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Evaluating the Choices of Strike Ranges for the Long Call Condor Strategy

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A B S T R A C T

This study proposes a new perspective on strike ranges to benefit long call condor strategy traders, enabling them to capture potential opportunities in response to market scenarios. We derive the analytical solutions for the long call condor strategy's fair value and risk sensitivity. We also explore how the choice of strike ranges influences the strategy's risk and rewards for traders. The findings suggest that a wider range of insider strikes lowers the profits of strategy traders, while a wider range for outsiders enlarges the profits. We recommend designing option portfolios with different strikes to enable strategy traders to capture potential interests more effectively if they expect specific market scenarios.

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1. Introduction

Investors enter the derivatives markets to pursue profits and manage potential risks by implementing appropriate strategies. Forming an options trading strategy is viable for traders to promote payoffs and mitigate risk, compared to holding plain vanilla options. Strategy traders attempt to select various options with different maturities, types, and strikes to respond effectively to market movements. In the context of these long-term and important issues, we examine how strategy traders select strike ranges based on their option positions to create value. Due to the difficulty in evaluating all trading strategies, we focus on one of the popular strategies, the long call condor (hereinafter, LCC) strategy, to examine how traders select appropriate option contracts with appropriate strike levels. Since little research has been conducted on the fair value and strike ranges of option trading strategies, deriving a formula for fair value, risk sensitivity, and options portfolio design is a challenging task that relies primarily on considering the valuation of the option strategies and analyzing the market scenarios.

The LCC strategy consists of one long in-the-money call, one short higher middle strike in-the-money call, one short middle out-of-the-money call, and one long highest strike out-of-the-money call, all with the same expiry date. The LCC strategy is implemented to achieve specific goals of stable returns in the face of market movement. Meanwhile, this strategy is profitable if the underlying price falls within the confines of the two breakeven points and is unprofitable when the underlying price exceeds either of the two breakeven points. The maximum possible profit is realized when the underlying security price falls somewhere between the strikes of the written options. A profit will also be made if the underlying security price moves slightly outside this range. However, a loss will be caused if it goes too far in either direction. Thus, the choice of strike prices in the LCC strategy is a matter for strategy traders to capture potential profits.

In this study, we re-examine the condor strategy to identify the impacts of strike ranges on the strategy value and risk management. We provide three remarkable viewpoints in the literature. First, the study aims to price the condor strategy by deriving the closed-form solution of the fair value for the long call condor strategy. The theoretical fair value of the condor strategy enables traders to assess accurately whether it is a better choice, considering the various components of call options based on their strike ranges. Specifically, we first derive the theoretical fair value of the condor strategy in the literature. Second, we derive the Greek letters to analyze the sensitivity of strategy values over risk exposures. The Greek letters benefit the analysis of strategy values in response to the various risk exposures. We believe this is the first work presenting the analytical risk measures of LCC trading strategies. Third, the strike ranges offer us an observation of how market movements influence the strategy values. A wider or narrower range of strike levels within the options portfolio significantly impacts the strategy's value and risks. Choosing a suitable structure of strike ranges in the condor strategy benefits traders by capturing relatively higher profits and mitigating potential risks. Combining the above three viewpoints to derive strategy value, acquire risk measures, and set strike range is crucial for the decision-making process of condor strategy traders.

This article proposes a new perspective, the strike range, to identify how options traders formulate an optimal condor strategy to create the value of their strategies. Our research results provide traders with a comprehensive understanding of the strategy, its potential outcomes, and practical guidance for implementing and managing trading situations. If the market scenario is correctly expected, we find that choosing a narrower strike range is preferred for traders who employ the LCC strategy. In that case, they can formulate the LCC strategy by planning an appropriate strike range in response to market movements.

We are concerned about the following issues, which we address through theoretical analysis to address the above considerations. First, this study answers the question of how we price the fair value of the LCC strategy. Evaluating fair value is crucial for assessing the strategy's performance under various scenarios. In our pricing task, the LCC strategy's fair value is the sum of the fair values of its option positions, as the strategy consists of four plain-vanilla options. The analytical solution of fair value can be carried out using a risk-neutral probability measure[2]. The estimated fair value results for

[1] Refer to Kwok (1998).

the LCC strategy vary with the market conditions, return volatility, and other factors.

Next, we explore how to implement risk management of the condor strategy. The traders of a condor strategy aim to reduce risk and increase the chances of success. However, that comes with reduced profit potential and increases the costs of trading several options legs. If the market conditions change, traders can adjust their LCC strategy by modifying the call options' strike prices by setting a stop-loss order at a predetermined price level. Zhong (2023) suggests that options trading is risky and challenging. It requires investors to conduct in-depth market analysis and develop effective trading strategies, while options traders must also understand risk management issues. Thus, we employ Greek letters to measure the degrees of risk exposure resulting from changes in underlying asset values, interests, return volatility, and contract maturity.

Finally, based on the results of the strategy value and Greek letters, this study examines how to choose appropriate strike ranges for condor traders. The LCC strategy is generally considered more suitable for traders in a range-bound market condition, where they believe the underlying security will experience minimal volatility and trade within a specified price range. The LCC strategy can be effective in a range-bound market because it is designed to generate profits when the underlying asset's price remains within a specific range. The strategy trader creates a profit zone within a specific price range, which can be profitable if the underlying asset's price remains within that range. According to the LCC strategy's portfolio of call options, the maximum potential profit occurs when the underlying price is within the range of the two middle strike prices. On the other hand, a possible loss occurs when the underlying price falls below the lowest strike price or rises above the highest strike price. Specifically, the study also discusses the special case of the long call butterfly strategy, a variant of the LCC strategy. The long call butterfly consists of two short calls at a middle strike and one long call at each lower and upper strikes. The upper and lower strikes are equidistant from the middle strike, and all options have the same expiration date. As the LCC strategy's two middle strikes are considered to approach each other, the LCC strategy gradually becomes the long call butterfly strategy.

Although the LCC is one of the rather complex options trading strategies, with four legs involved, it offers great flexibility in setting a strike range from which options traders can profit. Based on the above discussion, we examine potential interests in different ranges between four strikes in the LCC strategy. Therefore, to succeed in trading, traders should establish a policy for option portfolios with appropriate strike price choices to balance risk and reward when seeking potential opportunities in the financial markets.

Previous studies have demonstrated that the options portfolio strategy effectively generates profits while mitigating risks (Liu *et al*., 2021; Kang *et al*., 2022; Shivaprasad *et al*., 2022; Rustamov *et al*., 2024). We extend this stream of research by focusing on the strike ranges of condor strategy and analyzing how strategy traders capture potential interests from various market scenarios. We present our observations of strategy values across insider and outsider ranges of strike levels and recommend to traders how to select option contracts in the LCC strategy. Our findings suggest that wider or narrower strike ranges can directly impact strategy values. Traders should choose a narrower inside range to capture the maximum strategy interests and a wider outside range to gain more potential payoffs.

This study contributes to the literature on option trading strategies in the following ways. First, we derive and offer a fair value for the long condor strategy, enabling traders to evaluate its value more accurately and make better-informed decisions about whether to take this position. Previous studies do not provide concrete results of the strategy values of a condor. Second, the study also focuses on developing effective risk management for the condor strategy, helping traders better manage their risk exposure and potentially increase their returns. Third, we examine the strike ranges to explore how strategy traders determine an appropriate range of strikes for their options. Setting strike ranges is critical to capturing profits in response to market movements. Framing the closed-form solution of fair value for the LCC strategy, we can provide concrete recommendations for traders to incorporate into their option portfolios.

This study consists of five sections. Section 2 reviews the literature on the LCC strategy and risk management. Section 3 shows our research methodology, including given assumptions and derivations of closed-form solutions for fair value and Greek Letters based on the Black-Scholes model. Section 4 covers numerical analysis for our tasks, addressing the abovementioned issues and providing evident results, specifically in analyzing strike ranges across market scenarios. Section 5 concludes with a brief discussion of the managerial implications of this research.

2. Literature Review

The literature on options trading strategies has evolved from various perspectives, particularly in the context of spread trading. Practitioners and sophisticated traders employ various strategies in options markets, with a growing proportion of option spread trading (Chaput and Ederington, 2003; Falenbrach and Sandås, 2010; Stoltes and Rusnáková, 2012; Liu *et al.*, 2021; Hemler *et al.*, 2024). Chaput and Ederington (2003) reveal that option spread trading totals 29% of Eurodollar options trading volume, while Falenbrach and Sandås (2010) show that vertical call and put option spread trading represents 16% of FTSE 100 index options trading volume. Hemler *et al*. (2024) examine the relative performance of four options-based investment strategies versus a buy-and-hold strategy in the underlying stock. Their results show that options-based strategies can improve the risk-return performance of market traders' portfolios. Overall, the literature on options trading strategies suggests that while they can generate substantial profits, they also involve significant risks and require a thorough understanding of the market and options trading.

Previous literature also discusses the characteristics of condor strategies and examines the relationships between risk and reward. McKeon (2016) supports that long call condor strategies are limited, directional, or non-directional risks constructed to generate a limited profit when seeking little or no movement in the underlying. Niblock (2017) demonstrates that the primary benefit of long call condors is that they can be set up to accommodate anticipated market conditions over the intended holding period, enabling investors to target investment goals tailored to their desired risk-return profiles. In addition, McKeon (2016) finds that the long volatility condor strategy adds value for traders and investors seeking positively skewed return distributions.

Risk management is a complex and crucial consideration when implementing the spread strategy (Chen *et al*., 2010; Jongadsayakul, 2018; Ewa, 2022; Shivaprasad *et al*., 2022; Jain, 2023), particularly for condor and butterfly strategies, as the strategies involve both limited risk and reward. Specifically, Ewa (2022) presents the structure of the iron condor strategy to examine the impact of the underlying instrument's price on the strategy's value and the value of the Greek letters. The author demonstrates that all risk measures associated with the iron condor strategy fluctuate significantly over time, indicating that the strategy's values are highly sensitive to changes in its underlying factors. Jain (2023) suggests that the iron condor strategy should ideally be initiated on stocks with higher implied volatility and advises traders to verify that stock options are relatively liquid, exercising caution when executing the trade. Shivaprasad *et al*. (2022) examine the risk-return trade-off of the long straddle, long strangle, and long call butterfly strategies. They suggested that strategy investors can improve excess returns relative to the risks by choosing the appropriate strategy and analyzing the impact of risk on the payoff.

Our work is related to the extensive theoretical literature investigating the spread strategies that use more options. Specifically, we have mentioned that strategy traders consider forming the LCC strategy by combining four options with different strike prices. Choosing the strike ranges between options will influence profits and losses. Based on this important issue, the present article aims to derive the closed-form solution for the LCC strategy's fair value and Greek letters and then analyze the impacts of strike ranges on the fair values in response to market movements.

3. Methodology

This section presents the derivation of the fair value of a long call condor, along with its associated Greek letters. We first describe the assumptions used to derive our formula and then outline the process used to obtain it based on the Black-Scholes (1973) formula.

3.1 Assumptions

This section presents the assumptions used to derive the closed-form solution for the fair value of the LCC strategy. The strategy is constructed by holding four options: buying one in-the-money (ITM) call (low strike), selling one ITM call (lower middle), selling one out-of-the-money (OTM) call (higher middle), and buying one OTM call (high strike), all with the same expiry date and underlying assets. We give the options' underlying is a representative stock[2], whose price (S_t) of the underlying stock follows a geometric *Brownian* motion[3] (*GBM*):

$$\frac{dS_t}{S_t} = (r - q)dt + \sigma dW_t \tag{1}$$

where St represents the underlying stock's price at time t, q represents the continuous dividend yield of the underlying stock, r represents the risk-free interest rate, and σ represents the underlying stock's volatility. The geometric *Brownian* motion process frames in a complete probability space (Ω, Σ, $\boldsymbol{Q}$) with filtration $\{\Sigma_t\}$, where $W^P(t)$ is *Wiener* process under a real-world probability $\boldsymbol{P}$-measure, in which $\Delta W(t) = W(t) - W(t-\Delta t) \sim N(0, \Delta t)$.

For simplicity's sake and without the loss of generality, we make some assumptions consistent with the works of Black and Scholes (1973), Merton (1974), Zhang and Zhou (2024), and other researchers. First, to derive a closed-form solution, the options contracts are European-style. Second, the transactions of stocks, risky assets, risk-free assets, and derivatives occur continuously. Third, we assume that trading has no transaction costs, taxes, or short-selling restrictions. Fourth, options traders can access a riskless asset with a risk-free interest rate in a financial market.

3.2 Pricing the LCC Strategy

The LCC strategy is constructed by buying one call option with a lower strike price (K_1), selling one call with a lower middle strike price (K_2), selling one call with a higher middle strike price (K_3), and buying one call with a higher strike price (K_4). All four option contracts have the same expiration date, *T*.

$$V_t = +C_t(K_1) - C_t(K_2) - C_t(K_3) + C_t(K_4) \tag{2}$$

where V_t represents the strategy value of the LCC at time t, and the terms $C_t(K_i)$ represent the prices of the European call options with strike prices K_i, at time t. Furthermore, under a risk-neutral probability measure $\boldsymbol{Q}$, the underlying stock price has the following formula at maturity T, where τ ($= T - t$) represents the time to expiration of the options involved in the strategy.

$$S(T) = S(t)e^{\sigma W^Q(T-t) + (r - \frac{1}{2}\sigma^2)(T-t)}$$

By a risk-neutral probability measure approach, the value of a financial asset should be equal to the discounted value of the expected future cash flows, where the risk-free interest rate (r) is used to discount the future value and a risk-neutral probability is used to average the possible outcomes. Thus, under a probability measure-$\boldsymbol{Q}$, the LCC strategy's value[4] (V_t) is written as.

$$V_t = e^{-r(T-t)}E(V_T)$$

Taking the Black and Scholes option pricing model's analytical solution of European-style plain vanilla call, we have the following formula.

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[2] This strategy typically uses stocks or indexes as its underlying asset, and the choice of underlying asset depends on the investor's market outlook and preferences.

[3] Refer to Karatzas and Shreve (2000).

[4] Because the LCC strategy consists of four European plain vanilla call options, we can directly apply the results of Black and Scholes's option pricing model in its pricing process.

$$V_t = S_t e^{-q\tau}\left[N(d_{1,1}) - N(d_{2,1}) - N(d_{3,1}) + N(d_{4,1})\right]$$
$$-e^{-r\tau}\left[K_1 N(d_{1,2}) - K_2 N(d_{2,2}) - K_3 N(d_{3,2}) + K_4 N(d_{4,2})\right] \quad (3)$$

where,

$$d_{1,1} = \frac{\ln\left(\frac{S_t}{K_1}\right) + \left(r - q + \frac{\sigma^2}{2}\right)\tau}{\sigma\sqrt{\tau}} \quad (4)$$

$$d_{2,1} = \frac{\ln\left(\frac{S_t}{K_2}\right) + \left(r - q + \frac{\sigma^2}{2}\right)\tau}{\sigma\sqrt{\tau}} \quad (5)$$

$$d_{3,1} = \frac{\ln\left(\frac{S_t}{K_3}\right) + \left(r - q + \frac{\sigma^2}{2}\right)\tau}{\sigma\sqrt{\tau}} \quad (6)$$

$$d_{4,1} = \frac{\ln\left(\frac{S_t}{K_4}\right) + \left(r - q + \frac{\sigma^2}{2}\right)\tau}{\sigma\sqrt{\tau}} \quad (7)$$

$$d_{1,2} = \frac{\ln\left(\frac{S_t}{K_1}\right) + \left(r - q - \frac{\sigma^2}{2}\right)\tau}{\sigma\sqrt{\tau}} \quad (8)$$

$$d_{2,2} = \frac{\ln\left(\frac{S_t}{K_2}\right) + \left(r - q - \frac{\sigma^2}{2}\right)\tau}{\sigma\sqrt{\tau}} \quad (9)$$

$$d_{3,2} = \frac{\ln\left(\frac{S_t}{K_3}\right) + \left(r - q - \frac{\sigma^2}{2}\right)\tau}{\sigma\sqrt{\tau}} \quad (10)$$

$$d_{4,2} = \frac{\ln\left(\frac{S_t}{K_4}\right) + \left(r - q - \frac{\sigma^2}{2}\right)\tau}{\sigma\sqrt{\tau}} \quad (11)$$

where $N(d_i)$ represents the cumulative distribution function of the standard normal distribution based on the standard normal variables d_i. These equations are derived from the Black-Scholes option pricing model assumptions, which assume a continuous dividend yield and constant volatility.

3.3 Greek Letters

The main Greek letters associated with the LCC strategy include *Delta*, *Gamma*, *Rho*, *Theta*, and *Vega*. These Greek letters measure the sensitivities of strategy values over some strategy factors. Based on the closed-form solution (3) of the LCC strategy, we derive the following formulas:

$$Delta_t = e^{-q\tau}[N(d_{1,1}) - N(d_{2,1}) - N(d_{3,1}) + N(d_{4,1}) \quad (12)$$

$$Vega_t = S_t e^{-q\tau}[n(d_{1,1}) - n(d_{2,1}) - n(d_{3,1}) + n(d_{4,1}) \quad (13)$$

$$Gamma_t = \frac{e^{-q\tau}}{S_t\sigma\sqrt{\tau}}[n(d_{1,1}) - n(d_{2,1}) - n(d_{3,1}) + n(d_{4,1})] \quad (14)$$

$$Rho_t = \tau e^{-r\tau}[K_1 N(d_{1,2}) - K_2 N(d_{2,2}) - K_3 N(d_{3,2}) + K_4 N(d_{4,2})] \quad (15)$$

$$Theta_t = \frac{S_t \sigma e^{-q\tau}}{2\sqrt{\tau}}[n(d_{1,1}) - n(d_{2,1}) - n(d_{3,1}) + n(d_{4,1})] \tag{16}$$

$$-re^{r\tau}[K_1 N(d_{1,2}) - K_2 N(d_{2,2}) - K_3 N(d_{3,2}) + K_4 N(d_{4,1})]$$

$$+qS_t e^{-q\tau}[N(d_{1,1}) - N(d_{2,1}) - N(d_{3,1}) + N(d_{4,1})]$$

where $n(x)$ represents the probability density function of the standard normal distribution.

We have derived the closed-form solutions for these Greeks of long call condor strategy, in which these Greeks express several measures of risk exposures on the strategy values. Notably, the *Delta* value reflects the change in strategy values in response to movements in the underlying stock price (S_t). If the strategy's *Delta* approaches zero, the strategy is designed to neutralize small changes in the underlying asset's price. The *Gamma* reflects *Delta*'s movement, and the *Theta* indicates the change in strategy value over time. The *Vega* presents the sensitivity of strategy value over stock return volatility (σ). Finally, the *Rho* shows the strategy's interest rate risk. Due to the complexity of the Greek letters described above, we implement numerical calibrations for the strategy value, risk measurements, and the impact of the strike range.

4. Numerical Calibration

We implement a numerical procedure and perform comparative statics to examine how the strategy value changes in response to various factors. The results are generated using the 2023 version of the Matlab software. Specifically, we address several issues related to strategy values, sensitivity analyses, formulating an effective strategy of strike ranges in response to market fluctuations, and comparison issues with long call butterfly.

We specify a representative case to analyze the value and risk measures of the long-call condor strategy. That is a baseline case of the LCC strategy considered within the following scenario. The initial values of parameters in the LCC strategy pricing model (3) are set as follows: the current stock price S_t of \$100, the lowest strike K_1 of \$85, the middle lower strike K_2 of \$95, the middle higher strike K_3 of \$105, the highest strike K_4 of \$115, the risk-free rate r of 10%, the time to maturity $T-t$ of 1 year, the return volatility σ of 30%, and dividend yield rate q of 5%.

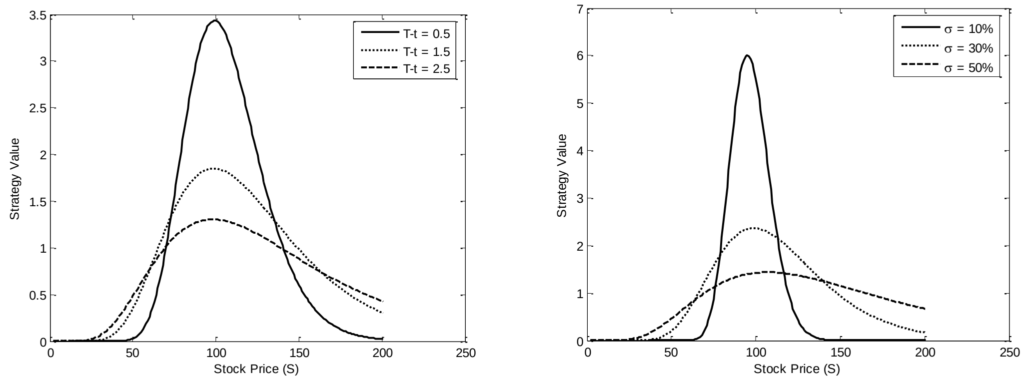
4.1 Strategy Values

Long call condor is an options trading strategy comprising four legs. These legs represent call options with different strike prices but the same expiration dates. We estimate the fair value of the representative long call condor strategy based on the determinants in pricing model (3). We show our results in Figure 1 and Table 1 and summarize our findings in the following descriptions.

Figure 1 illustrates the dynamics of the LCC strategy's fair value (V_t) about stock prices in a two-dimensional plot. First, the strategy values are relatively higher when the stock price is in a narrow range near two inside strikes (K_2, K_3). The results suggest that the LCC strategy traders seek maximum values by expecting invariant stock prices around the inside strikes. Strategy traders expect the underlying asset's price to remain stable, typically within the inside ranges (K_2, K_3) at expiry. Conversely, the strategy's value declines if the stock price deviates significantly from the inside range. Second, conversely to common recognition, a shorter-run LCC strategy has relatively greater strategy values, as shown in Panel A of Figure 1. As the time to maturity is shorter, the concrete terminal results tend to be identified, resulting in a higher value within the middle strike interval and a lower value outside the interval of the lowest and highest strike levels. Third, the strategy value is lower under these market conditions, which are characterized by higher return volatility. Panel B of Figure 1 shows that strategy values are relatively higher as the return volatility rate is 10%, and the fair value curve is depressed as the return volatility is 50%. The result implies that the LCC strategy is less feasible for creating value as the market varies highly. Higher return volatility disperses the stock price distribution, making it less likely for the stock price to remain within the range of middle strikes.

Therefore, the call condor strategy exhibits distinct values over time to maturity and return volatility compared to the plain vanilla call option[5].

Figure 1: Long Call Condor's Values



Panel A: Varying with maturity **Panel B: Varying with return volatility**

Note: The figure illustrates the fair value of the LCC strategy as it varies with the stock price, return volatility, and time to maturity. The initial values of parameters in the closed-form solution of long call condor strategy are set as follows: the current stock price S_t of \$100, the lowest strike K_1 of \$85, the second lower strike K_2 of \$95, the strike K_3 of \$105, the greatest strike K_4 of \$115, the risk-free rate r of 10%, the time to maturity T – t of 1 year, the return volatility σ of 30%, and dividend yield rate q of 5%

Table 1 presents the condor strategy (V_t) values as they vary with its determinants. First, the estimated value (V_t) decreases if the underlying stock price moves significantly to the downside or upside. The value increases as the underlying asset price approaches the range of two middle-strike prices. The maximum profits occur in the middle strikes (K_2 and K_3). This result notes that strategy traders should not expect the underlying stock price of the condor strategy to change significantly. Second, Panel B presents a negative relationship between the condor strategy values (V_t) and the lowest strike price (K_1). For example, if the K_1 gradually increases from \$66 to \$74, the strategy value (V_t) declines from \$15.6174 to \$7.6095. The reason for a declining trend for strategy values is that the profit is depressed as the lowest strike price increases. The feasible profit is reduced on narrower spans. Third, we see a negative impact of the riskless rate on the strategy values, as shown in Panel C of Table 1. Since the condor strategy trader receives a portfolio of call options with different strikes, the terminal values of the payoffs are thus reduced at the initial date, given a higher interest rate. The results are recommended to condor traders, who believe the strategy is more appropriate during a low market interest rate. Fourth, as shown in Panel D, the return volatility (σ) affects the condor values (V_t) inconsistently; however, the strategy value tends to be higher when return volatility is relatively lower. The reason for the inconsistent impacts is that the condor strategy is easily out-of-the-money, as the asset risk is higher, resulting in a lower possibility of receiving payoffs. Another reason is that the condor strategy offers higher payoffs at expiration if the terminal stock price is within the inner strikes; therefore, low-volatility underlying assets are preferred. However, as the time to maturity ($T – t$) increases, the maximum condor values (V_t) gradually shift to a location at a higher stock price.

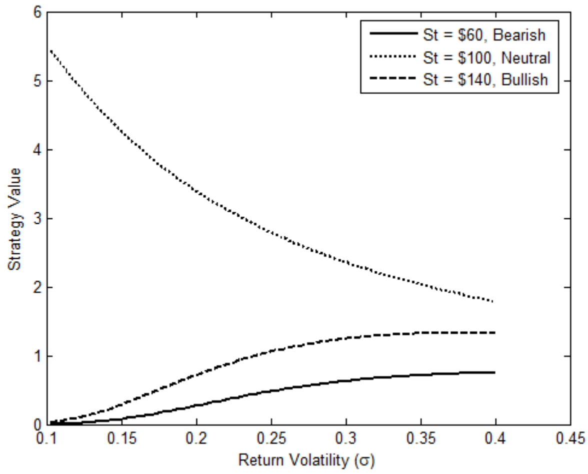
We have the following implications from the summary of the return volatility's impacts on the strategy values from Table 1 and Figure 1. The underlying stock's return volatility (σ) plays an important role in the LCC strategy under various market scenarios. If LCC traders expect the market to be neutral, they tend to choose the strategy that the current stock price falls within the insider range of strike prices. Given the neutral market, the lower return volatility benefits strategy traders since the strategy value of the options positions is expected to be higher. On the other hand, he thinks the current stock price is lower than K_1 or higher than K_4, which is a bullish or bearish market scenario. He prefers the stock price's more volatile dynamic since the underlying asset's terminal price is more likely in the insider ranges of two middle strikes, resulting in a high possibility of receiving payoffs[6].

[5] Note that the call option's value increases with the time to maturity and return volatility.

[6] We are thankful for the referee's recommendation to offer an analysis of strategy traders' choices under market scenarios.

Specifically, as shown in Panel B of Figure 1, the strategy value is relatively greater for the neutral market (the stock price falls in the insider range) and for the bullish and bearish markets (the stock price is lower than K_1 or higher than K_4, respectively).

Figure 2: Return Volatility and Market Condition



Note: The figure illustrates the fair value of the LCC strategy as it varies with return volatility under different market scenarios: bearish, neutral, and bullish. The initial values of parameters in the closed-form solution of long call condor strategy are set as follows: the current stock price S_t of $100, the lowest strike K_1 of $85, the second lower strike K_2 of $95, the strike K_3 of $105, the greatest strike K_4 of $115, the risk-free rate r of 10%, the time to maturity T – t of 1 year, the return volatility σ of 30%, and dividend yield rate q of 5%.

Table 1. Fair Values of LCC Strategy

Panel A: Stock price (S_t)					
	S = $60	S = $80	S = $100	S = $120	S = $140
$T = 2$	$0.7870	1.3607	1.5272	1.3732	1.0904
$T = 4$	0.6447	0.8438	0.8891	0.8383	0.7429
$T = 6$	0.4847	0.5773	0.5953	0.5705	0.5246
Panel B: Lowest strike price (K_1)					
	K_1 = $45	K_1 = $55	K_1 = $65	K_1 = $75	K_1 = $85
$T = 2$	28.9841	21.2051	13.9247	7.3281	1.5272
$T = 4$	21.5761	15.6628	10.2225	5.2963	0.8891
$T = 6$	16.7418	12.1467	7.9257	4.0799	0.5953
Panel C: Interest rate (r)					
	r = 3%	r = 6%	r = 9%	r = 12%	r = 15%
$T = 2$	1.6864	1.6374	1.5591	1.4558	1.3331
$T = 4$	1.0779	1.0190	0.9260	0.8089	0.6792
$T = 6$	0.7924	0.7294	0.6326	0.5169	0.3980
Panel D: Return volatility (σ)					
	σ = 3%	σ = 6%	σ = 9%	σ = 12%	σ = 15%
$T = 2$	3.0279	2.6269	2.2973	2.0297	1.8112
$T = 4$	1.6294	1.4694	1.3114	1.1715	1.0514
$T = 6$	0.9933	0.9368	0.8563	0.7752	0.7009

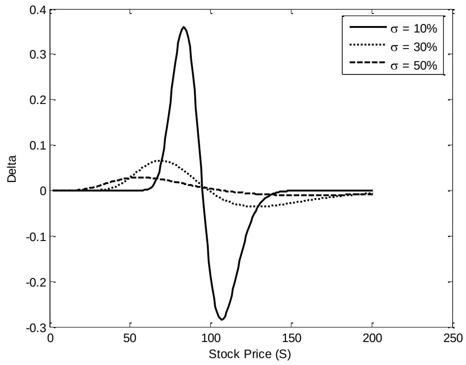
Note: The table presents the values of the LCC strategy, which vary with the stock price, return volatility, the lowest strike price, and the time to maturity. The initial values of parameters in the closed-form solution of long call condor strategy are set as follows: the current stock price S_t of $100, the lowest strike K_1 of $85, the second lower strike K_2 of $95, the strike K_3 of $105, the greatest strike K_4 of $115, the risk-free rate r of 10%, the time to maturity T – t of 1 year, the return volatility σ of 30%, and dividend yield rate q of 5%.

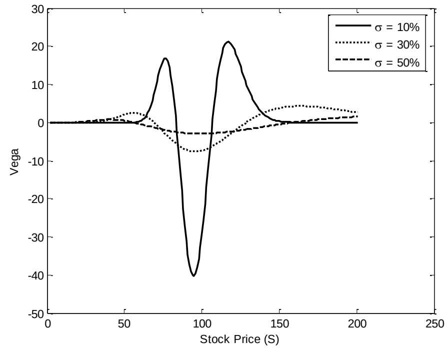
4.2 Sensitivity Analyses

A sensitivity analysis of a long call condor strategy would involve evaluating the impacts of changes in the strategy's determinants. By understanding these sensitivities, traders can make more informed decisions about the strategy's potential risks and rewards and adjust their positions accordingly. The study examines the characteristics of Greek letters

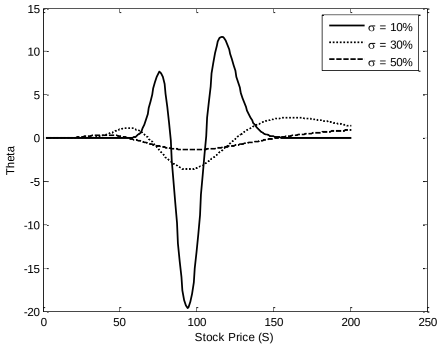
Figure 3 presents the Greek letters associated with the condor strategy. In Panel A, the *Delta* changes dramatically over the stock price. Notably, the *Delta* gradually increases from zero to its maximum value before the strike on K_2. Sudden decreases occur within the inner range (K_2, K_3), and subsequently, it increases from its minimum to zero after the strike K_4. A reason for a positive *Delta* is that the condor strategy payoff increases if the stock price increases over the range (0, K_2). Otherwise, a negative strategy *Delta* shows a decreasing trend in strategy values (V_t) if the stock price increases, as shown in the ranges (K_2, K_3). Option strategy traders should recognize the changing process in strategy values (V_t) as the stock price falls within the range of ($K_2 < S_t < K_3$), and condor traders carefully respond to changes in the underlying stock price by taking hedging behaviors using other instruments.

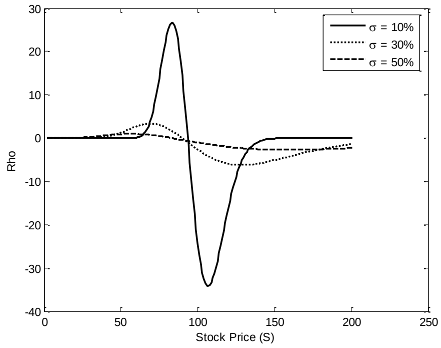
Figure 3: Greek Letters of Long Call Condor Strategy



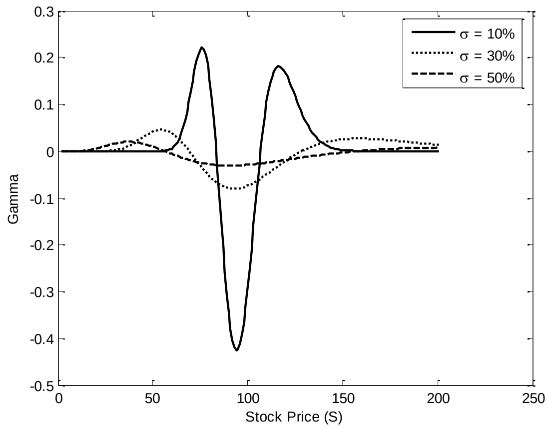


Panel A: *Delta* **Panel B: *Vegas***





Panel C: *Theta* **Panel D: *Rho***



Panel E: *Gamma*

Note: The figure presents the values of the LCC strategy's Greek letters as the stock price and return volatility vary. The initial values of parameters are listed in Figure 1.

Next, note that the LCC strategy consisted of two long and two short calls, resulting in a strategy with complicated *Vega* dynamics. Panel B of Figure 3 shows that *Vegas* performs with positive, negative, or zero values, depending on the different strike ranges. First, focusing on the negative, *Vega* appears in the two middle strikes (K_2, K_3). The results indicate that the condor strategy trader benefits from lower-risk market scenarios. Second, the *Vega* shows a positive value when the stock price is within the ranges (K_1, K_2) and (K_3, K_4). Given other conditions, the underlying asset's price with a higher return volatility (σ) appears in the above strike ranges; the effect is positive for the condor strategy's values (V_t) since a higher return volatility (σ) is more likely to sway the stock prices enter the inside range at the expiration date. Third, the *Vega* values are susceptible to zero as the stock price exceeds the highest strike (K_4) or is lower than the lowest strike (K_1). It means that changes in return volatility (σ) affect the condor strategy's values (V_t) less significantly. To summarize the results above, we suggest that strategy traders may consider taking positions in other options or securities negatively correlated with *Vegas* if they intend to hedge against movements in stock return volatility by observing the strategy's *Vegas*.

Next, the *Theta* measures the rate of change for the strategy value over time. Panel C in Figure 3 indicates a plot of the condor strategy's *Theta* dynamics. The *Theta* remarkably declined as the stock price rose in the strike ranges (K_1, K_2) and (K_3, K_4). The condor value (V_t) decays over time if the stock price (S_t) is in the strike ranges (K_1, K_2) and (K_3, K_4). However, if the underlying stock's price falls within the inside range (K_2, K_3), the *Theta* immediately increases in value above the inside range. Besides, the strategy's *Theta* will reach zero as stock return volatility (σ) increases. The reason is that when stock return volatility (σ) is larger, the time value of the options involved in the strategy tends to be ignored. As time passes, the time value of the options becomes less remarkable. Hence, investors who employ a long call condor strategy should consider the impact of stock return volatility (σ) on the strategy's *Theta*. Higher return volatility may suggest a need for a more inactive position adjustment in response to the time decay.

Moving our discussion to the *Rho*, we measure the sensitivity of the strategy value in response to changes in interest rates. Panel D in Figure 3 illustrates the dynamics of the strategy's *Rho*, which varies significantly with the stock price. The strategy's *Rho* increases in the range (K_1, K_2), then declines in the range (K_2, K_3), and subsequently increases in the range (K_3, K_4) as the underlying stock's price rises gradually. Due to the LCC strategy comprising four call options, the explanation of *Rho*'s dynamics involves the combined effects of long and short calls. Besides, a higher stock return volatility (σ) implies greater uncertainty about the underlying asset's future price movements, which reduces the impacts of interest rates (r), making the strategy less sensitive to changes in interest rates.

The *Gamma* measures the rate of change of the strategy's *Delta* in response to changes in the underlying asset's price. In the case of a long call condor strategy, which consists of four options positions, the overall *Gamma* of the strategy will depend on the individual *Gamma* values of each position. As shown in Panel E in Figure 3, the condor strategy appears to have a maximum negative *Gamma* between the strikes (K_2, K_3). This implies that strategy traders should reduce their reaction to *Delta* management, as the condor strategy's payoff curve is more pronounced, making it more likely for option traders to profit. Over the ranges of (K_1, K_2) and (K_3, K_4), the condor's *Gammas* are positive, implying that the change rate of *Deltas* is apparent, suggesting that strategy traders are encouraged to take an aggressive attitude to adjust positions in response to the market movements. Outside of the lowest and largest strikes, the *Gammas* are lower. Also, a higher return volatility mitigates the movements of Greek letters.

4.3 Strike Ranges

The primary issue of this study is how strategy traders formulate a portfolio of call options with different strike prices to maximize the LCC traders' profit. As a result, the choice of strike ranges plays a notable role in forming the LCC strategy. A wider or narrower strike range influences the possibility of creating strategy values in response to market conditions.

We examine numerical results from our theoretical valuation formula by adjusting the widths of strike ranges to identify changes in fair value for the LCC strategy. To address the issues we have identified, this study sets stock prices at \$130, \$100, and \$70 for the scenarios of bullish, neutral, and bearish markets. A neutral market responds with stability and remains near the initial stock price. Additionally, the width ($K_3 - K_2$) of the inside range and the width ($K_4 - K_1$) of the outside range are centered around the initial stock price of \$100.

A wider range of outside strikes allows strategy traders to make more profits. Table 2 shows the strategy's fair values varying with the outside ranges and presents a growing trend for LCC strategy's fair values over the width of outside strikes. For example, the fair value (V_t) increases from \$2.3598 to \$6.8598 if we widen the strike ranges (K_1, K_4) from (\$85, \$115) to (\$75, \$125) around the underlying stock's initial price. A lower lowest strike price (K_1) or a rising highest strike price (K_4) can widen the outside ranges and capture more potential profits in the LCC strategy. The economic implication is that strategy traders shall buy the options with the lowest strike and the highest strike price to construct the strategy. Although the former has relatively high costs and the latter has relatively low costs, the sum of two long call options may maintain a cost level.

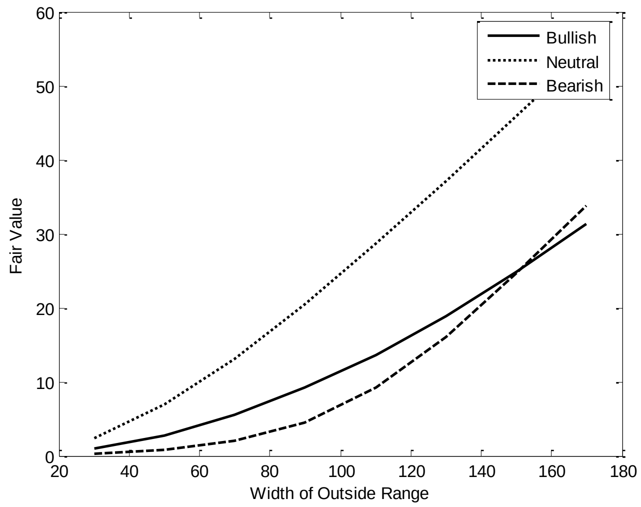
Table 2. LCC Strategy's Fair Values and the Width of Outside Ranges

(K_1, K_4)	V_t
(\$85, \$115)	\$2.3598
(\$75, \$125)	6.8598
(\$65, \$135)	13.0852
(\$55, \$145)	20.5073
(\$45, \$155)	28.6283

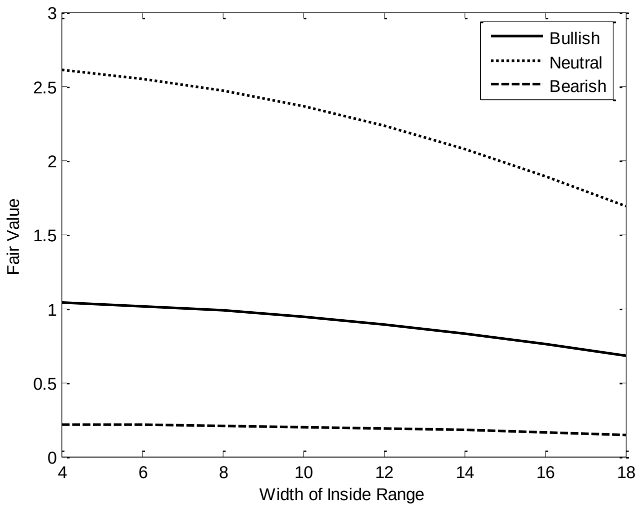
Note: The table presents the impacts of the width for outside ranges (K1, K4) of strike prices on the LCC strategy values. The initial values of parameters in the closed-form solution of long call condor strategy are set as follows: the current stock price S_t of \$100, the lowest strike K_1 of \$85, the second lower strike K_2 of \$95, the strike K_3 of \$105, the greatest strike K_4 of \$115, the risk-free rate r of 10%, the time to maturity T – t of 1 year, the return volatility σ of 30%, and dividend yield rate q of 5%.

Next, the study examines how market scenarios impact the results mentioned above. As shown in Pane A of Figure 4, widening outside ranges is more feasible for the neutral market than for the bullish and bearish markets. Three curves represent the dynamics of fair value for the LCC strategy over the widths of the outside ranges given three market scenarios. The fair values gradually increase over the widths of the outside ranges for all market scenarios. However, a wider range of outside strikes can boost profits more in the neutral market scenario because the future market price is more likely to fall in the range. Our findings suggest that a wider range of outside strikes is more appropriate for the neutral market.

Figure 4: Strike Ranges and Fair Value of LCC Strategy



Panel A: Outside ranges



Panel B: Inside ranges

Note: The figure illustrates the dynamics of fair value in response to changes in strike ranges. The sizes of the outside range ($K_4 - K_1$) and inside range ($K_3 - K_2$) are determined by adjusting the width of the strike ranges around the initial stock price. The initial setting of model parameters is listed in Figure 1. The setting of market scenarios is based on initial stock prices of \$130, \$100, and \$70 for bullish, neutral, and bearish markets.

Table 3 presents the numerical results of the strategy value as a function of the inside ranges of strike prices. A narrower width of the inside range (K_2, K_3) benefits the LCC strategy's values, given the market conditions of the stock price in the inside range. This implies that if the strategy traders set a narrower inside range of strike prices to capture the market conditions of a neutral scenario exactly, they tend to profit more. Conversely, strategy traders can easily capture the market conditions if the inside range is wider, but they will get lower profits. Note that a converse relationship appears between the inside range and strategy values.

Table 3. LCC Strategy's Fair and the Width of Inside Ranges

(K_2, K_3)	V_t
(\$98, \$102)	2.6119
(\$96, \$104)	2.4677
(\$94, \$106)	2.2281
(\$92, \$108)	1.8938
(\$90, \$110)	1.4662

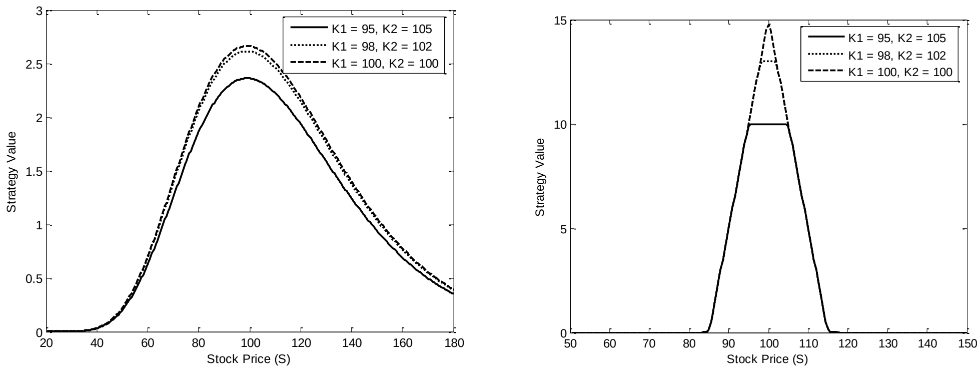
Note: The table presents the width impacts for the inside ranges (K_2, K_3) of strike prices on the LCC strategy values. The initial values of parameters in the closed-form solution of long call condor strategy are set as follows: the current stock price S_t of \$100, the lowest strike K_1 of \$85, the second lower strike K_2 of \$95, the strike K_3 of \$105, the greatest strike K_4 of \$115, the risk-free rate r of 10%, the time to maturity T – t of 1 year, the return volatility σ of 30%, and dividend yield rate q of 5%.

To identify the abovementioned issue, we further examine how market scenarios change the impact of the insider range's width ($K_3 - K_2$) on the strategy value. We implement a numerical analysis for a given case of market movements. There are three scenarios of market conditions: bullish (S_t = \$130), neutral (S_t = \$100), and bearish (S_t = \$70). We present our results using a 2-dimensional plot in Panel B of Figure 4. Although a wider inside range ($K_3 - K_2$) of strike prices can yield a lower fair value for the LCC strategy, the trader obtains relatively lower profits in both bearish and bullish markets and higher profits in the neutral market. The economic implication is that strategy traders can achieve greater profits by choosing an exact portfolio of options with a narrower range of strikes to capture specific market scenarios. Suppose the strategy traders remain in a bullish or bearish market. In that case, they should adjust their choice of inside ranges to align closer with the prevailing bullish or bearish market conditions, respectively.

4.4 Special Case: Long Call Butterfly Strategy

The study analyzes the effects of the strike range on the values of the LCC strategy. As the width ($K_3 – K_2$) of the insider range in the strike price gradually approaches zero, the LCC strategy's structure turns out to be the long call butterfly strategy[7]. The study thus examines and compares the two strategies mentioned above, displaying their results in a diagrammatic representation, as shown in Figure 5. Panels A and B present the strategy value over the underlying stock prices given three widths of insider range, i.e., (K_2, K_3) = (\$95, \$105), (\$98, \$102), and (\$100, \$100).

Figure 5: Comparison with Long Call Butterfly



Panel A: One year to maturity **Panel B: Appropriately maturity**

Note: The figure illustrates the dynamics of fair value when the inside range ($K_3 – K_2$) reduces to zero. The long call butterfly strategy is a special case of the LCC strategy, where $K_3 = K_2$. Panels A and B present the strategy values when $T – t = 1$ and 0.0001 years, respectively. The initial setting of model parameters is listed in Figure 1. The setting of market scenarios is based on initial stock prices of \$130, \$100, and \$70 for bullish, neutral, and bearish markets.

As the width of the insider range is zero, option traders exactly implement the long call butterfly strategy, in which they long a call with a relatively lower strike, long a call with a relatively higher strike, and short two calls with a middle strike. As shown in Panel A of Figure 5, far from one-year maturity ($T – t = 1$), the curves of strategy values exhibit similar trends to the underlying stock prices. However, the long call butterfly captures more values among the three cases, i.e., the width ($K_3 – K_2$) = 0. Panel B displays the strategy values at approximate maturity ($T – t = 0.0001$). With the reduction in the width of the insider strike range, the strategy value tends to be higher. The implication of the results suggests that LCC strategy traders can capture the highest payoffs if they can accurately predict the stock price's movement and choose the inner strike prices of the LCC strategy precisely. However, a wider insider range may be more appropriate for receiving potential interests if traders are unable to exactly estimate the terminal level of the underlying stock price, since a wider insider range is more likely to capture the interests of the LCC strategy, compared to the long call butterfly strategy that has a most narrow insider range.

5. Conclusions

In this article, we propose a new perspective, strike ranges, to examine the choices of option portfolios by strategy traders in the LCC strategy, aiming to capture potential strategy values. The study derives closed-form solutions for the fair value and Greeks of the LCC strategy, paving the way for further analysis of the strike range's impacts. We analyze the settings of strike ranges, how to influence strategy values, and how to respond to market scenarios appropriately.

Our study has the following main findings. First, the condor strategy values are relatively higher when the stock price is in a narrow range near two inside strike prices. If the underlying stock price deviates significantly from the two inside strike prices, the values of the profits turn out to be lower. Second, the strategy values vary according to several determinants in different ways. Our findings suggest that a long condor strategy trader benefits from the underlying asset, characterized by lower risk, interest rates, and short-run contracts. Third, the risk sensitivities, measured by the Greek letters,

[7] We thank the referees for suggesting that we examine the long call butterfly strategy, a special case of the LCC strategy, to enhance our statements.

show changes in appearance around the strikes. Strategy traders are susceptible to hedging behavior in response to various types of risk. Fourth, the strike range significantly impacts strategy values, where a wider insider range of strike prices lowers profits, and a wider outside range enlarges strategy traders' profits. Our findings suggest that selecting option portfolios with different strike prices can capture potential interests for strategy traders who expect precise market scenarios.

This paper provides a theoretical justification for strengthening strategy values and managing risks in the context of a specific options trading strategy analysis. The choice of strike ranges for holding the LCC strategy is critical to capturing the potential interests of practical strategy traders. Thus, this article contributes to identifying a strike issue framed in theoretical options trading strategy analysis.

While we have focused on the effects of the width of strike ranges on strategy values, this paper's analysis can be readily extended to other trading strategies that involve diverse options. More studies considering the effect of diverse maturities on option portfolios would be quite challenging and will be left to future work.

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