Extrapolation of Crude Oil Futures Implied Return by Black Scholes Model and Monte Carlo Simulation

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Abstract. Since the global COVID-19 outbreak in 2020, central banks around the world have adopted loose monetary policies to hedge against the downward pressure on the economy through quantitative easing. With the gradual increase in the number of currencies, from the beginning of 2022, global commodity prices began to rise continuously. Among them, the price of fossil fuels such as oil has hit record highs due to the intensification of geopolitical conflict between Russia and Ukraine. During this period, as the divergence in oil prices intensified, speculation opportunities in the derivatives market also emerged one after another. [1] Therefore, in this article, the principles of two pricing models, the Black Scholes Model and the Monte Carlo Model, are used to predict the price trend of Crude oil in the future. The implied volatility calculated according to the Black Scholes model will be used as the volatility of the oil futures price trend in the Monte Carlo model, and the current option premium will be used to reverse the implied return in the Monte Carlo simulation. It serves as a forecast of future yields for oil futures. By using the data from March to September 2022, the correlation coefficient between the predicted return and the actual return is 0.67, which is a relatively convincing prediction accuracy. However, the volatility of the predicted return will be higher than the actual return due to factors such as the volatility smile.

Keywords: Crude Oil; Black Scholes Model; Option; Monte Carlo Simulation; Derivatives.

1. Introduction

1.1 Background

Implied volatility and historical volatility are the two metrics most often used to measure price uncertainty on the market. How much market participants anticipate prices to change in the future is measured by implied volatility, which is based on option pricing. The amount of price variation in the past is analyzed through historical volatility. Under the continuous influence of uncontrollable factors, the market uncertainty has increased, so the implied volatility of the Brent crude oil market is higher than the historical volatility. These kinds of uncertainties are expected to keep implied volatility high until they are resolved.

When using historical volatility, the daily price change of the futures market in the previous month, that is, 30 days, is usually used as the price target. This historical volatility provides previous rapid price swings, while this statistic is constant looking backwards.

In general, implied volatility is usually calculated based on the cost of calls and puts on futures trading contracts. Therefore, when using the Black-Scholes option pricing model to measure crude oil futures option prices, the underlying factors include not only the current trading price of the crude oil futures contract, the exercise price of the option contract, but also the remaining futures contract price, the time to expiration, and the effect of expected future volatility on the price. Expected volatility takes into account the relationship of other underlying factors in the current Black-Scholes option pricing model to future volatility, and therefore also becomes implied volatility.

Historical volatility and implied volatility are not always the same and may differ, and these differences arise when investors' expectations of market movements differ from past price trends. Discussing with actual data, crude oil prices showed a rapid rebound after a sharp decline before July 1, which means that historical volatility increased during this period from June to early July. In recent months, the crude oil market has not experienced major fluctuations. From March to May, the price of Brent futures has remained within a small range. This means that although crude oil prices have fluctuated sharply in the short term, the changes in implied volatility have not changed in a similar magnitude according to historical volatility, which means that players in the market have not been affected by historical Changes in volatility change perceptions of future long-term risk expectations. Therefore, when measuring specific volatility, it is necessary to remove this data sample of violent price fluctuations from the calculation of historical volatility, and to re-establish the relationship between the two volatilities.

Over the previous four weeks, market expectations were mostly met by economic data, political actions, and oil market balances. starting with the hypothesis that global central banks and governments would provide stimulus to improve oil prices and prospects for economic expansion. Regarding a new bond-buying program, the European Central Bank has made pronouncements. After the Federal Open Market Committee meeting on September 12-13, the U.S. Federal Reserve System announced that it would begin a new round of quantitative easing purchases of government bonds and mortgage-backed securities. Additionally, the Chinese government formally announced intentions to invest $157 billion on infrastructure development. Crude oil prices continued to rise to around mid-August after rebounding in July, before falling into a narrow trading range on optimism about economic growth. Historical volatility trended downward during this period (late August-early September) before reaching a low on September 13. As the risk estimates for the market in the future period remain the same, including geopolitical, technical and market risks, historical volatility has shown a downward trend, and the decline in implied volatility has gradually decreased. In addition, external uncertainties, such as the Iranian nuclear program and the risk of production delays in oil-exporting countries, are also the two main potential factors that lead to OPEC price risk. In response, European governments and central banks have already taken action. The stabilization of the euro and the slowdown of China's economic growth will also bring expectations of future crude oil prices to fall. In conclusion, despite the recent reduction in historical volatility, market participants' expectations for future crude oil price volatility remain relatively high.

1.2 Related research

McKenzie et al. evaluated the probability of exercising an exchange-traded European call option in 2007. [2] To estimate factors in Black-Scholes models, the author of this study uses qualitative regression and maximum likelihood. 1% represents the Black-Scholes model's statistical significance. These findings show that when the Black-Scholes model is applied utilizing implied volatility and jump diffusion techniques, it is statistically more significant. The Black Scholes model, despite its flaws, was also shown to be rather accurate. They contrast the Black-Scholes model, which holds that volatility swings in response to changes in stock prices, with the Constant Elasticity of Variance (CEV) model. It's uncertain if share prices and volatility correlate with one another. Blattberg and Gonedes thought that the underlying stock's volatility was intrinsically random rather than assuming that it was random. McKenzie et al research 's focused on the stock market's rules, but the findings of their study may also be applied to the analysis of crude oil commodity prices from April to October 2022.

Macbeth (2018) claims that the call price of an option is determined using the BS model using market prices from January 1983 to December 1985. The BS model consistently determines a bullish price higher than what the market really sees. The two prices' sensitivity to expiry time varied significantly across the three investigated factors. [3]

To evaluate the accuracy of the Black and Scholes models, Gustafson et al. (2016) looked at the discrepancy between theoretical and real market prices. The five Swedish equities with the most options traded in 2007 were included in the OMX Nordic Exchange's statistics. In general, relative pricing mistakes for out-of-the-money observations are higher than those for in-the-money ones. [4] Additionally, it seems that options with a shorter remaining time to maturity are priced inaccurately compared to options with a longer remaining time to maturity, according to the association between relative pricing error and remaining time to maturity.

Beckers (1980) used S&P 500 options over the years 1972–1977 to test the Black–Scholes hypothesis that stock prices influenced the immediate volatility of those options.[5] Using S&P 500 options data from 1986 to 1995, Buraschi and Jackwerth (2001) conducted statistical analysis. Stochastic volatility and jump dispersion are additional risk variables. according to Buraschi and Jackwerth (2001). [6] The emphasis of Janková (2018) is on techniques for pricing derivative contracts. Black-Scholes differential equations are developed from them and are often used to price options contracts. [7] The creators of this model, Merton, Garman, and Kohlhagen (2007), created an updated version, although nothing is known about it. Option pricing models have several flaws and restrictions, and they often fail when tested against actual market data because they are based on irrational assumptions. According to the article, Merton changed the Black-Scholes model to eliminate the drawback of not paying dividends on the underlying stock. [8]

A sample of 74 warrants from 1994 to 2003 were used by Kyun (2004) to evaluate the model using daily prices. The findings demonstrate that the model price is much less than the market price and that, in certain system models, it differs from the numerous pricing variances mentioned above. When purchasing warrants on Bursa Malaysia, Black-Scholes users should pay close attention to any patterns of systematic departure. [9]

1.3 Objective

Numerous parts of option pricing are unknown because to the efficient and well-liked Monte Carlo trading simulation approach. In this study, the implied volatility of crude oil prices from March to October 2022 is calculated using the Black Scholes model. The future trend of crude oil prices is then predicted using Monte Carlo simulation and the implied volatility combined with the crude oil option price is used to measure the expected return of the crude oil price anticipated by the market and serve as a benchmark for investment decisions.

2. Method and Data

2.1 Black Scholes Model

The Black-Scholes model is a fundamental concept in modern finance theory. With additional risk factors and the impact of time taken into account, this mathematical formula determines the prospective value of derivatives based on other financial instruments.

$$\mathrm{C(S) = SN(d1) + Ke^{-rt}N(d2)} \tag{1}$$

The Black-Scholes algorithm is used to calculate implied volatility and employing it may provide investors with substantial gains. Implied volatility is a prediction of future volatility of the underlying asset in an option contract. The Black-Scholes model, which assumes that the price of the underlying asset moves in a geometric Brownian motion with constant drift and volatility, is used to price options.

The volatility, underlying asset price, option strike price, option expiration period, and risk-free rate are the inputs to the Black-Scholes equation. These factors potentially allow option sellers to determine a fair asking price for the options they sell. As shown in Fig.1, the crude oil price has a relatively high volatility.

Figure 1. Crude oil Price Trend

$$d1 = \frac{\ln\left(\frac{S}{K}\right)+\left(r+\frac{1}{2}*\sigma^2\right)*T}{\sigma*\sqrt{T}} \tag{2}$$

Similar to any other equation, Black-Scholes can be used to find any single variable when all other variables in the model are known. Asset prices, strike prices, maturities, and risk-free rates may all be predicted with a high degree of confidence using the Black-Scholes model. However, the volatility of the underlying asset changes over time, so by using parameters other than volatility and the price of the option in the market, a volatility can be derived inversely, and in this way, volatility can be accounted for Sexuality issues, and this volatility is called implied volatility. As such, such volatility may be viewed as an ongoing expectation of future volatility in the underlying asset created by market participants through price manipulation.

2.2 Monte Carlo Method

Another trustworthy technique for pricing options is Monte Carlo simulation. Contrary to the Black Scholes pricing principle, Monte Carlo simulation solely relies on the simulation of thousands of price jumps in the underlying asset's price trend prior to the option's expiration date, discounting and pricing the option premium by the expected return that the option will bring (Roth, 2011). Therefore, Monte Carlo simulation does not have the mathematical properties of the Black Scholes model, but relies on statistical logic to complete the pricing. [10]

In the pricing of call options, the expected return and volatility of the underlying asset are very important input parameters, which determine the payoff of the option on the maturity date. This volatility may thus be seen as a continuous expectation of the underlying asset's future volatility, which market actors have produced via price manipulation.

$$\mathrm{f(S)} = \max(\mathrm{ST} - \mathrm{K}, 0) \tag{3}$$

where the price of the underlying stock at the moment the option expires, T, is represented by the expression S = S(T). This equation generates one conceivable option value after expiry and after calculating this tens of thousands of times to get a sense of the potential estimation inaccuracy in price. This formula is also known as the option value at the moment T. When S(T) > K, the holder can purchase shares at K for S(T) market value, making a profit of S(T) - K. If S(T) > K, the holder can purchase shares at K for S(T) market value, making a profit of S(T) - K. Instead, if S(T) K, the holder does not create a call option and earns nothing. Therefore, in order to be able to price a reasonable call option price, it is only necessary to rely on countless underlying assets at time point T A clear distribution of option payoff can be obtained for pricing.

$$\{S_N^K = S^K T, k = 1,2,3, \dots, M\} \tag{4}$$

$$S_{N+1}^K = S_N^K + rS_N^K \Delta t + \sigma S_N^K \epsilon_{N+1}^K \sqrt{\Delta t} \tag{5}$$

As shown in Fig.2, the underlying asset price is stimulated with the equation above and this equation is also used to stimulate the oil price in the future 12 month (1 year).

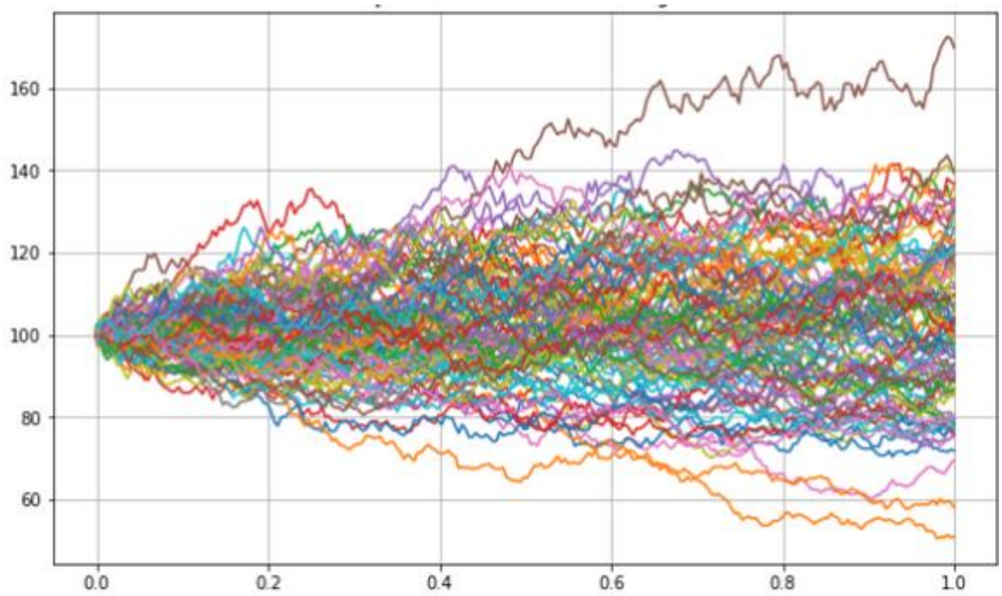

Figure 2. Stimulation of Crude Oil Spot Price in the next one year

As a consequence, the call option may be computed using a Monte Carlo simulation. This calculation result is crucial because it will be used to compare the call option value to that of the Black Scholes model and the market price. By doing so, this technique might change the simulation's settings.

$$\frac{1}{M} \sum_{K=1}^{M} f\left(S_N^K\right) = (1 + r\Delta t)^N \widetilde{C(s)} \tag{6}$$

$$C(s) = (1 + r\widetilde{\Delta t)^N} \{\frac{1}{M} \sum_{K=1}^{M} f(S_N^K)\} \tag{7}$$

When using the market price of implied volatility and option derived from the Black Sholes model as the parameters brought into the Monte Carlo simulation, r in the sample period can be simulated, and this r can be regarded as the market price for the underlying asset expected return in the future period.

Therefore, the implied volatility calculated by the Black Scholes model can be used as the volatility parameter in Monte Carlo Simulation, and combined with the current option premium, r can be obtained. This can also be treated as an implied return in the underlying asset.

3. Results and Discussion

In this part, as shown in Fig.3, the specific fit of the above forecast Crude oil daily return from March 2022 to September 2022 will be discussed. The Black Scholes model uses a parity call option premium to project the implied volatility of the market, which is used as the volatility in the Monte

Carlo model and as a factor in modeling future movements in the spot price of crude oil. This is done in order to predict market yields included in option prices in the market using the BSM and Monte Carlo methods.

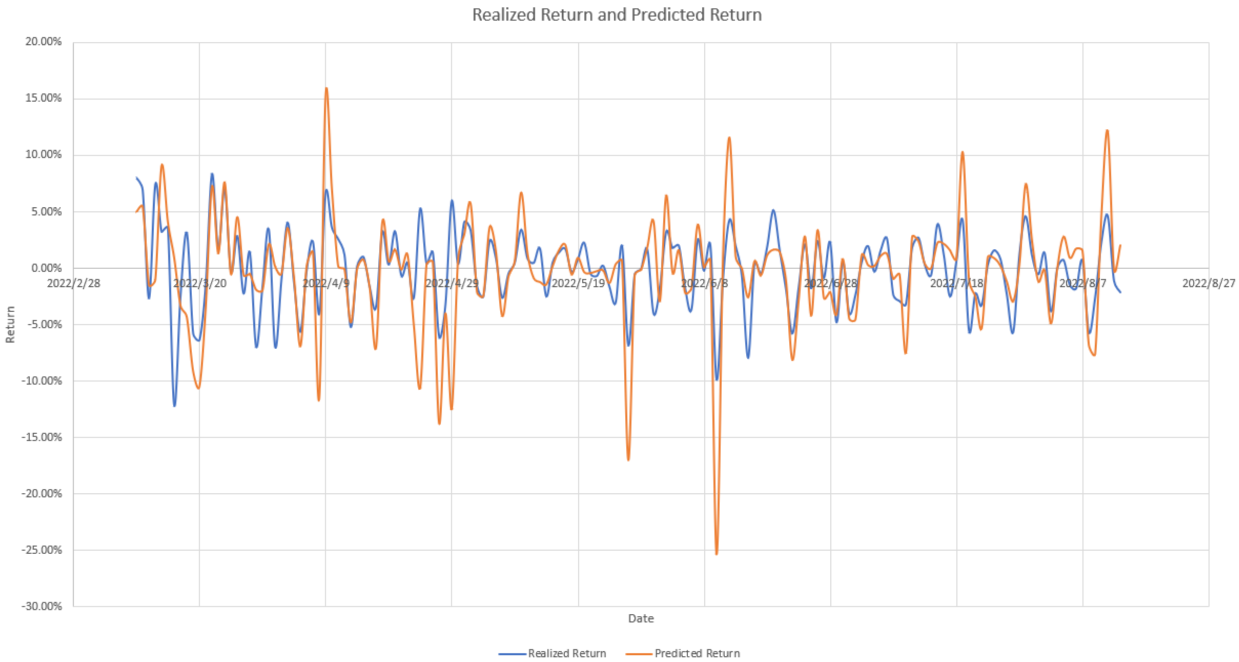

Figure 3. Realized Return and Predicted Return

In the above figure, the rate of return during this period is presented. Using the method used in this article to predict the future rate of return of Crude oil and the actual rate of return, the correlation coefficient is relatively high, but the predicted value is higher than the actual rate of return. The volatility is significantly higher than the realized return.

Table 1. Statistical Summary of Realized Return and Predicted Return

	Realized Return	**Predicted Return**
Average	-0.06%	0.16%
Standard Deviation	3.44%	5.94%
Correlation	0.6923	

According to the statistical data on the rate of return shown in Table 1 for these 6 months, the estimated rate of return can partially predict the price trend and rate of return of Crude oil in the future, and the correlation coefficient is 0.6923. However, since we use option premium to push back implied volatility, and implied volatility tends to have a volatility smile, it is very likely to result in an overestimation of volatility in the short term. Therefore, this is an important reason why the volatility of predicted return is significantly higher than that of realized return.

4. Conclusion

Since the worldwide COVID-19 outbreak in 2020, central banks all over the globe have enacted lax monetary policies as a kind of protection from the pressures placed on the economy by quantitative easing. Beginning in 2022, a steady growth in the number of currencies led to an increase in the price of commodities worldwide. Among them, the price of fossil resources like oil has increased to all-time highs as a result of the escalating geopolitical confrontation between Russia and Ukraine. As the difference in oil prices grew during this time, successive speculative possibilities in the derivatives market also appeared. Thus, the Black Scholes Model and the Monte Carlo Model's guiding principles are used in this article to forecast the price trend of crude oil. In the Monte Carlo model, the Black Scholes-calculated implied volatility will be utilized as the volatility of the oil futures price trend, and the present option premium will be used to reverse the implied return. It acts as a prediction of oil futures' yields in the future.

With data from March to September 2022, there is a 0.67 correlation coefficient between the expected return and the actual return, which is a quite impressive forecast accuracy. But because of things like the volatility smile, the expected return's volatility will be larger than the actual returns.

References

[1] Optimal Oil-based Exotic Options Strategies Under the Background of War: An Empirical Study in the Context of the Russia-Ukraine Conflict (2022).

[2] McKenzie, S., Gerace, D. & Subedar, Z., 2007. An empirical investigation of the black-scholes model: Evidence from the Australian Stock Exchange. Australasian Accounting, Business and Finance Journal, 1 (4), pp.71 – 82.

[3] Macbeth, J. D., and Merville, L. J. (1979). An empirical examination of the Black-Scholes Call option pricing model. Journal of finance, 34 (5), 1173 – 1186.

[4] Gustafsson, M. and Mörck, E., 2010. Black-Scholes Option Pricing Formula-An empirical study.

[5] Beckers, S. (1980). The constant elasticity of variance model and its implications for option pricing. Journal of finance, 35 (3), 661 - 673.

[6] Buraschi, A., and Jackwerth, J. (2001). The price of a smile: Hedging and spanning in option markets. Review of financial studies, 14 (2), 495 - 527.

[7] Janková, Z., 2018. Drawbacks and limitations of Black-Scholes model for options pricing. Journal of Financial Studies and Research, 2018, pp.1 - 7.

[8] Macbeth, J. D., and Merville, L. J. (1979). An empirical examination of the Black-Scholes Call option pricing model. Journal of finance, 34 (5), 1173 – 1186.

[9] Kyun, H.B., 2004. Empirical study of Black-Scholes warrant pricing model on the stock exchange of Malaysia. Research Report, Master of Business Administration.

[10] Roth, D. (no date) “Monte Carlo methods: Barrier option pricing with stable greeks and multilevel Monte Carlo Learning.” Available at: https://doi.org/10.21248/gups.6862.