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OPTION PRICING USING THE PARTIAL TAYLOR SERIES EXPANSION METHOD: A CASE STUDY OF BLUE-CHIP STOCKS ON THE INDONESIA STOCK EXCHANGE

Alfiano Akmal Wijaya[1], Rudianto Artiono[2*]
[1,2]Mathematics Department, Universitas Negeri Surabaya, Surabaya, East Java, Indonesia

*Correspondence: rudiantoartiono@unesa.ac.id

ABSTRACT

The Indonesian capital market is characterized by dynamic stock price volatility, which directly affects the value of derivative instruments, particularly stock options. Accurate option pricing is essential for supporting investment decision-making and risk management. The Black–Scholes model is a classical and widely used framework for option pricing; however, its assumption of constant volatility often fails to reflect actual market conditions. Therefore, this study aims to apply the Partial Taylor Series Expansion (PTSE) method as an alternative approximation approach and to evaluate its accuracy relative to the analytical Black–Scholes solution. This study adopts a quantitative approach using a blue-chip stock PT. XXXX listed on the Indonesia Stock Exchange during the period 2019–2024. Model parameters are determined based on historical stock price data, the risk-free interest rate, and historical volatility. European stock option prices are calculated using both the Black–Scholes model and the PTSE method and are compared using Mean Absolute Error (MAE) and Root Mean Square Error (RMSE). In addition, sensitivity analysis is conducted to examine the effects of volatility and time to maturity on option price differences. The results indicate that the PTSE method produces option price estimates with relatively small errors and a stable convergence pattern toward the Black–Scholes model, suggesting that PTSE is a practical and efficient approximation approach for pricing European stock options in the Indonesian capital market.

Keywords: Stock Options, Black–Scholes, Partial Taylor Series Expansion, Numerical Approximation, Indonesian Capital Market.

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PRELIMINARY

Modern financial markets are characterized by high volatility dynamics as a consequence of changes in macroeconomic conditions, monetary policy, and global uncertainty. Under such conditions, derivative instruments—particularly stock options—play an important role as hedging tools as well as speculative instruments that enable investors to manage risk in a more structured manner. Stock options grant the holder the right, but not the obligation, to buy or sell the underlying asset at a predetermined strike price and maturity date; therefore, accurate option pricing becomes a crucial factor in investment decision-making and risk management (Brenner & Subrahmanyam, 1994; Sloth Pedersen, 2014).

The Black–Scholes model represents a major milestone in option pricing theory, as it provides a closed-form analytical solution for European-style options. This model is built upon the assumptions that stock prices follow a geometric Brownian motion with constant volatility, the risk-free interest rate remains constant, and no arbitrage opportunities exist in the market (Brenner & Subrahmanyam, 1994; Estrella, 1995). However, numerous studies indicate that the assumption of constant volatility often fails to adequately represent real market conditions, particularly during periods of extreme market fluctuations and when return distributions exhibit nonlinear characteristics (De Jong, 2010; Estrella, 1995). These limitations have motivated the development of alternative approaches, either through more sophisticated volatility modeling or through mathematical approximation methods applied to the Black–Scholes solution.

In the context of the Indonesian capital market, blue-chip stocks play a strategic role due to their large market capitalization, high liquidity, and relatively stable performance compared to other stocks. Nevertheless, several studies have shown that blue-chip stocks listed on the Indonesia Stock Exchange (IDX) still experience significant price fluctuations, which directly affect the value of derivative instruments based on these stocks (Al-daniah & Ana Yuliana Jasuni, 2023; Bismark & Pasaribu, 2009; Hendrawan, 2020; Lubis, 2021). Therefore, the application of option pricing models in the Indonesian market requires careful evaluation to ensure that they realistically reflect domestic market characteristics.

One approach that has gained attention in the financial mathematics literature is the use of series expansion methods as an approximation technique for the Black–Scholes model. This method utilizes Taylor series expansion to approximate option prices through a series representation, thereby enabling more computationally efficient calculations (Aguilar, 2017, 2019; Estrella, 1995). Within this framework, Sobamowo developed the Partial Taylor Series Expansion (PTSE) method, which partially expands selected variables in the Black–Scholes partial differential equation without expanding the entire model structure. This approach has been shown to produce efficient and accurate analytical solutions for various payoff functions, while reducing computational complexity compared to conventional numerical methods (Sobamowo, 2022a, 2022b).

Although studies on Taylor series-based methods for option pricing have been extensively conducted from a theoretical perspective, empirical research applying the

PTSE method to blue-chip stock data in the Indonesia Stock Exchange remains relatively limited. Meanwhile, the characteristics of emerging markets such as Indonesia—which exhibit distinctive volatility dynamics and liquidity structures—necessitate the validation of option pricing methods based on local market data to ensure practical relevance (Bismark & Pasaribu, 2009; Hendrawan, 2020; Nugraha, 2022). Therefore, this study focuses on the application of the Partial Taylor Series Expansion method in pricing stock options on blue-chip stocks listed on the IDX using historical data from the period 2019–2024. This study aims to evaluate the accuracy of the PTSE method in comparison with the classical Black–Scholes model and to assess its potential as an efficient analytical alternative for stock option pricing in the Indonesian capital market.

Analytical and approximation-based approaches have been widely employed in mathematical research to address complex problems where exact solutions are computationally demanding, particularly in nonlinear and applied contexts. Several studies have emphasized that the use of structured analytical methods contributes to improved solution accuracy and computational efficiency in applied mathematics (Susanto, Hartati, & Standsyah, 2023). Consistent with this general methodological perspective, the present study applies the Partial Taylor Series Expansion as an efficient approximation technique for European option pricing in the Indonesian capital market.

METHODS

This study adopts a quantitative approach using a descriptive–comparative method to evaluate stock option pricing through mathematical modeling, historical volatility estimation based on time-series data, and numerical comparison between analytical and approximation methods (Brenner & Subrahmanyam, 1994; De Jong, 2010). The research object is restricted to a single blue-chip stock (PT. XXXX) listed on the Indonesia Stock Exchange (IDX) over the period January 1, 2019–December 30, 2024, selected due to its large market capitalization, high liquidity, and relative trading stability, which are essential for representing Indonesia's leading stocks in derivative analysis (Al-daniah & Ana Yuliana Jasuni, 2023; Bismark & Pasaribu, 2009; Lubis, 2021). The analysis focuses exclusively on European-style stock options to ensure consistency with the assumptions underlying the Black–Scholes model and series-based approximation methods, thereby avoiding early-exercise complexity (Aguilar, 2017; Brenner & Subrahmanyam, 1994; Estrella, 1995). Secondary data consist of daily adjusted closing prices obtained from Yahoo Finance and the risk-free interest rate proxied by the BI-7 Day Reverse Repo Rate published by Bank Indonesia (Bismark & Pasaribu, 2009; Hendrawan, 2020; Nugraha, 2022). Daily stock prices are transformed into log-returns using $R_t = \ln\left(\frac{S_t}{S_{t-1}}\right)$ to ensure stationarity and suitability for volatility estimation (Brenner & Subrahmanyam, 1994; Estrella, 1995; Hendrawan, 2020; Herwany et al., 2014), where historical volatility is computed as the standard deviation of daily log-returns and annualized by $\sigma_{ann} = \sigma_{day} \times \sqrt{252}$ assuming 252 trading days per year (Hendrawan, 2020; Herwany et al., 2014). Option prices are calculated using the Black–Scholes model as the analytical benchmark, which is given by equation (1) as follows

$$C(S,t) = S_t N(d_1) - Ke^{-r(T)} N(d_2) \tag{1}$$

with

$$d_1 = \frac{\ln\left(\frac{S_t}{K}\right) + (r + \frac{1}{2}\sigma^2)(T)}{\sigma\sqrt{T}}, \qquad d_2 = d_1 - \sigma\sqrt{T}$$

(Aguilar, 2017; Brenner & Subrahmanyam, 1994; Estrella, 1995; Zhu, 2005), and the Partial Taylor Series Expansion (PTSE) method as an approximation approach, where the option price function (1) is partially expanded with respect to the underlying stock price around S_0 up to the second order

$$C(S,t) \approx C(S_0,t) + \frac{\partial C}{\partial S}(S - S_0) + \frac{1}{2}\frac{\partial^2 C}{\partial S^2}(S - S_0)^2 \tag{2}$$

to balance analytical accuracy and computational efficiency (Sobamowo, 2022a, 2022b, 2022c).

The variables used in this study include the current stock price (S), strike price (K), risk-free rate (r), stock volatility (σ), and time to maturity (T), with option prices obtained from the Black–Scholes model C_{BS} and the PTSE method C_{PTSE}; a summary of parameters is provided as follows: S (current stock price, Rupiah), K (strike price, Rupiah), r (risk-free interest rate, decimal), σ (stock volatility, decimal), T (time to maturity, years), C_{BS} (option price from Black–Scholes, Rupiah), and C_{PTSE} (option price from PTSE, Rupiah) (Black & Scholes, 1973; Hull, 2022). The resulting option prices from both methods are evaluated using Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) to assess approximation accuracy and convergence behavior (Brenner & Subrahmanyam, 1994; Buetow Jr. & Sochacki, 2024), while sensitivity analysis is conducted by systematically varying volatility and time to maturity to examine the robustness and limitations of the PTSE method under different market conditions (Aguilar, 2017; Brenner & Subrahmanyam, 1994; Estrella, 1995; Jenny Pang, 2009).

RESULT AND DISCUSSION

This study employs daily adjusted closing price (Adjusted Close Price) data of PT. XXXX shares obtained from the Indonesia Stock Exchange (IDX) and Yahoo Finance over the period January 2019 to December 2024. The selection of PT. XXXX as the research object is based on its classification as a blue-chip stock with high liquidity and large market capitalization, which typically results in relatively stable price movements. These characteristics make the stock representative for European-style stock option pricing analysis in the Indonesian capital market (Widyawati & Rikumahu, 2015).

Based on the stock price data, daily log-returns are calculated to estimate historical volatility as a key input parameter in option pricing. The risk-free interest rate is proxied by the BI 7-Day Reverse Repo Rate. The estimated parameters indicate that the latest stock price is $S = 9.324{,}55$, the annualized volatility is $\sigma = 33{,}18\%$, the strike price is set at-the-money $(K = S)$, the risk-free interest rate is $r = 6\%$, and the time to maturity is $T = 0{,}5$ years.

A summary of the estimated parameters and the resulting option prices obtained from both methods is presented in Table 1.

Table 1. Parameter Values

Parameter	Values
Stock Price (S)	9.324,55
Strike Price (K)	9.324,55
Volatility (σ)	33,18%
Risk-Free Interest Rate (r)	6,00%
Time to Maturity (T)	0,5 $years$
Black-Scholes Option Price (C_{BS})	494,25
PTSE Option Price (C_{PTSE})	545,1
MAE	50,85
RMSE	50,85

Using the parameters in Table 1, the European call option price is computed using the Black–Scholes model as the analytical benchmark. The Black–Scholes formula for a European call option is given by

$$C_{BS} = S_t N(d_1) - K e^{-r(T)} N(d_2),$$

with

$$d_1 = \frac{\ln\left(\frac{S}{K}\right) + \left(r + \frac{1}{2}\sigma^2\right)(T)}{\sigma\sqrt{T - t}}, \qquad d_2 = d_1 - \sigma\sqrt{T}$$

Substituting the estimated parameters yields

$$d_1 = 0{,}2602, \qquad d_2 = 0{,}09$$

Using the cumulative distribution function of the standard normal distribution, the resulting European call option price is

$$C_{BS} = 494{,}25$$

This value represents the theoretical fair price of the option under the assumptions of the Black–Scholes framework and is used as the reference for evaluating the approximation accuracy of the PTSE method.

The Partial Taylor Series Expansion (PTSE) method is applied by expanding the option price function with respect to the underlying stock price around the expansion point S_0, which is set equal to the current stock price $S_0 = 9.324{,}55$. The expansion is truncated at the second order to balance analytical accuracy and computational efficiency.

The PTSE approximation is given by

$$C_{PTSE} \approx C(S_0, t) + \Delta(S - S_0) + \frac{1}{2}\Gamma(S - S_0)^2$$

where the Delta (Δ) and Gamma (Γ), denote the first and second derivatives of the option price with respect to the stock price, respectively. Based on the estimated parameters, the calculated sensitivity measures are

$$\Delta = 0{,}5970, \quad \Gamma = 0{,}00025$$

Substituting these values into the PTSE approximation yields an estimated option price of

$$C_{PTSE} = 545{,}10$$

The PTSE estimate is higher than the Black–Scholes benchmark, reflecting the convexity of the option price function captured by the Gamma component in the Taylor expansion.

Table 2. Comparison of Option Pricing Results

Method	Option Price (IDR)
Black-Scholes	494,25
PTSE	545,10

To quantify the approximation error of the PTSE method relative to the Black–Scholes benchmark, the Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) are computed as follows:

$$MAE = |C_{PTSE} - C_{BS}| = |545{,}10 - 494{,}25| = 50{,}85$$

$$RMSE = \sqrt{(C_{PTSE} - C_{BS})^2} = 50{,}85$$

The resulting error corresponds to approximately 10.2% of the Black–Scholes price. Despite this deviation, the magnitude of the error remains acceptable for an analytical approximation method, especially considering the computational efficiency offered by PTSE.

To further evaluate the robustness of the PTSE method, sensitivity analyses are conducted by varying volatility and time to maturity while keeping other parameters constant.

Table 3. Option Price with Volatility Variation

Volatility (σ)	Black-Scholes	PTSE	Absolute Difference
15%	224,15	238,5	14,35
25%	371,4	405,2	33,8
33,18%	**494,25**	**545,1**	**50,85**
45%	672,8	754,15	81,35

Table 4 shows that increasing volatility from 15% to 45% raises option prices under both methods; however, the absolute difference widens from 14,35 to 81,35. This occurs due to the increasing Gamma value and stronger nonlinearity of the option price function, which cannot be fully captured by a second-order Taylor expansion.

Tabel 4. Option Prices with Time-to-Maturity Variation

Time to Maturity (T)	Black-Scholes	PTSE	Absolut Difference
0,083 (1 **Month**)	201,1	205,45	4,35
0,25 (3 **Month**)	348,5	374,1	25,6
0,5 (6 Month)	**494,25**	**545,1**	**50,85**
1,0 (12 **Month**)	705,3	812,6	107,3

The results in Table 4 indicate that the smallest pricing difference occurs for short-term options (1 month), while the discrepancy increases substantially for longer maturities. This finding suggests that PTSE is highly accurate for short-tenor options but tends to overestimate prices for longer maturities. Overall, the results demonstrate that the PTSE method provides good accuracy in approximating the Black–Scholes model under moderate volatility and maturity conditions. Moreover, its computational efficiency makes PTSE a promising quick-proxy tool for estimating option prices of blue-chip stocks in the Indonesian Stock Exchange.

CONCLUSION

This study concludes that the Partial Taylor Series Expansion (PTSE) method can be employed as an effective approximation alternative for pricing European-style stock options, using the Black–Scholes model as the exact analytical benchmark. Based on the use of an adjusted closing price of 9,324.55 and an estimated volatility of 33.18%, the Black–Scholes option price is calculated at 494.25, while the PTSE method yields an option price of 545.10, resulting in a Mean Absolute Error (MAE) of 50.85. This difference indicates that the second-order PTSE approximation tends to produce more conservative (overestimated) option prices due to the convexity effect captured by the Gamma component of the Taylor expansion. Further sensitivity analysis demonstrates that the accuracy of the PTSE method is strongly influenced by volatility levels and time to maturity, with optimal performance observed under low-volatility market conditions and short-term maturities (1–3 months). Overall, the use of adjusted price data is shown to be crucial for obtaining more objective and consistent parameter estimates in option pricing models.

For future research, it is recommended that the PTSE method be extended to higher-order expansions to reduce truncation errors, particularly under extreme volatility conditions or for long-term option contracts exceeding one year. In addition, the scope of analysis may be broadened by comparing the computational efficiency of PTSE with other numerical methods, such as Monte Carlo simulation and binomial tree models, in order to provide a more comprehensive evaluation of its performance. Given its analytical simplicity and computational efficiency, the PTSE method also holds strong potential as a quick-proxy estimation tool for capital market practitioners to monitor option premiums in real time prior to conducting more advanced investment analyses.

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