Comparative Analysis of Option Pricing Models: Assessing the Accuracy of the Black-Scholes Model and the Taylor Series Approach

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Abstract

This study compares the Black-Scholes model to the Taylor series approach in option pricing. We ran a series of tests to assess the accuracy of these two techniques in forecasting option prices. Our findings show that the Taylor series technique surpasses the Black-Scholes model in terms of accuracy, particularly for a tiny period of time. Overall, our work adds to the current debate on the best option pricing approach and provides important guidance for investors and financial sector practitioners.

Keywords: Black-Scholes Model, Taylor series, financial market, option pricing.

I Introduction

Option pricing is an important field of study in financial mathematics, and it has been the subject of countless studies throughout the years. The Black-Scholes model (Fischer Black and Myron Scholes, 1973) and the Taylor series approach (Brook Taylor, 1715) are two of the most extensively utilized option pricing strategies. This research compares the Black-Scholes model with the Taylor series method to add to the continuing discussion on the optimal option pricing strategy. We took a series of tests to evaluate the accuracy of these two strategies in projecting option prices in two parts first when the asset price increase second when the time to expiration decreases.

This paper is organized as follows: Section II explains the description of the problem. Section III shows the data that we used for our experiment. Section IV introduces the methodology. Section V lists the results and sensitivity analysis, and Section VI describes the summary and our recommendations.

II Description of the problem

The issue addressed by this paper is the ongoing dispute over the appropriate option pricing strategy. While the Black-Scholes model is widely used and recognized as a standard model in finance, new research reveals that the Taylor series approach may provide more accurate pricing, particularly for small fluctuations in the underlying asset. The purpose of this research is to contrast the Black-Scholes model with the Taylor series approach and give insights into their different strengths and weaknesses. This research seeks to contribute to the current debate over the ideal option pricing strategy and provide information for investors and financial industry practitioners.

III Data

As data, we take call options for European-style S&P 100™ Index from yahoo finance and we chose options that will be expired on 16-06-2023. Individuals can use our GitHub link where they can run our project and choose other companies, but in our experiment, we choose European-style S&P 100™ Index. For reproducible purposes, we choose any random option. It is shown some of them:

	contractSymbol	lastTradeDate	strike	lastPrice	bid	ask	change	percentChange	volume	openInterest	impliedVolatilit
0	XEO230616C01300000	2022-07-05 14:53:53+00:00	1300.0	472.00	623.0	647.0	0.0	0.0	NaN	7	1.07906
1	XEO230616C01320000	2022-07-05 14:53:53+00:00	1320.0	455.50	605.0	629.0	0.0	0.0	NaN	7	1.06360
2	XEO230616C01780000	2022-09-16 13:31:08+00:00	1780.0	138.50	0.0	0.0	0.0	0.0	NaN	1	0.00001
3	XEO230616C01980000	2023-04-27 16:30:16+00:00	1980.0	5.74	0.0	0.0	0.0	0.0	NaN	1	0.03126
4	XEO230616C02000000	2023-04-27 16:30:16+00:00	2000.0	2.99	0.0	0.0	0.0	0.0	NaN	1	0.03126

IV Methodology

This study's methodology entails comparing the accuracy of the Black-Scholes model with the Taylor series technique in pricing choices with varying degrees of complexity. We ran a series of experiments on two different scenarios: when the asset price rises and when the time to expiry falls. To conduct our experiment, we first collect a sample of option pricing with varied strike prices and the same expiration date. Then we choose randomly one option from the data. Next, the option price is then calculated using the Black-Scholes model and compared to the real market values. Following that, we estimated the option prices using the Taylor series approximation method and compared them to both the real market prices and the theoretical values determined using the Black-Scholes model. We compare both methods in two different scenarios. First when the time gets close to the expiration date and second when the price of indx increases.

V Results

Taylor approximation using Time Greeks (Θ, etc.)

As it is mentioned in the IV section first we take random call option from the data and then calculate the Black-Scholes model to compare with the real price of call option from the data.

Black-Scholes Model:

$$C\left(S_{t,}t\right) = N(d_1)S_t - N(d_2)Ke^{-r(T-t)}$$

$$d_1 = \frac{1}{\sigma\sqrt{T-t}}\left[ln\left(\frac{S_t}{k}\right) + \left(r + \frac{\sigma^2}{2}\right)(T-t)\right]$$

$$d_2 = d_1 - \sigma\sqrt{T-t}$$

$$C(0,t) = 0 \text{ for all } t$$

$$C(S,t) \longrightarrow S - K \quad as \quad S \longrightarrow \infty$$

$$C(S,T) = max\{S - K, 0\}$$

$C(S_{t,}t)$ is the price of a European call option

K is the strike price; t is the current time

S_t is asset price; r is risk-free rate; T is the time option expiration;

Result of the Black-Scholes model:

```
Option data:
       contractSymbol             lastTradeDate  strike  lastPrice    bid  \
1  XEO230616C01320000 2022-07-05 14:53:53+00:00  1320.0      455.5  605.0

     ask  change  percentChange  volume  openInterest  impliedVolatility  \
1  629.0     0.0            0.0     NaN             7           1.063603

   inTheMoney contractSize currency
1        True      REGULAR      USD
Underlying asset price: 1894.969970703125
Strike price 1320.0
Expiration in years 0.19726027397260273
IV 1.0636033148193362
Black and Scholes - Call Option Price: 670.6780642992424
```

Then we use the Taylor series, we take the first, second, third, fourth, fifth, and sixth derivatives of option price with respect to time.

Taylor series:

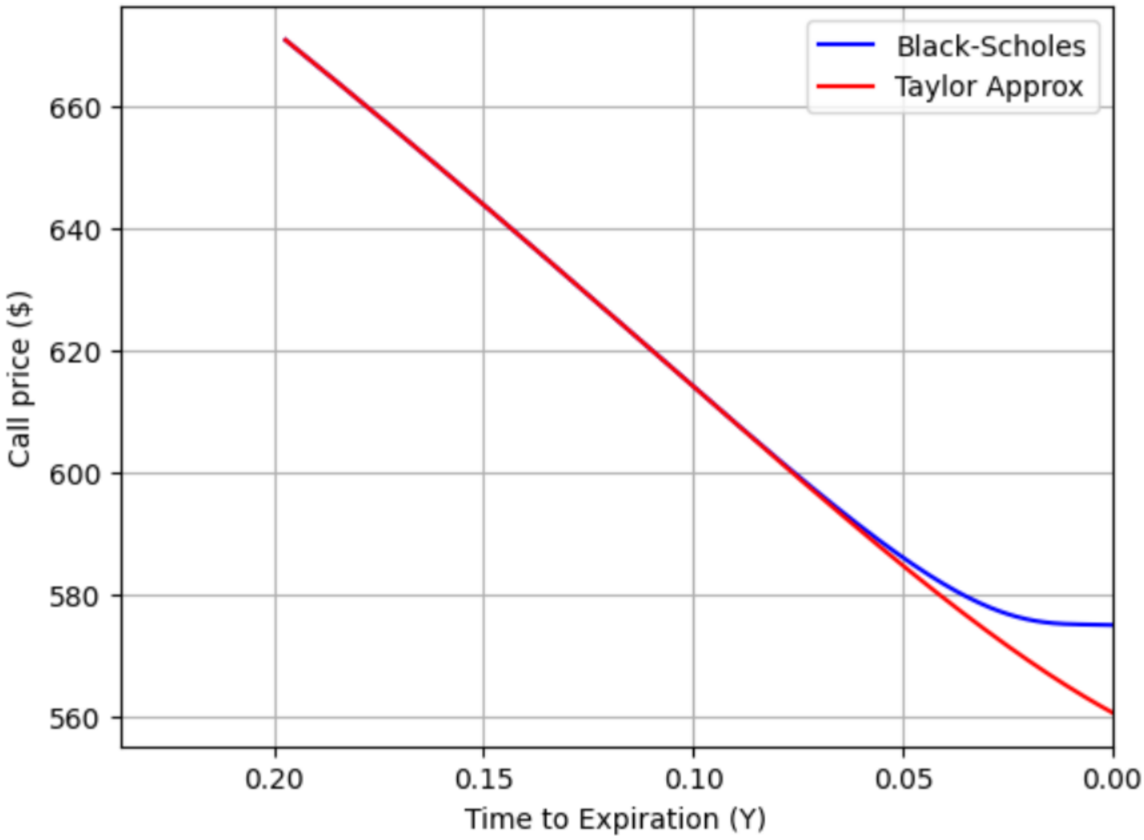
$$theta\ (\Theta) = f'(C_t) = \frac{\partial C_t}{\partial t}$$

$$f(C_t) = f(C_t) + \frac{f'(C_t)}{1!}(\Delta t)^1 + \frac{f''(C_t)}{2!}(\Delta t)^2 + \frac{f'''(C_t)}{3!}(\Delta t)^3 + \frac{f''''(C_t)}{4!}(\Delta t)^4 + \frac{f'''''(C_t)}{5!}(\Delta t)^5 + \frac{f''''''(C_t)}{6!}(\Delta t)^6$$

Δt *is difference in time*

C_t *is option price at time t*

Figure 1:

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The Taylor approximation at t = 0.19726027397260273 is 560.6599082032193
Black and Scholes at t = 0.19726027397260273 is 574.969970703125
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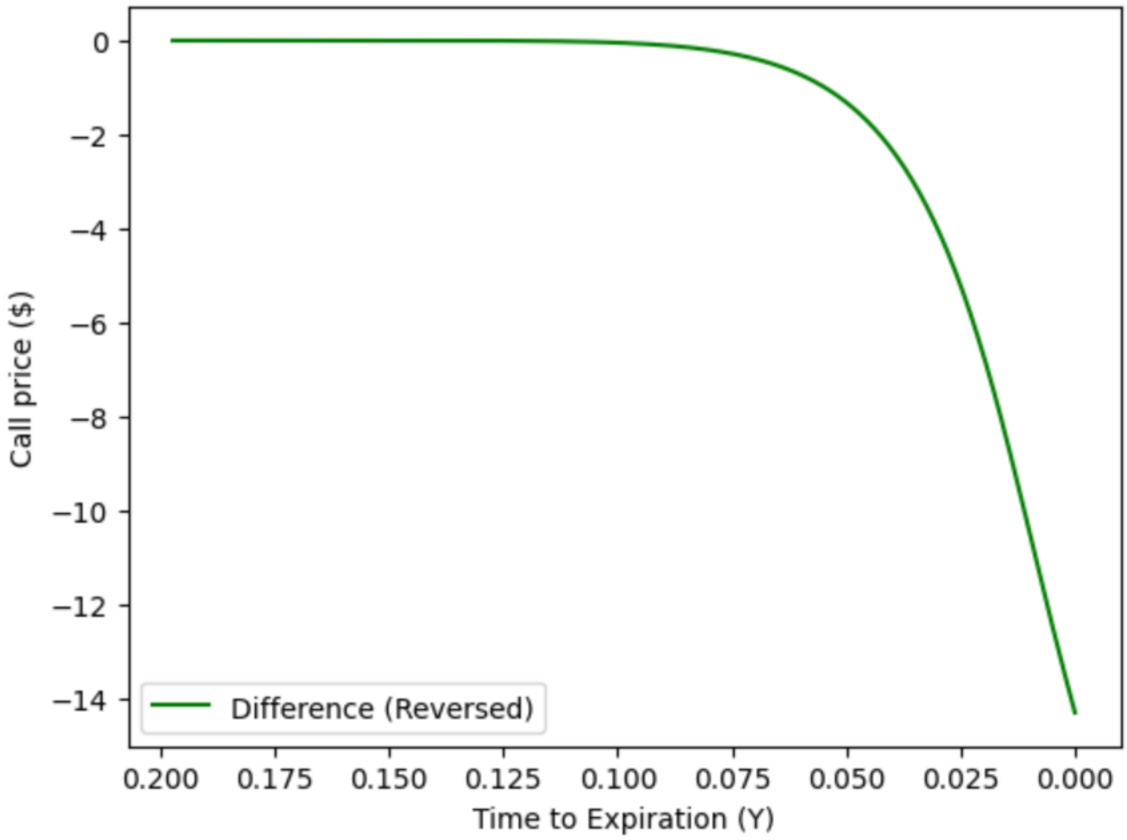
From the Figure1 we can see that as time gets close to the expiration date the price of the call option in both methods decreases and the results, at time t = 0.2, are close to each other.

But we can see that after time t = 0.08 we have different results. The Taylor series expansion only approximates the option's value at a particular moment by employing a small number of terms in the expansion. As it goes away from the point of expansion, the accuracy of the approximation declines. In other words, the Taylor series approximation works best around the point of expansion, but its accuracy declines as one moves away.

Figure 2:



In the Figure 2, we can closely see the difference between the two approaches.

Taylor approximation using Price Greeks (Δ, Γ, etc.)

In this part the idea is same but the difference is that we take the derivative of option with respect to asset price. Additionally, in the calculation of Taylor series instead of time difference Δt we use asset price difference ΔS.

$$\text{Delta } (\Delta) = f'(C_t) = \frac{\partial C_t}{\partial S}$$

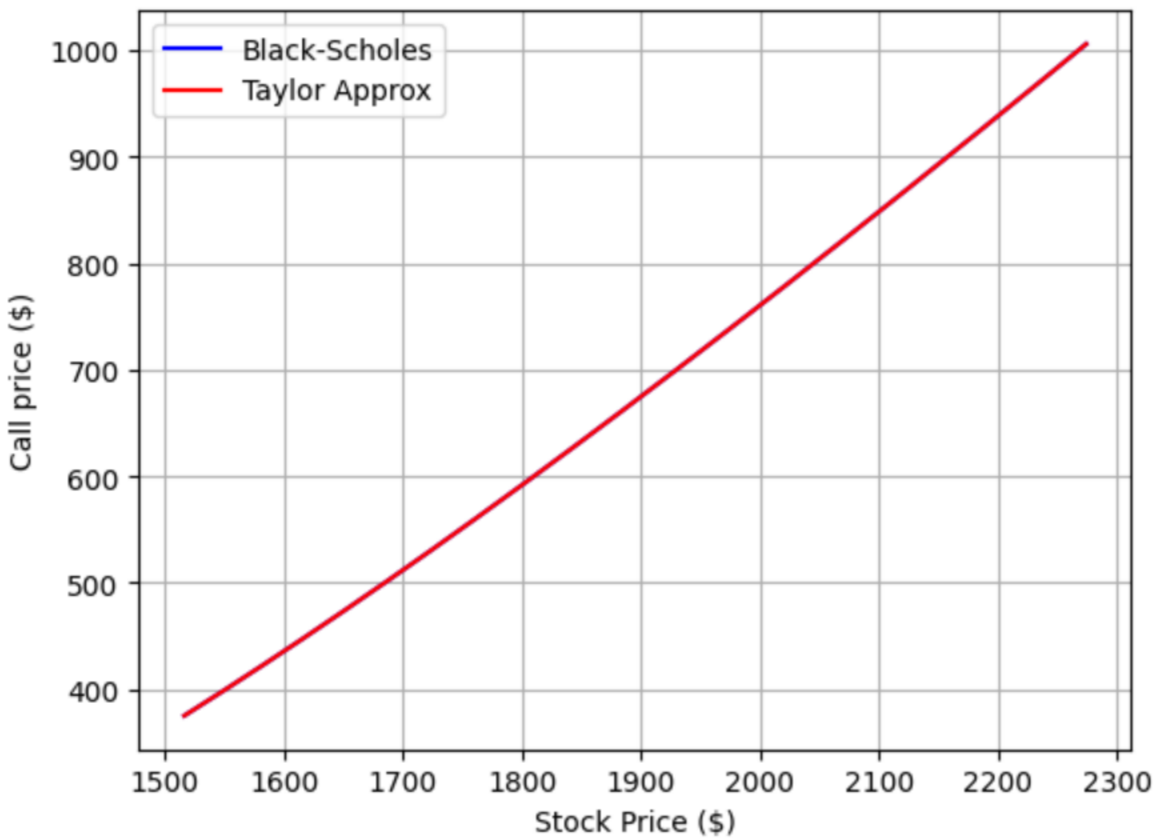
$$\text{Gamma } (\Gamma) = f'(C_t) = \frac{\partial\, delta(\Delta)}{\partial S}$$

$$f(C_t) = f(C_t) + \frac{f'(C_t)}{1!}(\Delta S)^1 + \frac{f''(C_t)}{2!}(\Delta S)^2 + \frac{f'''(C_t)}{3!}(\Delta S)^3 + \frac{f''''(C_t)}{4!}(\Delta S)^4 + \frac{f'''''(C_t)}{5!}(\Delta S)^5 + \frac{f''''''(C_t)}{6!}(\Delta S)^6$$

$\Delta S\ is\ difference\ in\ asset\ price$

$C_t\ is\ option\ price\ at\ time\ t$

Figure 3:

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The Taylor approximation at S = 1894.969970703125 is 670.6781418133562
Black and Scholes at S = 1894.969970703125 is 670.6781418126563
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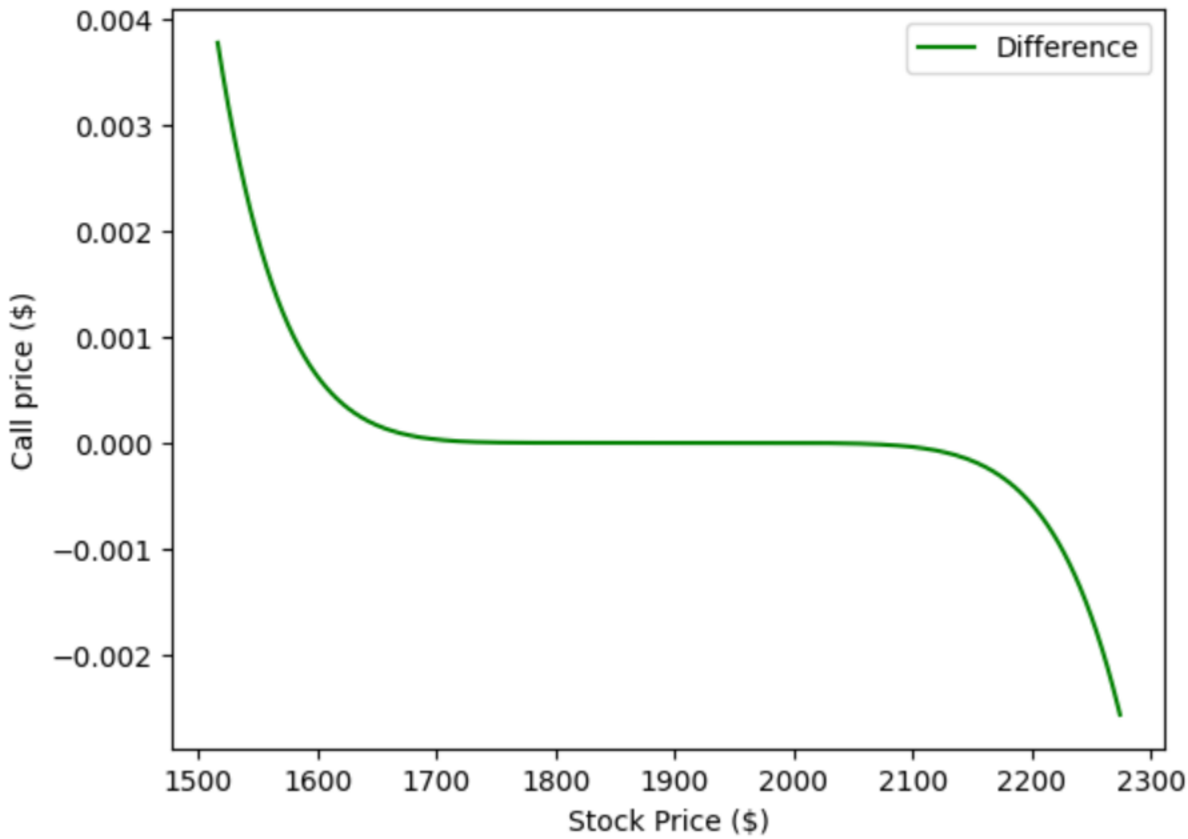
As we mentioned early the precision of the Taylor series approximation decreases as one gets away from the point of expansion. When compared to the Black-Scholes formula, this might result in errors at the beginning and end of the curve. When taking a derivative about time, there may be inaccuracies after the period. Figure 3 shows us the outputs of both methods, when the asset price $S = 1895$, are same 671.

Figure 4:



Even though with the Figure 3 we can not see the difference between methods but in the Figure 4 they are visible but it is very small value that is why we can not see them in the previous figure. Here we can see that when the asset price is between 1650 and 2150 we donot have any difference. They occure in the beginning and in the end.

VI Summary and Recommendation

According to our findings, using the Taylor series expansion approach with Greeks offers a snapshot of the option's value, demonstrating how it will respond to tiny changes in the underlying asset and time. It should be noted, however, that this approach is not ideal for large-scale forecasts since its accuracy decreases as one advances away from the site of expansion. In such instances, it is best to employ the entire model rather than depending simply on the Taylor series approximation. As a result, we recommend that financial analysts and practitioners use caution when using the Taylor series approach for option pricing, especially when making long-term projections or dealing with complicated options with varied features.

References:

Hull, John, 1946-. Options, Futures, and Other Derivatives. Boston :Prentice Hall, 2012.

Black, Fischer & Scholes, Myron S, 1973. "The Pricing of Options and Corporate Liabilities," Journal of Political Economy, University of Chicago Press, vol. 81(3), pages 637-654, May-June.

Taylor, B. (1715). Methodus Incrementorum Directa et Inversa. Philosophical Transactions of the Royal Society of London, 1715, 259-265.

Shreve, S. E. (2004). Stochastic Calculus for Finance II: Continuous-Time Models. Springer.

Jorion, P. (1997). Value at risk: The new benchmark for managing financial risk. McGraw-Hill.

McDonald, R. L. (2006). Derivatives markets (2nd ed.). Addison-Wesley.

Wilmott, P., Howison, S., & Dewynne, J. (1995). The mathematics of financial derivatives: A student introduction. Cambridge University Press.

GitHub: https://github.com/FinNijatTech/Taylor-Series-Approximation