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Simulation-Based Pricing and Settlement Price Distributions of Indonesian Structured Warrants

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ABSTRACT

The Indonesian capital market has experienced significant growth, marked by the introduction of Structured Warrants (SWs) as innovative financial instruments. This study aims to develop a robust simulation-based pricing model for Indonesian Call SWs utilizing the Geometric Brownian Motion (GBM) framework and to determine their settlement price distributions. Monte Carlo simulations were employed to accurately capture the specific characteristics of Indonesian Call SWs, notably their average-price settlement mechanism and conversion rates. The results indicate that the settlement prices conform to a lognormal distribution, validating the GBM assumption and aligning with key trading metrics such as implied volatility, which is widely utilized in the Indonesian SW market. Additionally, the Symmetrical Auto Rejection rule, which imposes realistic constraints on underlying asset price movements, significantly enhances model realism and better reflects actual market conditions. The findings reveal that simulated Indonesian Call SW prices are slightly lower compared to values derived from the Black-Scholes model adjusted for conversion rates, highlighting opportunities for further refinement of pricing methodologies. Investors can leverage these insights to better assess risks and returns by anticipating volatility and price trends, with paying close attention to conversion rates and settlement mechanisms. Issuers may benefit from improved pricing accuracy, thus minimizing mispricing risks, while regulators can utilize this research to assess current market rules and design policies aimed at increasing market efficiency and transparency.

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A. INTRODUCTION

The Indonesian capital market is experiencing significant growth, driven by a favorable demographic profile and a supportive regulatory environment. This growth is further fueled by the increasing adoption of digital technologies and the introduction of innovative financial instruments, such as Structured Warrants (SWs). Launched by the Indonesia Stock Exchange (IDX) in September 2022, following the discontinuation of Stock Options Contracts earlier that year, SWs offer investors the flexibility to participate in the price movements of underlying assets without direct ownership, potentially providing benefits such as leverage and risk management (Sasongko et al., 2024). The introduction of SWs by the IDX reflects the ongoing efforts to expand investment opportunities and cater to the evolving needs of Indonesian investors. Understanding the behavior of SWs is crucial for investors, issuers, and regulators in making informed decisions within this evolving market (Havizh, 2022).

A Structured Warrant (SW) is a derivative instrument that grants investors the right to buy (call) or sell (put) an underlying asset at a predetermined price on a specific expiration date. Unlike Traditional (Equity) Warrants, SWs can be issued by third parties or financial institutions, increasing liquidity and providing investors with a wider range of options. Indonesian SWs have a settlement price calculation based on the average of the underlying asset's closing price over the last 5 trading days before maturity (Sasongko et al., 2024). Similar instruments exist in other markets, including Derivative Warrants in Hong Kong, Covered Warrants in London and Taiwan. Singapore and Malaysia utilize the term "Structured Warrant" for similar instruments (Samsudin et al., 2021, 2022).

The payoff of a SW is determined by its type (Call or Put), the relationship between the settlement price and the strike/exercise price, and the conversion rate, which collectively define the potential profit or loss for the investor (Sasongko et al., 2024). Call SW holders profit when the settlement price exceeds the strike price, while Put SW holders profit when it falls below. When holders profit, the amount of profit is determined by the difference between the settlement price and the strike price, divided by the SW's conversion rate. This calculation does not yet account for the SW price/premium, which must be subtracted to determine the net profit or loss. Therefore, the break-even point becomes a critical consideration for SW holders. Conversely, if the settlement price is below the strike price for a Call SW or above the strike price for a Put SW, the holders' maximum loss is limited to the premium paid. Unlike Traditional Warrants or Options, SWs involve a settlement price that incorporates an averaging mechanism, which influences their price dynamics (Abínzano & Navas, 2013). Additionally, the conversion rate plays a significant role in determining the price and affordability of SWs, further distinguishing them from other derivatives.

Structured Warrants traded on the IDX have specific characteristics, including underlying assets based on highly liquid and fundamentally sound stocks from the IDX30 index, availability limited to Call SWs (until February 2025), maturity ranging from 2 to 24 months, and European-style exercise, allowing exercise only at maturity (Sasongko et al., 2024). The settlement price is calculated as the average of the underlying asset's closing price over the last 5 trading days before maturity, with automatic cash settlement for in-the-money options occurring within 3 days after maturity. Trading occurs on both primary and secondary markets, and PT. Kliring Penjaminan Efek Indonesia (KPEI) provides guarantees for secondary market trading and settlement, enhancing investor confidence (Havizh, 2022).

Investing in SWs traded on the IDX offers several advantages, including enhanced liquidity due to secondary market makers, simplified automatic exercise processes, relatively low entry costs making them accessible to a wider range of investors, the potential for higher returns compared to direct stock investments due to the gearing effect, and capped losses limited to the premium paid, providing a degree of risk mitigation. However, to maximize potential returns, investors should carefully align their SW choices with their expectations of the underlying asset's price movements. Call SWs are ideal for bullish market outlooks, while Put SWs are suited for bearish market expectations—where such options are available. However, it is important to note that only Call SWs are currently available in the Indonesian capital market. While potential profits can be realized when a SW is exercised in-the-money (i.e., has a positive payoff), investors must also consider the break-even point to mitigate potential losses. As with any investment, investors should assess their risk tolerance and investment strategy before committing to SWs. While potential losses are limited to the premium paid, exclusive reliance on SWs may lead to substantial risks, as the amplified exposure could result in significant losses if the market moves unfavorably (Karunianto & Robiyanto, 2023). Therefore, SWs are best utilized as a complementary tool within a diversified investment portfolio to potentially hedge against market risks, balancing the opportunity for higher returns with the safety of a more diversified approach.

Due to their European-style exercise, Structured Warrants exhibit similarities to European Equity Options. However, key differences—including the settlement price calculation, a relatively shorter time to maturity, the influence of the conversion rate, specific trading parameters, and rules for Indonesian SWs—require adjustments to standard Option pricing models (Sasongko et al., 2024). While pricing models used for European Equity Options could potentially be adapted to determine Indonesian SW prices or premiums, future research is necessary to develop and validate appropriate pricing models for Indonesian SWs. The settlement price of Indonesian SWs is determined by the average of the underlying asset's closing price over the last 5 trading days before maturity. This characteristic classifies them as Path-Dependent Options, a type of Exotic Option known as Asian Options, which are commonly found in Asian markets. Unlike European Equity Options, where the payoff is solely determined by the underlying asset's price at expiration, the payoff of Asian Options, and consequently, the Indonesian SWs, is based on the average price of the underlying asset throughout its lifecycle. Additionally, the influence of the conversion rate, specific trading parameters, and rules can make Indonesian SWs more unique.

Global research on warrants has extensively examined various aspects of pricing, trading behavior, and risk management strategies. Key studies such as Abínzano & Navas (2013) and Shiu et al. (2013) explore the complexities of warrant valuation, considering leverage, credit risk, and interest rates. Research by C. Y. Chan et al. (2012) further investigates market efficiency in warrant pricing, while Florianová (2015) discusses the use of hedging strategies in warrant trading. Additionally, studies by Baule & Blonski (2015) and Hassan et al. (2022) address demand dynamics and the role of warrants in Islamic finance. Finally, Farkas & Váradi (2021) explore the speculative behavior of individual investors using leveraged warrants. Collectively, these works provide a comprehensive understanding of warrant dynamics, highlighting factors such as pricing, market efficiency, investor behavior, and the growing importance of warrants in global finance.

In Asia, a significant body of research has focused on the markets of China, Hong Kong, and Taiwan, with notable contributions from Y. C. Chan & Wei (2001) and Chung et al. (2014), who examine the effects of warrant issuance on underlying stock behavior, including price and volume movements. Further, Chang et al. (2013), Chen et al. (2013), Powers & Xiao (2014), Tang & Wang (2013), and Wang & Zhu (2013) have explored various pricing models, investigating the relationship between credit ratings, mispricing, and the nature of warrants as derivatives. (Zhou, 2015) introduces alternative pricing methods, using Monte Carlo simulations and Levy processes to address the challenges in pricing Chinese warrants. These studies collectively enrich our understanding of implied volatility in Asian markets, shedding light on pricing efficiency, market behavior, and the links between warrants and underlying stocks. Empirical research within ASEAN markets, particularly in Singapore, Malaysia, and Indonesia, has significantly advanced the understanding of implied volatility in Structured Warrants and Options. Pioneering studies by Samsudin & Mohamad (2016) and Samsudin et al. (2021, 2022)have enhanced our understanding of the factors influencing implied volatility in these emerging markets. Their work has contributed to the development of more accurate forecasting models and improved risk management practices. As ASEAN markets continue to grow, understanding the volatility and pricing dynamics in these regions is crucial for both investors and regulators.

Recent studies have begun to explore the emerging Structured Warrant market in Indonesia. Havizh (2022) emphasizes the importance of investor protection in the Structured Warrant market, highlighting gaps in the current regulatory framework. Jayadi & Sumarti (2023) propose a portfolio optimization model that integrates Structured Warrants, showcasing their potential for enhancing investment returns. Karunianto & Robiyanto (2023) investigate market efficiency and identify abnormal profit opportunities in the Structured Warrant market. Sasongko et al. (2024) introduce PROSWAPTOR, a simulation tool designed to estimate Structured Warrant prices, offering significant utility to investors. These studies provide an important foundation for understanding the characteristics of Indonesian Structured Warrants, though future research is required to refine the pricing model, explore the regulatory impact, and analyze the broader economic effect of these financial instruments.

The Indonesian Structured Warrant market has witnessed a marked expansion, with a growing number of securities firms assuming the role of issuers. Notable participants include RHB Sekuritas, Maybank Sekuritas, CGS International Sekuritas, KGI Sekuritas, and Korean Investment & Sekuritas Indonesia. These firms actively disseminate real-time data on their issued Structured Warrants, encompassing pricing, trading metrics, and implied volatility. The pervasive use of implied volatility data, derived from models predicated on the Geometric Brownian Motion (GBM) assumption, highlights the continued reliance on this framework for pricing Indonesian Structured Warrants, despite the fundamental discrepancies between these instruments and European Equity Options. Despite their growing popularity, the pricing of Indonesian SWs remains a complex and challenging task. While SWs have gained significant traction in the Indonesian capital market, a comprehensive understanding of their pricing dynamics — particularly the factors that influence SW prices— remains largely unexplored and elusive. Existing pricing models, primarily developed for European Equity Options, may not adequately capture the complexities of the average-price settlement mechanism inherent in SWs. The key motivation of this research is to bridge this gap by developing a robust simulation model tailored to the specific characteristics of Indonesian SWs.

One of the primary challenges in pricing SWs stems from the distinctive features of the Indonesian market and the average-price settlement mechanism. In contrast to European Equity Options, where the payoff is determined by the underlying asset's price at expiration, SWs utilize a settlement price based on the average of the closing prices over a specified period before maturity. This characteristic introduces significant complexities, especially when combined with other factors such as the conversion rate, market volatility, and specific trading parameters and rules for Indonesian SWs which can greatly influence the pricing process. To address these challenges, this study aims to develop a robust simulation model to more accurately estimate the price of Indonesian SWs. The proposed model will generate a large number of potential price paths for the underlying asset, from which SW prices will be derived. Additionally, the simulation will also capture a distribution of settlement prices, offering insights into the average-price settlement mechanism. This dual approach will help refine the pricing process and provide a more accurate and comprehensive understanding of the dynamics of Indonesian SWs pricing. The primary objectives of this research are threefold: (G1) to develop a robust simulation model that accurately estimates the price/premium of Indonesian SWs, (G2) to identify and analyze key factors influencing SW pricing, and (G3) to determine the settlement price distributions in order to enhance the understanding of the average-price settlement mechanism. This study also provides practical insights for investors, issuers, and regulators, ultimately improving the understanding of SWs and contributing to a more efficient and transparent market in Indonesia.

B. METHODS

There are three models known for pricing European Equity Options: Black & Scholes Model (1973), Binomial Options Pricing Model by Ross et al. (1979), and Trinomial Options Pricing Model by Boyle (1988). The Black & Scholes model operates under the assumption of continuous time prices, whereas the Binomial and Trinomial models work under the assumption of discrete time price lattices. A common assumption imposed on the movement of underlying assets in those models is Geometric Brownian Motion. This assumption states that the price of an underlying asset at a given time is lognormal distributed, or equivalently, the natural logarithm of the returns of the underlying asset over a given time interval is normally distributed.

1. Geometric Brownian Motion (GBM) and Black-Scholes Formula

If the price of an underlying asset at the time t is denoted by $S(t)$, where prices are available in discrete time intervals of length Δt (e.g., daily), then GBM states that the rate of change of the underlying asset price at the time t is given by the following differential equation, with constant annual drift μ and annual volatility σ, as shown in Equation (1).

$$\Delta S(t) = \mu\, S(t)\, \Delta t + \sigma\, S(t)\, \sqrt{\Delta t}\, Z, \quad \text{with } Z \sim \mathrm{N}(0,1) \tag{1}$$

The solution to the differential equation in (1) is given by the function of the underlying asset price based on prices at discrete time intervals of length Δt, as shown in Equation (2).

$$S(t + \Delta t) = S(t) \exp\left\{\left(\mu - \frac{\sigma^2}{2}\right)\Delta t + \sigma\sqrt{\Delta t}\, Z\right\}, \quad \text{with } Z \sim \mathrm{N}(0,1) \tag{2}$$

The model in Equation (2) implies that the natural logarithm of returns is normally distributed with mean $(\mu - \sigma^2/2)\Delta t$ and variance $\sigma^2 \Delta t$ as shown in Equation (3).

$$\ln\left(\frac{S(t + \Delta t)}{S(t)}\right) \sim \mathrm{N}\left(\left(\mu - \frac{\sigma^2}{2}\right)\Delta t, \sigma^2 \Delta t\right) \tag{3}$$

Equation (3) has a special additive property for returns, meaning that the total return over a period can be calculated by summing the returns over smaller sub-periods. This implies that the distribution of returns for longer time intervals, such as $[0, T]$, is also normally distributed.

$$\ln\left(\frac{S(T)}{S(0)}\right) = \mathrm{N}\left(\left(\mu - \frac{\sigma^2}{2}\right)T, \sigma^2 T\right) \tag{4}$$

Based on Equation (4), the price of an underlying asset at the time T, $S(T)$, is log-normally distributed with an expected value equal to the expected value of $S(0)$ compounded at the continuous growth rate μ as shown in Equation (5) and the variance is given by the equation (6).

$$\mathrm{E}[S(T)] = S(0)\exp(\mu T) \tag{5}$$
$$\mathrm{Var}[S(T)] = S(0)^2 \exp(2\mu T)\,[\exp(\sigma^2 T) - 1] \tag{6}$$

If **O** denotes a European Equity Option with a set of characteristics including the type of option, maturity time T, $S(T)$, and strike price K, then the payoff of **O** is given by Equation (7). The price of **O** can be obtained through the risk-neutral expectation of the payoff of **O** with a risk-free interest rate r, as shown in Equation (8).

$$\mathrm{Payoff}(\mathbf{O}) = \begin{cases} \max\{S(T) - K, 0\}, & \text{for Call Option} \\ \max\{K - S(T), 0\}, & \text{for Put Option} \end{cases} \tag{7}$$

$$\mathrm{Price}(\mathbf{O}) = e^{-rT}\,\mathrm{E}[\mathrm{Payoff}(\mathbf{O})] \tag{8}$$

Considering that $S(T)$ follows the Geometric Brownian Motion and equating the annual drift μ with a risk-free interest rate r, Black & Scholes give the formula based on (7) and (8) to determine the price of a European Call Option expressed by Equation (9a) and the price of a European Put Option expressed by Equation (9b), where $\Phi(\star)$ is the standard normal distribution function at $\star$ and the values of d_1 & d_2 are respectively given by Equations (10a) & (10b).

$$C_{\mathbf{O}} = S(0)\,\Phi(d_1) - K\exp(-rT)\,\Phi(d_2) \tag{9a}$$

$$P_{\mathbf{O}} = K\exp(-rT)\,\Phi(-d_2) - S(0)\,\Phi(-d_1) \tag{9b}$$

$$d_1 = \frac{\ln\left(\frac{S(0)}{K}\right) + \left(r + \frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}} \tag{10a}$$

$$d_2 = d_1 - \sigma\sqrt{T} \tag{10b}$$

The European Option pricing formula in Equation (9) indicates that the upfront premium for an option is directly tied to the underlying asset's price movements. This direct exposure often results in quite high option prices, potentially deterring novice investors.

2. Monte Carlo Simulation for Pricing Indonesian Call Structured Warrants

Given that the Structured Warrants (SWs) available in the Indonesian Capital Market are currently limited to Call SWs, this discussion will also be confined to Asian Call Options. The payoff at maturity of an Average Price Asian Call Option, where Options are launched at a time $t = 0$ with a daily interval Δt, the number of trading days is n, and maturity is at $t = T$ on the $(n + 1)$th trading day, is given by Equation (11) with $\mathbf{\Lambda_C}$ denotes the Asian Call Option with a set of characteristics including the maturity time T, strike price K, and a set value of the underlying asset price $\{ S(i\Delta t) \mid i = 0, 1, 2, 3, \dots, n\}$. Considering that the settlement price of SWs is calculated as the average of the underlying asset's daily closing prices in the 5 days before maturity, $\sum_{i=n-4}^{n} S(i\Delta t)/5$, the payoff of an Indonesian Call SW is expressed by Equation (12) with $\mathbf{\Omega_C}$ denotes the Indonesian Call SW with a set of characteristics including the maturity time T, strike price K, conversion rate c_r, and a set value of the underlying asset's daily closing prices in the 5 days before maturity $\{ S(i\Delta t) \mid i = n-4, n-3, n-2, n-1, n \}$.

$$\text{Payoff}(\mathbf{\Lambda_C}) = \max\left\{\frac{1}{n}\sum_{i=0}^{n} S(i\Delta t) - K, 0\right\} \tag{11}$$

$$\text{Payoff}(\mathbf{\Omega_C}) = \frac{1}{c_r}\max\left\{\frac{1}{5}\sum_{i=n-4}^{n} S(i\Delta t) - K, 0\right\} \tag{12}$$

An important factor to consider before calculating the price/premium of Indonesian Call SW is the conversion ratio (or rate, c_r), which is a ratio that states how many SWs must be owned to obtain the same exposure as the performance of the underlying asset price. For example, a conversion ratio 2: 1 or rate $c_r = 2$ means the number of SWs that must be owned is twice the number of underlying assets traded. A method for pricing Indonesian SWs needs to be proposed, as a closed-form solution or formula for pricing Asian options (the closest instrument with similar characteristics to Indonesian SWs) is not/has not been available. Therefore, an estimation can be calculated to obtain an approximation for pricing Indonesian SWs. One method that can be used for this approximation is through Monte Carlo simulation. While estimating the price, this simulation can also be used to model the settlement price distributions of Indonesian SWs.

The fundamental principle of the Monte Carlo simulation method is to obtain an approximation for a specific value by calculating the expectation or relevant statistics of a large number of independent simulation samples. This concept is based on the Law of Large Numbers. The Monte Carlo simulation method involves two basic steps: (i) simulating a large number of samples from a random variable by generating random numbers to obtain independent and identically distributed random samples; and (ii) calculating an approximation of the desired value through the expectation or relevant statistics of the samples obtained in step (i). Assuming that the asset price movement follows Geometric Brownian Motion as stated in Equation (2), the forward price path can be simulated starting from the asset price at $t = 0$, namely $S(0)$, with a daily time step Δt for n trading days until it reaches the time of maturity $t = n\Delta t$. The simulation of the price path can be obtained in two ways. The first way is by generating random numbers as stated in Equation (3) and then calculating the asset price as stated in (2) recursively one by one for each increment of $i\Delta t$ with $i = 1, 2, 3, \ldots, n$. Meanwhile, the second way is by generating n random numbers as stated in Equation (3) and then calculating the asset price on all n trading days through Equation (2) in the form of multiplication between $S(0)$ and the exponential likelihood factor of the accumulation of random numbers until the n-th trading day. Both methods can produce a simulated price path for n trading days.

It is assumed that the underlying asset price for Indonesian SW follows Geometric Brownian Motion with a constant daily volatility $\sigma\sqrt{\Delta t}$ and risk-neutral rate $(r - \sigma^2/2)\Delta t$. Let X_i be a random sample of the random variable as stated in Equation (3) for $i = 1, 2, 3, \ldots, n$, that is

$$X_i = \ln\left(\frac{S(i\Delta t)}{S\big((i-1)\Delta t\big)}\right) \sim \mathrm{N}\left(\left(r - \frac{\sigma^2}{2}\right)\Delta t, \sigma^2 \Delta t\right) \tag{13}$$

By generating random numbers from the standard normal distribution, $Z_i \sim \mathrm{N}(0,1)$, the random sample X_i can be obtained through the following equation:

$$X_i = (r - \sigma^2/2)\Delta t + \sigma\sqrt{\Delta t}\, Z_i \tag{14}$$

Based on Equations (13), (14), and the initial asset price of Indonesian SW, $S(0)$, the simulated prices for each day during n trading days, namely: $S(\Delta t), S(2\Delta t), S(3\Delta t), \ldots, S(n\Delta t)$, can be represented by a price path in Equation (15a) or (15b).

$$S(\Delta t) = S(0)e^{X_1},\ \ S(2\Delta t) = S(\Delta t)e^{X_2},\ \ S(3\Delta t) = S(2\Delta t)e^{X_3}, \ldots,\ \ S(n\Delta t) = S\big((n-1)\Delta t\big)e^{X_n} \tag{15a}$$

$$S(\Delta t) = S(0)e^{X_1},\ \ S(2\Delta t) = S(0)e^{X_1+X_2},\ \ S(3\Delta t) = S(0)e^{X_1+X_2+X_3}, \ldots,\ \ S(n\Delta t) = S(0)e^{X_1+\cdots+X_n} \tag{15b}$$

If the payoff of Indonesian Call SW is calculated for each simulated path of the underlying asset price as in Equation (12), then for M simulations, the price/premium of Indonesian Call SW can be calculated by taking the average of all payoffs, and then multiplying it by the continuous discount factor to obtain its present value as expressed in Equation (16). The variance of the price/premium is given by Equation (17). The 95% confidence interval estimate for the price/premium is given by the closed interval expression in Equation (18).

$$\hat{C}_{\mathrm{SW}} = \frac{\exp(-nr\Delta t)}{M} \sum_{j=1}^{M} \mathrm{Payoff}_j(\mathbf{\Omega_C}) \tag{16}$$

$$\widehat{\omega}^2_{\mathrm{CSW}} = \left(\frac{\exp(-2n\mu\Delta t)}{M-1} \sum_{j=1}^{M} \Big(\mathrm{Payoff}_j(\mathbf{\Omega_C})\Big)^2\right) - \frac{M}{M-1}\hat{C}^2_{\mathrm{SW}} \tag{17}$$

$$\left[\hat{C}_{\mathrm{SW}} - \frac{1.96\widehat{\omega}_{\mathrm{CSW}}}{\sqrt{M}},\ \ \hat{C}_{\mathrm{SW}} + \frac{1.96\widehat{\omega}_{\mathrm{CSW}}}{\sqrt{M}}\right] \tag{18}$$

Meanwhile, the Monte Carlo simulation can be repeated, for example, N times, to obtain a more accurate estimate of the price/premium of Indonesian Call SW. As the number of simulated price paths increases to NM, the confidence interval estimate surrounding the price or premium of Indonesian Call SW becomes more precise. Thus, if $\hat{C}_{\mathrm{SW},k}$ is the result of the k-th estimation of the price/premium through M simulated price paths calculated by Equation (16), then the estimate of the price/premium of Indonesian Call SW through N estimations is expressed by Equation (19) with its variance in the Equation (20). Note that the standard error of the estimate in (19) is denoted by $\mathrm{SE}(\hat{C}) = \widehat{\omega}_{\hat{C}}/\sqrt{N}$. Thus, the 95% confidence interval estimate of the price/premium of Indonesian Call SW is given by Equation (21). For other confidence levels –such as 80%, 90%, 98%, and 99%– the value of 1.96 can be replaced with 1.28, 1.64, 2.33, and 2.58, respectively.

$$\hat{C} = \frac{1}{N}\sum_{k=1}^{N} \hat{C}_{\mathrm{SW},k} \tag{19}$$

$$\widehat{\omega}_{\hat{C}}^2 = \left(\frac{1}{N-1}\sum_{k=1}^{N} \hat{C}_{\mathrm{SW},k}^2\right) - \frac{N}{N-1}\hat{C}^2 \tag{20}$$

$$\left[\hat{C} - (1.96)\mathrm{SE}(\hat{C}), \hat{C} + (1.96)\mathrm{SE}(\hat{C})\right] = \left[\hat{C} - \frac{1.96\widehat{\omega}_{\hat{C}}}{\sqrt{N}}, \hat{C} + \frac{1.96\widehat{\omega}_{\hat{C}}}{\sqrt{N}}\right] \tag{21}$$

The Monte Carlo estimation procedure described above can be repeated L times, resulting in LNM simulated price paths of the underlying asset, thus obtaining a more robust estimate of the price/premium of Indonesian Call SW through this method.

3. Capturing the Settlement Price Distributions of Indonesian Structured Warrants

While the pricing of Indonesian SWs was the focus of the previous section, the distribution of settlement prices, $\sum_{i=n-4}^{n} S(i\Delta t)/5$, can be captured simultaneously within the simulation process. The settlement price distribution is estimated by modeling the settlement prices derived from each simulated path of the underlying asset in the Monte Carlo simulation. By simulating M paths, M settlement prices are analyzed using descriptive statistics, a histogram to identify the distribution, Maximum Likelihood Estimation (MLE) to estimate the parameters, and the Kolmogorov-Smirnov (KS) goodness of fit test. Repeating the M simulations for LN iterations can further refine the distribution model parameters, making them more robust. Assuming the underlying asset prices follow a Geometric Brownian Motion (GBM) process, the distribution of settlement prices is tested for lognormality. The goodness-of-fit test evaluates whether the settlement prices from the Monte Carlo simulations align with a lognormal distribution, consistent with the GBM assumption. The results will provide valuable insights into the validity of this lognormal distribution assumption, which is crucial for deriving analytical pricing formulas in future research.

4. Impact of Volatility, Parameters, and Regulatory Rules on Simulation

Other important aspects to consider in the pricing and settlement price distribution of Indonesian SWs include the interdependence of parameters in the Geometric Brownian Motion (GBM) model. This model serves as the assumed price movement framework for the underlying asset of Indonesian SWs, with key parameters being volatility and the risk-free interest rate. Additionally, regulations in the Indonesian capital market, such as the Symmetrical Auto Rejection rule, also govern the underlying asset price movement of Indonesian SWs.

The price movement range of Indonesian SWs' underlying assets following GBM will not exceed the Symmetrical Auto Rejection limits, denoted as α_{SAR}, which are 20%, 25%, or 35%, depending on the asset price for sequential ranges: more than IDR 5000, IDR 200 up to 5000, or IDR 50 up to 200. Based on the daily logarithmic returns volatility $\sigma\sqrt{\Delta t}$, Symmetrical Auto Rejection limits α_{SAR}, GBM assumption, and Z-score of 3 (indicating a 99.73% confidence interval for asset price distribution), by equating the μ with r, the daily risk-free interest rate $r\Delta t$ is derived as the solution to the inequalities in Equations (22a) and (22b).

$$S(t+\Delta t) = (1-\alpha_{\text{SAR}})S(t) < S(t)\exp\left\{\left(r-\frac{\sigma^2}{2}\right)\Delta t - 3\sigma\sqrt{\Delta t}\right\} \tag{22a}$$

$$S(t+\Delta t) = (1+\alpha_{\text{SAR}})S(t) > S(t)\exp\left\{\left(r-\frac{\sigma^2}{2}\right)\Delta t + 3\sigma\sqrt{\Delta t}\right\} \tag{22b}$$

The solution to this system of inequalities, presented in Equation (22), shows that the daily risk-free interest rate $r\Delta t$ must fall within the interval expressed in Equation(23).

$$r\Delta t \in \left(\ln(1-\alpha_{\text{SAR}}) + \frac{\left(\sigma\sqrt{\Delta t}\right)^2}{2} + 3\sigma\sqrt{\Delta t},\ \ \ln(1+\alpha_{\text{SAR}}) + \frac{\left(\sigma\sqrt{\Delta t}\right)^2}{2} - 3\sigma\sqrt{\Delta t}\right) \tag{23}$$

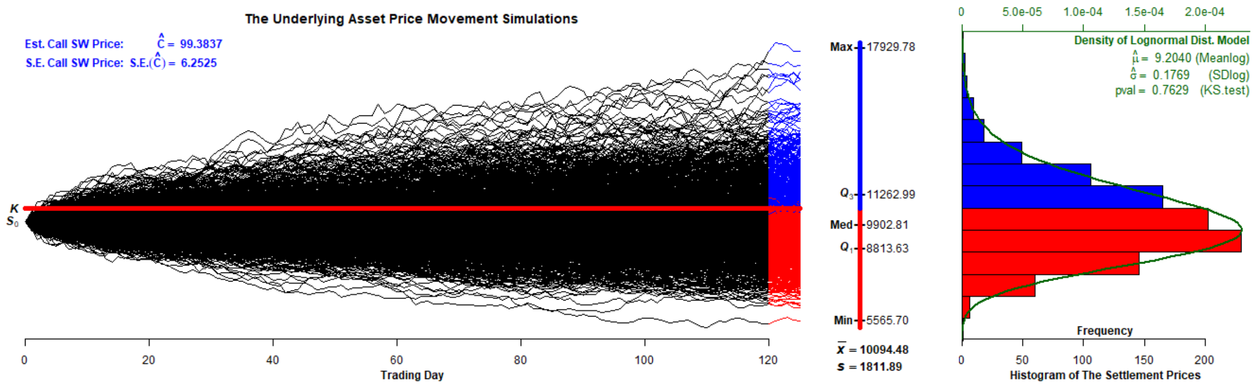
Based on the interval expression in Equation (23), it is evident that the daily risk-free interest rate $r\Delta t$ depends on the daily logarithmic returns volatility $\sigma\sqrt{\Delta t}$ and the Symmetrical Auto Rejection rule in the Indonesian capital market to the simulation framework for the pricing and capturing settlement price distribution of Indonesian SWs.

C. RESULT AND DISCUSSION

The analysis examines a hypothetical case of Indonesian Call Structured Warrants (SWs), where the underlying asset's price movement follows Geometric Brownian Motion (GBM). Parameters for this case include a conversion rate of $c_r = 5$, a strike price of $K = 10628.325$, an initial underlying asset price $S(0) = 10000$, an annual volatility of $\sigma = 25\%$ ($\sigma\sqrt{\Delta t} = 0.0158$), an annual risk-free interest rate $r = 2.5\%$ ($r\Delta t = 0.0001$), and a time to maturity of $T = 0.5$ years or 125 trading days. This setup serves as the foundation for further simulation-based pricing of Indonesian SWs and analysis of their settlement price distribution. Additionally, the setup parameters comply with the discussion in Section B.4, where the daily risk-free interest rate $r\Delta t$ falls within the interval determined by daily logarithmic returns volatility $\sigma\sqrt{\Delta t}$ and Symmetrical Auto Rejection limits of $\alpha_{\text{SAR}} = 20\%$, given the asset price of 10000.

Using Equation (9a), the theoretical premium is calculated as $C_0 = 500$, without incorporating the conversion rate. Since the Black & Scholes formula calculates the price per unit of the underlying asset, it does not adjust for the conversion rate, resulting in a higher premium that might be less accessible for Indonesian investors. While the conversion rate could divide the price to $\hat{C} = 100$, making it more affordable, the unique average-price settlement mechanism of SWs complicates this adjustment. The absence of an analytical pricing formula for this mechanism makes Monte Carlo simulations a practical alternative. These simulations offer a robust method for estimating SW prices and analyzing settlement price distributions until analytical solutions are developed in future research.

The Monte Carlo simulation generated $M = 1000$ price paths for the underlying asset, following the process outlined in Equations (15a) or (15b). All the paths are illustrated in Figure 1 (a), where each path starts from $S(0)$. A red horizontal line represents the strike price K. At the endpoints of each path, specifically for the closing prices of the underlying asset over the last five trading days, the points are marked in blue if the settlement price is greater than K, and in red if the settlement price is less than K. Blue points indicate a positive payoff (in-the-money), while red points represent a payoff of zero.



(a) **(b)** **(c)**

Figure 1. (a) Simulated Price Paths, (b) Descriptive Statistics, and (c) Distribution of Settlement Prices

The price/premium of Indonesian SW was calculated from simulated price paths. First, payoffs were computed as described in Equation (12), which involved calculating the settlement prices and subsequently determining the prices using Equation (16), followed by the variance of prices as outlined in Equation (17). From a single Monte Carlo simulation, the estimated price of Indonesian SW was $\hat{C}_{\text{SW}} = 99.3837$. Based on the variance obtained via Equation (17), the standard error of the price estimate was $\widehat{\omega}_{\text{CSW}}/\sqrt{M} = 6.2525$. The 95% confidence interval for this price estimate, calculated using Equation (18), was the close interval $(87.1288, 111.6386)$. This result closely approximates the price obtained using the Black & Scholes Formula divided by the conversion rate $c_r = 5$, which was 100, as the 95% confidence interval encompasses this value. However, this does not necessarily imply that the estimate is entirely accurate. Repeating the simulation is necessary to achieve more reliable results.

The settlement prices, $\sum_{i=n-4}^{n} S(i\Delta t)/5$, derived from the simulated price path. Their descriptive statistics, including the minimum, quartiles, median, mean, and standard deviation, are summarized in Figure 1 (b). Figure 1 (c) presents the histogram of settlement prices, with blue bars representing values greater than (positive payoff) and red bars representing values below the strike price K (zero payoff). An overlay on the histogram shows the estimated lognormal density function fitted to the settlement prices. Figure 1 (c) includes two axes: one for the frequency of the histogram and another for the height of the estimated lognormal density function. The lognormal distribution model was estimated using parameters such as *Meanlog*, *SDlog*, and *p-value* from the Kolmogorov-Smirnov (KS) goodness-of-fit test. The KS test yielded a *p-value* $0.7629 > 0.05$, indicating that the null hypothesis—that the settlement prices follow a lognormal distribution model with *Meanlog* 9.2040 & *SDlog* 0.1769—cannot be rejected. This result validates the hypothesis that settlement prices conform to a lognormal distribution. Consequently, it confirms that the assumption of lognormality aligns well with the characteristics of Geometric Brownian Motion, further supporting its application in pricing models.

The results from a single Monte Carlo simulation, discussed previously, can be enhanced by repeating the simulation $N = 1000$ times. This means that a total of $NM = 10^6$ price path for the underlying asset is generated, with each estimation based on $M = 1000$ price paths. These estimations are denoted by $\hat{C}_{\mathrm{SW},k}$ for $k = 1, 2, 3, \dots, N$. Subsequently, the price/premium of Indonesian Call SW was estimated by Equation (19), with its variance computed via Equation (20), and the 95% confidence interval determined by Equation (21). Table 1 summarizes the estimation results obtained from the N repetitions of the Monte Carlo simulations.

Table 1 shows the estimated Indonesian Call SW price/premium $\hat{C} = 98.2670$, with the standard error $\hat{\omega}_{\hat{C}}/\sqrt{N} = 0.1987$ and the 95% confidence interval $(97.8775, 98.6565)$. Based on the results, the estimated price/premium of Indonesian Call SW shows a significant difference compared to the price/premium obtained using the Black & Scholes Formula divided by the conversion rate $c_r = 5$, which is 100. While the difference is only around 1.75% lower, the 95% confidence interval no longer encompasses the value of 100. This is because the repetition of the simulation $N = 1000$ times reduced the standard error of the price/premium estimate, thus narrowing the confidence interval and yielding a more accurate estimate.

Table 1. Descriptive Statistics of Settlement and Call Prices from $N = 1000$ Repetitions

Statistics	Lower Lim. (95% of C.I.)	Estimated Value	Std. Err. Value	Upper Lim. (95% of C.I.)
Minimum	5649.8023	5670.8515	10.7396	5691.9007
1st Quartile	8858.9920	8863.0778	2.0846	8867.1636
Median	9966.5427	9970.8774	2.2116	9975.2121
Mean	10119.6570	10123.2387	1.8274	10126.8204
Std. Dev.	1778.7144	1781.4441	1.3927	1784.1738
3rd Quartile	11210.2394	11215.7048	2.7886	11221.1703
Maximum	17500.0966	17566.5508	33.9058	17633.0050
Meanlog	9.2070	9.2073	0.0002	9.2077
SDlog	0.1744	0.1747	0.0001	0.1749
Call Price	97.8775	98.2670	0.1987	98.6565

Figure 2 illustrates how the estimates converge toward the price/premium of Indonesian Call SW as the number of repetitions increases, from $N = 1$ to $N = 1000$. The confidence intervals for the price/premium estimates are shown at confidence levels of 80%, 90%, 95%, and 99%. It can be observed that, even before $N = 100$, the confidence intervals for all levels no longer encompass the value of 100. Based on the estimated Indonesian Call SW price obtained at this stage, Figure 3 presents its payoff diagram. It can be observed that investors incur a loss with a maximum cap of the price/premium $\hat{C} = 98.2670$ if the settlement price does not exceed $K + 5\hat{C} = 11119.66$, and make a profit if it exceeds this threshold. This indicates that the conversion rate plays an important role in making the price/premium of the Indonesian Call SW more affordable, but this factor also makes the profit harder to reach.

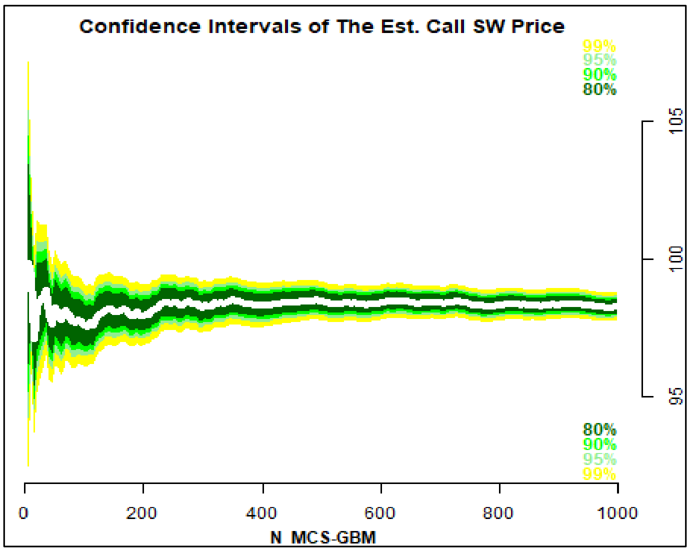


Figure 2. Convergence of Estimated Call SW Price and Confidence Intervals Across $N = 1000$ Simulations

Based on Table 1 and considering that the procedure has not been repeated for the next level of L, the lognormal distribution parameters for the settlement prices, namely *Meanlog* and *SDlog*, have converged. This is evident as the estimated Meanlog is 9.2073 with a very small standard error of 2×10^{-4}, and SDlog is 0.1747 with an equally small standard error of 10^{-4}. The *p-values* from the repetition ($N = 1000$) are also consistently 100% greater than 0.05, meaning all values are greater than 0.05. This indicates that the settlement price distribution model can be confidently confirmed as lognormal with these parameters.

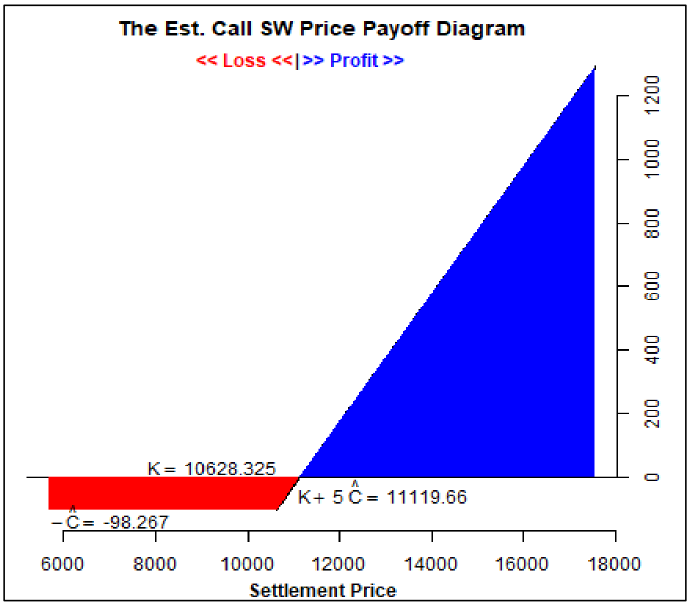


Figure 3. Payoff Diagram Based on Estimated Indonesian Call SW Price/Premium

Furthermore, the findings align closely with existing literature on lognormal distributions. For instance, Asmussen & Rojas-Nandayapa (2008) explore the asymptotics of sums of log-normal variables under a Gaussian copula framework, while Gao et al. (2009) examine the asymptotic behavior of tail densities for correlated lognormal variables. These studies emphasize the robustness of lognormal models, particularly in scenarios involving correlations among variables, which is relevant to the settlement price in this study. However, while these works focus on sums of lognormal variables, the settlement price distribution examined here corresponds to an averaged lognormal case, potentially introducing distinctive features.

Botev & L'Ecuyer (2017) and Asmussen et al. (2019) further advance the understanding of lognormal distributions by providing precise methodologies for modelling the right tail of dependent lognormal variates and deriving orthonormal polynomial expansions for lognormal sum densities. Nevertheless, the categorization of settlement prices as a correlated averaged lognormal distribution remains unexplored in this article. The derivation of specific parameters for such distributions, as proposed in the aforementioned references, is identified as a direction for future research. This gap presents an opportunity to refine the analytical understanding of settlement price distributions in Structured Warrants, thereby enhancing the theoretical and practical applicability of such models.

The NM simulation procedure can be repeated up to $L = 100$ iterations for more robust estimates. This means a total of $LNM = 10^8$ price paths for the underlying asset were generated. With 125 trading days, a total of 1.25×10^{10} asset prices were generated for this study. Table 2 presents the estimated price/premium of the Indonesian Call SW and the lognormal model parameters for the settlement price distribution. The estimated price/premium of the Indonesian Call SW was $\hat{C} = 98.2946$, with a minimal standard error of 0.02. These results indicate that the Indonesian Call SW price/premium is slightly lower than the value obtained using the Black & Scholes Formula for a European Call Option, divided by the conversion rate ($c_r = 5$), which yields 100. In this hypothetical case, the Indonesian Call SW price/premium was approximately 1.7% lower.

Table 2. Estimated Price/Premium and Lognormal Model Parameters for the Indonesian Call SW

Statistics	Estimated Value	Std. Err. Value
Meanlog	9.2074	0.00002
SDlog	0.1746	0.00001
Call Price	98.2946	0.02086

Future research could explore the reasons for the price difference, particularly once analytical formula for the Indonesian Call SW price/premium is developed. These findings also have implications for the Indonesian capital market, where implied volatility—a metric closely tied to the Black-Scholes Formula—is still widely used. Given the continued relevance of the Geometric Brownian Motion assumption, the price/premium of Indonesian Call SWs in the market should not differ significantly from the Black-Scholes-derived value divided by the conversion rate. This study supports the findings of Jayadi & Sumarti (2023), who, using the Binomial Option Pricing model, observed that Indonesian Call SWs traded in the market are currently overpriced.

D. CONCLUSION AND SUGGESTIONS

The research successfully developed a robust simulation-based pricing model for Indonesian Call Structured Warrants (SWs) and analyzed their settlement price distributions. This study identified and confirmed unique features of Indonesian SWs, notably the average-price settlement mechanism, conversion rates, and specific trading parameters such as the Symmetrical Auto Rejection rule, setting them apart from European Equity Options. Key findings include: Firstly, the Monte Carlo simulation approach successfully captures the pricing dynamics and settlement price distributions of Indonesian SWs. The results validate that SW prices are significantly influenced by factors such as the average-price settlement mechanism, conversion rates, and market volatility. Importantly, the Symmetrical Auto Rejection rule, imposing constraints on asset price movements, enhances the model's realism by reflecting actual market conditions more accurately. Secondly, the research confirms that settlement prices conform to a lognormal distribution, supporting the Geometric Brownian Motion (GBM) framework. This finding aligns closely with implied volatility metrics widely adopted by issuers in the Indonesian market, particularly due to the relatively short maturity periods of Indonesian SWs. However, discrepancies identified suggest the necessity for alternative or enhanced modelling to address scenarios where asset price movements deviate from GBM assumptions. Thirdly, the conversion rate significantly impacts Indonesian SW pricing. While lowering the cost per unit, thereby increasing affordability, conversion rates also proportionally raise the break-even point. This dual impact underscores both advantages and risks associated with SW investments, highlighting the importance of considerable underlying asset price movements for profitability. Fourthly, simulated Indonesian Call SW prices were slightly lower compared to those derived from the Black-Scholes formula adjusted for conversion rates. This discrepancy highlights the potentials for refining analytical pricing models specifically tailored to Indonesian SW characteristics, particularly focusing on capturing the nuances of the average-price settlement mechanism more accurately.

Practical implications from this research are as follows: (1) Investors should leverage simulation-based insights to better assess risks and returns associated by anticipating with SW investments, paying close attention to conversion rates and settlement mechanisms. This informed approach can significantly enhance decision-making regarding investment and trading strategies; (2) Issuers can use these insights to improve pricing accuracy and transparency in the design of Indonesian SW products, thereby minimizing mispricing risks and attracting a broader investor base; and (3) Regulators are advised to refine existing frameworks, particularly focusing on enhancing investor protection and adjusting market rules like the Symmetrical Auto Rejection rule. A clearer understanding of these rules' implications on SW pricing dynamics can lead to more efficient and transparent markets. The outcomes of this study contribute to a more comprehensive understanding of Indonesian SWs, offering practical insights for stakeholders and paving the way for more efficient and transparent markets. Future research should specifically focus on developing analytical pricing formulas that complement simulation-based methods, emphasizing models that can better handle deviations from the GBM assumption. Detailed studies addressing the impact of specific market rules on pricing dynamics and comparative analyses between Call and Put SWs will also be valuable for future investigation.

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