BSOPM and BOPM Models in Banknifty Options : A Study on Their Applicability and Risk Framework

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Abstract

Purpose : In the financial market, frequent changes in RBI's repo and reverse repo rates influenced the overall securities trading in the stock market's derivative segment [1]. The study focused on scrutinizing the applicability of the "BSOPM & BOPM models" to the BANKNIFTY index call and put options on different moneyness scenarios by using three different interest rates.

Methodology : This study analyzed 648 samples of BANKNIFTY index call & put options for both models and compared them to assess suitability using risk-free interest rates (MIBOR, 10-year government bond) & risk-including interest rates involving 'Yield Curve Risk,' 'Basis Risk,' nd 'Repricing Risk' [2]. Further, it considered the moneyness of OTM, ATM, and ITM strike prices for each date of the month till expiry and applied SPSS's paired *t*-test & RMSE statistical test for analyzing both models.

Finding : By analyzing SPSS's paired *t*-test, we observed that both models revealed significant differences in option pricing across all levels of moneyness and risk-related variables incorporated into this study, but a comparison of RMSE values identified the BOPM model's better performance across all computed option prices[3].

Practical Implications : This research provides useful information for option traders, investors, financial institutions, and policymakers to make more accurate and data-driven financial decisions using option pricing models in different market scenarios.

Originality : The study concentrated on considering risk-free and risk-including interest rates at various market scenarios and used a particular one-month option price sample for observations of BSOPM & BOPM for the BANKNIFTY index.

Keywords : **BSOPM, BOPM, BANKNIFTY, options, interest rates, moneyness**

JEL Classification Codes : C30, G13, G32

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[1] The Reserve Bank of India (RBI) employs repo and reverse repo interest rates as tools to execute monetary policy, address inflation concerns, and foster economic stability. Through the manipulation of these rates, the RBI endeavors to regulate inflation, bolster economic growth, and ensure the overall financial stability of the nation.

[2] See, Reserve Bank of India (1997).

[3] A lower RMSE value indicates better predictive performance (Ulrich et al., 2023).

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Options contracts, similar to forward and futures contracts, serve as derivative instruments. Predominantly utilized by speculators and hedgers, these contracts are valued for their adaptability and versatility as effective hedging tools (Hull, 2007). An option agreement confers upon the holder the privilege to purchase or sell a designated amount of the underlying equity (such as a stock, index, commodity, or currency) at a predetermined price within a specified timeframe. The two principal types of options contracts are known as "call" and "put" (Dar & Anuradha, 2018). The pricing of a stock option is influenced by six key factors: the underlying asset's current price, the strike price, the remaining time until expiration, stock price volatility, the risk-free interest rate, and anticipated dividends throughout the option's lifespan (Khan et al., 2013). This relationship holds significant importance in options trading (Ulrich et al., 2023). According to Bakshi et al. (1997), every option pricing model needs to incorporate three fundamental assumptions: the underlying price process (distributional assumption), the interest rate process, and the market price of factor risks. Various alternatives are available for each of these assumptions.

The Black-Scholes Option Pricing Model

During the early 1970s, Black and Scholes (1973), in collaboration with Merton (1976), introduced a pioneering concept in stock options pricing - the Black-Scholes model. This model has had a substantial impact on the strategies employed by debt traders in pricing and managing options. Specifically tailored for stocks without dividend payouts, the model utilizes sophisticated mathematical formulas to compute the BSMOP fair price of call/put options by the European method.

For European Call

A call option provides the holder with the right, without any obligation, to buy an underlying asset at a predetermined price on a specified date with continuous-time movement. The European Call option premium can be calculated by using the following equations:

$$C_o = S_o N(d_1) - Ke^{-Rf\,t} N(d_2) \qquad (1)$$

$$d_1 = \frac{\ln\left(\frac{S_o}{K}\right) + \left(R_f + \frac{\sigma^2}{2}\right) t}{\sigma\sqrt{t}} \qquad (1a)$$

$$d_2 = \frac{\ln\left(\frac{S_o}{K}\right) + \left(R_f - \frac{\sigma^2}{2}\right) t}{\sigma\sqrt{t}} = d_1 - \sigma\sqrt{t} \qquad (1b)$$

For European Put

A put option provides the holder with the right, without any obligation, to sell an underlying asset at a predetermined price on a specified date with continuous-time movement. The European put option premium can be calculated by using the following equation:

$$P_o = Ke^{-Rf\,t} N(-d_2) - S_o N(-d_1) \qquad (2)$$

Where,

C_o represents "call option price," P_o denotes "put option price," S_o is "the underlying asset price," K signifies "the

strike price," σ indicates "the underlying volatility," R_f is "the risk-free interest rate," t stands for "time until expiration," $N(d)$ represents "a standard normal distribution with a mean of 0 and a standard deviation of 1," d_1 represents "Moneyness Adjusted for Volatility," d_2 represents "Risk-Adjusted Probability Factor," e is "the base of the natural logarithm (2.71828)" and ln denotes "the natural logarithm function."

Modification in Equations (1), 1(a), 1(b), & (2) of BSOPM by Replacing the Interest Rate R_f by R_{IIR}

***(a) Call Option Premium*: -**

$$C_o = S_o\, n(d_1) - Ke^{-RIIRt}\, n(d_2) \qquad (3)$$

$$d_1 = \frac{\ln\left(\frac{S_o}{K}\right) + \left(R_{IIR} + \frac{\sigma^2}{2}\right) t}{\sigma\sqrt{t}} \qquad (3a)$$

$$d_2 = \frac{\ln\left(\frac{S_o}{K}\right) + \left(R_{IIR} - \frac{\sigma^2}{2}\right) t}{\sigma\sqrt{t}} = d_1 - \sigma\sqrt{t} \qquad (3b)$$

***(b) Put Option Premium*: -**

$$P_o = Ke^{-RIIRt}\, n(-d_2) - S_o\, n(-d_1) \qquad (4)$$

Where,
R_f represents "risk-free interest rate" and R_{IIR} represents "risk-including interest rate."

The Binomial Option Pricing Model (BOPM)

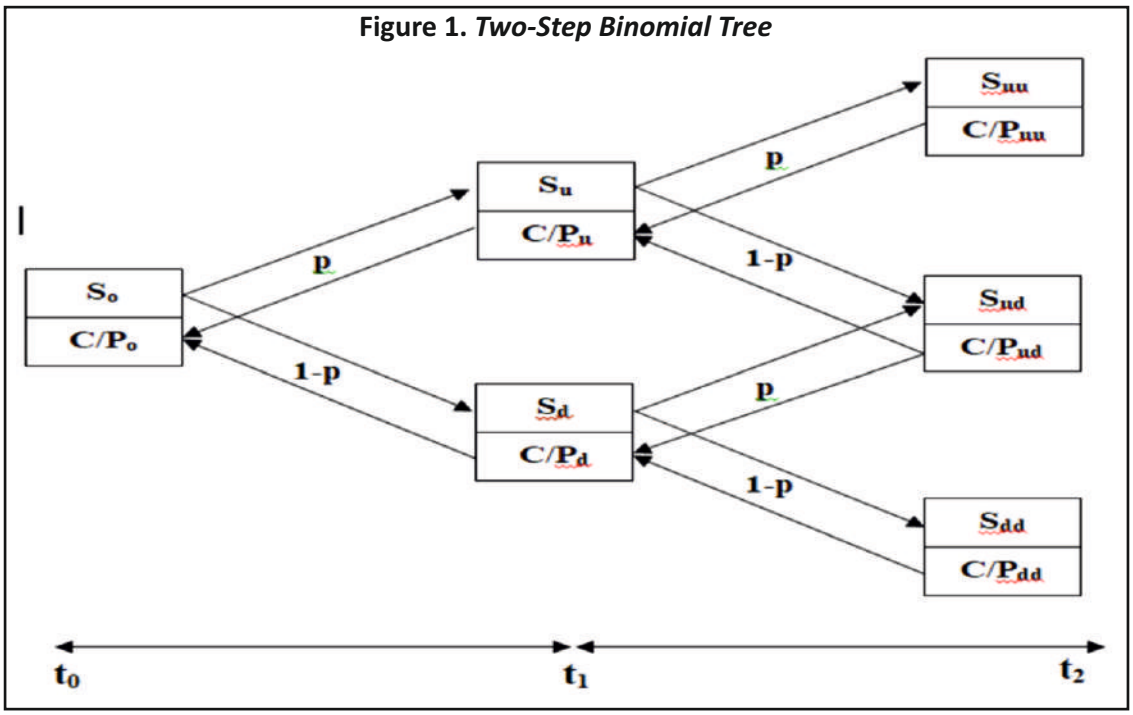
The BOPM, which was formulated by Cox et al. (1979), serves as an expansion of the renowned "Black-Scholes model." Consequently, it presents an alternative mathematical methodology for assessing the value of options. According to this model, the underlying asset's price fluctuates in discrete up or down intervals, forming a binomial tree to represent possible price paths (Chalasani et al., 1999). This study explores the valuation of option prices through the utilization of a two-step binomial tree methodology (Costabile et al., 2011; Cox et al., 1979).

Figure 1 depicts a model spanning two periods, encompassing time intervals from 0 to 2, representing the Binomial model. Stock prices in the Binomial model move up and down with a probability over time. At time intervals "t_1" and "t_2," the price has the potential to rise or fall, respectively. With more time steps, the binomial model becomes more accurate. This option pricing methodology is known as the "Binomial tree," where the various prices 'branch' out over time. The formula is expressed in the form of equations for pricing these financial instruments.

For European Call

A call option offers the holder the non-obligatory right to buy an underlying asset at a predetermined price on a specified date, with its price influenced by the probabilistic movements of the underlying stocks' value over the "discrete time frame."

Figure 1. ***Two-Step Binomial Tree***



$$C_o = \frac{[C_u * p + C_d * (1-p)]}{e^{rt}} \qquad (5)$$

(Here, the rate of risk-free fluctuates continuously)

$$C_u = S_u - K; \{(S_u - K, 0)\}; \qquad (5a)$$

$$C_d = S_d - K; \{(S_d - K, 0)\}; \qquad (5b)$$

$$p = \frac{(e^{rt} - S_d)}{(S_u - S_d)} \qquad (5c)$$

$$S_u = S_o * u; S_d = S_o * d \qquad (5d \& 5e)$$

$$u = e^{(\sigma * \sqrt{\Delta t})}; d = \frac{1}{u} \qquad (5f \& 5g)$$

$\{\Delta t = T/2\}$; (where σ is the underlying asset's volatility);

For European Put

A put option offers the holder the non-obligatory right to sell an underlying asset at a predetermined price on a specified date, with its price influenced by the probabilistic movements of the underlying stocks' value over the "discrete time frame."

$$P_o = \frac{[P_u * p + P_d * (1-p)]}{e^{rt}} \qquad (6)$$

$$P_u = K - P_u; \{(K - P_u, 0)\}; \quad (6a)$$

$$P_d = K - P_d; \{(K - P_d, 0)\}; \quad (6b)$$

$$p = \frac{(e^{rt} - P_d)}{(P_u - P_d)} \quad (6c)$$

$$P_u = P_o * u; P_d = P_o * d \quad (6d \& 6e)$$

$$u = e^{(\sigma * \sqrt{\Delta t})}; d = \frac{1}{u} \quad (6f \ \& 6g)$$

$\{\Delta t = T/2\}$; (where σ is the underlying asset's volatility);

Where,
C_o represents "the call option price," C_u denotes "the upper price for call payoff," C_d denotes "the down price for call payoff," P_o represents "the put option price," P_u denotes "the upper price for put payoff," P_d denotes "the down price for put payoff," S_o stands for "the price of the underlying asset," S_u is "the upper stock price," S_d is "the down stock price," variables u and d represent the factors for "upward and downward price movement," K signifies "the strike price," p is "the risk-neutral probability," σ denotes "the underlying stocks' volatility," r is "the risk-free interest rate," t represents "the time to expiration," and e is "the numerical constant approx. equivalent to 2.71828 (Natural log function's base)."

Modification in Equations (5) & (6) of BOPM by Replacing the Interest Rate R_f by R_{IIR}

***(a) Call Option Premium*: -**

$$C_o = \frac{[C_u * p + C_d * (1 - p)]}{e^{RIIRt}} \quad (7)$$

***(b) Put Option Premium*: -**

$$P_o = \frac{[P_u * p + P_d * (1 - p)]}{e^{RIIRt}} \quad (8)$$

where,
R_f represents "risk-free interest rate" and R_{IIR} represents the "risk-including interest rate."

Moneyness

Moneyness pertains to how an option signifies a profitable or unprofitable position, representing the relationship between the underlying stock's current price and the strike price of the option contract, typically associated with

Table 1. ***Options Contracts of Various Moneyness***

Moneyness	For Call Option	For Put Option
ITM	Exercise Price < Stock Price	Exercise Price > Stock Price
ATM	Exercise Price = Stock Price	Exercise Price = Stock Price
OTM	Exercise Price > Stock Price	Exercise Price < Stock Price

call or put options. Table 1 shows the correlation between the underlying stock's current price and strike price that Moneyness sorts options into three categories. The parameter of the option's moneyness is measured by the strike price divided by the stock price (Bakshi et al., 1997; Bendob & Bentouir, 2019).

Banknifty

This index takes into account 12 of the largest and most liquid banking stocks in India. Sathiyan and Panda (2016) noticed improved banking access but highlighted rural and low-income disparities, advocating for more branches and financial literacy.

Risk-Free Interest Rate

It is a theoretical measure representing the potential rate of return on investment, free from any financial or monetary risk (Khan et al., 2013).

For Replacing Risk-Free Interest Rate

A modification is applied to the BSOPM and BOPM models to accomplish the objective of this study. This modification involves substituting the variable of the risk-free interest rate with three distinct kinds of risk factors:

(a) *Yield Curve Risk (R_{YC})* : Repricing mismatches make banks vulnerable to changes in the slope and shape of the yield curve. When unexpected changes in the yield curve occur, this can have a negative impact on banks' earnings and their economic value.

$$R_{YCi} = (LTIR_i - STIR_i) \ldots\ldots\ldots\ldots n \text{ times} \qquad (9)$$

$$\text{Yield Curve Risk} = \frac{1}{n} \sum_{i=1}^{n} (R_{YCi}) \qquad (9a)$$

(b) *Basis Risk (R_B)*: Another major source of interest rate risk is basis risk, which arises from the imperfect correlation between interest rates earned or paid on different financial instruments with similar repricing characteristics.

$$\text{Basis Risk} = \frac{1}{n} \sum_{i=1}^{n} \{ (\frac{1}{n} \sum_{i=1}^{n} R_{Bi(STIR)}) + (\frac{1}{n} \sum_{i=1}^{n} R_{Bi(STIR)}) \} \qquad (10)$$

(c) *Reprising Risk (R_{RP})*: Repricing anomalies can make banks vulnerable to shifts in the yield curve, such as changes in its slope or shape. When the yield curve shifts unexpectedly, this may adversely affect a bank's earnings or its underlying economic value.

$$\text{Repricing Risk in Repo} - \text{rate}$$

$$= | \frac{1}{n} \sum_{i=1}^{n} (\text{Change } \% \times n_1) + (\text{Change } \% \times n_2) + \ldots | \qquad (11)$$

$$\text{Repricing Risk in Reverse Repo} - \text{rate}$$

$$= \left| \frac{1}{n} \sum_{i=1}^{n} (\text{Change}\,\% \times n_1) + (\text{Change}\,\% \times n_2) + \ldots \right| \quad (11a)$$

Repricing Risk

$$= \frac{\sum_{i=1}^{n} R_{RP\ (\text{Repo} + \text{Reverse Repo})}}{n} \quad (12)$$

For Computing a New Risk Including Interest Rate: By adding the value of all the above-calculated risk rates, for calculating the Risk-Including interest rate in the equation given below:

$$R_f = R_{IIR} = \frac{\sum_{i=1}^{n} R_{YCi}}{n} + \frac{\sum_{i=1}^{n} R_{Bi}}{n} + \frac{\sum_{i=1}^{n} R_{RPi}}{n} \quad (13)$$

$$\text{Or, } R_f = R_{IIR} = \frac{1}{n} \sum_{i=0}^{n} (R_{YCi} + R_{Bi} + R_{RPi})$$

where, R denotes the calculated risk, which is computed n times by using various bank interest rates for risk, including interest rate and restructured BSOPM and BOPM Call/Put option pricing formula. It will replace the new value of R_{IIR} in the equation of the option models above.

Error Estimates and Statistical Tools

The Root Mean Square Error (RMSE)

The performance of the many competing models for forecasting is evaluated using the RMSE error estimates tool in the majority of empirical studies (Chauhan & Gor, 2021; Dikshita & Singh, 2019; Reddy, 2019; Ulrich et al., 2023).

$$RMSE = \sqrt{\frac{1}{N} \sum_{t=1}^{n} (P_a - P_c)^2} \quad (14)$$

where,
P_c = Calculates the model price of the option;
P_a = Actual market price of the option;
N = Number of observations.

Literature Review

Ahamed and Ahammed (2024) found the model to be a reliable tool for measuring financial distress with 96.6% accuracy. Faniband and Jadhav (2023) analyzed geopolitical risks from the top 10 economies on India's stock market using quantile regression. GPRT and China notably impacted all segments, while others varied. The findings would aid investors in risk management and strategy. Routh (2023) explored the inflation interaction of different equilibrium conditions of the market and how deposit interest rates, stock market returns, and inflation interacted with each other. Dey and Singh (2022) explored how news drives stock volatility, sustains price trends, and triggers varied investor reactions, guiding informed decisions and future research.

Narayanaswamy et al. (2022) examined risk-return dynamics in various automobile segments, revealing significant differences among companies over multiple time frames. Chauhan and Gor (2021) scrutinized three models for Indian options and found that the modified distribution within the generalized Black-Scholes model exhibited the lowest RMSE. Nayak and Barodawala (2021) concluded that macroeconomic variables, including money supply, forex reserves, WPI, and interest rates, significantly influenced equity returns, with strong long-run linkages observed in the Indian stock market. Kanojia and Malhotra (2021) studied the Indian stock market jumps, indicating that these bubbles might burst due to reported fraudulent activities, causing a domino effect across interconnected markets. Dikshita and Singh (2019) and Reddy (2019) tested the different volatility estimator tools, such as ME, RMSE, MAE, MPE, MAPE, MASE, and ACFI, for forecasting accuracy.

Bendob and Bentouir (2019) revealed overpricing in every Moneyness type, with heightened volatility in the ATM moneyness. While the Monte Carlo Simulation excelled in lower volatility scenarios, the Black-Scholes and Binomial models outperformed the entire sample. Mutum and Das (2019) found frequent violations at thinly traded levels, making it challenging to extract abnormal profits due to liquidity and maturity constraints. Dar and Anuradha (2018) discovered that there was no notable distinction in the means of European options when utilizing both models of BOPM and BSOPM for a single period. Coelho and Reddy (2018) indicated discrepancies between call option prices in Nifty's Financial Services Index. Sathiyan and Panda (2016) observed significant improvements in banking access in Indian states but highlighted persistent disparities in rural and low-income areas. Makkar and Singh (2013) concluded that there is no statistically significant difference in the financial performance of public and private sector banks in India. Khan et al. (2013) modified the Black-Scholes option pricing model, adding variables based on risk-free interest rate assumptions. Empirical testing against the original formula revealed differing market prices. Savitha and Deepika (2013) demonstrated that the put-call ratio serves as a valuable contrarian indicator, helping forecast future stock market behavior. Prasad and Verma (2013) suggested that the performance of small stocks closely mirrors that of larger stocks. Similarly, Parikh and Baruah (2013) confirmed the overreaction hypothesis in the Indian context, observing phenomena of short-term momentum and long-term reversal in the Nifty 50 stocks. Bammi (2013) utilized greenhouse gas emissions data to construct portfolios based on emission levels, providing insights into the intersection of environmental and financial performance.

Costabile et al. (2011) and Ulrich et al. (2023) emphasized the importance of selecting a technique for the volatility surface and stressed the use of precise approaches, such as the one-dimensional kernel smoother, for reliable skewness spanning regressions and resilient volatility surfaces. Chalasani et al. (1999) introduced novel exercise rule estimation for American options, demonstrating advantages over the Hull-White method. Rubinstein (1994) emphasized the importance of using prices for valuable information, extending this concept to financial economics, suggesting the inference of future spot interest rates, inflation, and the business cycle turns from current bond prices. Macbeth and Merville (1980) indicated that uniform equity prices, coupled with consistent elasticity in variance diffusion processes, affirmed the Cox model's precision in option pricing. In their earlier work, Macbeth and Merville (1979) demonstrated a tendency to undervalue in-the-money (ITM) options and overvalue out-of-the-money (OTM) options, with the extent influenced by the position of option contracts and time until expiration. Cox et al. (1979) emphasized the simple two-state process's role in option pricing through arbitrage, suggesting restrictions on other securities' movements for an exact formula. Black and Scholes (1973) revolutionized finance with their model, introducing a valuation framework for options and corporate liabilities that significantly impacted risk management, investment strategies, and standardized derivatives' valuation. Similarly, Black and Scholes (1972) showed that applying variance during the option term reduced portfolio excess return fluctuation, underscoring the importance of precise variance estimates.

Overview and Importance of the Proposed Study

While reviewing the literature on the applicability of BSOPM and BOPM in various capital markets, it was found that various studies have been carried out on the application of the BSOPM & BOPM independently on the Indian capital market and other capital markets beyond the boundary of India. However, these studies mainly focused on the applicability and risk framework of the BSOPM & BOPM on call & put options for a specific period on the BANKNIFTY index. Further, no research has been traced on the applicability of BSOPM & BOPM together on both call option and put option of the same period in the Indian capital market by applying risk-including interest rate & risk-free interest rate at different moneyness levels of the BANKNIFTY index. The importance of the proposed study will be helpful to options dealers/options traders/investors to assess which model provides a more consistent option pricing mechanism for BANKNIFTY call and put options under various moneyness scenarios.

Statement of the Problem

The options market is expanding rapidly, encouraging traders or investors to trade and earn easy money by hedging their positions and attracting researchers for analysis of relevant studies. The researchers have conducted several studies frequently to find the applicability of various pricing models for making assumptions on the pricing of options. BSOPM & BOPM have contributed to their groundbreaking work in option pricing theory. Till now, BSOPM is only considered a benchmark for option pricing by NSE and relies on risk-free interest rates (such as government bond yields) to evaluate the option prices. However, the financial institutions and investors faced actual market risks like yield curve risk, basis risk, and repricing risk. Over time, many researchers found in their study that BSOPM & BOPM option prices are underpriced and overpriced in different frameworks, and option prices behave differently compared to the market price. Therefore, it is decided to incorporate the risk-including interest rate in this study. This needs to be determined by incorporating market-based fixed deposit interest rates of large capitalized private banks that are part of the BANKNIFTY index and exploring the applicability of both models in BANKNIFTY option pricing.

A few research works have been done on a comparison between BSOPM and BOPM in the Indian option context. In this study, an attempt is made to combine the study on the applicability of pricing models along with research done on historical volatility. In India, no study covers conducting experimental tests of BSOPM and BOPM on the BANKNIFTY index derivative of both call & put options for a specific month. The present study tries to do such experimental tests for testing the applicability and comparability of the two option pricing models for both call & put options by applying risk-including interest rate & risk-free interest rate at different moneyness levels of the BANKNIFTY index.

Research Gap

After reviewing various kinds of literature, the study has attempted to explore the applicability and risk framework of option pricing models by assuming the market conditions. However, the research work found limited studies that examined the applicability of both BSMOP & BOPM with risk-including interest rates, particularly in the BANKNIFTY index. No studies have been conducted on the performance of BSOPM and BOPM across moneyness (ATM, ITM, and OTM) with risk-free & risk-including interest rates. In this study, risk is calculated by incorporating interest rates using long-term and short-term fixed deposit rates of large-cap private banks. These banks are part of the BANKNIFTY index, where private banks have a significant weightage of 84.20%. This high representation highlights the dominant influence of private banks on the index, making their interest rates highly

relevant and suitable for accurate risk calculations. This research work aims to fill these gaps by examining the pricing accuracy between two models in the BANKNIFTY index derivative segment for a specific period as a leading indicator for options traders, investors, financial institutions, and policymakers to make more accurate and data-driven financial decisions.

Potential Contribution

This study presents an in-depth analysis of the comparative performance of BSOPM and BOPM, thereby contributing empirical insights to the literature. This study clarifies the limitations and possibilities of their use by evaluating the practical applicability of both models under different financial scenarios. Its findings will also contribute to helping investors, policymakers, and financial institutions in choosing effective pricing models. Also, it provides important data to strengthen risk management and strategic decision-making processes, which contribute to financial stability and improved decision-making.

Research Aim and Questions

To examine the applicability between both BSOPM & BOPM models by applying risk-including interest rate & risk-free interest rate at different moneyness levels of call & put options of BANKNIFTY. The study will address the following research questions:

- How do BSOPM and BOPM perform under risk-including and risk-free interest rate assumptions?
- Which model provides a more accurate pricing estimate across ATM, ITM, and OTM strike prices?
- What are the significant differences, if any, between the theoretical and actual market prices of options?

Research Methodology

A descriptive and quantitative research study utilized historical numerical market data and statistical methods to evaluate the applicability and comparability of the two option pricing models for both call & put options by applying risk-including interest rate & risk-free interest rate at different moneyness levels of the BANKNIFTY index.

Research Design

- ***Methods of Data Collection:*** The study is based on secondary data. The data of BANKNIFTY index call & put options prices and historical closing prices were collected from the NSE website. Also, Banks' Fixed Deposit Interest Rates (Scripbox), Repo and Reverse Repo Rates (RBI), Overnight MIBOR Interest Rate (FBIL), and other relevant source links are mentioned in the references.
- ***Tools and Techniques Used for Data Analysis:*** Statistical tools and Excel were used to analyze and validate the study's data. Parametric paired sample *t*-tests (via SPSS) allow comparison of the models' outputs with actual market prices, while Root Mean Square Error (RMSE) measures prediction accuracy.

Sampling Techniques

- ***Frame:*** The BANKNIFTY options data were collected from January 2, 2023, to January 25, 2023 (18 trading

days), each with a monthly expiration, i.e., 25th Jan. 2023. Historical volatility was computed by collecting closing price data spanning from January 3, 2022, to January 24, 2023, covering an exact one-year period for each option.

↳ ***Unit:*** Both models have involved BANKNIFTY call and put options with strike prices of moneyness (OTM, ATM, ITM) at three different interest rates for each date.

↳ ***Size:*** A total of 648 [(18+18)*3*3*2] samples were taken for the study.

↳ ***Justification:*** The sampling frame includes contracts at OTM, ATM, and ITM strike prices that are analyzed at three different interest rates for each day in the dataset. This approach provides a robust evaluation of the effectiveness of both models in different financial scenarios.

Analysis Intended and Software Used

SPSS software was used in paired *t*-tests to compare option prices predicted by BSOPM and BOPM to actual market prices. In addition, the accuracy of the forecasts was assessed through the calculation of RMSE. SPSS was selected due to its statistical power and reliability.

Reliability Values of Scales

This research is mainly based on historical financial data, so it does not use scales. Nevertheless, the accuracy of the RMSE and paired *t*-test results provides reliability in the research findings.

Time Period of the Study

The period of study has been selected and focused on one-month data spanning from January 2, 2023, to January 25, 2023 (18 trading days). The data for this study pertains to the BANKNIFTY options listed and traded on the NSE in India. Further, only secondary financial data has been used in the study, due to which there was no need for human respondents or primary data collection.

Hypothesis Statements

↳ **Null Hypothesis (H_0):** There is no significant difference b/w the Black-Scholes Option Price Model (BSOPM)/Binominal Option Price Model (BOPM) and Actual Market Prices. At 95% level of confidence, if the *p*-value > 0.05, then the null hypothesis is accepted.

Data Analysis and Results

We computed fair prices using both BSOPM & BOPM. Tables 5 & 6 show paired sample *t*-test results of 18 sets. Makkar and Singh (2013) used a paired sample *t*-test and found no significant financial performance difference between public and private banks. Further, Table 7 shows the RMSE values with ranks. Also, the calculation process of the new risk-including interest rate is elaborated in Tables 2, 3, and 4.

Calculation Process of Risk Including Interest Rate

We modified the actual risk-free interest rate (R_f) to develop the risk-including interest rate (R_{IIR}). The calculation

Table 2. ***Short-Term and Long-Term Fixed Deposit Interest Rates***

Bank (i)	Symbol	$STIR_i$ (%)	$LTIR_i$ (%)
HDFC Bank Ltd.	HDFCBANK	3.00	7.00
ICICI Bank Ltd.	ICICIBANK	3.00	7.00
Kotak Mahindra Bank Ltd.	KOTAKBANK	2.75	7.00
Axis Bank Ltd.	AXISBANK	3.50	7.00
Indusind Bank Ltd.	INDUSINDBK	3.25	7.25
Yes Bank Ltd.	YESBANK	3.25	7.00

Note. Where, Bank: (i); Short-term interest rate of bank: $STIR_i$; Long-term interest rate of bank: $LTIR_i$.

Table 3. ***Calculation of Yield Curve Risk***

Symbol	$STIR_i$ (%)	$LTIR_i$ (%)	$R_{yci} = (LTIR_i - STIR_i)$
HDFCBANK	3.00	7.00	4.00
ICICIBANK	3.00	7.00	4.00
KOTAKBANK	2.75	7.0	4.25
AXISBANK	3.50	7.00	3.50
INDUSINDBK	3.25	7.25	4.00
YESBANK	3.25	7.00	3.75
	Total		**23.50**

process is based on the average summation of the yield curve risk, basis risk, and repricing risk. In Table 2, all large-cap private banks' long-term & short-term fixed deposit interest rates have been selected for calculating all three types of risks.

Yield Curve Risk

Calculate the disparity in risk between the long-term and short-term rates for each bank and subsequently determine the mean value.

Computing by equation (9a)

$$Yield\ Curve\ Risk = \sum_{i=1}^{6} \frac{1}{6}(1+2+3+\cdots\ldots\ldots\ldots\ldots..+6)$$

$$= \frac{23.50\%}{6} = 3.917\%$$

Calculation of Basis Risk

Calculate the disparity in risk between the long-term and short-term rates of all feasible combinations for each pair of banks of all the large capitalization private banks mentioned in Table 2, and subsequently determine the mean value.

A Pearson product-moment correlation is often generated to measure how much two variables are linearly related. According to McCain (1990), Pearson correlation is the most frequently used similarity metric in author

co-citation analysis (ACA), and other researchers (Andrews, 2003) employed this method in their research. All possible combinations of differences for the short-term interest rate and the long-term interest rate are through the Pearson correlation matrix. The detailed results are available with the authors and are not included here because of space constraints.

Computing by equation (10)

$$\text{Average between short \& long} - \text{term FD interest rate} = \frac{0.317 + 0.083}{2} = 0.2\%$$

Calculation of Reprising Risk

It is calculated by the RBI guidelines, where the interest rate increases or decreases. Analyzing the changes in both the repo rate and reverse repo rate aids in assessing repricing risk. First, calculate the percentage change in "the repo and reverse-repo rate," and subsequently ascertain the average value. The data of repo-rate & reverse repo-rate has been extracted from the RBI website over the last 10 years and accumulated their change % with the total nos. of times for calculating the repricing risk. The detailed data and results are available with the authors.

Table 4 reflects changed interest rate numbers over time. These changes can affect the market inconsistently due to increases & decreases in the interest rate of repo-rate and reverse repo-rate. Additionally, it has been observed that the RBI has continuously decreased the repo rate & reverse repo rate since 2012, and the fluctuation of this type of interest rate comes under the repricing risk.

Table 4. ***Calculation of No. of Changes in Repo & Reverse Repo Rate***

Repo-Rate			Reverse Repo-Rate		
Change %	**No. of Times**	**Remarks**	**Change %**	**No. of Time**	**Remarks**
0.25	16	Increase	0.25	17	Increase
0.50	02	Increase	0.50	03	Increase
(0.25)	13	Decrease	(0.25)	13	Decrease
(0.35)	01	Decrease	(0.35)	01	Decrease
(0.40)	01	Decrease	(0.40)	01	Decrease
(0.50)	02	Decrease	(0.50)	02	Decrease
(0.75)	01	Decrease	(0.90)	01	Decrease
Total	**36**		**Total**	**38**	

For Calculating the Repricing Risk in Repo-Rate

The data is compiled by equation (10) to take the average difference of repo-rate calculated by the authors.

$$\text{Repricing Risk in Repo} - \text{rate} = \left| \frac{1}{n} \sum_{i=1}^{n} (\text{Change \%} \times n_1) + (\text{Change \%} \times n_2) + \ldots \right|$$

$$= \left| \frac{1}{36} \sum_{i=1}^{36} \{0.25 \times (16 + 13)\} + \{0.50 \times (02 + 02)\} + \{0.35 \times (1)\} + \{0.40 \times (1)\} + \{0.75 \times (1)\} \right|$$

$$= \left| \frac{1}{36} \sum_{i=1}^{36} \{0.25 \times (29)\} + \{0.50 \times (4)\} + \{0.35 \times (1)\} + \{0.40 \times (1)\} + \{0.75 \times (1)\} \right|$$

$$= \left| \frac{1}{36} \sum_{i=1}^{36} \{7.25 + 2 + 0.35 + 0.40 + 0.75\} \right| = 0.2986$$

For Calculating the Repricing Risk in Reverse Repo Rate

The data is compiled by equation (11) to take the average difference of the reverse repo rate calculated by the author.

Repricing Risk in Reverse Repo – rate

$$= \left| \frac{1}{n} \sum_{i=1}^{n} (\text{Change}\,\% \times n_1) + (\text{Change}\,\% \times n_2) + \ldots \right|$$

$$= \left| \frac{1}{38} \sum_{i=1}^{38} \{0.25 \times (17 + 13)\} + \{0.50 \times (03 + 02)\} + \{0.35 \times (1)\} + \{0.40 \times (1)\} + \{0.90 \times (1)\} \right|$$

$$= \left| \frac{1}{38} \sum_{i=1}^{38} \{0.25 \times (30)\} + \{0.50 \times (5)\} + \{0.35 \times (1)\} + \{0.40 \times (1)\} + \{0.90 \times (1)\} \right|$$

$$= \left| \frac{1}{38} \sum_{i=1}^{38} \{7.5 + 2.5 + 0.35 + 0.40 + 0.90\} \right| = 0.3066$$

Final Repricing Risk Computing by Equation (12)

$$= \frac{\sum_{i=1}^{n} R_{RP(\text{Repo + Reverse Repo})}}{n} = \frac{0.2986 + 0.3066}{2} = 0.3026\%$$

Concluding Calculation of Risk Including Interest Rate

By adding the value of all the above-calculated risk rates for calculating the risk-including interest rate in equation (13) given above.

$$R_f = R_{IIR} = 3.917 + 0.2 + 0.303 = 4.42\%$$

Calculation of Option Prices

The actual market prices (MP) samples of BANKNIFTY call & put option prices were taken from January 2, 2023, to January 25, 2023, and collected from the NSE website – Actual market prices (MP) and model theoretical fair prices, including the necessary data for call and put option pricing, across various risk factors (risk-including interest rate, MIBOR interest rate, and 10-year bond interest rate) and all moneyness levels (ITM, ATM, OTM) for BANKNIFTY derivative options. The detailed results of the test can be obtained from the author upon request.

Numerical Results

Tables 5 & 6 show the SPSS output of paired sample *t*-test for all moneyness levels and risk factors, comparing differences between BSOPM/BOPM call & put option prices with market prices of one-month BANKNIFTY Index on all moneyness levels and risk factor scenarios.

Table 5. ***SPSS Output of Paired Sample t-test for Call Option Prices***

Money-ness	Stock Options	Paired Differences					*t*	*df*	Sig. (2-tailed)	Null Hypothesis Acceptance/ Rejection	Conclusion
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference						
					Lower	Upper					
					Risk-Including Interest Rate						
ITM	BSOPM Price-MP	–101.99	52.38	12.35	–128.04	–75.94	–8.26	17	0.000	Rejected	Significant Difference
	BOPM Price-MP	–57.15	37.12	8.75	–75.60	–38.69	–6.53	17	0.000	Rejected	Significant Difference
ATM	BSOPM Price-MP	–106.35	51.54	12.15	–131.98	–80.71	–8.75	17	0.000	Rejected	Significant Difference
	BOPM Price-MP	–57.15	37.12	8.75	–75.60	–38.69	–6.53	17	0.000	Rejected	Significant Difference
OTM	BSOPM Price-MP	–111.57	55.73	13.14	–139.29	–83.86	–8.49	17	0.000	Rejected	Significant Difference
	BOPM Price-MP	–66.74	39.43	9.29	–86.34	–47.13	–7.18	17	0.000	Rejected	Significant Difference
					Risk-Free Interest Rate - MIBOR						
ITM	BSOPM Price-MP	–114.67	58.67	13.83	–143.84	–85.49	–8.29	17	0.000	Rejected	Significant Difference
	BOPM Price-MP	–118.50	57.63	13.58	–147.16	–89.84	–8.72	17	0.000	Rejected	Significant Difference
ATM	BSOPM Price-MP	–123.21	61.79	14.56	–153.93	–92.48	–8.46	17	0.000	Rejected	Significant Difference
	BOPM Price-MP	–69.71	40.86	9.63	–90.03	–49.39	–7.24	17	0.000	Rejected	Significant Difference
OTM	BSOPM Price-MP	–57.05	36.94	8.71	–75.42	–38.68	–6.55	17	0.000	Rejected	Significant Difference
	BOPM Price-MP	–78.38	43.69	10.30	–100.11	–56.65	–7.61	17	0.000	Rejected	Significant Difference
					Risk-Free Interest Rate (10 Y Bond)						
ITM	BSOPM Price-MP	–123.42	63.37	14.94	–154.94	–91.91	–8.26	17	0.000	Rejected	Significant Difference
	BOPM Price-MP	–126.91	62.20	14.66	–157.84	–95.98	–8.66	17	0.000	Rejected	Significant Difference
ATM	BSOPM Price-MP	–131.26	66.28	15.62	–164.22	–98.30	–8.40	17	0.000	Rejected	Significant Difference
	BOPM Price-MP	–78.37	44.05	10.38	–100.28	–56.46	–7.55	17	0.000	Rejected	Significant Difference
OTM	BSOPM Price-MP	–65.43	39.95	9.42	–85.29	–45.56	–6.95	17	0.000	Rejected	Significant Difference
	BOPM Price-MP	–86.43	47.13	11.11	–109.86	–62.99	–7.78	17	0.000	Rejected	Significant Difference

Table 6. ***SPSS Output of Paired Sample t-test for Put Option Prices***

Money-ness	Stock Options	Paired Differences					*t*	*df*	Sig. (2-tailed)	Null Hypothesis Acceptance/ Rejection	Conclusion
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference						
					Lower	Upper					
Risk-Including Interest Rate											
ITM	BSOPM Price-MP	–165.39	67.54	15.92	–198.98	–131.80	–10.39	17	0.000	Rejected	Significant Difference
	BOPM Price-MP	–159.45	67.77	15.97	–193.15	–125.75	–9.98	17	0.000	Rejected	Significant Difference
ATM	BSOPM Price-MP	–153.15	65.27	15.39	–185.61	–120.69	–9.95	17	0.000	Rejected	Significant Difference
	BOPM Price-MP	–120.56	44.93	10.59	–142.90	–98.21	–11.38	17	0.000	Rejected	Significant Difference
OTM	BSOPM Price-MP	–98.04	39.98	9.42	–117.92	–78.16	–10.41	17	0.000	Rejected	Significant Difference
	BOPM Price-MP	–108.31	41.10	9.69	–128.74	–87.87	–11.18	17	0.000	Rejected	Significant Difference
Risk-Free Interest Rate - MIBOR											
ITM	BSOPM Price-MP	–153.22	60.61	14.29	–183.36	–123.08	–10.73	17	0.000	Rejected	Significant Difference
	BOPM Price-MP	–147.86	61.10	14.40	–178.25	–117.48	–10.27	17	0.000	Rejected	Significant Difference
ATM	BSOPM Price-MP	–142.14	58.81	13.86	–171.39	–112.90	–10.26	17	0.000	Rejected	Significant Difference
	BOPM Price-MP	–108.40	38.52	9.08	–127.55	–89.24	–11.94	17	0.000	Rejected	Significant Difference
OTM	BSOPM Price-MP	–86.42	33.79	7.96	–103.22	–69.62	–10.85	17	0.000	Rejected	Significant Difference
	BOPM Price-MP	–97.18	35.29	8.32	–114.73	–79.63	–11.68	17	0.000	Rejected	Significant Difference
Risk-Free Interest Rate (10 Y Bond)											
ITM	BSOPM Price-MP	–145.01	55.79	13.15	–172.75	–117.27	–11.03	17	0.000	Rejected	Significant Difference
	BOPM Price-MP	–140.03	56.48	13.31	–168.12	–111.95	–10.52	17	0.000	Rejected	Significant Difference
ATM	BSOPM Price-MP	–134.70	54.32	12.80	–161.71	–107.68	–10.52	17	0.000	Rejected	Significant Difference
	BOPM Price-MP	–100.17	34.29	8.08	–117.22	–83.11	–12.39	17	0.000	Rejected	Significant Difference
OTM	BSOPM Price-MP	–78.55	29.78	7.02	–93.36	–63.74	–11.19	17	0.000	Rejected	Significant Difference
	BOPM Price-MP	–89.65	31.55	7.44	–105.34	–73.96	–12.06	17	0.000	Rejected	Significant Difference

The information provided in Table 5 reveals that, across all cases, the *p*-values obtained from the SPSS output are consistently below 0.05, prompting the rejection of the null hypothesis. Besides, the *t*-statistic surpasses the critical value. Hence, there is a significant difference b/w calculated "Black-Scholes Option Pricing Model (BSOPM)/Binominal Option Pricing Model (BOPM) prices" and "actual market prices" for BANKNIFTY Index call options at all moneyness levels and different risk factors.

Table 6 is intricately organized into sections based on moneyness (ITM, ATM, OTM) and various risk factors (calculated risk-including interest rate, risk-free interest rate-MIBOR, risk-free interest rate-10 year govt. bond). Notably, the SPSS output reveals a *p*-value consistently below 0.05 across all cases, leading to the rejection of the null hypothesis. The *t*-statistic surpasses the critical value, indicating a substantial difference between put option prices calculated using BSOPM/BOPM and market prices within the specified moneyness and risk factors. These findings hold significance for options trading and pricing strategies, hinting at potentially profitable opportunities in the options market.

Tables 5 & 6 provide evidence that the option pricing models (BSOPM and BOPM) do not align with the market prices for call and put options in various scenarios, indicating potential trading or pricing opportunities based on these discrepancies. The null hypothesis in all the cases can be rejected for any of the three reasons:

- The option market demonstrates inefficiencies.
- The measurements of inputs for option pricing models have been inaccurately determined.
- Certain adjustments are required for the mathematical structure of both BSOPM and BOPM due to the identified inaccuracies.

Statistical Comparison

Table 7 displays a comprehensive evaluation of option pricing models based on the root mean squared error (RMSE) rankings across different scenarios. It considers variations in option moneyness, interest rate types, and two option pricing models (BSOPM and BOPM) for both CALL and PUT options. Lower RMSE values indicate better model accuracy. Interestingly, the BOPM outperforms the BSOPM in several scenarios, particularly for ATM and ITM options. These results offer insights into the effectiveness of each model under diverse market conditions, aiding practitioners in selecting appropriate models for option pricing.

Table 7. ***RMSE Ranking Comparison Analysis***

Moneyness	Interest Rate	Model	CALL		PUT	
			RMSE	Rank	RMSE	Rank
ITM	RIIR	BSOPM	113.99	10	177.94	18
		BOPM	67.58	3	128.22	9
	MIBOR	BSOPM	128.06	13	164.16	15
		BOPM	80.23	6	114.68	7
	10Y Govt. Bond	BSOPM	137.93	16	154.81	13
		BOPM	89.3	8	105.57	6
ATM	RIIR	BSOPM	117.55	11	172.51	17
		BOPM	55.55	1*	105.46	5
	MIBOR	BSOPM	131.07	14	159.34	14
		BOPM	67.41	2	92.44	2

	10Y Govt. Bond	BSOPM	140.57	17	150.4	11
		BOPM	76.08	4	83.71	1*
OTM	RIIR	BSOPM	124.03	12	165.77	16
		BOPM	76.96	5	115.44	8
	MIBOR	BSOPM	137.06	15	153.2	12
		BOPM	89.14	7	103.06	4
	10Y Govt. Bond	BSOPM	146.22	18	144.67	10
		BOPM	97.81	9	94.75	3

Note. *Lowest RMSE values indicate.

Conclusion and Discussion

The crux of our analysis reveals a significant difference in theoretical prices computed under the Black-Scholes option pricing model (BSOPM) and the binomial option pricing model (BOPM) by applying risk including interest rate and two distinct risk-free interest rates, when compared to the actual prices of BANKNIFTY call and put options in three distinct moneyness levels. The BSOPM and BOPM both indicate significant differences in option pricing in various scenarios. When it comes to risk-including interest rates, options at different levels, such as "In-the-Money, At-the-Money, and Out-of-the-Money" have significant price variations in both models. Similarly, whether we consider the risk-free interest rate (MIBOR) or the risk-free interest rate based on the 10-year Govt. bond, options at various levels consistently have notable price differences in both the BSOPM and BOPM. In summary, both models reveal significant differences in option pricing across all levels of moneyness and risk-related variables incorporated into this study. However, statistical comparison also reveals that BOPM attains the first rank for both Call (RIIR) and Put (10 Year Govt. Bond) options at ATM moneyness (Refer to Table 7).

Managerial/Theoretical Implications

This study shows that neither the BSOPM nor the BOPM were consistently aligned with actual market prices, but the BOPM outperformed the BSOPM by achieving all 1 to 9 ranks in both call and put options based on RMSE. The findings provide important insights for policymakers, investors, researchers, and financial institutions. They highlight the importance of selecting an appropriate pricing model, especially when valuing the At-The-Money (ATM) moneyness option. This can improve the accuracy of asset valuation, support better forecasting, better financial decision-making, and develop risk management strategies.

The banking sector plays a major role in the financial market. NSE has calculated the option prices by using defined variables such as MIBOR (for risk-free rate), BSOPM, and implied volatility. This research study has tried to replace all possible variables to find a more reliable possibility to calculate the option prices by focusing only on banking sector-related data. A major theoretical input of this research is an endeavor to redefine with a customized approach to determine the new risk-including interest rates using bank sector data. It has also examined the BANKNIFTY index to find the impact on banking index options by changing the bank interest rate on all possible prospectuses. This study provides a further study area by focusing on ATM moneyness with BOPM over a longer period.

Limitations of the Study

The study is limited to analyzing the BANKNIFTY index by incorporating risk-including interest rates for select large-cap private banks (i.e., 84.20% weightage in Banknifty). The study covers trading days of the entire month (January 2–25, 2023) up to monthly expiry. Variables used in option pricing models, such as historical volatility, risk-free interest rates (MIBOR, 10-year bond), and risk-including interest rates (yield curve, basis, repricing risk), are included. BSOPM and BOPM have been applied to Banknifty call and put options at moneyness (OTM, ATM, ITM) strike prices at three interest rates. The study is limited to NSE options, excluding other exchanges and option pricing models.

Scope for Future Research

A review of the literature shows that there has been relatively little research on option pricing from various perspectives. The present study has attempted to investigate the applicability of BSOPM and BOPM. Future research can improve the applicability of the models by excluding periods of market crisis, reducing the effect of volatility and improving accuracy. The research study may compare the different index options with all the option stocks added to them. A longer research study period and comparative analysis between different option models can determine the appropriate model. Option pricing can be compared by incorporating implied and GARCH volatility, which can improve pricing accuracy.

Authors' Contribution

Rinky collected and analyzed the data by conceptualizing the study idea and creating a draft methodology. Dr. Shakti Singh provided expert guidance on structured methodology throughout the research process. Sachin assisted in finding relevant literature reviews and then applying tests for statistical analysis. Rinky drafted the manuscript based on the results by compiling the data and arrived at the conclusions by comparing both models in different market scenarios. Dr. Shakti Singh provided valuable guidance for the accuracy and reliability of the research by critically evaluating the findings. Finally, Dr. Shakti Singh reviewed and refined the final manuscript to ensure clarity and academic excellence in the research.

Conflict of Interest

The authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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