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PRICING OF THE ASIAN OPTION WITH THE KAMRAD-RITCHKEN'S TRINOMIAL MODEL

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ABSTRACT

Asian Option determines its payoff option value by the average stock during the option period. This research aims to determine the price of Asian Option by average arithmetic using Kamrad-Ritchken's Trinomial method. The Kamrad-Ritchken trinomial model is one of the models in the trinomial method used to determine the option value that provides a procedure for determining the barrier parameter or stock price tendency (λ). The stock price tendency makes the trinomial model right on the dotted line of possible stock prices. This study is different from previous studies because the focus of this study is to determine the price of Asian options, both call options and put options with different maturity time variables. The data used for this research are taken from the NVIDIA Corporation (NVDA) data from August 2nd, 2021 – September 29th, 2023. Next, several parameters of option value are determined, which are the initial stock price (S_0), contract price (K), risk-free interest rate (r), period (T), stock return (R_t), variance (s^2), volatility (σ), stock price trend (λ), stock price increase (u), stock price decrease (d), stock price increase opportunity (p_u), fixed stock price opportunity (p_m), stock price decrease opportunity (p_d), and barrier (b). These parameters are used to calculate the price of Asian Option. According to the calculation result by average arithmetic using Kamrad Ritchken's Trinomial method, the longer the maturity date of an option, the more expensive the option price will be.

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1. INTRODUCTION

Financial derivative is one of the traded instruments in the financial market. Its price depends on basic variables. The derivative products traded in the spot market and capital market are stock, obligation, and foreign exchange. It is used in general to minimize investment risk, as a hedging tool, and to reduce transaction costs.

An option is a financial contract between the option seller and the option buyer [1]. The seller provides a right to the buyer. However, the seller does not have the responsibility to sell or buy an asset in the meantime, whether the price reaches the negotiated price, and is executed before or after the period of option. According to execution time, there are two kinds of option: European style, where option execution is implemented after the period; and American style, where option execution is implemented anytime during the period [2].

The development of options calls for the development of the tools used in option price prediction and future calculation to minimize the risk and optimize the profit. In determining option contract price, several models can be implemented: Black-Scholes model [3][4][5][6], Trinomial model [7][8][9], Monte-Carlo Simulation [10][11], The Quasi Monte Carlo Method [12][13], et cetera. Some studies examine each of these models.

Artanadi, et al. [14] researched the pricing of Asian Options using Monte Carlo-Control Variate. This research states that the method can reduce the variance of Monte Carlo's Standard. Lestari, et al. [15] researched the pricing of Asian Options using the Black-Scholes model, in which they used average geometric data. The results of this research can be a reference for investors selling their option; they likely sell their option if the option price in the market is higher than the average geometric option price. Sulastri, et al. [16] researched the pricing of the option using Kamrad-Ritchken's Trinomial with the GARCH model's volatility. This research states the simulation of call-up barrier option experiences strike price increases with a stable barrier and initial price. It results in the decrease of call-up barrier options both in and out.

Stock option prices with average Arithmetic can be determined numerically, including using the binomial or Trinomial method. The trinomial method which has three stock movements, namely up, stable, or down, is more flexible in following stock price movements when compared to the binomial method [8][17]. The trinomial method is a simple method but has a small error [18]. The Trinomial model is more realistic [19] and converges faster than the binomial method [20][21]. There are 3 models in the Trinomial method, namely the Hull-White Trinomial, Boyle Trinomial, and Kamrad-Ritchken Trinomial. Specifically, the Boyle and Kamrad-Ritchken Trinomial models converge faster to the Black-Scholes model [21]. In the Kamrad-Ritchken trinomial model, there are constraints that are useful for minimizing errors in determining option prices [22]. The trinomial model finds the best parameter value by adjusting the stock price tree so that it will lie exactly on one of the possible stocks.

Asian Option is an option where the payoff value depend on average stock during the period [23]. Asian Option is an exotic one, because the payoff value is not only depend on stock price of the period, but also the average stock price during the period [22].

NASDAQ-100 is a historical index made by National Associate of Securities Dealers (NASD) in 1985, along with NASDAQ Financial-100 centered on financial companies. NASDAQ-100 Index Exchange is an American stock including the largest companies in technology industries. According to the listed stock in NASDAQ-100 Index Exchange, NVIDIA Corp.'s stock is quite interesting. NVIDIA stock is used as an option pricing object because from 2021 – 2023, NVIDIA Corp.'s stock sale is continuing to increase. This increase happens because the company develops innovation based on the trending AI (Artificial Intelligence).

This study is different from previous studies. Previous studies conducted a study on the determination of the price of Asian European call options using different volatility value scenarios and different N values [22]. Meanwhile, this study not only examines call options but also put options using different maturity scenarios. This study focuses on the application of the Kamrad-Ritchken method in determining and analyzing Asian option prices based on different maturity times.

In this research, the price of put and call on NVIDIA Corporation stock in Asian Option will be calculated using the Trinomial method of Kamrad-Ritchken. The calculation can provide an analysis and can be implemented as a guideline for investors in pricing the stock option. Determining the options value can be used as a guideline by investors in predicting the price of put options and call options before executing the option. The results of the analysis can be used as a reference in bargaining the option price especially in the market outside the stock exchange, both for long-term or short-term options.

2. RESEARCH METHODS

The method used in this research is Trinomial Kamrad-Ritchken model. This model is applied to NVIDIA stock data. The obtained data is secondary data, taken from www.finance.yahoo.com in the form of NVIDIA Corp. stock's daily closing data from August 2, 2021 – September 29, 2023. The 5.50% interest rate of Central Bank of America in September 2023 is used for this research, and taken from www.global-rates.com. This research applies the documentation method to collecting written data of NVIDIA Corp.'s price stock. The Kamrad-Ritchken trinomial model is one of the models in the trinomial method used to determine the option value which provides a procedure for determining the stock price tendency parameter (λ). Stages in determining the price of Asian options using the Kamrad-Ritchken Trinomial model are as follows:

1. Obtaining daily closing data of NVIDIA Corporation stock's price through Yahoo Finance.
2. Calculating the return value of NVIDIA Corporation stock's price with the following formula [24]:

$$R_t = \frac{P_t - P_{t-1}}{P_{t-1}} \tag{1}$$

R_t is stock return, P_t is stock price of the current period, and P_{t-1} is stock price of the past period

3. Calculating return variance of NVIDIA Corporation stock with the following formula [14]:

$$s^2 = \frac{1}{n-1}\sum_{t=1}^{n}(R_t - \bar{R})^2 \tag{2}$$

$$\bar{R} = \frac{1}{n}\sum_{t=1}^{n} R_t \tag{3}$$

s^2 is variance, n is amount of stock price closing data, and $\bar{R}$ is Stock return average

4. Calculating the volatility of NVIDIA Corporation stock price with the following formula [14]:

$$\sigma = \sqrt{s^2 \times T} \tag{4}$$

σ is volatility and T is trading day of stock price

5. Determining risk-free interest rate
6. Calculating the average stock price to determine the barrier
7. Determining period value (T) and Δt
8. Determining the parameter value of λ, u, d, p_u, p_m and p_d
   a. Parameter value of stock price trend (λ) with the following formula:

$$\lambda = \frac{\eta}{n_0} \tag{5}$$

$$\eta = \frac{ln\left(\frac{S(0)}{b}\right)}{\sigma\sqrt{\Delta t}} \tag{6}$$

$$n_0 = \|\eta\| \tag{7}$$

η is the amount of movement from initial stock price to barrier, $S(0)$ is initial stock price, b is barrier up, λ is stock price trend parameter, $\Delta t = \frac{T}{N}$, where T = period and N = data sample

   b. Parameter value of stock price increase (u) and stock price decrease (d) with the following formula:

$$u = e^{\lambda\sigma\sqrt{\Delta t}} \tag{8}$$

$$d = e^{-\lambda\sigma\sqrt{\Delta t}} \text{ or } d = \frac{1}{e^{\lambda\sigma\sqrt{\Delta t}}} = \frac{1}{u} \tag{9}$$

c. Stock price increase opportunity (p_u), stable stock price opportunity (p_m), and stock price decrease opportunity (p_d) with the following formula:

$$p_u = \frac{1}{2\lambda^2} + \frac{\left(r - \frac{1}{2}\sigma^2\right)\sqrt{\Delta t}}{2\lambda\sigma} \tag{10}$$

$$p_m = 1 - \frac{1}{\lambda^2} \tag{11}$$

$$p_d = \frac{1}{2\lambda^2} - \frac{\left(r - \frac{1}{2}\sigma^2\right)\sqrt{\Delta t}}{2\lambda\sigma} \tag{12}$$

9. Determining expected NVIDIA Corporation stock price with the following formula:

$$E\left(S_{t_i}\right) = S_0(p_u u + p_m + p_d d)^i \tag{13}$$

with $i = N-1, N-2, \ldots, 1, 0$ that shows the time interval

10. Calculating average arithmetic of expected stock price with the following formula:

$$A = \frac{1}{N}\sum_{i=1}^{N} E\left(S_{t_i}\right) \tag{14}$$

11. Determining the possible stock price on (i, j) node until (S_{jN}) is obtained with the following formula:

$$S_{ji} = S_0 u^j d^{i-j} \tag{15}$$

S_0 is initial stock price, $j = 0, 1, \ldots, i + (i+1)$, shows the index of stock price increase, and $i = N-1, N-2, \ldots, 1, 0$, shows the time interval

12. Determining payoff value of call option and put option in Asian option with the following formula:

$$C_{jN} = max\left[S_{jN} - \left(\frac{1}{N}\sum_{i=1}^{N} E\left(S_{t_i}\right)\right), 0\right] \tag{16}$$

$$P_{jN} = max\left[\left(\frac{1}{N}\sum_{i=1}^{N} E\left(S_{t_i}\right)\right) - S_{jN}, 0\right] \tag{17}$$

C_{jN} is call option payoff on period, P_{jN} put option payoff on period, $E\left(S_{t_i}\right)$ is expected Stock Price when t_i, S_{jN} is Asian option stock price on period

13. Determining the price of call option and put option with the following formula:

$$C_{ji} = e^{-r\Delta t}\left(p_u C_{j+2\,i+1} + p_m C_{j+1\,i+1} + p_d C_{j\,i+1}\right) \tag{18}$$

$$P_{ji} = e^{-r\Delta t}\left(p_u P_{j+2\,i+1} + p_m P_{j+1\,i+1} + p_d P_{j\,i+1}\right) \tag{19}$$

Calculation of Asian option prices with the Kamrad-Ritchken Trinomial model using MATLAB software.

3. RESULTS AND DISCUSSION

This research uses 545 daily closing stock price data with a period of two years, namely August 2, 2021 - September 29, 2023. The daily closing stock price data of NVIDIA Corporation is shown in Table 1.

Table 1. Daily Closing Stock Price Data of NVIDIA Corporation

t	Date	Daily Closing Stock Price Data
0	2 August 2021	197.50
1	3 August 2021	198.15
2	4 August 2021	202.74
⋮	⋮	⋮
542	27 Sep 2023	424.68
543	28 Sep 2023	430.89
544	29 Sep 2023	434.99

Source: *www.finance.yahoo.com*

The recent stock price will be used as the main reference in calculating option price. According to Table 1, the recent stock price is $S_0 = \$434.99$ and \$248.82 as the barrier. The barrier value is obtained from the average stock price for the period from August 2, 2021 to September 29, 2023. The fixed contract price in this research is \$377.50. The risk interest rate is 5.50%, taken from Central Bank of America's interest rate on September 2023's period. Stock price returns are used to determine the level of return for each trading period and profit expectations in the future. Stock returns total 544 data because there are 545 daily closing stock price data. Below is the obtained stock return value according to Table 2.

Table 2. Calculation Result of NVIDIA Corporation's Stock Return.

t	Daily Closing Stock Price Data	Stock Return
0	197.50	-
1	198.15	0.00329
2	202.74	0.02316
⋮	⋮	⋮
542	424.68	0.1392
543	430.89	0.01462
544	434.99	0.00952

According to the obtained stock return value, the average stock return $\bar{R}$ obtained using Equation (3) is 0.002087 and variance value s^2 obtained using Equation (2) is 0.001299870. This variance is implemented to obtain the stock price volatility using Equation (4), which is $\sigma = 0.809403781$.

This research implements 0.25-year, 0.5-year, 0.75-year, 1-year, 1.25-year, and 1.5-year period. According to these, the amount of measurement is 90 because it can reach 3 month's period, thus resulting in the rough calculation of Δt. When the maturity period is 0.5 year, $\Delta t = \frac{0.5}{90} = 0.00556$. Δt values for other maturity periods as in Table 3.

Table 3. Δt

T (year)	N	Δt
0.25	90	0.00278
0.5	90	0.00556
0.75	90	0.00833
1	90	0.01111
1.25	90	0.01389
1.5	90	0.01667

This research also needs to calculate the λ parameter in the consequence of applying Kamrad-Ritchken's Trinomial. The λ parameter is used to find the u, d, p_u, p_m and p_d parameter on each period using Equation (5), Equation (8), Equation (9), Equation (10), Equation (11), and Equation (12). Below are the parameters in consecutive:

Table 4. Parameter to Obtain Stock Option Price

Parameter	Period (T)					
	0.25 year	0.5 year	0.75 year	1 year	1.25 year	1.5 year
λ	1.0072526	1.0287840	1.0799983	1.0911903	1.1849553	1.0691438
u	1.0439052	1.0640324	1.0830694	1.0975703	1.1181982	1.1181982
d	0.9579414	0.9398209	0.9233019	0.9111034	0.8942958	0.8942958
p_u	0.4840153	0.4602138	0.4144388	0.4036573	0.3396227	0.4170878
p_m	0.0143489	0.0551747	0.1426585	0.1601553	0.2878097	0.1251617
p_d	0.5016358	0.4846115	0.4429027	0.4361875	0.3725676	0.4577505

After the parameter is obtained, the expected value of the stock price can be calculated in Equation (13). Then, the average arithmetic value (A) in Equation (14) for each period can be obtained. Below is the average arithmetic of expected stock price in consecutive:

Table 5. The Average Arithmetic of Expected Stock Price

Parameter	Period (T)					
	0.25 year	0.5 year	0.75 year	1 year	1.25 year	1.5 year
A	438.02568	441.08493	444.16638	447.27154	450.39450	453.55730

Before determining the price of the call option and put option, the stock price on the node (i, j) should be calculated. Below is the common pattern of trinomial tree:

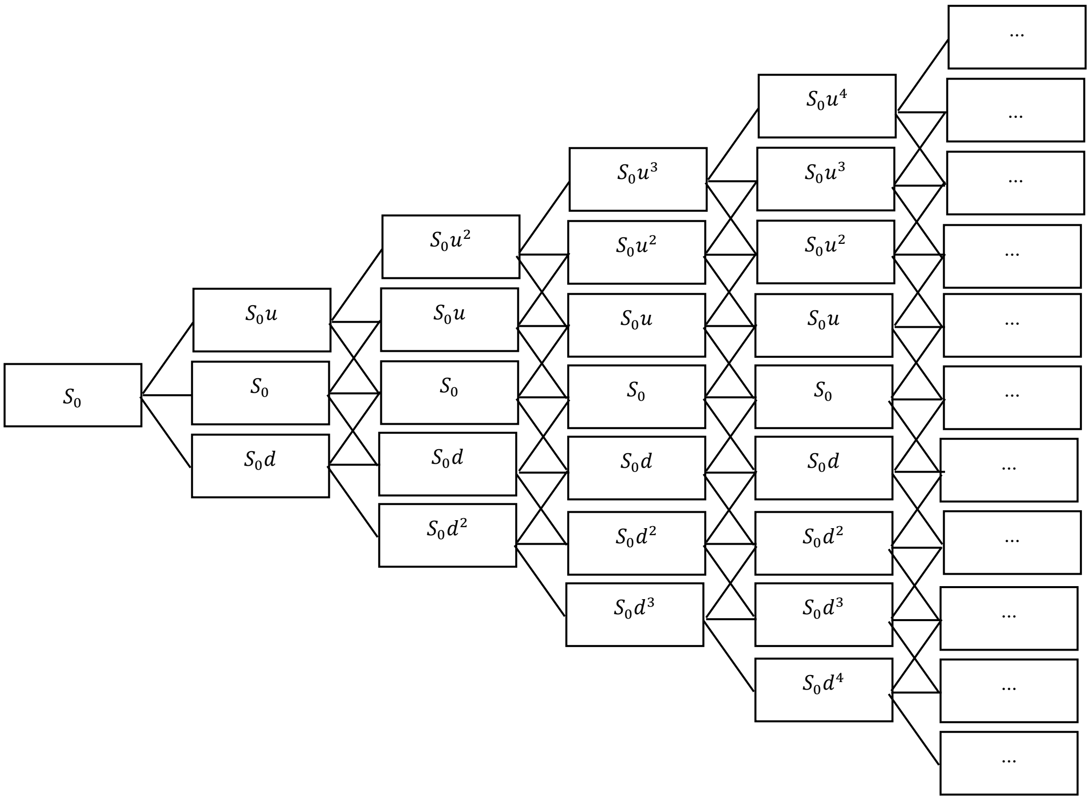

Figure 1. Common Pattern of Trinomial Tree

The stock price of NVIDIA Corporation in each node (i, j) as shown in **Figure 2**.

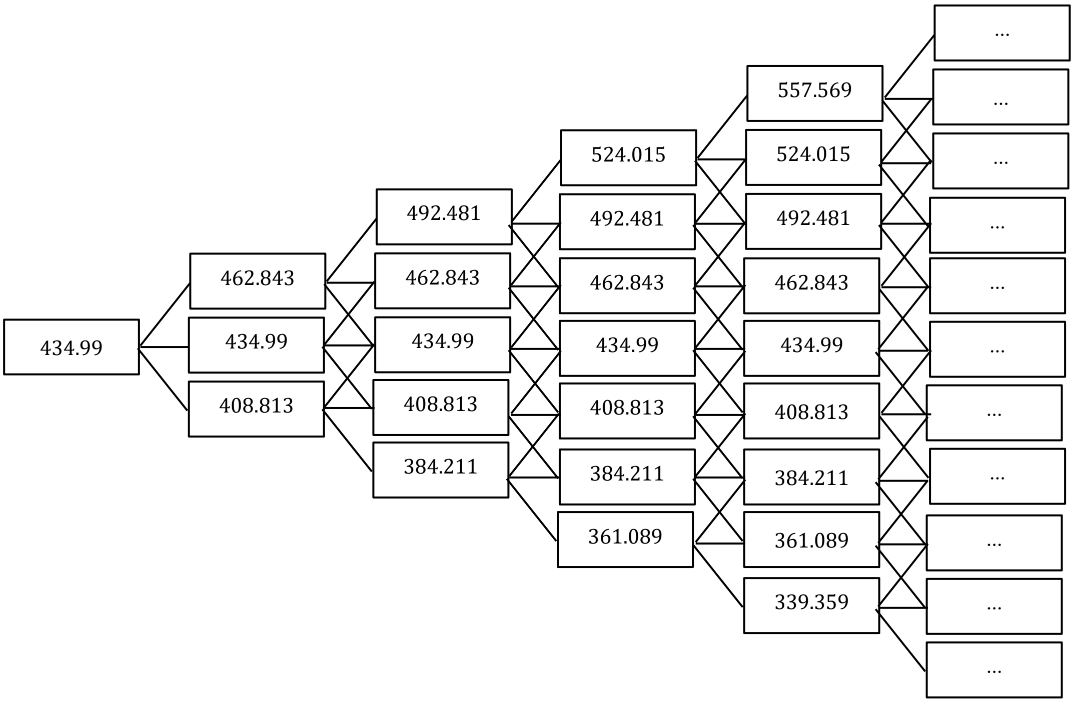

Figure 2. NVIDIA Corporation's Stock Price in Node (i,j)

After obtaining the stock price value at node (i, j) the next step is to determine the option payoff value. The payoff value is obtained by calculating the difference between the stock price value at maturity and the arithmetic mean value of the stock price expectations. The payoff value is the option value at maturity (at node 90) obtained through **Equation (16)** for the call option and **Equation (17)** for the put option. This value is used to determine the option value at the previous node (node 89) using **Equation (18)** and **Equation (19)**. The option value at node 89 is used to find the option value at node 88, and so on until the option value at node 0 is obtained. According **Figure 2**, the payoff of put option and call option are as in **Table 6**.

Table 6. Option Payoff on 0.5-year Period

Node (*i,j*)	Option payoff	
	put	call
180,90	0	115548.5405507
179,90	0	108568.3927344
178,90	0	102008.3037237
⋮	⋮	⋮
2,90	439.2380129	0
1,90	439.3491591	0
0,90	439.4536166	0

After the option payoff for each period is obtained, the price of put option and call option can be determined. The calculation result of put Asian option using **Equation (18)** for 0.5-year period and t_{544} is $P_{0.0} = 94.49942382$. Below is the complete chart of the calculation:

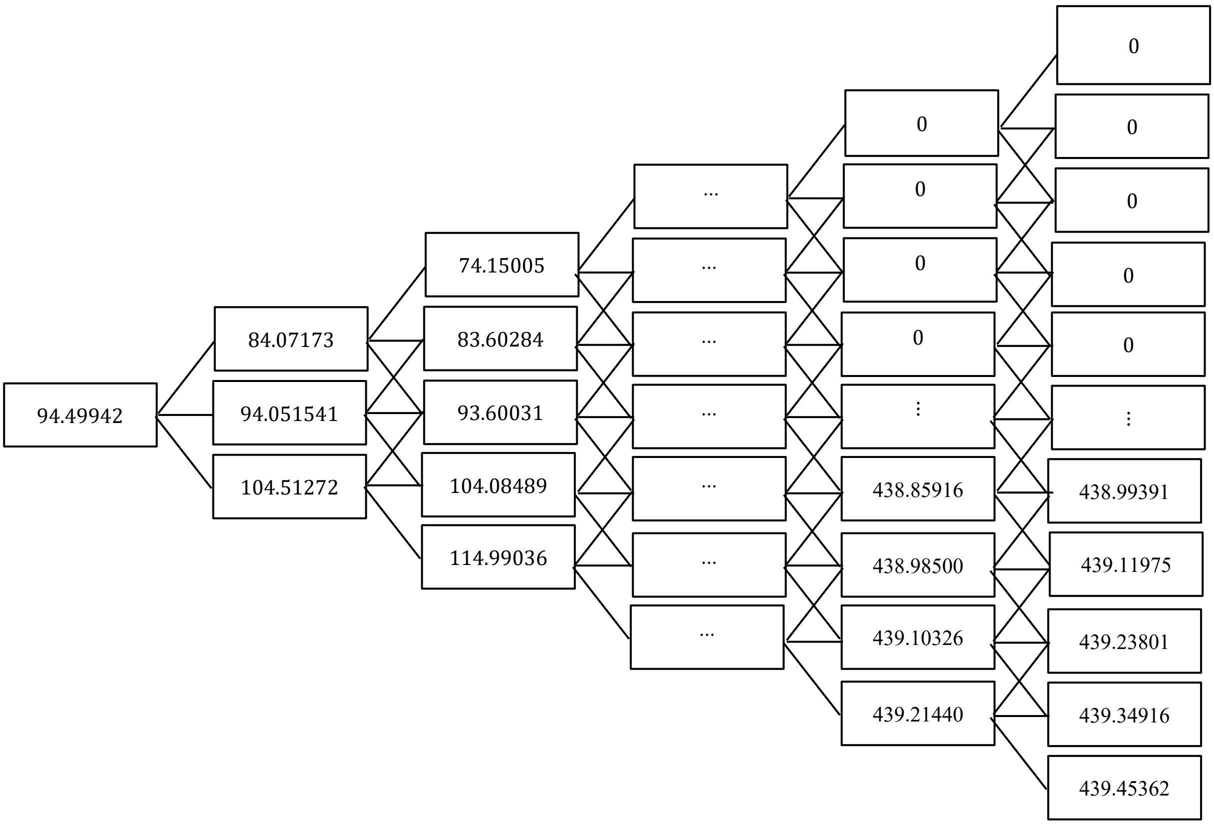

Figure 3. Asian Put Option Price of NVIDIA Corporation's Stock

The calculation result of call Asian option using **Equation (19)** for 0.5-year period and t_{544} is $C_{0.0} = 100.3520383$. Below is the complete chart of the calculation:

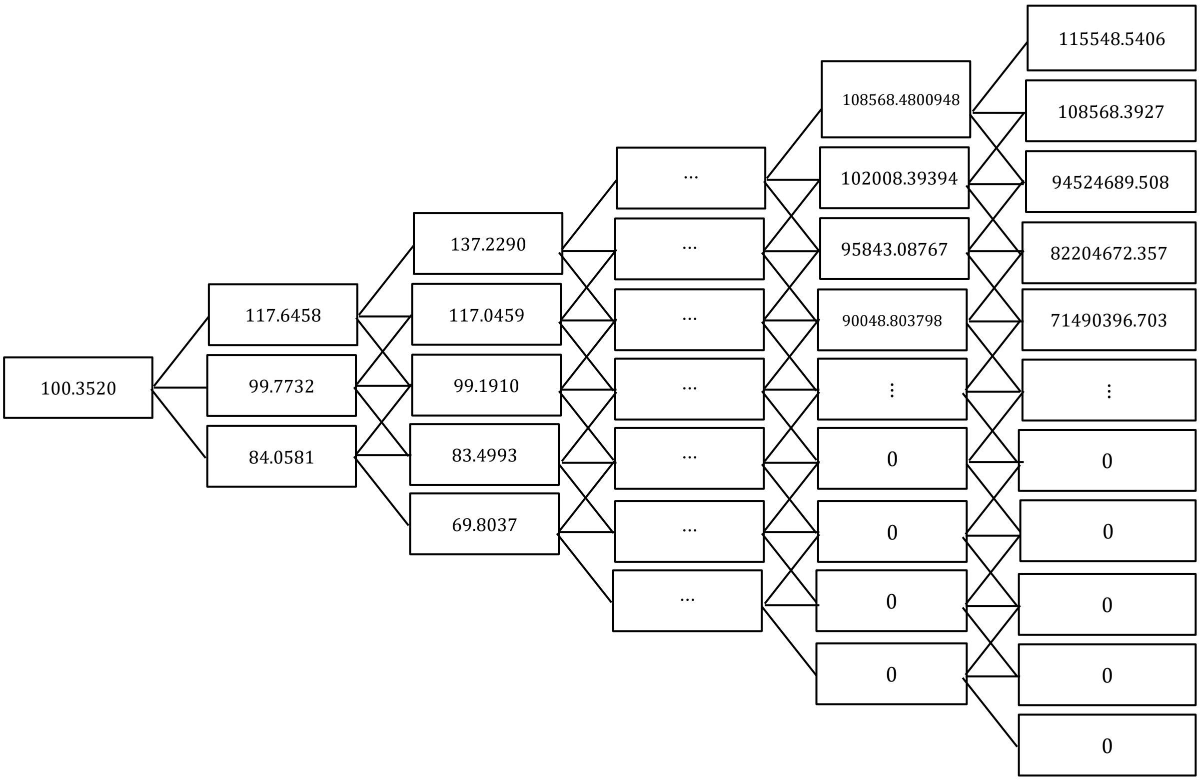

Figure 4. Asian Call Option Price of NVIDIA Corporation's Stock

The prices of Asian put and call option with time period 0.25-year, 0.5-year, 0.75-year, 1-year, 1.25-year, and 1.5-year, and agreement price K = $377,50 is shown in Table 7.

Table 7. Asian Option Price of NVIDIA Corporation's Stock

T (Year)	Trinomial of Kamrad-Ritchken	
	Put option price	Call option price
0.25	$68.09500	$71.03686
0.5	$94.49942	$100.35203
0.75	$113.76957	$122.50053
1	$129.27324	$140.85170
1.25	$142.29799	$156.68533
1.5	$153.58788	$170.77306

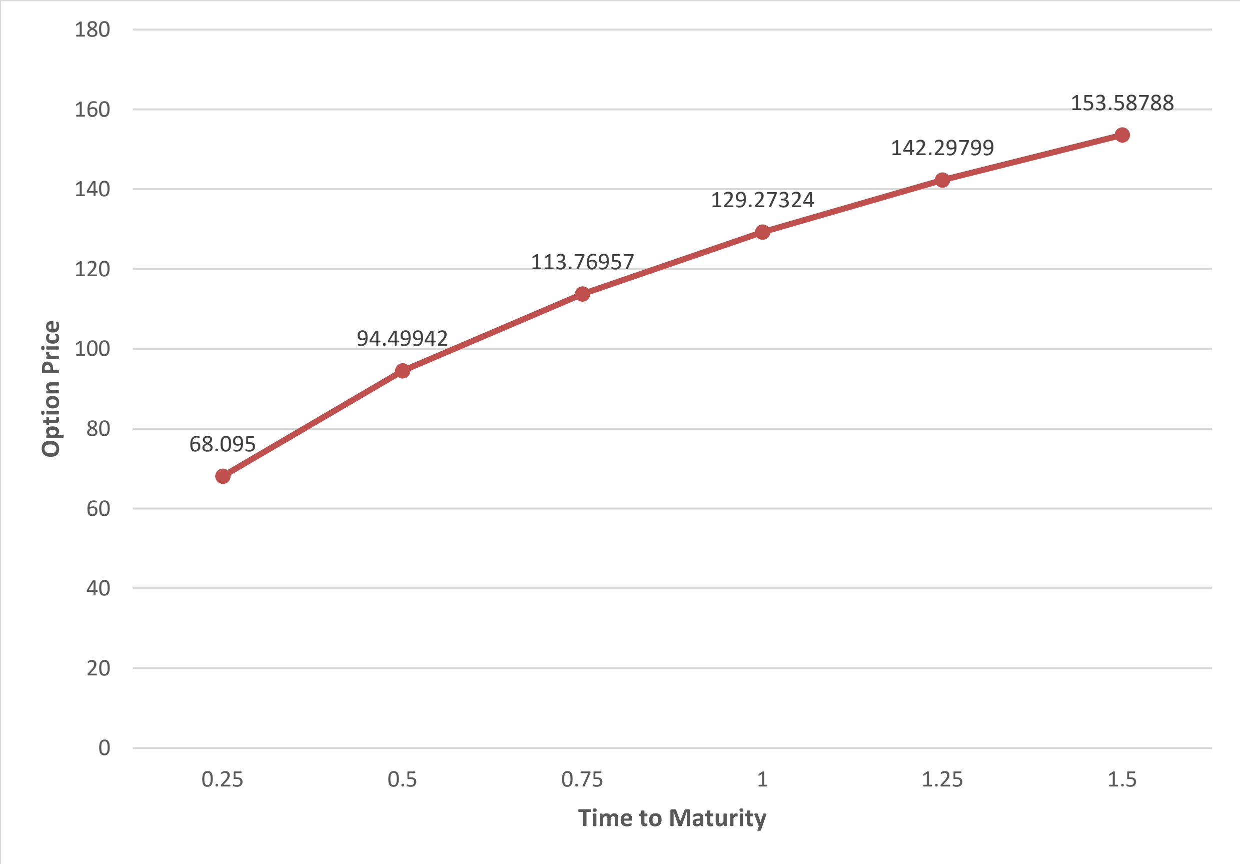

Figure 5. Put Option Price

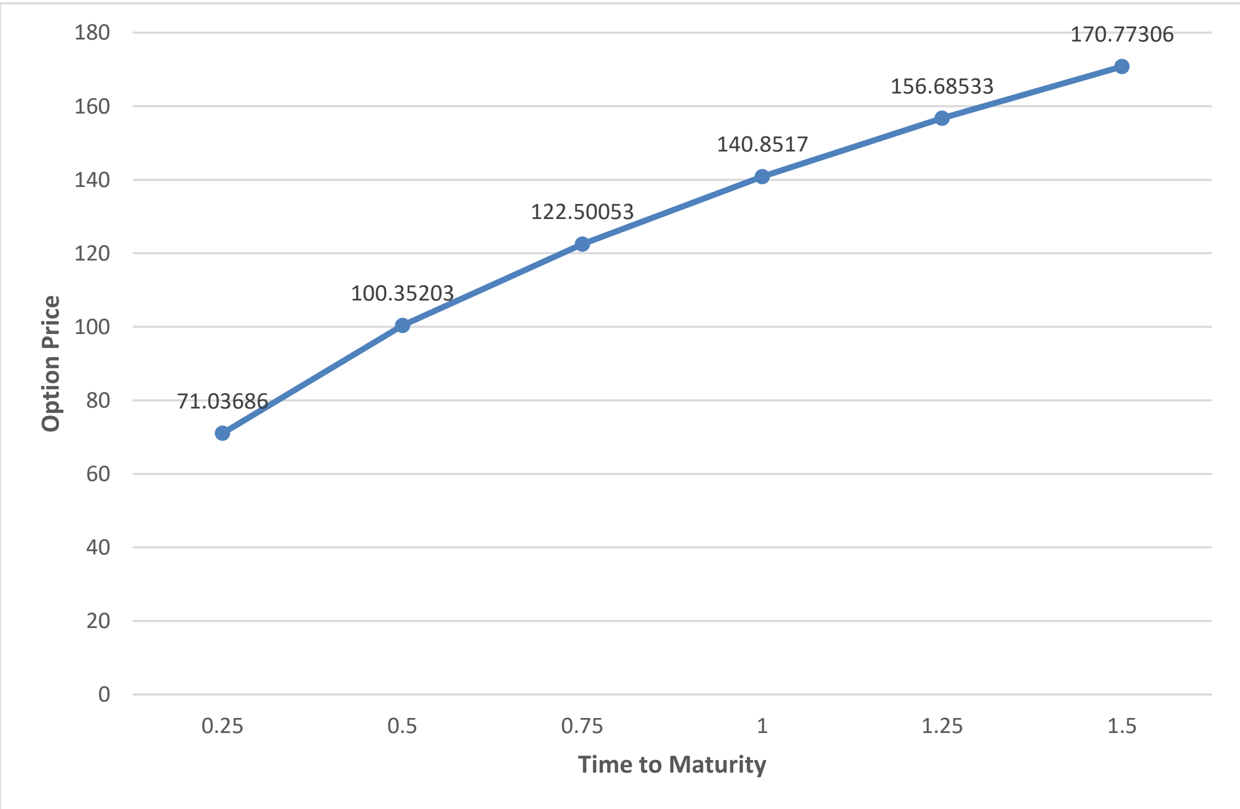

Figure 6. Call Option Price

This study analyzes the price of Asian options using the Kamrad-Ritchken Trinomial model based on different maturity dates. According to Figure 5 and Figure 6, there is increasing price movement in both put option and call option as the period goes. The longer the maturity period, the higher the chance of the stock price being above or below the exercise price. These results empirically indicate that the price of Asian options increases as the maturity date increases. The same thing also happens to American options but not always to European options. The longer the maturity date, the price of American options also increases but there is no definite relationship between the maturity date and the price of European [2]. In other words, maturity is one of the variables that affects the price of Asian options.

The results can be used as a reference by investors in negotiating Asian option prices on the Over The Counter (OTC) market. In the OTC market there is no option price set by market management so that buyers and sellers can bargain over the price until a price agreement is reached.

4. CONCLUSIONS

According to section Results and Discussion, the put price of Asian option at 0.25-year, 0.5-year, 0.75-year, 1-year, 1.25-year, and 1.5-year periods consecutively are $68.09500 $94.49942; $113.76957; $129.27324; $142.29799; and $153.58788. The call price of Asian option at each period consecutively are $71.03686; $100.35203; $122.50053; $140.85170; $156.68533; and $170.77306. It can be concluded that the longer the maturity date of an option, the more expensive the option price will be. For further research, Asian Options with the Kamrad-Ritchken trinomial model can be analyzed from the perspective of varying N and varying contract prices.

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