Assessing Effect of Market Sentiment on Pricing of European Currency Options

[*]Wael Dammak

University of Lyon, University Claude Bernard Lyon 1, Institute of Financial and Insurance Sciences, LSAF-EA2429, F-69007, Lyon, France

Faculty of Economics and Management of Sfax, LREG-LR18ES27, Sfax, Tunisia

[*]Corresponding author

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ABSTRACT

The discrepancy between theoretical predictions and actual prices in currency options markets poses a significant challenge in financial economics. Despite extensive research, traditional models, including the Garman and Kohlhagen (1983) model, overlook critical factors such as investor sentiment, assuming complete market efficiency. Addressing this gap, this study integrates investor behavior into the currency option pricing model. Utilizing daily data from five pairs of currency call options spanning from January 1, 2018, to November 24, 2022, the study investigates the impact of this integration on the accuracy of currency call price predictions. Results reveal a marked enhancement in prediction accuracy, as evidenced by a reduced root mean squared error. The incorporation of market sentiment proves to be crucial, enhancing the Garman and Kohlhagen model's precision and offering a more reliable approach for estimating currency call prices. The findings underscore the significant role of investor behavior in asset pricing, emphasizing the need for its consideration in future models and theories.

Keywords: Option Pricing; Garman and Kohlhagen Pricing Model; Market Sentiment; Implied Volatility; Investor's Behavior.

JEL Classification: G13, G14, G15, G17

INTRODUCTION

In recent decades, there has been significant growth in the financial market's use of hedging instruments, especially derivatives. These tools are essential for reducing the impact of uncertain or unfavorable price changes in underlying assets. The options market, in particular, has gained popularity due to the flexibility and versatility of these instruments. They are useful for purposes like hedging, speculation, and arbitrage. Additionally, they offer investors opportunities to profit from favorable market trends. This surge in interest has prompted both academic researchers and practitioners to explore in-depth the challenges of valuing options, leading to the development of various option pricing models.

The development of option pricing models dates back to Louis Bachelier's work in 1900. The most notable among these models is the Black-Scholes model (B-S model), which was recognized with the Nobel Prize in 1973. However, it falls short in accurately pricing currency options as it only considers the domestic risk-free interest rate, whereas currency exchange involves both domestic and foreign risk-free interest rates. This necessitates a more comprehensive model. The Black-Scholes model, initially developed for simulating the dynamics of financial markets and evaluating non-dividend paying stocks, proved inadequate for the broader range of options such as stock-options, index options, and currency options.

In response, the Garman and Kohlhagen model (G-K model) emerged in 1983, offering a more accurate method for valuing European currency options. It was designed to enhance the Black-Scholes model and address its limitations, especially the assumption that borrowing and lending occur at the same risk-free rate, which is not always the case in the currency market. The G-K model accounts for the difference in domestic and foreign risk-free interest rates by adjusting the value of the underlying currency. This approach has led to a more precise valuation of currency options.

Furthermore, the G-K model is significant as the first direct application of the B-S model and has become a cornerstone for numerous theoretical research papers on currency option pricing. It employs the traditional arbitrage argument developed by Black, Scholes, and Merton, and the technique of forming a risk-free portfolio. This model assumes constant domestic and foreign currency interest rates and adapts the B-S model's assumptions for European options with an exchange rate as the underlying instrument. The model likens the currency to an asset paying a dividend equal to the foreign interest rate, a novel approach at the time.

Despite its advantages, the G-K model does have limitations, particularly in its valuation biases stemming from its assumptions. Factors such as transaction and information costs, information asymmetry, and restrictions on short selling can introduce biases in valuation due to market frictions and constraints, making arbitrage operations less effective in correcting valuation errors. This aspect has been explored in various studies, including works by Jensen (1978), Grossman and Stiglitz (1980), Longjin et al. (2016), Allen and Gorton (1993), Pour (2016), Duffie et al. (2002), Feng and Chan (2016), Bohl et al. (2016), Zghal et al. (2020) and ammak et al. (2023).

Behavioral finance studies have illuminated the significant influence of psychology on investor decision-making, often leading to inefficient market behaviors. A key research avenue emerging from this field suggests that the assumption of investor rationality is not always realistic. Indeed, numerous studies have highlighted how valuation errors may occur when rational investors interact with less rational counterparts, such as noise traders, as demonstrated by De Long et al. (1990a/b) and Ramiah et al. (2015), or with overconfident investors, as shown in studies by Daniel et al. (2002) and Abreu and Brunnermeier (2003). A central aspect of market behavior in these studies is sentiment, which can be quantitatively measured and offers a promising research direction, perhaps more so than other psychological biases. Consequently, there has been a shift in focus towards developing currency option pricing models that are more adaptable and can address these behavioral intricacies. In parallel, the entry of physicists and mathematicians into the field of option pricing has catalyzed the creation of models that are both more complex and realistic. These models aim to achieve an optimal solution by integrating advanced mathematical and physical concepts, reflecting the evolving nature of this field.

Our research aims to evaluate the impact of market sentiment on the pricing of European currency options. A key contribution of our study is the integration of investor sentiment into the G-K model (1983). This integration is crucial for reflecting the diverse behaviors of participants in the currency options market. We have achieved this by using implied volatility as a proxy for investor sentiment, which is then incorporated into the G-K model to enhance the accuracy of currency call price predictions.

This approach provides critical insights into the dynamics of the currency options market, highlighting the significance of considering market sentiment in the valuation process. Our investigation further explores the effects of embedding market sentiment into the G-K model's valuation of currency options. This methodology allows for a deeper understanding of how market dynamics, particularly volatility, interact with currency options.

By acknowledging the influence of market sentiment on valuation, our study aims to deliver more precise currency call price forecasts, thereby enriching our understanding of financial market operations. Consequently, the primary goal of this paper is to examine the robustness of the G-K model when it includes sentiment behavior. This examination is applied to five currency call option pairs over the period from January 1, 2018, to November 24, 2022. The findings are expected to offer valuable perspectives on the efficacy of the G-K model under the influence of market sentiment.

The structure of this paper is organized as follows: Section two offers a comprehensive review of the relevant literature in the field. In section three, we delve into the G-K model, with a particular focus on incorporating sentiment behavior and examining the sensitivity of currency option prices to market sentiment and its key determinants. Section four is dedicated to detailing the data and methods employed in our study. The findings of our research are presented in the fifth section, where we provide a thorough description of the results. The paper concludes with a final section offering some concluding remarks and insights drawn from our study.

LITERATURE REVIEW

Existence of imperfections

The distinct characteristics of currency options, as compared to stock-options, necessitate diverse valuation models. In this regard, Feiger and Jacquillat (1979) attempted to model a bond contract that included an option for the holder to choose the currency for receiving the principal and interest, essentially combining a traditional bond with a currency option. However, their model was complex, and an analytical solution proved elusive. Following these initial efforts, Slutz (1982) further investigated currency option bond pricing and proposed analytical formulas for the European currency option. Despite these advancements, a comprehensive solution remained out of reach, leading researchers to explore alternatives based on the Black-Scholes (1973) model.

Garman and Kohlhagen (1983) were then the first to provide an analytical solution for currency option pricing using the traditional arbitrage argument. They faced the challenge of accounting for both domestic and foreign interest rates, treating the foreign interest rate as a dividend rate on the underlying exchange rate. Employing Ito's lemma and the no-arbitrage principle, they derived an appropriate partial differential equation and developed an analytical solution akin to the Black-Scholes model. Despite its widespread use for pricing European currency options, the G-K model has limitations. It is based on the assumption of market efficiency, which implies rational behavior of economic agents and the absence of imperfections in financial markets. However, these assumptions are not fully representative of reality and are difficult to empirically verify. Market constraints, such as information costs and short selling restrictions, can introduce biases in valuation.

The financial market theory acknowledges various imperfections, including information costs (Grossman and Stiglitz, 1980; Easly and O'hara, 1987; Bellalh, 1999; Argenziano et al., 2016; Weller, 2018; Maclennan and Wood, 2021), costs of information transmission (Bhuyan et al., 2016, Ahmed and Huo, 2019), and asymmetric information (Ahmad et al., 2021; Ranaldo and Somogyi, 2021; Dammak, Ben Hamad et al, 2023). These factors play a crucial role in the pricing of financial asset models and in international portfolio selection.

Classical financial theory traditionally assumes rational behavior among economic agents. However, behavioral finance provides a more nuanced and realistic view of market dynamics by factoring in psychological influences. This approach emphasizes the significant impact of psychology on option pricing and its contribution to market inefficiencies. In particular, behavioral finance identifies instances where valuation errors arise from interactions between rational and irrational investors. Our research corroborates the presence of 'noise traders', as identified in studies by Shleifer and Summers (1990), Chu et al. (2019), and Alsaygh and Alhusseini (2022). Additionally, we observe the phenomenon of overconfidence among investors, a behavior documented in works by Abreu and Brunnermeier (2003), Fitri and Cahyaningdyah (2021), and Parhi and Pal (2022).

The connection between market sentiment and option pricing

Market sentiment, a key aspect of behavioral finance, plays a crucial role in option pricing. It reflects market expectations about future volatility and the direction of the underlying asset's price, significantly influencing option values. Consequently, there has been extensive research exploring the link between market sentiment and option pricing, with many studies affirming sentiment's substantial impact on option prices.

Han (2008) conducted an empirical test using three sentiment measures: the valuation error index of the S&P 500 by Sharpe (2002), the investors' intelligence index, and the trading volume of S&P 500 futures contracts. He found a significant correlation between these sentiment measures and the performance of S&P 500 index options. Similarly, Glaser et al. (2009) demonstrated that sentiment positively affects future returns, utilizing sentiment data from warrants. Mahani and Poteshman (2008) and Bauer et al. (2009) also observed that option prices could be influenced by market sentiment in the options market.

Sheu and Wei (2011) used measures like future volatility, the ARMS index, option volatility, and the put-call volume ratio to study sentiment's impact on option prices. Yang and Gao (2014), focusing on the Chinese stock index futures market, concluded that stock sentiment and stock index futures sentiment significantly affect these markets. Yang et al. (2016) proposed an option pricing model incorporating market sentiment, showing that indicators like the put/call ratio and implied volatility, which reflect market sentiment, significantly impact option prices.

Zghal et al. (2020) found that results using the Black-Scholes model, accounting for imperfections like market sentiment and information asymmetry, were more accurate than those from the traditional model. Similarly, Dammak et al. (2022) observed more reliable and accurate results using the G-K model with dynamic information costs, examining data on continuous call futures for the EUR/USD pair. Boutouria et al. (2021) studied the effect of incorporating sentiment into option valuation, using data from 30 French companies listed on the CAC40 index. Their findings suggested that adding sentiment to the Black-Scholes model improves its pricing performance. Finally, Wang et al. (2022) conducted an empirical study on December call-options for the SSE 50 ETF options, revealing a significant correlation between investor sentiment and option prices, with the latter showing heightened sensitivity to sentiment. These studies collectively underscore the pronounced impact of market sentiment on option pricing, highlighting its importance in financial market analysis.

The importance of volatility in option pricing

Significant research in the literature underlines the pivotal role of volatility in option pricing, where inaccurate volatility estimates can lead to substantial errors. To tackle this issue, various methods have been employed. Blair et al. (2010) examined S&P 100 options, and Corrado and Miller (2005) investigated both S&P 100 and Nasdaq 100 options, finding that implied volatility is a more reliable predictor of future performance than historical volatility.

Nagarajan and Malipeddi (2009) analyzed the impact of sentiment on the pricing of Indian CNX Nifty index call options from April 2002 to December 2008. They discovered that using the previous day's implied volatility in the Black-Scholes model yielded closer approximations to actual prices than the Modified Black-Scholes model, which incorporates non-normal skewness and kurtosis as per Corrado and Sue (1996). Sheu and Wei (2011) employed future volatility as a sentiment measure to explore its effect on option prices and volatility. Soini and Lorentzen (2019) observed a significant positive correlation between implied volatility and both oil futures and transaction cost measures in the options market. Jeon et al. (2019) demonstrated that during periods of high uncertainty, option-implied volatility efficiently predicts future volatility. Fassas and Siriopoulos (2021) evaluated the informational value of publicly available implied volatility indices regarding realized volatility and underlying asset returns. They noted a substantial contemporaneous relationship between changes in implied volatility and the returns of the underlying asset, though the response of implied volatilities in commodities, bonds, currencies, and volatility differs from equities. Dammak et al. (2023) showed that the modified G-K model, considering information costs, consistently produces higher average implied volatility than the classical model. This finding highlights the importance of accounting for information costs in pricing currency options and the significant effects of information asymmetry in the market.

Consequently, these studies emphasize the crucial role of implied volatility in option pricing and its influence on market sentiment. They suggest that implied volatility is a more effective predictor of option prices and can serve as a sentiment indicator. Moreover, these studies reveal that the relationship between implied volatility and market sentiment varies across different financial instruments and in times of high uncertainty. These insights underline the necessity of considering both implied volatility and market sentiment in analyzing currency option prices.

Garman and Kohlhagen Model Considering the Sentiment Behavior

Garman and Kohlhagen model

Based on the assumptions that include the neutral delta hedging technique, Garman and Kohlhagen (1983) suggested that the sale of a call option for a foreign currency can be perfectly hedged by the purchase of a

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quantity of foreign government bonds with r_f as the interest rate. On the other hand, according to the G-K model and under a number of assumptions based on the market efficiency, the value of a European currency call according to this model can be calculated through the partial differential equation on condition that there is no arbitrage opportunity:

$$\frac{1}{2}.\sigma^2.S^{2\frac{\delta^2 V}{\delta S^2}} + (r_d - r_f)S\frac{\delta V}{\delta S} - r_d V + \frac{\delta V}{\delta t} = 0 \qquad (1)$$

where, V represents the price of the currency option which is considered as a function of two variables: the exchange rate 'S' and the time 't', $\delta^2 V/\delta S^2$ is the second derivative of V relative to S, $\delta V/\delta S$ is the first derivative of V relative to S,$\delta V/\delta t$ is the first derivative of V relative to t, σ is the exchange rate volatility, r_d is the domestic risk-free interest rate and r_f is the foreign risk-free interest rate.

In fact, equation (1) can be rewritten:

$$\frac{1}{2}.\sigma^2.S^{2\frac{\delta^2 V}{\delta S^2}} + \frac{\delta V}{\delta t} = r_d V - (r_d - r_f)S\frac{\delta V}{\delta S} \qquad (2)$$

Looking at equation (2), we noticed that the left-hand side represents the change in the value of the currency option V due to the effect of time while the right-hand side represents the risk-free return of a long currency option position and a short position consisting of $\frac{\delta V}{\delta S}$ the exchange rate.

With the boundary condition that the European currency call option must be verified at maturity (T). In fact, it is a condition to get the value of the call at maturity, which is equal to:

$$C_T = max[S_T - X; 0] \qquad (3)$$

Moreover, the value of a put is equal to:

$$P_T = max[X - S_T; 0] \qquad (4)$$

where, S_T represents the value of the exchange rate at maturity and X is the exercise price.

Then, the analytical solution that coincides with that of the B-S model through the partial derivatives of the equation of the call price can be written as follow:

$$C_t = S_t e^{-r_f \tau} N(d_1) - X e^{-r_d \tau} N(d_2) \qquad (5)$$

where, C_t is the value of a European currency call paying an interest rate r_f, St is the price of the underlying asset, X is the strike price of the call, r_f is the interest rate of the foreign currency, r_d is the interest rate of the domestic currency, τ is the period of time calculated in year or fraction of year and N(.) is the cumulative distribution function of a normal distribution: N (0,1).

Finally, d_1 and d_2 can be calculated as follow:

$$d_1 = \frac{\ln\left(\frac{S}{X}\right) + (r_d - r_f)\tau + \frac{1}{2}\sigma^2\tau}{\sigma\sqrt{\tau}} \qquad (6)$$

and

$$d_2 = d_1 - \sigma\sqrt{\tau} \qquad (7)$$

where, σ represents the volatility of the underlying asset.

Moreover, using the parity relationship, we noticed that the price of a European currency put is:

$$P_t = S_t e^{-r_f \tau} N(-d_1) + X e^{-r_d \tau} N(-d_2) \qquad (8)$$

Therefore, to determine the price of a currency call option using the standard G-K model formula, we have created a procedure in Visual Basic (VBA) called "Currency Call_GK" to simplify the calculation. Then, the computation of the currency call price is based on the input of various factors, including the underlying price, the exercise price, the domestic and foreign risk-free interest rates, the time to maturity expressed as a fraction of a year, and volatility.

The Garman and Kohlhagen model considering the market sentiment

The traditional G-K model (1983) has been criticized for neglecting investor behavior and assuming market efficiency. In this study, we aim to investigate the impact of market sentiment on European currency option pricing by incorporating the investor's sentiment into the G-K model. Previous studies have emphasized the importance of implied volatility in option pricing as it can serve as a powerful predictor of market sentiment of option pricing models. Our contribution involves the use of implied volatility ($\widehat{\sigma}$)as a measure of investor sentiment, which enables us to account for the heterogeneity of participants' behavior in the currency options market.

Then, the formula for calculating the currency call price with the sentiment is presented as follows:

$$C_t = S_t e^{-r_f \tau} N(d'_1) - X e^{-r_d \tau} N(d'_2) \tag{9}$$

Using the new parity relationship:

$$C_t - P_t = S e^{-r_f \tau} + X e^{-r_d \tau} \tag{10}$$

We find then the new formula of the European currency put option pricing of Garman and Kohlhagen modified in the presence of Market sentiment.

$$P_t = S_t e^{-r_f \tau} N(-d'_1) + X e^{-r_d \tau} N(-\mathrm{d}'_2) \tag{11}$$

with,

$$\mathrm{d}'_1 = \frac{\ln\left(\frac{\mathrm{S}}{\mathrm{X}}\right) + (\mathrm{r_d} - \mathrm{r_f})\tau + \frac{1}{2}\widehat{\sigma}^2\tau}{\widehat{\sigma}\sqrt{\tau}} \tag{12}$$

and

$$\mathrm{d}'_2 = \mathrm{d}'_1 - \widehat{\sigma}\sqrt{\tau} \tag{13}$$

where, $\mathrm{C_t}$ is the value of a European currency call paying an interest rate $\mathrm{r_f}$, $\mathrm{P_t}$ is the value of a European currency put, St is the price of the underlying asset, X is the strike price of the call, r_f is the interest rate of the foreign currency, r_d is the interest rate of the domestic currency, τ is the period of time calculated in year or fraction of year, N(.) is the cumulative distribution function of a normal distribution: N (0,1) and $\hat{\sigma}$ represents the volatility of the underlying asset considering market sentiment, with $\hat{\sigma}$ = Volatility of returns+$\sigma_{irrational}$.

The sensitivity of the currency option price with market sentiment to its determinants

Understanding the sensitivity of currency option prices to market sentiment, especially in response to changes in its determinants, is crucial for developing effective hedging strategies for option portfolios. In the unpredictable environment of option trading, where option prices fluctuate in response to variations in key factors, this knowledge becomes particularly important. 'Greeks' are metrics used to measure the sensitivity of an option's premium to specific determinants. These include the price of the underlying asset, time to expiration, volatility (which is modified by market sentiment), and the risk-free interest rate. Each Greek provides valuable insights into how changes in these determinants can impact the value of an option, thereby guiding traders in managing their positions and mitigating risks effectively.

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The Delta

The delta measures the sensitivity of an option's premium to a small change in the price of the underlying currency. It is the slope of the curve that links the option price to the price of the underlying. From a mathematical point of view, the delta is the partial derivative of the value of the currency option in relation to that of the underlying.

The delta of a European currency call with the sentiment is written as follow:

$$\Delta_C = \frac{\partial C}{\partial S} \tag{14}$$

$$\Delta_c = \frac{\partial C}{\partial S} = e^{-r_f \tau} N(d'_1) = e^{-r_f \tau} \int_{-\infty}^{d'_1} \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}} dx \tag{15}$$

According to the Black-Scholes model, the delta of a European call with sentiment on a non-dividend paying share is:

$$\Delta_C = N(d'_1) \tag{16}$$

And the delta of a European put with sentiment on a non-dividend paying share is:

$$\Delta_P = N(d'_1) - 1 \tag{17}$$

The delta of a currency call option with the sentiment is always positive and varies from 0 to 1. This means that there is an increasing relationship between the exchange rate of the currency and the value of the premium. Therefore, if the currency rate increases, it is natural to pay more for the right to buy it at the same fixed price.

The Delta of a currency put option with the sentiment is written as follows:

$$\Delta_P = \frac{\partial P}{\partial S} \tag{18}$$

$$\Delta_p = \frac{\partial P}{\partial S} = -e^{-r_f \tau} N(-d'_1) = -e^{-r_f \tau} \int_{-\infty}^{-d'_1} \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}} dx \tag{19}$$

The delta of a put option with the sentiment is always negative and varies from -1 to 0. This means that a rise in the exchange rate of the underlying currency leads to a fall in the value of the premium.

The delta represents the probability that the option will be in-the-money at expiration and therefore exercisable. For an in-the-money option, the delta is very close to 1 (for a call) and -1 (for a put). Thus, any change in the support is reflected in the option premium. For an out-of-the-money option, the delta is close to 0 because the probability of exercise is very low. The delta also represents the hedge ratio, that is, the number of shares to buy or sell to establish a perfect hedge. Hedging a short position in the call option with a delta hedge involves a long position of Δ_C units of the underlying at a given moment. On the other hand, hedging a long position in the call option with a delta hedge involves a short position of Δ_C units of the underlying at a given moment. Regarding the put option, a long position is covered by a long position of Δ_P units of the underlying asset, and a short position is covered by a short position of Δ_P units of the underlying asset (since Δ_P is negative).

The Gamma

The gamma measures the sensitivity of delta to the underlying price. Mathematically, the gamma is the partial derivative of delta with respect to the underlying, in other words, it is the second derivative of the option price with respect to the underlying price.

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Gamma is written as:

$$\Gamma_C = \frac{\partial \Delta_C}{\partial S} = \frac{\partial^2 C}{\partial S^2} \quad (20)$$

and,

$$\Gamma_p = \frac{\partial \Delta_P}{\partial S} = \frac{\partial^2 P}{\partial S^2} \quad (21)$$

According to the model, the gamma of the European call and put with the sentiment on a foreign currency is:

$$\Gamma_c = \Gamma_p = \frac{e^{-r_f.\tau}}{s\hat{\sigma}.\sqrt{\tau}} . \frac{e^{-\frac{d_1'^2}{2}}}{\sqrt{2\pi}} \quad (22)$$

If the gamma is low, the delta is relatively insensitive to changes in the underlying currency price; otherwise, the delta changes slowly and it is not necessary to frequently adjust the portfolio to maintain a delta-neutral portfolio. As a result, the curve representing the variation in the overall position value is flat. On the other hand, if the gamma is high in absolute value, the delta is very sensitive to changes in the underlying asset price. The curve representing the variation in the portfolio value is convex if the gamma is positive and concave if the gamma has a negative value. Thus, gamma is sensitive to changes in implied volatility modified by the market sentiment. In this case, If the modified implied volatility increases, gamma decreases for positive value and increases for negative value.

The Theta

It is the rate of change in the currency option with sentiment value with respect to its life. Mathematically, this is determined according to the following equation:

For a currency call option:

$$\theta_C = \frac{\partial C}{\partial \tau} \quad (23)$$

And, for a currency put option:

$$\theta_P = \frac{\partial CP}{\partial \tau} \quad (24)$$

For the model considering market sentiment, the theta of the European call on a foreign currency is equal to:

$$\Theta_c = \frac{\partial C}{\partial \tau} = -r_f.Se^{-r_f.\tau}N(d'_1) + r_d.Xe^{-r_d.\tau}N(d'_2) + \frac{\hat{\sigma}}{2\sqrt{\tau}} S.e^{-r_f.\tau} \frac{e^{-\frac{d_1'^2}{2}}}{\sqrt{2\pi}} \quad (25)$$

And for a currency put option, theta is equal to:

$$\Theta_c = \frac{\partial C}{\partial \tau} = -r_f.Se^{-r_f.\tau}N(-d'_1) + r_d.Xe^{-r_d.\tau}N(-d'_2) + \frac{\hat{\sigma}}{2\sqrt{\tau}} S.e^{-r_f.\tau} \frac{e^{-\frac{d_1'^2}{2}}}{\sqrt{2\pi}} \quad (26)$$

The theta of a call option (put option) is the sum of three components. The first is negative (positive). The second is positive (negative) and reflects that with the increase in the option's lifetime, the disbursement (inflow) of the exercise price is postponed, increasing (reducing) the value of the currency call option (put option). The third component is the most important. Its value is positive and identical for the call option and put option and depending also to the increasing of the implied volatility modified by the market sentiment. It corresponds to the time value of the option and increases with maturity, meaning that a market holder buyer (seller) of short-term options, which are by far the most liquid in the market, loses (gains) money as this maturity approaches, all other things being equal. The theta of an option is usually negative as the option loses its time value as the maturity approaches. The theta of a parity option is often higher than that of an in-the-money or out-of-the-money option since it has the highest time value.

The Vega: the sensitivity of the currency option price to a variation of volatility modified with the market sentiment

In reality, volatility fluctuates over time, and traders need to take this source of risk into account when designing their strategies. The Vega measures the sensitivity of the option value to a change in volatility if market sentiment is taken into account. Mathematically, it corresponds to the rate of change of the option value following a change in the volatility of the underlying, i.e:

For a currency Call option:

$$\vartheta_C = \frac{\partial C}{\partial \hat{\sigma}} \tag{27}$$

And, for a Put option:

$$\vartheta_P = \frac{\partial P}{\partial \hat{\sigma}} \tag{28}$$

The Vega of the currency call and currency put options for the G-K model with market sentiment are equal and positive and are given by the following formula:

$$Véga_c = Véga_p = \frac{\partial C}{\partial \hat{\sigma}} = \frac{\partial P}{\partial \hat{\sigma}} = Se^{-r_f.\tau}.\frac{e^{-\frac{d_1'}{2}}}{\sqrt{2\pi}}.\sqrt{\tau} > 0 \tag{29}$$

The vega is highest when the currency option is at parity and approaches 0 as the options approach deeply in-the-money or deeply out-of-the-money. A high Vega means that the value of the currency option is highly sensitive to small changes in volatility (when market sentiment is taken into account), whereas a low Vega indicates that the value of the currency option is relatively insensitive to changes in volatility (there is no effect of market sentiment).

The Rhô

The rhô measures the sensitivity of the currency option price to changes in the domestic and foreign interest rates. Mathematically, it is represented as the partial derivative of the currency option price with respect to the domestic interest rate (r_d) and the foreign interest rate (r_f).

Either, for a currency call option:

$$\rho_C = \frac{\partial C}{\partial r} \tag{30}$$

And, for a currency put option:

$$\rho_P = \frac{\partial P}{\partial r} \tag{31}$$

The calculation of options on foreign currencies requires determining two rho values for each option, whether it is a call or a put option. The first value, represented by p^d, measures the risk associated with the domestic interest rate, while the second value, represented by p^f, measures the risk associated with the foreign interest rate. The calculation of the derivatives of the currency call option and currency put option in relation to r_d and r_f results in the following values:

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$$p_c^d = \frac{\partial C}{\partial r_d} = Xe^{-r_d \cdot \tau} N(d'_2)\tau > 0 \quad (32)$$

$$p_p^d = \frac{\partial P}{\partial r_d} = Xe^{-r_d \cdot \tau} N(-d_2)\tau > 0 \quad (33)$$

$$p_c^f = \frac{\partial C}{\partial r_f} = Se^{-r_f \cdot \tau} N(d'_1)\tau > 0 \quad (34)$$

$$p_p^f = \frac{\partial P}{\partial r_f} = Se^{-r_f \cdot \tau} N(-d'_1)\tau > 0 \quad (35)$$

In fact, taking market sentiment into account, the value of a call option (or put option) is influenced by the modified implied volatility with market sentiment. Specifically, an increase in the modified implied volatility leads to an increase in the value of a call option (or decrease in the value of a put option) due to an increase in the present value of the exercise price. Conversely, a decrease in the modified implied volatility leads to a decrease in the value of a call option (or increase in the value of a put option). Therefore, the value of a call option (put option) increases (decreases) with the domestic interest rate due to the decrease (increase) in the present value of the exercise price to be paid (received). Conversely, the value of the call option (put option) decreases (increases) with the foreign interest rate. In fact, due to the interest rate parity, the probability of a depreciation of the underlying currency increases when the foreign interest rate increases. As a result, for a fixed exercise price, the value of the right to buy (sell) a depreciating currency must decrease (increase). It is also possible to calculate a global rho measuring the risk of an option portfolio with respect to the domestic interest rate or the foreign interest rate. It can be given by the following formula

$$\mathrm{P}_G = \frac{\partial V}{\partial r} = \sum_i n_i \, \rho_i = \sum_i n_i \frac{\partial V_i}{\partial r} \quad (36)$$

DATA AND EMPIRICAL ISSUES

Data source and description

In this study, we selected five pairs of continuous futures call options, which were obtained from the Thomson Reuters database and quoted in the Russian Trading System. Our sample consisted of 1279 daily observations for each pair, covering the period from January 1, 2018 to November 24, 2022. These foreign currency options are of a European type. Then, the selected currency Call options and the related variables and their measures are displayed in Table 1.

Moreover, in this paper, we consider the currency option and the premise that individuals in the market exhibit varying behaviors and make different choices as a result. In other words, we take into account the fact that the heterogeneity of investors can affect the market behavior and introduce irrationality into the G-K (1983) model when calculating the currency call option prices. Therefore, to account for the effect of the sentiment on the currency call option valuation, we consider the dependence of the investor’s strategies on volatility, such as chartist and fundamentalist investors being more active in the market when volatility is low or high, respectively.

Consequently, to assess the performance of the G-K model in valuing the currency options in the presence of the sentiment behavior, we conducted an empirical analysis to calculate the price of a currency call using the G-K model with and without sentiment behavior. Then, the comparison between these two models is made using the mean square error (MSE) criteria.

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Table 1. Pairs of currency call options and variables

Pairs of currency call options	The variables	Measures of the variables
EUR/USD futures continuous call **EUR/QAT** futures continuous call **EUR/JPY** futures continuous call **EUR/RUB** futures continuous call **USD/RUB** futures continuous call	**S:** price of the underlying asset, **X:** strike price of the currency option, **T:** time to maturity, **C:** price of the currency call option, **P:** price of the currency put option, **σ :** volatility of the underlying asset, **r_d:** the domestic interest rate, **r_f:** the foreign interest rate,	**EURIBOR**: the foreign interest rate of the EUR/USD, EUR/QAT, EUR/JPY and EUR/RUB pairs, **LIBOR:** the domestic interest rate of the EUR/USD pair and the foreign interest rate of the USD/RUB pair, **Mow IBOR**: the domestic interest rate of the EUR/RUB and USD/RUB pairs, **TIBOR:** the domestic interest rate of the EUR/JPY pair, **QIBOR:** the domestic interest rate of the EUR/QAT pair.

Note: EURIBOR, LIBOR, Mow IBOR, TIBOR and QIBOR represent the measures of r_d and r_f.

Implied volatility calculation

The Implied Standard Deviation (ISD), which is also known as historical volatility, is calculated using past option prices observed in the market for the underlying asset. On the other hand, implied volatility is derived from the current prices of options and the underlying asset on the day of the valuation. As a result, implied volatility is considered to be a more accurate representation of the conditions as it reflects the current market value and incorporates the expectations of future events. Unlike the ISD, implied volatility, which is calculated based on the present option price, is in general an unobservable quantity that requires estimation.

Regarding the G-K implied volatility, it is comparable to the Black-Scholes implied volatility as it determines the volatility value that aligns the option price calculated using the G-K formula with the observed option price in the market. The calculation of implied volatility for a given currency call, the price of which is available on the market noted C_{MKT}, from the G-K equation can be found by considering a function of one unknown variable (the implicit volatility $\widehat{\sigma}$) which equalizes the theoretical call $C(r_{d;}\, r_f\ T; X; S;\ \widehat{\sigma})$ to that of the market. We have then the following relationships:

$$C_{MKT} = S_t e^{-r_f \tau} N(d_1) - X e^{-r_d \tau} N(d_2)$$

$$C_{MKT} = S_t e^{-r_f \tau} N\left(\frac{\ln(S/X) + (r_d - r_f)\tau + \frac{1}{2}\widehat{\sigma}^2\tau}{\widehat{\sigma}\sqrt{\tau}}\right) - X e^{-r_d \tau} N\left(\frac{\ln(S/X) + (r_d - r_f)\tau + \frac{1}{2}\widehat{\sigma}^2\tau}{\widehat{\sigma}\sqrt{\tau}} - \widehat{\sigma}\sqrt{\tau}\right)$$

$$C_{MKT} = S_t e^{-r_f \tau} N\left(\frac{\ln(S/X) + (r_d - r_f)\tau + \frac{1}{2}\widehat{\sigma}^2\tau}{\widehat{\sigma}\sqrt{\tau}}\right) - X e^{-r_d \tau} N\left(\frac{\ln(S/X) + (r_d - r_f)\tau - \frac{1}{2}\widehat{\sigma}^2\tau}{\widehat{\sigma}\sqrt{\tau}}\right)$$

$$C_{MKT} = S_t e^{-r_f \tau} N\left(\frac{\ln\left(\frac{S}{X}\right) + \left(r_d - r_f + \frac{1}{2}\widehat{\sigma}^2\right)\tau}{\widehat{\sigma}\sqrt{\tau}}\right) - X e^{-r_d \tau} N\left(\frac{\ln\left(\frac{S}{X}\right) + \left(r_d - r_f + \frac{1}{2}\widehat{\sigma}^2\right)\tau}{\widehat{\sigma}\sqrt{\tau}}\right) = C_{GK}(\widehat{\sigma}) \qquad (37)$$

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In fact, the Black and Scholes model makes it possible to calculate the price of a call option given the underlying price S, the exercise price X, the risk-free rate r, the remaining time until maturity$T$, and the volatility σ. All parameters are either known or observable except for the volatility, which must be estimated. This method involves solving for σ, the unknown, in the following equation:

$$Value_{\mathrm{i}} = \text{ Price } (\widehat{\sigma}?)_{\mathrm{i}} \qquad (38)$$

with: Value_i is the theoretical value of option i (call or put), which will be calculated by the model, and Price $(\widehat{\sigma})_i$ is the price quoted and observed in the market for option i.

The solution to this equation is not immediate. It is necessary to proceed by successive approximations, as in determining the internal rate of return of an investment project. Thus, it is possible to deduce a unique value for volatility, knowing the market price of the call. Continuing this approach, calculating the implied volatility requires finding the solution to a nonlinear equation with one unknown, which requires the use of numerical methods to invert the valuation formulas. In the following, we present the interpolation method1 used in this paper.

Therefore, to solve equation (37) and calculate the Black-Scholes implied volatility, an interpolation algorithm was used and programmed in Visual Basic (VBA). This method involves calculating the implied volatility based on the Black-Scholes formula using the market value of the option. This method involves creating two adjacent sequences of volatility from a bounded interval that converge towards the real value of volatility. The value of the option $C_t(\sigma)$ is first calculated for a maximum volatility σ_{max} and a minimum volatility σ_{min}. These two volatility bounds are initialized with a value close to 1 for σ_{max} and close to 0 for σ_{min}. The value of the option is respectively denoted by $C_{max} > C$ for the maximum volatility value σ_{max}, and by $C_{min} < C$ for the minimum volatility value σ_{min} (where C is the market value of the option). Next, the value of the option $C_t(\sigma)$is calculated for each average of the bounds in the volatility interval, i.e.:

$$\sigma = \frac{\sigma_{max} - \sigma_{min}}{2} \qquad (39)$$

$$\text{If}, C_t(\sigma) < C \quad => \quad C_{min} = C_t(\sigma) \text{ and } (\sigma_{min} = \sigma) \qquad (40)$$

$$\text{If}, C_t(\sigma) > C \quad => \quad C_{max} = C_t(\sigma) \text{ and } (\sigma_{max} = \sigma) \qquad (41)$$

This iterative calculation stops when the difference $|C_t(\sigma) - C|$ becomes lower than a certain value fixed in advance. The method involves introducing different values of volatility into the G-K model to get as close as possible to the observed price of the option. This convergence mechanism is achieved through successive approximations.

Subsequently, the implied volatility calculated will be utilized to determine the currency call price using the G-K model that incorporates the sentiment behavior while taking into account the irrationality of some investors. Moreover, a VBA program was developed to perform this calculation, which involves determining the value of the currency option based on the implied volatility$\hat{\sigma}$ which considers the impact of the sentiment on the investor's behavior in the market. in other words:

with,

$$\hat{\sigma} = \textit{Volatility of returns} + \sigma_{irrational} = \sigma_{rational} + \sigma_{irrational} \qquad (42)$$

then,

$$\sigma_{irrational} = \hat{\sigma} - \sigma_{rational} \qquad (43)$$

[1] There are other methods such as the Newton-Raphson method and the recursive algorithm.

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EMPIRICAL RESULTS AND DISCUSSION

In this section, we undertake the task of calculating the price of a European currency call option, first without considering market sentiment and then by incorporating it. This approach allows us to empirically assess the impact of including market sentiment in the G-K model for currency option valuation. Our comparison between these methods involves defining and calculating the following key variables:

- **CGK**: This represents the price of a European currency call option as determined by the G-K model formula from 1983.
- **CGKS**: This denotes the price of a European currency call option calculated using the G-K model, but in this case, the model is modified to account for the presence of market sentiment.
- **CM**: This is the observed market price of a European currency call option.

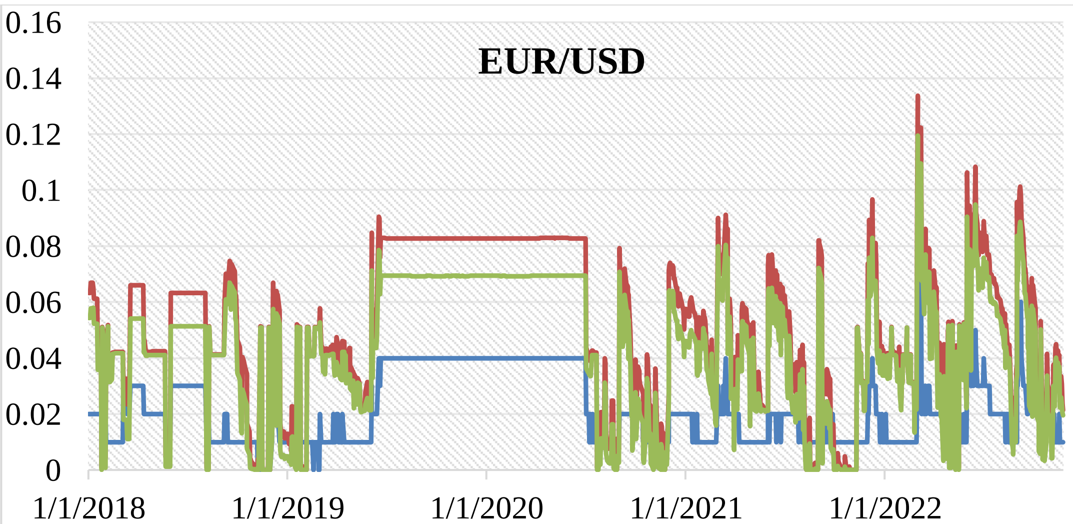
By analyzing these variables, we aim to provide a clear understanding of how the incorporation of market sentiment can influence the valuation of currency options as compared to the traditional G-K model.

Currency option pricing model with market sentiment analysis

Figure 1 illustrates the CGK, CGKS, and CM values for the selected currency call option pairs examined in our study. The graphs display the progression of the estimated currency call prices, calculated using the G-K model, both with and without the incorporation of sentiment behavior. Notably, the CGKS values, which factor in sentiment behavior, align more closely with the observed market prices (CM) across all studied pairs compared to the CGK values derived from the standard G-K model (1983). This observation implies that accounting for the diversity in investor behavior can yield more accurate results.

To further assess the effectiveness of this novel approach against the traditional G-K model (1983), we performed a valuation error analysis utilizing the mean square error (MSE)[2] criteria for all pairs included in our research. We compared the outcomes by calculating the MSE, the variation in MSE, and the relative change in MSE between the two models. Significantly, negative MSE variation and relative changes in MSE values suggest that the G-K model, when considering sentiment behavior, outperforms the standard model. This is indicated by its ability to generate currency option price estimates that more closely mirror the market prices. The detailed results of this analysis are presented in Table 2.

Figure 1. Values of the currency call option according to the GK model, GKS model and the call market price



[2] $MSE(C_{GK}) = \frac{1}{n}\sum(C_{GK} - C_M)^2$ and $MSE(C_{GKS}) = \frac{1}{n}\sum(C_{GKS} - C_M)^2$

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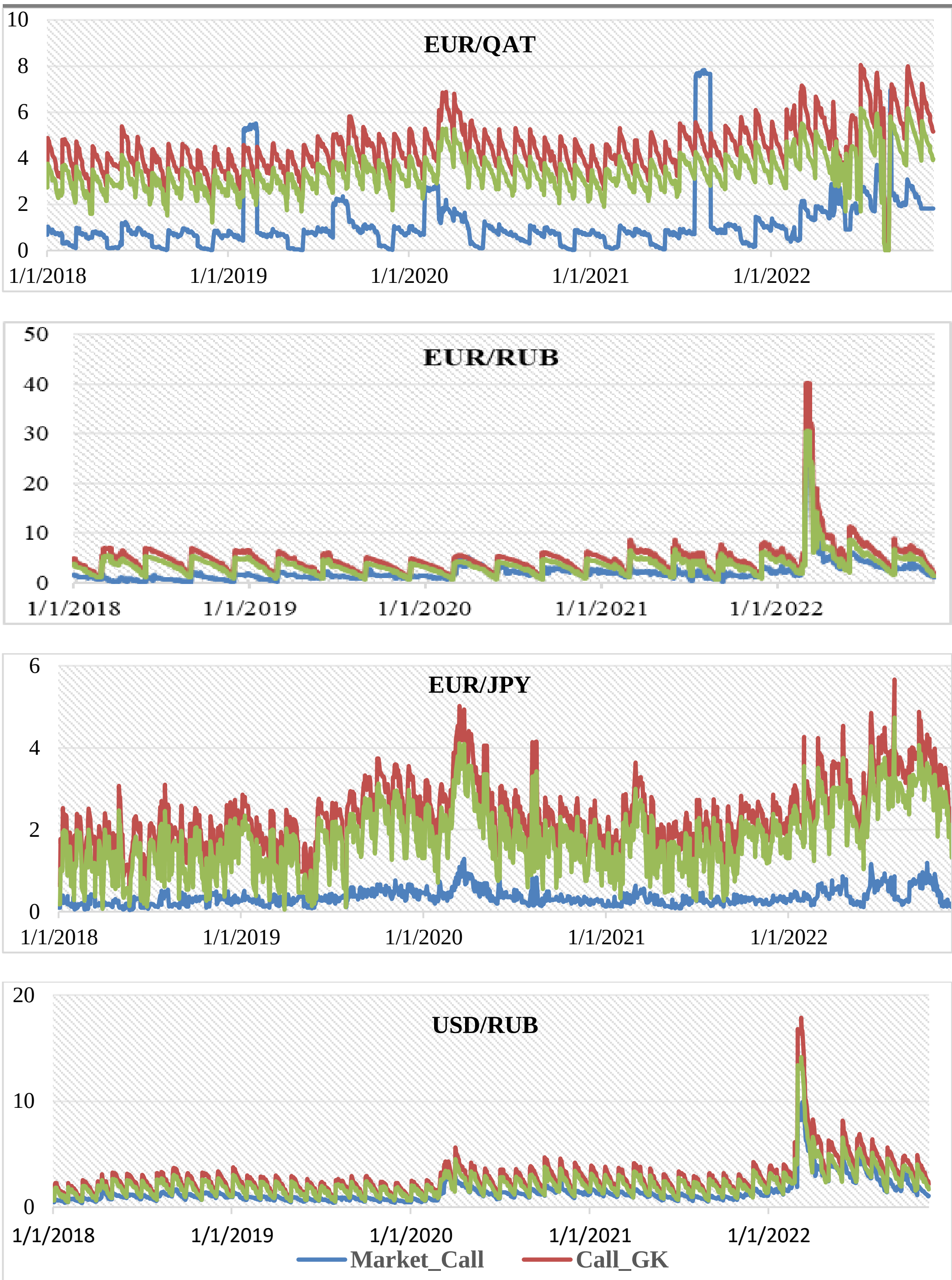

Table2. The MSE and its relative change

Pairs	MSE Call_GK	MSE Call_GKS	MSE Variation	Relative change inMSE in %[3]
EUR/USD	0,00117516	0,00071066	-0,0004645	-39,526636%
EUR/QAT	12,4443969	6,52940096	-5,91499591	-47,531399%
EUR/JPY	4,54112141	2,57029948	-1,97082194	-43,399455%

[3] The relative change in the MSE in percentage is calculated as follows: $\frac{(MSE(C_{GKS})-MSE(C_{GK}))}{MSE(C_{GK})} * 100$

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EUR/RUB	10,433503	4,15616231	-6,27734065	-60,165226%
USD/RUB	2,61609274	0,9692192	-1,64687354	-62,95165%

Note: The table below illustrates the Mean Squared Errors of studied observations. MSE Variation represents the difference between the average errors of our modified model considering market sentiment and the average errors of G-K model (1983). Relative change in MSE denotes the relative deviation of the average errors of both models.

Table 2 showcases the comparative net performance of the G-K model, specifically the version that accounts for sentiment behavior, against the standard G-K model. Our analysis revealed a significant reduction in the MSE for all evaluated currency call option pairs, with a relative change in MSE ranging between 40% and 63%. For example, in the case of the EUR/RUB pair, the MSE value decreased from 10.43 to 4.16, marking a relative change of approximately 60%. These findings underscore the superior accuracy of the G-K model that includes sentiment behavior over the conventional G-K model (1983).

Notably, the EUR/RUB and USD/RUB pairs exhibited more than 60% variation in MSE, underscoring the effectiveness of the sentiment-inclusive model. To further illustrate this point, we provide graphs that compare the MSE values of both models for each currency option pair studied. These visual representations clearly depict how the sentiment-integrated model more accurately reflects the market values of currency options compared to the basic G-K model. This results reinforce the importance of considering behavioral factors like market sentiment in financial models, which traditionally may rely heavily on quantitative and historical data. The findings suggest a need for a more holistic approach to option pricing, one that blends traditional financial theories with insights from behavioral finance.

Figure 2 clearly demonstrates that, the G-K model, when augmented with market sentiment, consistently outperforms the traditional G-K model in estimating the prices of currency call options. This finding highlights the significant influence of unobservable volatility, shaped by investor behavior, on the valuation of currency options. Notably, for the five currency pairs analyzed, incorporating sentiment into the G-K model results in more precise estimates compared to those derived from the standard G-K model established in 1983. In conclusion, the sentiment-enhanced G-K model emerges as a superior tool, offering a more accurate reflection of the market prices of European currency options.

Figure 2. The Mean Squared Deviation (MSD) of the standard Garman and Kohlhagen model and the model taking into account the sentiment

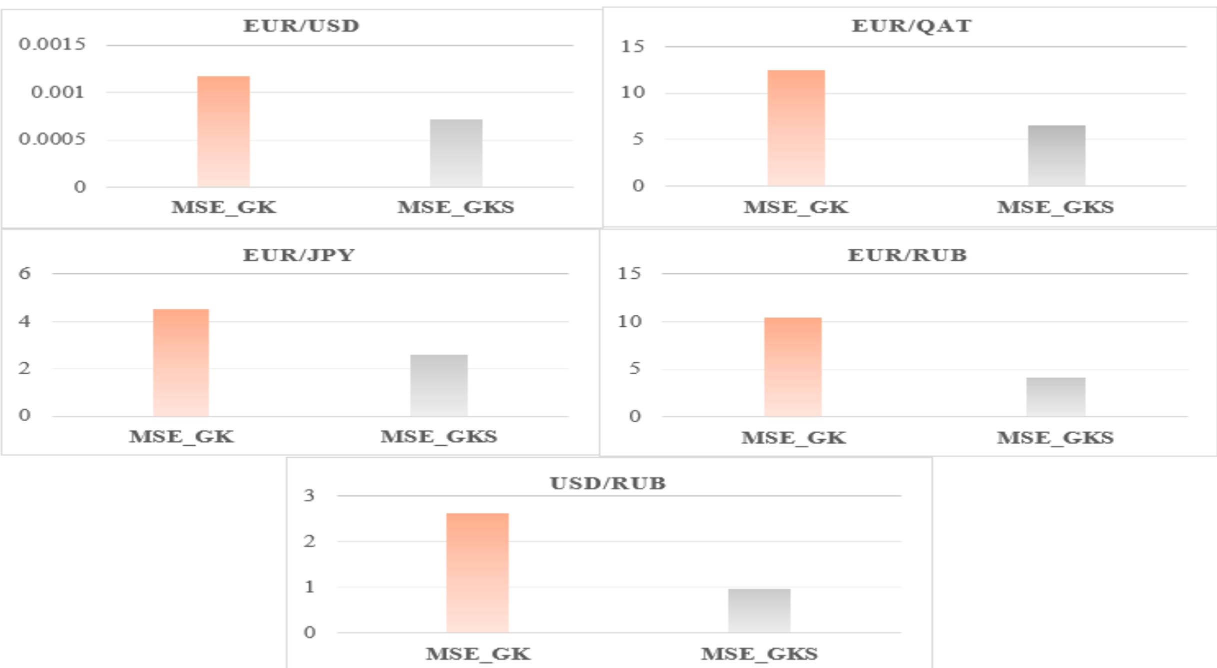

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Figure 3 illustrates the atypical patterns of implied volatility for various currency call option pairs, plotted against their strike prices. Despite the widespread adoption of the Black and Scholes model (1973) in financial markets, real-world market data often contradicts one of its core assumptions: the constancy of implied volatility. Instead, the volatility curve frequently shows a convex shape relative to the option's exercise price, a phenomenon known as the 'volatility smile'. This observation is further supported by empirical studies, such as those by Cont (2001), which indicate that return distributions are more left-skewed and have fatter tails than a normal distribution would suggest.

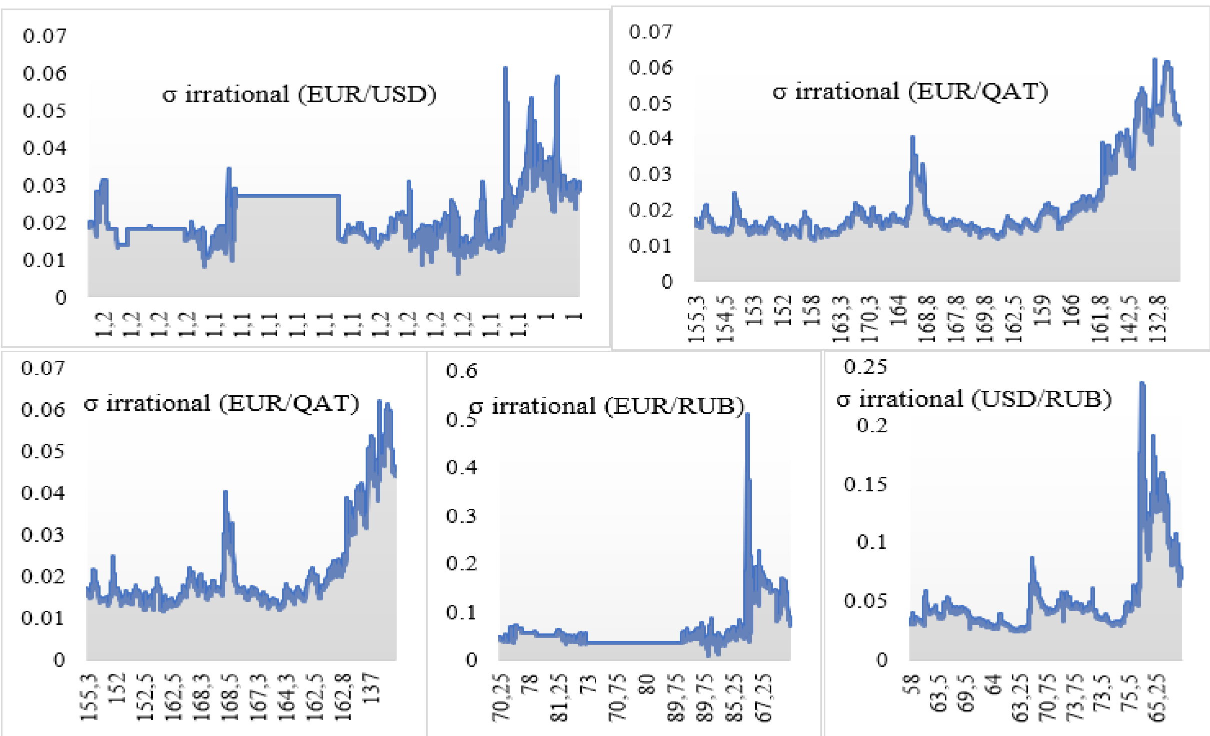
Moreover, several market assumptions integral to the Black-Scholes model, like the absence of transaction costs, information costs, market sentiment influences, or continuous trading, do not hold true in actual market environments. These unrealistic assumptions challenge the model's reliability and often lead to a noticeable discrepancy between the theoretical values predicted by the model and the actual market values observed. This divergence highlights the need for models that can more accurately capture the complexities and nuances of real-world financial markets

Volatility smiles, as depicted in option pricing models, are often seen as an indicator of excess demand for options whose exercise prices significantly deviate from the current market price. Brière and Chancari (2004) suggest that these smiles can be insightful in understanding investor expectations and psychology. They point out that the risk-neutral distribution implied by option prices typically exhibits fatter tails compared to the historical distribution of returns. This difference between the two distributions is used by them as a measure of risk aversion.

Their research indicates that when market participants ascribe a higher likelihood to extreme market events than what historical data suggests, leading them to pay a premium for options as a hedge against these perceived risks, it is a sign of risk aversion. This behavior is reflected in the relationship between option prices and implied volatility. Therefore, the disparity between the risk-neutral distribution (derived from option prices) and the historical distribution of returns can serve as an effective gauge of market risk aversion.

Understanding these nuances and limitations of the Black-Scholes model provides valuable insights for investors and market participants. It helps them better comprehend financial market dynamics and refine their investment strategies, taking into account not just historical data, but also market psychology and investor sentiment.

Figure 3. The irrational implied volatility as a function of strike



DISCUSSION

Market sentiment, reflecting investors' perceptions and attitudes towards the economy and financial markets, significantly influences investment decisions and, consequently, the prices of financial assets. Recognizing its importance is essential for understanding market trends and making informed investment decisions. However, market sentiment is inherently volatile, often rapidly shifting in response to economic developments, necessitating that investors stay alert to these changes.

Our research underscores the considerable impact of integrating market sentiment into the calculation of implied volatility on the valuation of currency options using the G-K model. Implied volatility, a measure of market-perceived uncertainty regarding future exchange rates, is crucial in option valuation as it mirrors expectations for future rate variability. When market sentiment is factored into this measure, it provides a more nuanced perspective on anticipated currency exchange rate movements.

For instance, positive sentiment towards a currency typically leads to higher implied volatility, reflecting expectations of greater price fluctuations. Conversely, negative sentiment can reduce implied volatility, indicating expectations of smaller exchange rate changes. This incorporation of sentiment into the G-K model results in more precise currency option valuations, closely mirroring market expectations for future exchange rate trends.

The impact of market sentiment extends to the valuation of currency options; high implied volatility can increase option prices, while lower volatility can decrease them. Additionally, sentiment influences option demand: positive sentiment boosts demand for call options, raising their prices, and negative sentiment does the same for put options.

The influence of integrating market sentiment into implied volatility on currency option valuation is complex and varies with different currencies and market conditions. Nevertheless, including market sentiment leads to more accurate valuations that faithfully reflect market expectations regarding future exchange rate fluctuations.

CONCLUSION

This study underscores the critical role of market sentiment in determining the price of currency options. This sentiment reflects the market's expectations for future volatility and price movements of the underlying asset. While the traditional G-K model assumes neutral risk attitudes among investors and equates the expected rate of return with the risk-free rate, findings from economics and neuroeconomics suggest that currency call options are influenced by subjective opinions, psychological factors, and market sentiment. This highlights the relevance of behavioral finance in understanding investor behavior and its integration into investment strategies.

Our paper has specifically focused on the impact of including market sentiment in the valuation of currency options. We conducted a comparative analysis of call option valuations using the G-K model, both with and without the sentiment factor. Our analysis, covering data from five currency call options from January 1, 2018, to November 24, 2022, revealed that incorporating the market sentiment factor—reflecting the divergent behaviors of investors in the market—significantly improves the model's pricing performance. The inclusion of sentiment in the valuation formula yielded estimates that align more closely with actual market prices.

In essence, including market sentiment in option valuation enhances the precision of pricing. Market sentiment encapsulates the collective perceptions and expectations of market participants regarding future price movements of the underlying asset. By factoring in this sentiment, the pricing model more accurately mirrors market participant expectations, leading to better forecasts of future volatility and price trends of the underlying currency. This approach not only yields a more precise valuation of currency options but also reduces the likelihood of pricing biases, thereby enhancing the overall accuracy of the pricing model.

However, it's important to acknowledge the limitations of our study. While the integration of market sentiment significantly enhances the G-K model, our approach relies on the accurate measurement of sentiment, which can be challenging due to its subjective nature. Additionally, the model's reliance on historical data may not fully capture sudden market shifts or unprecedented events.

For future research, exploring more sophisticated methods of quantifying market sentiment would be beneficial. This could involve harnessing advanced data analytics techniques, such as machine learning algorithms, to analyze market news, social media trends, or investor surveys for a more nuanced understanding of sentiment. Further, extending the study to include a broader range of currency pairs and different market conditions would provide a more comprehensive view of the model’s applicability. It would also be valuable to examine the interplay between market sentiment and other behavioral factors, such as investor overconfidence or herd behavior, to deepen our understanding of their collective impact on currency option pricing. Finally, investigating the model's performance during periods of high market volatility or economic crises could offer insights into its robustness and reliability in diverse market scenarios.

DECLARATION OF COMPETING INTEREST: NONE.

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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AUTHOR

Wael Dammak holds a PhD in finance and is associated with the University of Lyon, specifically at the University Claude Bernard Lyon 1. He is part of the Institute of Financial and Insurance Sciences, LSAF-EA2429, located in Lyon, France.

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