Pricing Analysis of TSLA-Linked Barrier Reverse Convertibles: A Monte Carlo Simulation Approach

Lixi Gao

School of Information Engineering, Zhongnan University of Economic and Law, Wuhan 430073, China
gaolixi99@outlook.com

Abstract. Barrier reverse convertible bond is a structured product that combines fixed income with embedded options, and its pricing research is of great significance to the market. Due to the high volatility of Tesla stock, it is hard for traditional pricing models to provide accurate results. This study uses Monte Carlo simulation as the pricing method to generate possible stock price paths, based on Tesla's daily trading data from January 2024 to December 2025. The results show a fair value of $712.49, a discount rate of 28.75%, a knock-in probability of 85.01%, and a probability of principal loss of 69.91%. The Delta value is 8.2391, and the Gamma value is -59.5478. The results confirm the applicability and effectiveness of Monte Carlo simulation in pricing assets with high volatility. Its path simulation can precisely address the path dependence issue of this Tesla-linked product and capture the volatility risk of the asset. This paper not only enriches the literature in the field of structured product pricing, providing a reference for the pricing of similar products, but also sets up the foundation for building better pricing models in the future.

Keywords: Barrier Reverse Convertible Bonds, Monte Carlo Simulation, High Volatility Assets, Tesla Stock.

1 Introduction

Barrier reverse convertible bond is a structured product that combines fixed income with embedded options, which is widely favored by the market because it can balance risk and return. Tesla stocks with high volatility become a hot asset in structured products. However, the frequent volatility of this stock makes it difficult for traditional pricing models to accurately capture the risk premium, which brings some challenges to the pricing of barrier reverse convertible bonds.

Monte Carlo simulation is a classic method used for derivative pricing. Its first application in derivative pricing was in European option pricing, where it randomly generated price paths of the asset and discounted the final returns, thus pioneering a new paradigm in asset pricing [1]. As market complexity grows, the random volatility of the underlying assets became more remarkable. Existing research has identified limitations in the assumptions of the B S model and proposed pricing methods for

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options under random volatility, which further confirms the flexibility of Monte Carlo simulation in dealing with multi factor dynamic processes [2].

In terms of barrier option pricing, scholars have continuously improved the accuracy of Monte Carlo simulation. Some studies enhanced Monte Carlo method by improving random number generation and path sampling and effectively reduced the first-pass error in barrier option pricing [3]. Another study used G-Brownian motion to describe the volatility of asset prices and built a convertible bond pricing model combined with Monte Carlo simulation. Its analysis results showed that this model is more suitable for the actual price trend than the B-S model [4]. Other scholars studied callable barrier convertible bonds, producing discount formulas and integral equations for early redemption [5].

Domestic research in this field has also made steady progress. Some scholars used the B-S model and delta hedging strategy to price convertible bonds, proving the volatility has a significant impact on pricing results [6]. Another study combined a jump-diffusion model with importance sampling in Monte Carlo simulation, offering a useful approach for pricing assets with high volatility [7]. In recent years, many studies have incorporated machine learning into the least squares Monte Carlo simulation, improving the pricing accuracy of convertible bonds in China [8]. Some scholars have built a sensitivity analysis framework for autocallable products and proved nonlinear effects of volatility and risk-free rate on pricing [9]. Furthermore, some researchers studied autocallable reverse convertible bonds in detail. The study successfully calculated the equilibrium coupon rate of the product, proving the impacts of asset prices and volatility on pricing [10].

While existing research has achieved considerable progress in pricing methods and sensitivity analysis of barrier reverse convertible bonds, it remains insufficient in pricing high volatility assets. Some models do not fully consider the volatility of assets and the path dependence of autocallable bonds. There is also no systematic verification for pricing these linked products. Based on this, this paper uses Monte Carlo simulation as the pricing method by generating stock price paths randomly. This paper assumes that Monte Carlo simulation can effectively adapt to the high volatility of Tesla stock, solve pricing problems in barrier reverse convertible bonds, and obtain the fair value and risk parameters for the product.

2 Method

2.1 Data Sources and Descriptions

The core data of this paper comes from the Yahoo Finance Public Database, which fully obtains Tesla's daily trading data from January 2, 2024, to December 12, 2025, with a total of 490 valid observations. The data not only contains the price fluctuation characteristics of the target assets under different market cycles but also supports the calculation of core pricing parameters such as long-term volatility, which meets the integrity, timeliness and reliability requirements of academic research. The definitions of key parameters are presented in Table 1.

Table 1. Parameter term definitions

Symbol	Implication
S_t	T-times TSLA daily closing price
σ	Annualized volatility
S_0	Initial fixed price of TSLA on January 2,2024
B	Barrier price ($S_0 \times 82\%$)
r	Risk-free interest rate (4.5%)
T	Product term (1 year)
C	Annualized coupon rate (18%)

Data types are mainly divided into two categories. One category is basic asset transaction data, including the daily closing price which can directly reflect the price level of the underlying asset, and the daily logarithmic rate of return ($\log Return = \ln(S_t/S_{t-1})$) calculated based on the closing price, which is used for volatility measurement and price distribution verification. Another category is pricing support data where the risk-free rate is taken as the yield on a one-year U.S. Treasury (4.5%), and the annual coupon rate of the product is set at 18% to match TSLA's high volatility. The core data of Tesla's stock are shown in Table 2.

Table 2. TSLA core data

Indicators	Results
Maturity	1 year
Nominal value	1,000 USD
Average daily closing price	239.41 USD
Annualized volatility	63.26%
Initial fixed price S_0	248.42 USD
Barrier price B	203.71 USD

To intuitively present the characteristics of the TSLA dataset, the following visualizations are provided:

Figure 1 displays TSLA's 2024-2025 daily adjusted closing price, with fluctuations between 150 dollars (September 2024) and over 450 dollars (December 2025). Its over 18 percent drawdowns justify the BRC's 82 percent knock-in level, matching historical volatility.

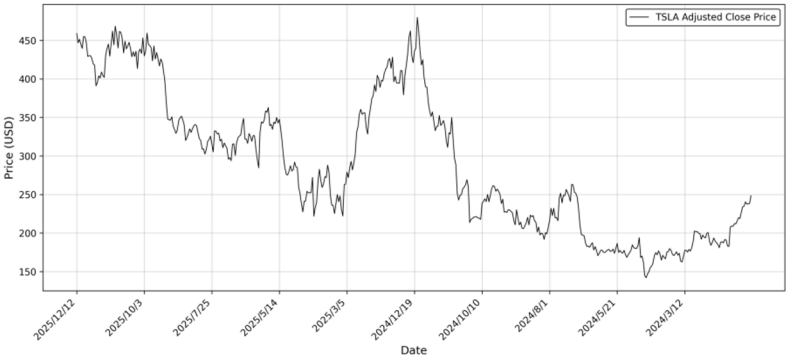


Fig. 1. TSLA historical stock price trend (2024-2025).

Figure 2 shows TSLA's time-varying volatility, averaging 62.38 percent with a maximum of 77.51 percent. High dynamic volatility validates Monte Carlo simulation over constant-volatility models for BRC pricing.

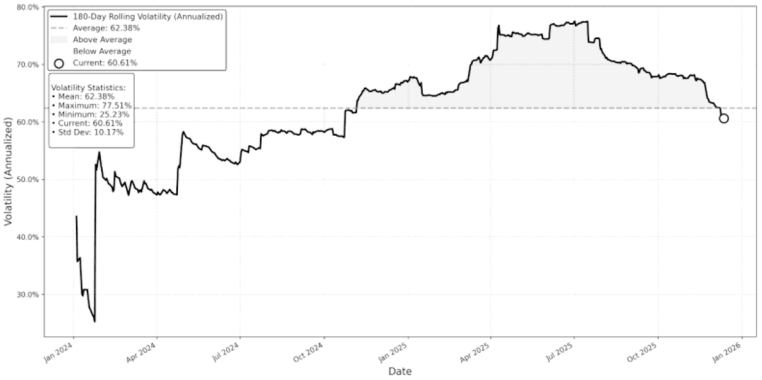


Fig. 2. TSLA 180-day rolling volatility trend (annualized)

2.2 Selection and Explanation of Indicators

The volatility rate σ is 63.26%, which is the annualized volatility of TSLA in 2024; the initial fixed price S_0 adopts the closing price of TSLA on January 2, 2024 (248.42 USD), which matches the pricing starting point; the barrier price B is set at 203.71 USD, adapting to TSLA's high volatility characteristics in 2024-2025. Select the product theoretical price V, $Delta$ index ($\Delta = \partial V/\partial S$) and $Gamma$ index ($\Delta = \partial^2 V/\partial S^2$) to reflect the product value, price sensitivity and volatility sensitivity respectively to meet the core pricing and risk analysis needs.

2.3 Method Introduction

In view of the path dependence of obstacle-based reverse convertible bonds, this paper adopts the Monte Carlo simulation method for pricing. The steps are as follows:

Based on the geometric Brownian motion model, with the initial price of S_0=248.42 USD, r=4.5% and σ=63.26% are substituted, Δt=1/252 is set, and 10,000 stock price paths for 2025-12-12 to 2026-12-12 are generated. Model formula:

$$S_{t+\Delta t} = S_t \cdot \exp\left[(r - \sigma^2/2)\Delta t + \sigma\sqrt{\Delta t} \cdot Z_t\right] \tag{1}$$

In which $Z_t \sim N(0,1)$, covers all market situations.

The maturity income of each simulated path is divided into two categories:

$$\text{Payoff} = \begin{cases} 118, & \mathrm{S_t} \geq 203.71 \text{ USD} \\ 100, & \text{existence } \mathrm{S} < 203.71 \text{ USD} \end{cases} \tag{2}$$

The maturity income of 10,000 simulated paths is discounted at a risk-free interest rate (4.5%), and the average value of all path incomes is taken as the theoretical price of the product:

$$V = e^{-0.045\times1} \cdot 1/10000 \sum_{i=1}^{10000} \text{Payoff}_i \quad (3)$$

Use the numerical differentiation method to calculate the Delta and Gamma indicators, adjust the initial price to ±1 USD, and calculate the formula:

$$\Delta = \frac{V(249.42) - V(247.42)}{2}, \Gamma = \frac{V(249.42) - 2V(248.42) + V(247.42)}{1^2} \quad (4)$$

3 Results and Discussion

This paper's final pricing results reveal the product's risk and value features. The product has a fair value of $712.49 against a nominal value of $1,000, which equates to a 28.75% discount rate. If Tesla's stock price drops below 82% of its initial price (i.e., $203.70) at maturity, the product's knock-in clause will be triggered, with an 85.01% probability. When no knock-in event takes place, investors can obtain an 18% annual coupon rate, with a 30.09% probability. The probability of principal loss is 69.91%, in which case investors receive Tesla shares rather than full cash repayment. The pricing results are presented in Table 3.

Table 3. TSLA barrier reverses convertible pricing results.

Terms	Results
Fair value	712.49 USD
Discount rate	28.75%
Knock-in probability	85.01%
Probability of 18% coupon rate	30.09%
Probability of principal loss	69.91%
Delta	8.2391
Gamma	-59.5478

The knock-in probability from this study matches Tesla's historical volatility. From 2024 to 2025, the stock's daily return standard deviation stood at 4.2%, and price swings exceeded 5% on 32% of trading days. This reflects the inherent volatility of Tesla's stock price, making this barrier reverse convertible bond a high-risk product, and the product's calculated discount rate is consistent with this risk level.

From the coupon receipt probability obtained in this study, it can be seen that the product's core lies in the trade-off between return and risk. The 18% annual coupon is far higher than the risk-free rate in 2025, while investors can only earn this return if Tesla's annual price decline does not exceed 18%. Tesla experienced three such declines in 2024, so this probability is corresponding to actual market performance.

This study calculates a Delta value of 8.2391, meaning the barrier reverse convertible bond's value changes by $8.2391 for each $1 movement in Tesla's stock

price. This figure is higher than that of common equity-linked bonds, and it directly shows the product's extremely high sensitivity to underlying stock's price fluctuations. Gamma value stands for a product's nonlinear risk exposure, measuring the change in Delta value for each $1 movement in the underlying stock price. The Gamma value calculated in this study is -59.5478, which shows that the product's price sensitivity will fluctuate sharply as Tesla's stock price changes.

Figure 3 shows Tesla's simulated 1-year stock price paths, marked with the knock-in and initial prices.

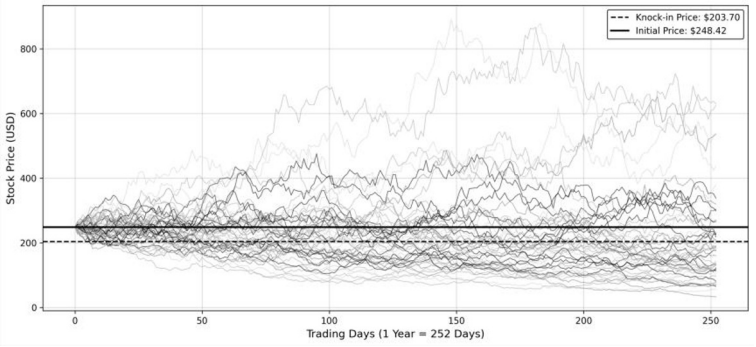


Fig. 3. TSLA simulated paths

This barrier reverse convertible bond is suitable for high risk-tolerance investors who are long on Tesla. Such investors must be willing to bear equity exposure in exchange for the potential of high coupon returns. The 69.91% principal loss probability calculated in this study also indicates that the product should not be treated as a substitute for fixed-income products.

For issuers, the relatively high knock-in probability reduces liability risk. In most instances, issuers can meet their payment duties by delivering Tesla shares rather than cash. A negative Gamma value, however, increases hedging costs. For this reason, issuers need to limit the product's issuing scale to control the costs of Delta and Gamma hedging.

4 Conclusion

This paper focuses on the pricing of barrier reverse convertible bonds linked to Tesla's stock, using Monte Carlo simulation as the pricing method. With Tesla's daily stock trading data from 2024 to 2025, the paper simulates 10,000 stock price paths and obtains the product's pricing results. It proves that Monte Carlo simulation is highly suitable for Tesla's high-volatility stock. It also successfully solves the pricing problems of barrier reverse convertible bonds.

In theory, this paper studies the effectiveness and applicability of Monte Carlo simulation in pricing Tesla-linked barrier reverse convertible bonds. It enriches the literature in the field of structured product pricing and also supplements the risk

parameter analysis of this product. In practice, the research results can provide practical and feasible guidance for market participants.

Although this paper has some contributions, there are still many limitations. The geometric Brownian motion model assumes constant volatility and no price jumps, which may cause the model to underestimate the actual knock-in probability. Meanwhile, this study does not fully consider factors such as Tesla's dividend policy and the credit risk of the issuer, which may affect the actual pricing of the product in the real market. Therefore, future research can incorporate stochastic volatility models and jump diffusion models and combine actual market factors to further improve the calculation accuracy and practical fit of the pricing model.

In summary, this paper completes the pricing and analysis of Tesla-linked barrier reverse convertible bonds through strictness and comprehensive Monte Carlo simulation, and the research has both theoretical value and practical significance. The results can not only provide a reference for the pricing of similar products and offer a scientific basis for the actual decisions of market participants but also lay a foundation for developing more precise and realistic pricing models in the future.

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