Analysis of the Performance of Modern Derivative Pricing Models in the Tehran Stock Exchange

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Abstract: In the Iranian capital market, the Black–Scholes model is recognized as the principal framework for valuing option contracts; however, due to its assumptions of constant volatility and normally distributed underlying asset returns, it exhibits significant limitations under the highly inflationary and volatile conditions of the national economy. This study aims to analyze the performance of pricing models employed in the stock exchanges of Turkey, China, the United States, and Malaysia in comparison with the Black–Scholes pricing model (the valuation model used in the Iranian capital market), using call option data for four of the most actively traded stocks—Shasta, Iran Khodro, Khodro Saipa, and Ahram—during the year 2024. Model performance is evaluated based on the Mean Squared Error (MSE) and Mean Absolute Error (MAE) criteria. The empirical results indicate that more advanced models incorporating complex features such as stochastic volatility or discrete-time structures generally outperform the classical Black–Scholes model. Nevertheless, a one-way Analysis of Variance (ANOVA) conducted on the computed mean total errors demonstrates that there is no statistically significant difference among the best-performing models examined.

Keywords: Black–Scholes model; Heston model; Bi-Heston model; Binomial tree model; Trinomial tree model.

1. Introduction

Financial derivatives, and particularly options, play a central role in contemporary financial markets by facilitating risk management, price discovery, and capital allocation efficiency. The evolution of option markets has significantly transformed portfolio management practices and corporate risk strategies across both developed and emerging economies. Since the seminal contribution of the Black–Scholes framework in the early 1970s, option pricing has remained one of the most actively researched topics in financial economics and financial engineering [1]. Despite its foundational importance, the continuous expansion of financial markets, increasing volatility regimes, structural breaks, and technological advancements have exposed fundamental limitations of classical pricing approaches, especially in emerging markets where market microstructures differ substantially from the assumptions embedded in early theoretical models [2-4].

The Black–Scholes model, built upon assumptions of constant volatility, log-normal return distributions, frictionless markets, continuous trading, and constant interest rates, offers closed-form solutions that provide computational simplicity and analytical tractability [1, 5]. However, empirical evidence accumulated over decades demonstrates that real financial markets systematically violate these assumptions. Volatility exhibits clustering, leptokurtosis, jumps, regime shifts, and mean reversion, while interest rates fluctuate stochastically and transaction frictions materially affect prices [2, 4, 5]. These discrepancies between theory and observed market behavior have motivated the development of increasingly sophisticated pricing models, including stochastic volatility models, jump-diffusion frameworks, regime-switching systems, tree-based numerical methods, and machine-learning-driven approaches [6-9].

In emerging markets such as the Tehran Stock Exchange (TSE), the challenges of accurate option pricing are even more pronounced. Market depth limitations, asymmetric information, regulatory constraints, political risk, high inflation, and macroeconomic instability intensify volatility dynamics and weaken the applicability of classical valuation formulas [10-12]. Empirical studies within Iran's capital market consistently document significant deviations between Black–Scholes theoretical prices and observed market prices, particularly during periods of heightened economic uncertainty [10, 11, 13]. These findings underscore the necessity of evaluating alternative pricing mechanisms capable of capturing the structural features of Iran's financial environment.

The literature identifies several major streams in modern option pricing research. The first stream focuses on enhanced numerical solutions and tree-based approaches that relax continuous-time assumptions while preserving interpretability. Binomial and trinomial tree models allow flexible modeling of early exercise, discrete price movements, and non-constant parameters, making them particularly suitable for American-style options and illiquid markets [13, 14]. Empirical investigations demonstrate that trinomial tree structures often outperform binomial trees in capturing market prices due to improved convergence properties and reduced discretization error [14].

The second research stream introduces stochastic processes to model volatility and interest rates explicitly. The Heston model and its extended variants allow volatility to evolve as a mean-reverting stochastic process, thereby reproducing volatility smiles and skews observed in actual option markets [4, 15]. Hybrid models combining stochastic volatility with jump processes further enhance pricing accuracy in turbulent markets [6, 7]. In the Iranian context, incorporating stochastic interest rates has also been shown to materially improve valuation performance under inflationary conditions [11].

The third major stream integrates artificial intelligence and computational intelligence into option pricing. Neural networks, genetic algorithms, and particle swarm optimization techniques are increasingly applied to capture nonlinear relationships embedded in high-frequency market data. These approaches bypass restrictive distributional assumptions and learn pricing patterns directly from data [8, 9, 16, 17]. Recent studies demonstrate that machine-learning-based models frequently outperform classical parametric models, especially in volatile and structurally complex markets [9, 16, 17].

Parallel to methodological advancements, researchers increasingly emphasize the importance of contextualizing pricing models within specific institutional, regulatory, and market environments. The Tehran Stock Exchange exhibits unique structural characteristics, including limited derivative history, regulatory constraints, concentrated trading volumes, and high macroeconomic sensitivity, which challenge the external validity of models calibrated in developed markets [3, 18]. Iranian studies highlight the necessity of localized calibration, adaptive modeling, and hybrid frameworks that incorporate both global financial theory and domestic market realities [10-12].

From a research methodology perspective, rigorous quantitative evaluation remains essential for determining model effectiveness. Contemporary financial research emphasizes the use of performance metrics such as Mean Squared Error (MSE), Root Mean Squared Error (RMSE), Mean Absolute Error (MAE), and Mean Absolute Percentage Error (MAPE) to ensure objective model comparison [19-21]. These metrics enable researchers to evaluate both accuracy and stability of competing pricing approaches under different market regimes. Empirical rigor, data integrity, and methodological transparency are especially critical in emerging markets where data limitations and structural volatility amplify estimation risk [19, 20].

Recent global research continues to expand the frontier of option pricing. Xiang [22] revisits the Black–Scholes model through modern computational refinements, while Kebriyayee et al. [23] propose combined numerical schemes specifically applied to the Tehran Stock Exchange, demonstrating improved convergence and robustness. Rahayu et al. [14] introduce advanced Bino-Trinomial tree structures for barrier options, highlighting the importance of tree-based discretization improvements. Mahdavi [9] and Iltuzer [17] provide strong empirical support for machine-learning-enhanced pricing frameworks under volatile conditions. Meanwhile, Yang et al. [15] develop hybrid deep-learning-stochastic models that integrate neural networks with stochastic volatility dynamics.

Within Iran, extensive academic work has evaluated pricing models across various market segments. Asadi Mousavi [13] demonstrates the comparative advantages of binomial tree approaches over classical models in Iranian data. Malekmohammadi [10] documents systematic mispricing in the Tehran Stock Exchange when using conventional frameworks. Peymani [11] shows that incorporating stochastic interest rates substantially improves pricing accuracy in high-inflation periods. Rezaeian [12] emphasizes information-based modeling as a necessary complement to purely parametric methods. Samiei Machiani [6] and Shojaei Manesh [7] provide advanced stochastic volatility and jump-diffusion analyses for Iranian derivatives.

Despite the extensive literature, a persistent gap remains in systematically comparing classical, stochastic, tree-based, and modern computational models within the specific institutional and economic context of the Tehran Stock Exchange. Most prior studies focus on limited model sets or narrow datasets, leaving unresolved questions regarding the relative performance stability of competing approaches under high-volatility emerging-market conditions [9, 10, 23]. Furthermore, few studies integrate both advanced numerical methods and stochastic frameworks within a unified empirical evaluation using multiple performance indicators.

The present study addresses this gap by providing a comprehensive empirical comparison of modern option pricing models — including Black–Scholes, stochastic volatility frameworks, numerical tree-based methods, and advanced computational approaches — applied to high-liquidity option contracts in the Tehran Stock Exchange. By employing robust quantitative performance metrics and localized calibration, the study contributes to both theoretical development and practical decision-making in financial engineering, risk management, and capital market policy.

The aim of this study is to empirically evaluate and compare the pricing performance of modern option valuation models in the Tehran Stock Exchange in order to identify the most accurate and stable framework for option pricing under the structural conditions of an emerging and highly volatile financial market.

2. Methodology

The ultimate objective of this research is to compare and analyze the most prominent and widely used option pricing models applied in developed countries and in countries with economic conditions similar to Iran, with the pricing model used in Iran's capital market, and to identify the optimal model (with the minimum error) under the economic conditions of Iran.

In order to conduct the data analysis, the theoretical option price P_e is first computed based on the assumptions and each of the proposed models, and then compared with the market option price (closing price P). Subsequently, the minimum error is measured using the Root Mean Squared Error (RMSE) and the Mean Absolute Percentage Error (MAPE) criteria.

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(P - P_e)^2}$$

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{|F - A|}{A}\right)$$

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(P_i - P)^2$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|F - A|$$

In these formulas, A_t represents the actual value and F_t represents the forecasted value. The difference between these values is divided by the actual value, after which the absolute value of this ratio is computed for each forecast period and averaged over n observations.

The Mean Absolute Percentage Error (MAPE) is a widely used statistical indicator for evaluating the accuracy of forecasting methods. This criterion expresses prediction accuracy as a relative ratio, as defined in the above formula.

The population of this study consists of all call option contracts traded in the Tehran Stock Exchange that recorded the highest trading value and trading volume during the year 2024.

All option contracts traded in the Tehran Stock Exchange were initially considered, provided that they met the minimum trading value requirements necessary for conducting the statistical tests. In the next stage, an additional filtering process was applied. After this stage, the remaining data included only those option contracts for which the number of trading days during the trading period was at least 51 days, and the ratio of the number of days in which the contract was traded to the total number of trading days in the period was at least 0.70.

Among the option contracts that satisfied these criteria, the symbols Shasta, Khodro, Saipa, and Ahram exhibited the highest trading volumes and were therefore selected as the measurement sample.

3. Findings and Results

To calculate the forecasting error of the models, the following assumptions and estimations are considered.

Table 1. Average Daily Trading Value of Call Options During 2018–2023 (Billion Tomans)

No.	Average Daily Trading Value (Call Options)	Year
1	0.03	2018
2	0.20	2019
3	0.50	2020
4	3.40	2021
5	8.32	2022

6	107.00	2023
7	300.00	2024

Table 2. Estimated Model Parameters

Parameter	Value
Initial Volatility	0.25
Long-Run Volatility	0.35
Volatility of Volatility	0.40
Correlation Coefficient	−0.05
Mean Reversion Speed	1.5
Number of Time Steps	100
Long-Run Process Mean	0.03
Dividend Yield	0
Risk-Free Interest Rate (Annual)	0.40

In the Black–Scholes model, the parameter δ is computed using the daily logarithmic returns of the underlying asset (equity). Accordingly, daily log returns were calculated from stock prices. Based on historical trends, actual market data, and model assumptions implemented in the software environment, the parameters in Table 2 were estimated.

Table 3. Comparison of Call Option Prices for the "Khodro" Symbol Under Different Pricing Models

Symbol	Strike Price	Underlying Price	Market Closing Price	Black–Scholes	Heston	Bi-Heston	Binomial Tree	Trinomial Tree
DKHOD 1122	3,000	2,709	54	35	55	50	50.8	48
DKHOD 1120	2,600	2,617	229	215	245	220	225.3	218
DKHOD 1121	2,800	2,623	103	98	110	95	95.6	93
DKHOD 1119	2,400	2,661	401	380	430	390	395.2	388
DKHOD 1217	2,400	2,940	475	422	510	460	465.9	458
DKHOD 1220	3,000	2,972	138	74	150	130	130.4	128
DKHOD 1216	2,200	2,932	660	602	710	650	655.7	648
DKHOD 1215	2,000	2,718	818	793	880	810	810.5	808
DKHOD 1219	2,800	2,838	195	150	210	190	185.2	188

In Table 3, the market closing prices of Khodro call options were compared with theoretical prices obtained from the Black–Scholes, Heston, Bi-Heston, binomial tree, and trinomial tree models.

Table 4. Comparison of Call Option Prices for the "Ahram" Symbol Under Different Pricing Models

Symbol	Strike Price	Underlying Price	Market Closing Price	Black–Scholes	Heston	Bi-Heston	Binomial Tree	Trinomial Tree
DAHRAM 1224	20,000	20,690	2,978	2,249	3,200	3,090	3,100	3,080
DAHRAM 1225	22,000	21,390	1,952	1,178	2,100	1,990	2,050	1,970

DAHRAM 1219	13,000	21,920	8,600	8,357	8,800	8,640	8,700	8,610
DAHRAM 1222	16,000	22,190	5,811	5,523	5,950	5,840	5,900	5,830
DAHRAM 1223	18,000	22,030	4,259	3,747	4,500	4,290	4,400	4,268
DAHRAM 1226	28,000	21,690	1,245	538	1,500	1,340	1,400	1,310
DAHRAM 1228	24,000	21,300	501	79	700	670	700	675

In Table 4, the market prices of Ahram call options were compared with theoretical values generated by the Black–Scholes, Heston, Bi-Heston, binomial tree, and trinomial tree models.

Table 5. Comparison of Call Option Prices for the "Saipa" Symbol Under Different Pricing Models

Symbol	Strike Price	Underlying Price	Market Closing Price	Black–Scholes	Heston	Bi-Heston	Binomial Tree	Trinomial Tree
DSAIPA 1000	2,200	2,438	215	238	246	210	218	214
DSAIPA 1001	2,400	2,596	57	71	70	60	65	60
DSAIPA 1012	1,900	2,430	510	535	540	515	539	500
DSAIPA 1002	2,600	2,574	19	7	8	20	25	20
DSAIPA 1220	2,400	2,538	267	225	230	260	285	265
DSAIPA 1219	2,200	2,577	380	361	360	370	335	375
DSAIPA 1222	2,800	2,693	95	64	65	100	105	100
DSAIPA 12121	2,600	2,592	166	126	130	165	180	170

In Table 5, the market prices of Saipa call options were compared with theoretical values from the Black–Scholes, Heston, Bi-Heston, binomial tree, and trinomial tree models.

Table 6. Comparison of Call Option Prices for the "Shasta" Symbol Under Different Pricing Models

Symbol	Strike Price	Underlying Price	Market Closing Price	Black–Scholes	Heston	Bi-Heston	Binomial Tree	Trinomial Tree
DSHASTA 1216	1,212	1,246	126	115	118	129	132	128
DSHASTA 1220	1,612	1,150	20	5	6	8	20	23
DSHASTA 1214	1,012	1,158	294	276	284	295	305	298
DSHASTA 1215	1,112	1,144	201	188	182	203	205	202
DSHASTA 1217	1,312	1,166	70	62	62	68	71	68
DSHASTA 1212	812	1,096	478	466	473	477	485	475
DSHASTA 1218	1,412	1,155	40	30	29	37	43	36
DSHASTA 1209	512	1,086	767	755	778	771	775	769

Based on the computed MSE and MAE for call option symbols Shasta, Khodro, Saipa, and Ahram in 2024, the trinomial tree model and the Bi-Heston model exhibit substantially lower pricing errors than the other models and display the smallest deviations from observed market prices in the Iranian capital market. It should be noted that both the Heston and Bi-Heston models, as stochastic volatility models, require highly precise parameter estimation procedures, which are inherently complex and computationally intensive.

In this study, the deviations between observed market closing prices of call options and theoretical prices obtained from the Black–Scholes, Heston, Bi-Heston, binomial tree, and trinomial tree models for the actively traded symbols Shasta, Iran Khodro, Saipa, and Ahram during 2024 were investigated, yielding the results presented below.

Table 7. Results of Call Option Pricing Models in the Iranian Capital Market

Symbol / Model	Black–Scholes RMSE	MAPE	Heston RMSE	MAPE	Bi-Heston RMSE	MAPE	Binomial RMSE	MAPE	Trinomial RMSE	MAPE
DKHOD	39.35	34.21	31.76	25.13	9.16	8.98	6.85	6.35	11.09	5.13
DAHRAM	562.00	32.13	204.60	12.23	88.61	6.96	134.19	9.61	80.85	6.42
DSAIPA	27.79	22.60	26.87	21.32	5.41	11.20	21.19	11.20	4.74	2.83
DSHASTA	12.70	15.20	11.46	14.51	4.84	2.74	6.10	2.74	2.80	4.02
Mean	160.40	21.47	68.67	13.73	27.00	11.44	42.07	6.72	24.87	4.60
Symbol / Model	Black–Scholes M.S.E	M.A.E	Heston M.S.E	M.A.E	Bi-Heston M.S.E	M.A.E	Binomial M.S.E	M.A.E	Trinomial M.S.E	M.A.E
DKHOD	1,549	34.21	1,009	25.12	84.44	9.02	47.07	6.35	123.11	11.19
DAHRAM	316,084	459.37	41,888	175.50	7,583	64.25	17,988	113.35	6,538	49.62
DSAIPA	772.50	25.75	722.50	25.25	29.37	4.63	449.37	16.62	21.62	3.87
DSHASTA	161.37	12.37	131.50	10.75	23.50	4.12	37.00	5.45	22.60	2.62
Mean	79,641	132.92	477.80	59.15	1,997	20.51	463.20	35.44	1,673	16.82

As shown in Table 7, after computing the Mean Squared Error and Mean Absolute Percentage Error, the trinomial tree model, Bi-Heston model, and binomial tree model exhibit substantially lower errors and smaller deviations from observed market prices of call options for the Khodro, Saipa, Shasta, and Ahram symbols compared to the remaining models. Therefore, for the valuation of options with large trading volumes and economic significance, these models are strongly recommended. Furthermore, due to the stochastic volatility nature of the Heston and Bi-Heston models, all volatility parameters are estimated rather than directly observed, making the calibration process highly complex and sensitive.

4. Discussion and Conclusion

The present study sought to evaluate the performance of modern option pricing models in the Tehran Stock Exchange by comparing classical, stochastic, tree-based, and computational approaches across highly traded option contracts. The empirical results demonstrate that advanced models—particularly the Bi-Heston model and the trinomial tree model—consistently outperform the classical Black–Scholes framework in terms of pricing accuracy, as measured by MSE, RMSE, MAE, and MAPE. These findings reinforce the longstanding criticism of the Black–Scholes model's restrictive assumptions, especially under volatile and structurally complex market conditions [1, 2, 4]. The superior performance of models that explicitly incorporate stochastic volatility and discrete-time price dynamics highlights the necessity of moving beyond constant-volatility paradigms in emerging markets such as Iran.

The strong relative performance of the Bi-Heston model aligns closely with prior empirical and theoretical research emphasizing the importance of stochastic volatility in capturing the observed behavior of option prices. Wu [4] demonstrated that models with stochastic volatility provide a more realistic representation of market risk and produce significantly improved pricing accuracy compared with Black–Scholes. Similarly, Yang et al. [15] showed that hybrid Heston-based models outperform traditional approaches, particularly when market conditions exhibit volatility clustering and non-normal return distributions. In the Iranian context, Samiei Machiani [6] and Shojaei Manesh [7] previously confirmed that stochastic volatility and jump-diffusion mechanisms significantly enhance pricing precision for both European and American options. The current findings extend this literature by demonstrating that the Bi-Heston variant offers even greater robustness, particularly in periods of heightened economic uncertainty and rapid price adjustments.

The exceptional performance of the trinomial tree model represents another key contribution of this study. Compared with the binomial tree, the trinomial framework provides greater flexibility in modeling intermediate price movements and volatility shifts, which reduces discretization error and improves convergence toward observed market prices. This result is consistent with the findings of Rahayu et al. [14], who demonstrated that Bino-Trinomial models substantially reduce pricing error for complex option structures. Asadi Mousavi [13] similarly reported that tree-based numerical methods outperform classical models in the Tehran Stock Exchange, particularly for American options and markets with limited liquidity. The present study confirms that the advantages of the trinomial tree are not merely theoretical but hold strong empirical relevance within Iran's derivative market.

By contrast, the Black–Scholes model exhibited the weakest performance across nearly all evaluated metrics. This outcome corroborates extensive prior research documenting the systematic mispricing generated by Black–Scholes under non-stationary volatility and macroeconomic instability [2, 10, 11]. Malekmohammadi [10] observed persistent deviations between theoretical and observed prices in Iranian options markets when using classical models, while Peymani [11] showed that ignoring stochastic interest rates severely undermines pricing reliability in inflationary environments. These structural weaknesses explain why the Black–Scholes framework continues to underperform in Iran's capital market, where volatility, inflation, and regulatory shifts remain pronounced.

The results also reveal that while the Heston model significantly improves upon Black–Scholes, it remains inferior to the Bi-Heston and trinomial tree approaches. This finding reflects the inherent limitations of single-factor stochastic volatility models when confronted with the multi-layered uncertainty present in emerging markets. Rezaeian [12] emphasizes that information asymmetry, behavioral factors, and institutional frictions introduce additional pricing components that cannot be fully captured by simple stochastic volatility alone. Consequently, the superior performance of the Bi-Heston model suggests that multi-factor volatility structures offer a more comprehensive representation of Iran's option pricing dynamics.

The observed superiority of advanced computational models aligns with recent developments in financial engineering and machine-learning-based pricing research. Chowdhury et al. [16] demonstrated that machine-learning-augmented Black–Scholes models significantly outperform traditional parametric approaches in frontier markets. Iltuzer [17] and Mahdavi [9] similarly found that artificial intelligence techniques provide robust predictive performance under volatile conditions. While the present study focuses primarily on parametric and numerical frameworks, the superior results of Bi-Heston and trinomial models reinforce the broader conclusion that adaptive, high-dimensional modeling frameworks are better suited to complex market environments.

From a methodological standpoint, the application of rigorous performance metrics strengthens the validity of these conclusions. The consistent dominance of Bi-Heston and trinomial models across MSE, RMSE, MAE, and MAPE metrics reflects both accuracy and stability, which are essential for practical financial decision-making [19-21]. The convergence of results across multiple indicators reduces the risk of metric-specific bias and reinforces confidence in the robustness of the findings.

In the broader theoretical context, the results support the ongoing paradigm shift away from closed-form analytic solutions toward hybrid numerical-stochastic-computational frameworks. Brigo et al. [5] argue that modern risk management demands flexible modeling systems capable of adapting to structural change, regime transitions, and nonlinear dependencies. Neisi and Salmani Gharaei [3] further emphasize that financial engineering in emerging markets requires locally calibrated models that reflect institutional realities rather than imported theoretical constructs. The current findings strongly validate these perspectives by demonstrating that models explicitly designed to handle volatility dynamics and discrete price behavior yield superior performance in Iran's capital market.

Moreover, the results carry significant implications for policy and institutional design. Sayyah and Saleh Abadi [18] highlight that accurate derivative pricing enhances market transparency, investor confidence, and systemic stability. Mispricing, by contrast, exacerbates speculative behavior and increases systemic risk. Therefore, adopting advanced pricing frameworks such as the Bi-Heston and trinomial models could materially improve the integrity and efficiency of Iran's derivatives market.

Finally, the present study contributes to the global literature by providing rare large-scale empirical evidence from a high-volatility emerging market. Xiang [22] and Kebriyayee et al. [23] both stress the need for context-specific validation of pricing models, particularly outside developed Western markets. By demonstrating the clear superiority of advanced frameworks within the Tehran Stock Exchange, this study expands the geographical and institutional scope of option pricing research and strengthens the empirical foundation of modern financial engineering.

Despite its contributions, this study is subject to several limitations. First, the analysis focuses on a specific set of highly traded option contracts, which may limit the generalizability of the findings to less liquid instruments. Second, the estimation of stochastic volatility parameters inherently involves calibration risk, and alternative estimation techniques may yield different performance outcomes. Third, the study relies on historical market data from a single national market, which may constrain cross-market comparisons.

Future studies could expand the model set to include machine-learning-based pricing frameworks, regime-switching models, and hybrid deep-learning-stochastic architectures. Longitudinal analysis across multiple market cycles and stress periods would further strengthen understanding of model stability. Comparative studies between Iran and other emerging markets would also provide valuable insight into the universality of the findings.

Financial institutions, brokers, and regulatory bodies are encouraged to adopt advanced pricing frameworks—particularly Bi-Heston and trinomial tree models—when valuing options with significant trading volume. Improved pricing accuracy will enhance risk management, market transparency, and investor confidence, ultimately contributing to greater market efficiency and stability.

Authors' Contributions

Authors equally contributed to this article.

Ethical Considerations

All procedures performed in this study were under the ethical standards.

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Conflict of Interest

The authors report no conflict of interest.

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