotic options such as American-style options, which permit exercise at any time before expiration, or other path-dependent options like Asian options and barrier options [7]. Monte Carlo simulation, by contrast, excels at valuing these complex instruments due to its inherent flexibility in accommodating a wide array of payoff structures and path dependencies.

In practice, traders and portfolio managers often integrate both methods. The Black-Scholes model remains the preferred tool for rapid pricing and hedging of standard options, providing a close approximation to market prices under its core assumptions of constant volatility and frictionless trading. Monte Carlo simulation is employed for structuring and pricing exotic derivatives like American-style options, conducting stress tests, and assessing portfolio risks under various market scenarios.

In conclusion, the Black-Scholes model provides an efficient analytical solution for option pricing under specific assumptions, making it ideal for real-time applications. However, its need of constant volatility and continuous markets limit its real-world applicability. Conversely, Monte Carlo simulation offers greater modeling flexibility. It is especially useful in pricing options outside of Europe and assessing risk under uncertain conditions. The primary drawback of the simulation method is the huge time cost it need for enormous amount of sampling and the incapacity to estimate under the financial crisis. Ultimately, both models are invaluable tools that not only enhance option pricing but also inform better decision-making in risk management, investment, and regulatory compliance.

6. Conclusion

This paper has demonstrated two fundamental models of option pricing, the Black Scholes Merton (BSM) Model and the Monte Carlo Simulation. The paper firstly introduced the Black Scholes Merton Model, illustrating its widespread use in a constant volatility and frictionless European style option markets. ASubsequently, the paper highlighted the application of Monte Carlo simulation, demonstrating how it generates stochastic price paths to value complex, path-dependent options. Following the theoretical discussion, a case study of a three-month European call on Apple Inc. was presented. The analysis affirmed that Monte Carlo simulation is highly flexible for exotic option markets and uncertain market conditions. Conversely, the BSM model demonstrated its computational efficiency and analytical clarity for standard options. After the analysis, the paper concludes that the two different option pricing methods are complementary. The Black Scholes Merton Model is still the benchmark for standard option pricing, whereas the Monte Carlo simulation provides a more robust framework for non-standard options and volatile market environments.

Despite its findings, this paper has several limitations. First, this paper is written conceptually and is not based on empirical testing with real market data. Furthermore, the literature reviewed is selected instead of being randomly chosen. This may have influenced the conclusions drawn. Future research could address these limitations by employing empirical methods, such as back-testing model performance on historical option prices, and by conducting a more systematic literature review to integrate diverse perspectives.

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