

Modeling Term Life Insurance Premiums Using Monte Carlo Simulations with Stochastic Interest Rates Based on The Indonesia Mortality Table IV

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ABSTRACT

This study addresses the limitation of deterministic interest rate assumptions in actuarial premium calculations, which may lead to inaccurate pricing, particularly for long-term life insurance products. In practice, interest rates are influenced by economic conditions and exhibit stochastic behavior, making fixed-rate assumptions less realistic. Therefore, incorporating interest rate uncertainty is essential to obtain more accurate and reliable premium estimates. The objective of this study is to determine the net premium of term life insurance by integrating stochastic interest rates using the Vasicek model and Monte Carlo simulation. A quantitative approach is employed using actuarial modeling based on the Indonesian Mortality Table IV (TMI IV) and the equivalence principle. Interest rates are modeled as a mean-reverting stochastic process, and Monte Carlo simulation with 10,000 iterations is applied to estimate the distribution of premiums under uncertainty.

The results show that premiums increase significantly with higher entry age and longer coverage periods, reflecting increased mortality risk and longer exposure to uncertainty. Male premiums are consistently higher than female premiums due to higher mortality probabilities. The premium distribution is approximately normal, with increasing variability observed for longer-term policies. Sensitivity analysis indicates that the long-term mean interest rate parameter has the strongest influence on premium values, while volatility mainly affects the dispersion of premiums rather than their expected value. Overall, the stochastic approach provides a more realistic and comprehensive framework compared to deterministic methods, as it captures both expected values and uncertainty. The findings of this study can support more accurate pricing, improved risk management, and better decision-making in the life insurance industry, particularly in the Indonesian context.

Keywords: Actuarial premium, Monte Carlo simulation, Stochastic interest rate, Term life insurance, Vasicek model

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INTRODUCTION

Life insurance is an essential financial instrument designed to mitigate the economic impact of premature death by transferring risk from individuals to insurance institutions. Among various products, term life insurance is widely preferred due to its simplicity and affordability, as it provides protection over a fixed period with a predefined death benefit. Determining an appropriate premium for such products is a central task in actuarial science, requiring accurate modeling of both mortality risk and financial factors (1,2).

The calculation of life insurance premiums is influenced by multiple actuarial components such as age, gender, mortality probability, and interest rates. These factors determine the present value of expected benefits and premiums, and therefore play a crucial role in ensuring the fairness and sustainability of insurance products (3). The premium of term life insurance is determined by several key components, including mortality rates, interest rates, contract duration, and the characteristics of the insured. Among these factors, interest rates play a crucial role as they directly affect the discounting process used in actuarial valuation (4).

In classical actuarial practice, the valuation of life insurance contracts is typically performed under the assumption of a constant interest rate. However, this assumption is often unrealistic, as interest rates in financial markets exhibit stochastic behavior influenced by economic conditions, inflation, and monetary policy. The use of deterministic interest rates may therefore lead to inaccurate pricing and inadequate risk assessment, particularly for long-term insurance products (5).

In many actuarial studies, the assumption of a constant interest rate is still commonly applied. However, this assumption does not adequately reflect real economic conditions, as interest rates tend to fluctuate over time. Ignoring this variability may lead to less accurate actuarial valuations, particularly in long-term financial products such as insurance and pension funds. Empirical evidence shows that incorporating stochastic interest rate models, such as the Vasicek model, produces more realistic estimates of actuarial liabilities compared to constant interest rate assumptions, highlighting the importance of considering interest rate dynamics in actuarial modeling (6).

Interest rate fluctuations also play a crucial role in the financial stability of insurance companies, as they directly affect both asset valuation and liability estimation. Changes in interest rates can significantly influence solvency levels and the overall financial performance of insurers. This indicates that interest rate uncertainty is not only a theoretical concern but also a key risk factor in insurance practice, reinforcing the need for more robust and dynamic modeling approaches (7).

Deterministic approaches assume constant returns or interest rates over time, which limits their ability to accurately represent real-world conditions. In contrast, stochastic approaches treat these variables as random, allowing for more flexible and realistic modeling of financial uncertainty. As a result, stochastic models are generally more suitable for capturing the variability of financial outcomes in insurance products compared to deterministic methods (8).

To address these limitations, stochastic interest rate models have been introduced in actuarial and financial modeling. One of the most prominent models is the Vasicek model, which describes interest rate dynamics using a mean-reverting stochastic process. This model captures the tendency of interest rates to fluctuate around a long-term equilibrium level while incorporating random shocks. Its mathematical tractability and economic relevance make it suitable for applications in insurance pricing and financial risk analysis (9).

In traditional actuarial calculations, interest rates are often assumed to be constant,



which is less appropriate for long-term insurance products where rates are influenced by economic factors such as inflation and market dynamics. To overcome this limitation, stochastic interest rate models such as the Vasicek and Cox–Ingersoll–Ross (CIR) models have been introduced to better capture interest rate variability (10).

Traditional fixed interest rate assumptions often fail to capture market volatility, leading to potential misestimation in actuarial calculations. The Vasicek stochastic interest rate model provides a more realistic representation of interest rate dynamics due to its mean-reverting property, making it particularly suitable for long-term insurance valuation. Empirical results indicate that models incorporating Vasicek interest rates produce more robust and reliable estimates compared to deterministic approaches (11).

Alongside stochastic modeling, Monte Carlo simulation has become a widely used numerical method for solving complex problems in finance and actuarial science. By generating a large number of random scenarios, this method enables the estimation of expected values and probability distributions of uncertain variables. In the context of life insurance, Monte Carlo simulation allows actuaries to obtain not only a single premium estimate but also the distribution and variability of premiums under uncertain interest rate conditions (12).

Monte Carlo simulation is a probabilistic method used to model uncertainty by generating random variables based on historical data distributions. This method enables the projection of future outcomes under uncertain conditions and is particularly useful in financial risk analysis. By incorporating random variability into the model, Monte Carlo simulation allows decision-makers to evaluate possible future scenarios rather than relying on a single deterministic estimate (13).

Monte Carlo simulation has been widely applied in actuarial science to estimate insurance premiums and reserves by incorporating uncertainty in key variables such as interest rates, contract duration, and benefit structures. The method allows actuaries to analyze the impact of various risk factors on premium values, providing a more comprehensive understanding of insurance pricing under uncertainty (14).

Monte Carlo methods are also widely used to estimate expected values and probability distributions of complex random variables, particularly when analytical solutions are difficult to obtain. Advanced techniques such as Markov Chain Monte Carlo (MCMC) enable the estimation of complex probability distributions through iterative sampling, making them highly suitable for actuarial and financial modelling (15).

In Indonesia, mortality assumptions are based on the Indonesian Mortality Table IV (TMI IV), which provides standardized mortality probabilities for the population. While this table serves as a reliable foundation for actuarial calculations, its application is often combined with fixed interest rate assumptions. Integrating TMI IV with stochastic interest rate modeling can therefore enhance the realism and robustness of premium estimation.

Based on the above background, this study aims to determine the net premium of term life insurance by incorporating stochastic interest rates modeled using the Vasicek process and applying Monte Carlo simulation techniques. This approach is expected to produce a more comprehensive representation of premium uncertainty and provide valuable insights for actuarial practice, particularly in the Indonesian life insurance industry.

MATERIAL AND METHODS

2.1. Research Type

This quantitative investigation employs actuarial modeling and Monte Carlo simulation techniques. By taking interest rate uncertainty into account, this method seeks to

determine the net premium of term life insurance.

Based on mortality probability, the actuarial model is utilized to determine the present value of insurance benefits and the premium annuity. The contemporary actuarial mathematics literature has extensively covered the basic ideas of life insurance and annuity contract valuation (16,17)

Additionally, stochastic interest rate changes are modeled using Monte Carlo simulation, which produces a more realistic premium distribution than a deterministic approach.

2.2. Research Data and Sources

The Indonesian Life Insurance Association (AAJI) produced the Indonesian Mortality Table (TMI IV), which is used in this study. The annual death probabilities for males and females between the ages of 0 and 111 are shown in this mortality table. The actuarial model uses the data as the foundation for determining survival odds. The mortality data is available on the information center page of the official AAJI website: <https://aaji.or.id/PusatInformasi/Lainnya> (18)

The main parameters used from the mortality table are:

- a) q_x : the probability that an individual aged x dies within one year
- b) p_x : the probability that an individual aged x survives for one year

The relationship between the two is given by:

$$p_x = 1 - q_x \quad (1)$$

In addition, the survival function l_x is used, which represents the number of individuals still alive at age x .

2.3. Discrete Term Life Insurance Model

An n -year term life insurance model is used in this study, where the benefit payment is paid at the end of the year of death.

Let:

x = entry age of the insured

n = coverage period

S = sum assured (benefit amount)

The insurance company provides a reward equal to S if the insured passes away during the coverage period.

One of the basic contract forms in actuarial mathematics, the term "life insurance model" is frequently used to calculate premiums and value life insurance contracts (16).

2.4. Present Value of the Insurance Benefit

For an n -year term life insurance policy, the actuarial present value of the death benefit is written as

$$A_{x:n}^1 = \sum_{k=1}^n v^k {}_{k-1}p_x q_{x+k-1} \quad (2)$$

where

$$v = (1 + i)^{-1} \quad (3)$$

is the annual interest rate, and is the discount factor.

The anticipated present value (EPV) of the death benefit payment is represented by this figure. The foundation for determining the value of life insurance contracts is the idea of actuarial present (16,17).

2.5. Present Value of the Premium Annuity

As long as the insured is still alive at the end of the coverage period, annual premiums are paid. The premium annuity's current value is stated as

$$\ddot{a}_{x:n} = \sum_{k=0}^{n-1} v^k {}_k p_x \quad (4)$$

The present value of all yearly premium payments made during the coverage term is represented by this figure.

The actuarial mathematics literature extensively discusses this annuity model, which is crucial to the computation of life insurance contract premiums (16).

2.6. Premium Equivalence Principle

The equivalency principle, which asserts that the expected present value of benefits received equals the expected present value of premiums paid, is used to calculate the net premium.

Mathematically,

$$P \times \ddot{a}_{x:n} = S \times A_{x:n}^1 \quad (5)$$

Thus, the annual net premium can be calculated as

$$P = \frac{S A_{x:n}^1}{\ddot{a}_{x:n}} \quad (6)$$

A key idea in the theory of life insurance premium determination is the equivalency principle (17).

2.7. Vasicek Stochastic Interest Rate Model

The Vasicek model is used in this work to model the interest rate stochastically rather than assuming it is constant.

The mean reversion feature of this model, which indicates that interest rates typically return to a long-term average level, captures the dynamics of interest rates.

The stochastic differential equation of the Vasicek model is

$$dr_t = \kappa(\theta - r_t)dt + \sigma dW_t \quad (7)$$

where:

r_t : interest rate at time t

κ : speed of mean reversion

θ : long-term mean level

σ : interest rate volatility

W_t : Wiener process

Vasicek first presented this model in his examination of the interest rate term structure (19)

2.8. Monte Carlo Simulation

In order to account for interest rate uncertainty, premiums were calculated using Monte Carlo simulation. To get a numerical approximation of a random variable's expected value, this method uses random number generation. To generate a reliable estimate of the premium distribution, the simulation was run through 10,000 iterations.

In each simulation iteration, the following steps are carried out:

1. Use the usual normal distribution to generate random integers.
2. Use the Vasicek model to create the annual interest rate path.
3. Using the simulated interest rate path, calculate the discount factor.
4. Determine the death benefit's present value.
5. Determine the premium annuity's present value.
6. Use the equivalency principle to calculate the premium

Because Monte Carlo simulation can numerically estimate the distribution of complex variables, it is frequently employed in actuarial and financial modeling (20)

2.9. Monte Carlo Simulation Algorithm

The simulation algorithm can be summarized as follows.

Step 1. Parameter Initialization

- a) entry age x
- b) coverage period n
- c) sum assured S
- d) Vasicek parameters $\kappa, \theta, \sigma, r_0$
- e) number of simulations N

Step 2. Interest Rate Simulation

$$r_{t+1} = r_t + \kappa(\theta - r_t)\Delta t + \sigma\sqrt{\Delta t}Z_t \quad (8)$$

where $Z_t \sim N(0,1)$.

Step 3. Calculate the Discount Factor

$$v_t = e^{-r_t} \quad (9)$$

Step 4. Calculate the Present Value of the Benefit

This is computed using mortality probabilities from the mortality table.

Step 5. Calculate the Present Value of the Premium Annuity

Step 6. Calculate the Premium

$$P_i = \frac{S \times A_{x:n}^1}{\ddot{a}_{x:n}} \quad (10)$$

This process is repeated for N simulations to obtain the distribution of premiums.

2.10. Software Used

With the aid of a number of numerical computing libraries, such as NumPy, Pandas, Matplotlib, and SciPy, the Python programming language was used to perform the computations and simulations in this study. Numerical computing software makes it possible to run Monte Carlo simulations with many iterations, which improves the stability and computational efficiency of the expected value estimate.

RESULTS AND DISCUSSION

3.1. Synopsis of the TMI IV Mortality Table Information

The primary source for determining life insurance rates in Indonesia is the Indonesian Mortality Table (TMI IV), which is the official mortality table released by the Indonesian Life Insurance Association (AAJI). The values of q_x (the likelihood of mortality at exact age x) for the male and female groups from age 0 to 111 comprise the data used in this study, totaling 112 data rows.

The data exploration revealed that, males have a minimum of 0.000190 (young adult ages) and a maximum of 1.000000 (age 111, deterministic death). The minimum and maximum values of q_x for females are 0.000180 and 1.000000, respectively. Males have a higher death risk than females in all age groups, as seen by the average q_x for males (0.087007) being higher than for girls (0.072728).

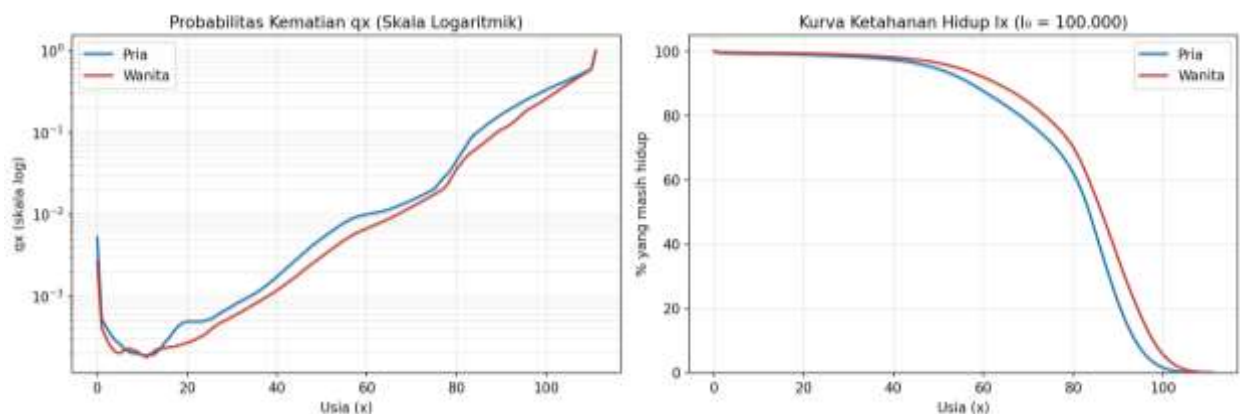


Figure 1. Death Probability Curve q_x (Logarithmic Scale) and Survival Curve l_x Based on TMI IV

The q_x curve for both sexes is displayed on a logarithmic scale in Figure 1 (left panel). The curve has the distinctive "U" or "J" shape that is frequently seen in demographic studies: mortality is comparatively high in infancy (q_0 for males = 0.00524), sharply declines during childhood, reaches its minimum around ages 10–12, and then gradually rises with age. In practically every age group, the male curve (blue) is consistently higher than the female curve (red), suggesting that men are systematically more likely to die.

The survival curve l_x with an initial population of $l_0 = 100,000$ is shown in the right panel of Figure 1. It is clear from the curve that females are more likely to survive at all ages. For instance, there is a notable gender difference in life expectancy at age 65, with almost 80% of girls and 72% of males from the original population still alive.

3.2. Outcomes of Simulating Stochastic Interest Rates with the Vasicek Model

The Vasicek (1977) model is used in this work to simulate the interest rate stochastically rather than as a deterministic constant. This model was selected because of its capacity to reflect two crucial aspects of interest rates in financial markets: volatility, which may be adjusted based on market conditions, and mean reversion, which is the propensity to return to a long-term average value.

The following model parameters are used: $\kappa = 0.30$ (speed of mean reversion), $\theta = 1.5\%$ (volatility), $\theta = 6.5\%$ (long-term mean, according to the BI Rate), and $r_0 = 6.5\%$. The Vasicek model's stochastic differential equation is as follows:

$$dr_t = \kappa(\theta - r_t)dt + \sigma dW_t \quad (11)$$

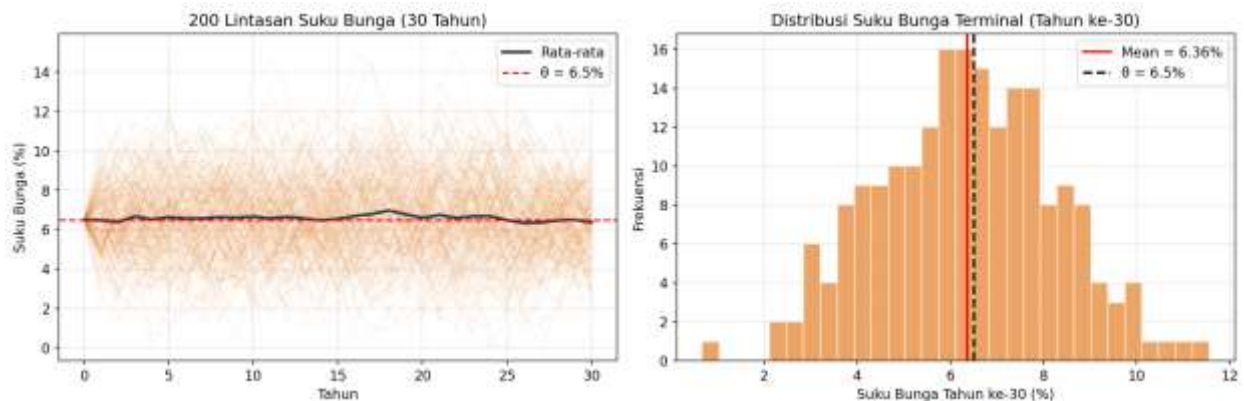


Figure 2. Vasicek Model Simulation of 200 Interest Rate Paths (left) and Terminal Interest Rate Distribution in Year 30 (right)

200 simulated interest rate courses over a 30-year period are shown in Figure 2 (left panel). Paths that diverge significantly from $\theta = 6.5\%$ tend to be drawn back toward this level over time, demonstrating the mean reversion phenomena. The model's mean-reverting property is validated since the thick black line, which shows the average of all simulated trajectories, closely matches the red dashed θ line.

The distribution of interest rates at the end of year 30 from the 200 simulations is displayed in the right panel. In accordance with the mathematical solution of the Vasicek model, where the steady-state distribution is Gaussian with mean θ and variance $\sigma^2/(2\kappa)$, the distribution appears roughly normal with a mean near $\theta = 6.5\%$. The theoretical variance with the given parameters is

$$\frac{0,015^2}{(2 \times 0,30)} = 0,000375$$

which corresponds to a standard deviation of approximately 1.94%.

3.3. Results of the Monte Carlo Simulation for Term Life Insurance Rates

The actuarial equivalency principle, which states that the expected present value of premiums paid (APV of the premium annuity) must equal the expected present value of death payments (APV of the benefit), is used to determine the net premium of an n-year term life insurance policy. The following formula is applied:

$$P = \frac{A_{x:n}^1}{\ddot{a}_{x:n}} \quad (12)$$

where:

$A_{x:n}^1$ = APV of the death benefit

$\ddot{a}_{x:n}$ = APV of the premium annuity

Ten thousand iterations of the Monte Carlo simulation were run for every scenario. The Vasicek model is used to construct a whole interest rate path in each iteration. The APV of the benefit, the APV of the annuity, the net premium, and the stochastic discount factor are then computed. The mean, standard deviation, and 95% confidence interval are then estimated by statistical analysis of the resultant 10,000 premium values.

3.3.1. Net Premium Summary Table

The annual net premium estimates for all examined scenarios are shown in Table 1, assuming a sum assured (SA) of IDR 1,000,000,000 (IDR 1 billion).

Table 1. Term Life Insurance Net Premium Summary (SA = IDR 1 Billion)

Gender	Entry Age	Term (years)	Mean Premium (IDR)	Std Dev (IDR)	Rate (%)
Male	25	10	666,439	13,088	0.07%
	25	20	970,523	37,335	0.10%
	25	30	1,500,164	105,044	0.15%
	35	10	1,543,599	35,293	0.15%
	35	20	2,529,043	113,743	0.25%
	35	30	3,466,054	217,654	0.35%
	45	10	4,422,524	99,065	0.44%
	45	20	5,917,440	193,677	0.59%
	45	30	6,939,844	300,710	0.69%
	55	10	8,914,103	136,190	0.89%
Female	55	20	10,352,694	234,223	1.04%
	25	10	497,822	9,632	0.05%
	25	20	691,939	24,352	0.07%
	25	30	1,000,917	61,919	0.10%
	35	10	1,058,681	22,109	0.11%
	35	20	1,618,904	66,442	0.16%
	35	30	2,272,994	142,207	0.23%

Gender	Entry Age	Term (years)	Mean Premium (IDR)	Std Dev (IDR)	Rate (%)
	45	10	2,686,405	58,055	0.27%
	45	20	3,791,802	138,704	0.38%
	45	30	4,816,081	250,769	0.48%
	55	10	5,950,991	106,108	0.60%
	55	20	7,598,196	229,579	0.76%

Table 1 shows that longer coverage durations and higher entry ages result in a large rise in the net premium. A 55-year-old guy with a 20-year term pays IDR 10,352,694 annually (1.04% of SA), a rise of more than 15 times, whereas a 25-year-old male with a 10-year term pays roughly IDR 666,439 annually (0.07% of SA). Longer coverage terms also result in higher premium standard deviations, which indicate more uncertainty brought on by long-term changes in interest rates. This finding emphasizes how stochastic interest rates affect premium variability, especially for longer-term plans.

3.3.2. The Monte Carlo simulation's premium distribution

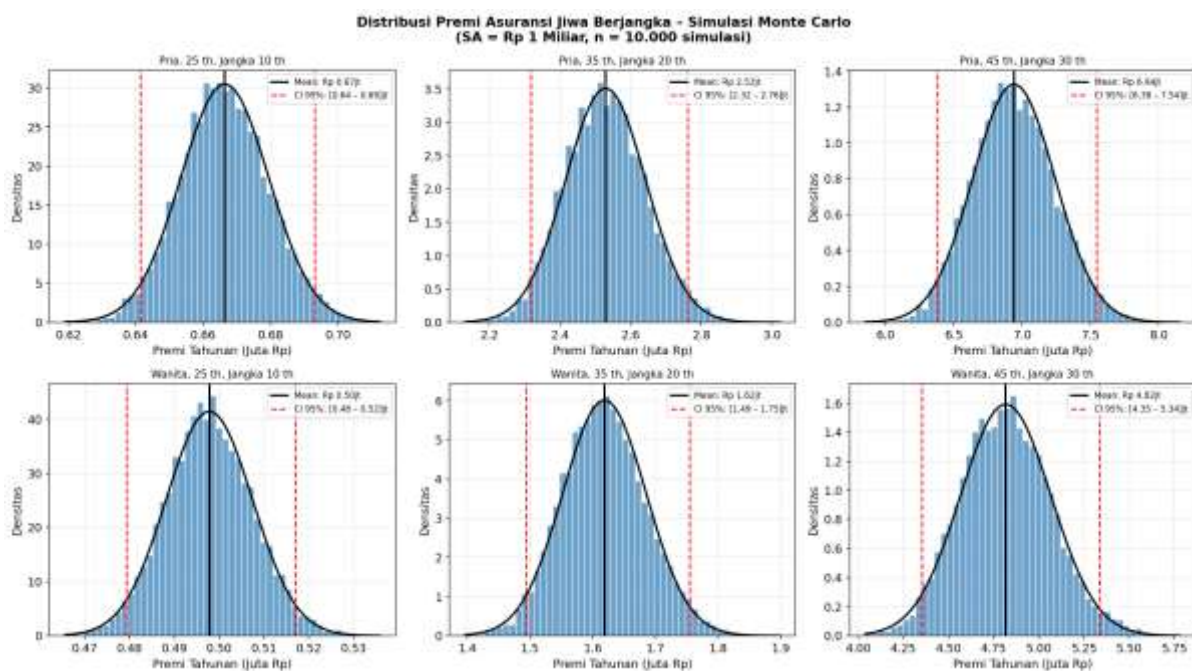


Figure 3. Shows the premium distribution for six representative scenarios based on 10,000 Monte Carlo simulations (SA = IDR 1 billion).

The premium distribution histograms derived from 10,000 Monte Carlo simulations for six example situations are shown in Figure 3.3. A normal distribution fitted to the simulated data is shown by the black curve in each panel, the mean premium value is shown by the thick black vertical line, and the boundaries of the 95% confidence interval are shown by the red dashed lines.

In both cases, the Monte Carlo simulations' premium distributions visually nearly approximate a normal distribution. This happens because, in accordance with the Central

Limit Theorem, the premium is a linear function of numerous independent random variables (interest rate values at each period). Technical reserve calculations and statistical interpretation are made easier by the symmetric and roughly normal distribution.

Longer coverage terms result in a wider 95% confidence interval. For instance, the 95% CI range for a 45-year-old male with a 30-year term is [IDR 6,380,477 – IDR 7,544,645], or roughly IDR 1.16 million. This suggests that long-term product premium uncertainty rises as a result of stochastic interest rates, which has significant ramifications for risk management in insurance firms.

3.4. Analysis of Premium Sensitivity

3.4.1. Impact of Coverage Term and Entry Age

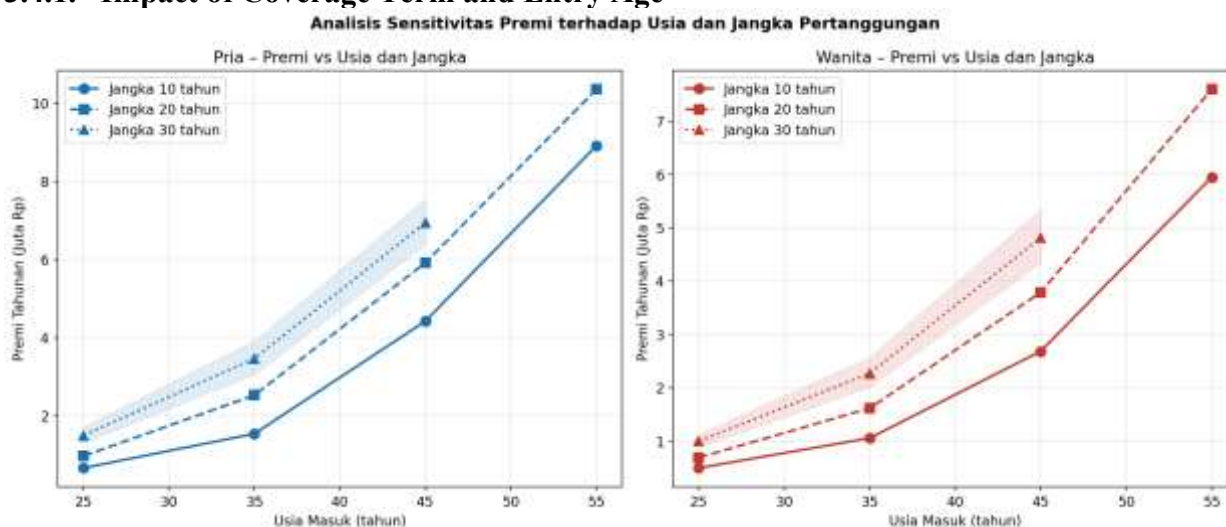


Figure 4. Premium Sensitivity to Coverage Term and Entry Age for Men (left) and Women (right)

The link between entry age and annual premium for three distinct coverage terms (10, 20, and 30 years) is shown in Figure 3.4. For both genders, two key conclusions are consistently noted:

1. In relation to entry age, premiums rise at an increasing (nonlinear) rate. The premium increase between the ages of 25 and 35 is substantially less than that between the ages of 45 and 55. This is in line with the death patterns seen in the TMI IV mortality table and represents the growing mortality risk at older ages.
2. Premiums are higher for longer coverage durations, but the pace of growth shows a diminishing marginal benefit. This happens because, after discounting, the contribution of these early years to the APV of benefits is extremely minimal because long-term premiums cover times when the likelihood of death is still quite low (younger ages).

3.4.2. Comparison of Premiums by Gender

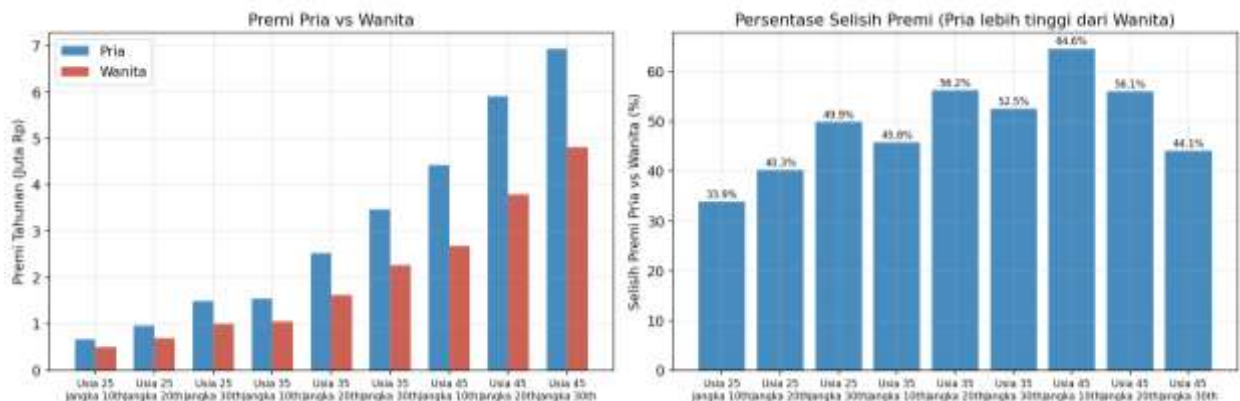


Figure 5. Shows the percentage difference in premiums (right) and a comparison of male and female premiums (left)

A methodical comparison of premiums for male and female policyholders is shown in Figure 5. For every combination of entrance age and coverage period, male rates are consistently higher than female premiums. The percentage difference between male and female premiums, which varies from 25% to 50%, is shown in the right panel.

The 30-year coverage duration has the biggest premium difference. The male premium (IDR 1,500,164) is around 50% more than the female premium (IDR 1,000,917) for an entering age of 25 with a 30-year term. This discrepancy only represents the cumulative mortality differences in the TMI IV mortality table, where a male's chance of dying during the next 30 years is substantially higher than a female's. These results are in line with gender-based underwriting procedures that are frequently used in the Indonesian and global life insurance markets.

3.4.3. Premium Heatmap by Term and Age

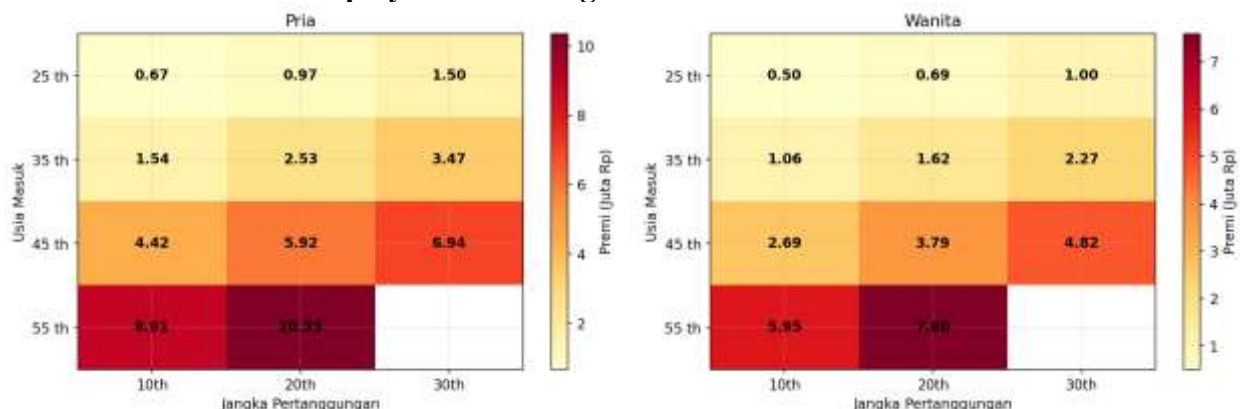


Figure 6. Heatmap of Annual Premiums (Million IDR) by Coverage Term and Entry Age for Men (left) and Women (right)

A premium heatmap, which enables a thorough visualization of premium patterns, is shown in Figure 3.6. The color gradient, which goes from yellow (low premiums) to dark red (high premiums), clearly shows how premiums climb with both entering age and coverage period. The greatest premiums, which total IDR 10.35 million for men and IDR 7.60 million for women annually, are found in the darkest cells (age 55 with a 20-year term).



It should be mentioned that the combination of a 30-year term and an entrance age of 55 was not examined since it is practically impractical (the insured would be 85 at the conclusion of the coverage period, and the resulting premium would be extraordinarily high, making the product economically uncompetitive). Actuaries can use this heatmap as a useful pricing tool when creating premium tables for insurance products.

3.5. Vasicek Model Parameter Sensitivity Analysis on Premiums

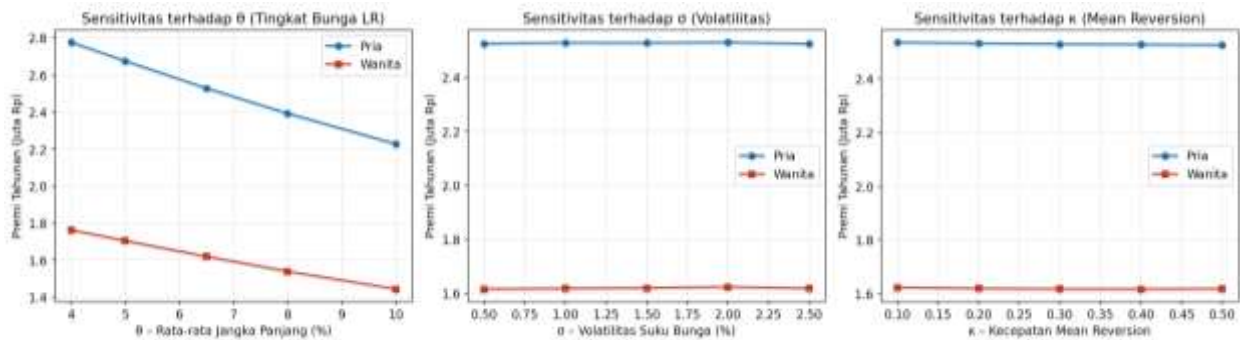


Figure 7. Premium Sensitivity to Vasicek Model Parameters: θ (left), σ (middle), and κ (right) -Scenario: Male and Female, Age 35, 20-Year Term

A sensitivity study of premiums in relation to the three Vasicek model parameters for a benchmark scenario (entry age 35, coverage term 20 years, SA = IDR 1 billion) is shown in Figure 7.

The impact of θ (the long-term mean interest rate) on premiums is displayed in the left panel. There is a definite inverse relationship: the resulting premium decreases as the value of θ increases. The male premium drops from about IDR 3.2 million to about IDR 1.8 million as θ rises from 4% to 10%. Economically speaking, this makes sense: higher interest rates result in larger discount factors, which lower the present value of death benefits (the premium formula's numerator). The consequence is that insurance firms might have to raise premiums in low-interest-rate circumstances, like the post-pandemic period.

The impact of σ (interest rate volatility) is displayed in the middle panel. It's interesting to note that because the curve is practically flat, volatility has very little effect on the mean premium. This happens because the premium formula is based on the expected present value, which is the average of all simulations. Because premiums have a roughly symmetric distribution, volatility mostly expands the distribution without changing the mean. Therefore, rather than the mean premium itself, volatility mostly impacts the uncertainty or risk that the insurance firm faces.

The influence of κ (the speed of mean reversion) is shown in the right panel. It has less of an impact than θ . Higher values of κ cause premiums to somewhat decline because interest rates converge toward θ more quickly, shortening the period of time below the long-term mean level. These results demonstrate the significance of precisely calibrating θ using market data, confirming that θ is the most sensitive parameter in the context of premium modeling.

3.6. Normality Test of Premium Distributions and Descriptive Statistics

The results of the D'Agostino-Pearson normality test (using normaltest from the scipy.stats package) for six example situations are shown in Table 3.2, along with detailed descriptive statistics of premium distributions from the Monte Carlo simulations.

Table 2. Normality Test and Descriptive Statistics for Premium Distributions ($n = 10,000$ simulations)

Scenario	Mean (IDR)	Median (IDR)	Std Dev (IDR)	Skewness	Kurtosis	Normality p-value
Male, 25, 10-year	666,439	666,108	13,088	0.0993	-0.0295	0.0002
Male, 35, 20-year	2,529,043	2,525,613	113,743	0.1606	-0.0597	0.0000
Male, 45, 30-year	6,939,844	6,929,315	300,710	0.1717	-0.0402	0.0000
Female, 25, 10-year	497,822	497,649	9,632	0.0922	0.0174	0.0008
Female, 35, 20-year	1,618,904	1,617,139	66,442	0.1756	-0.0144	0.0000
Female, 45, 30-year	4,816,081	4,811,548	250,769	0.1703	-0.0019	0.0000

Several significant findings regarding the premium distributions may be drawn from Table 2:

- The distributions are roughly symmetric since the mean and median are fairly near in all cases (difference $< 0.1\%$). The 30-year term scenario (male, 45-year entry: mean IDR 6,939,844 vs. median IDR 6,929,315) shows the biggest difference, which is consistent with a little positive skewness.
- The somewhat positive skewness values, which range from 0.09 to 0.18, indicate that the premium distributions have somewhat longer right tails. This suggests a tiny but not insignificant chance that low-interest-rate situations may result in extremely high premiums, which is important for solvency evaluations and stress tests.
- The tail thickness of the premium distributions is comparable to a normal distribution (mesokurtic), as indicated by kurtosis values that are near zero (between -0.060 and $+0.017$). No high tail risk is shown by the lack of significant kurtosis.
- The null hypothesis of perfect normality is statistically rejected when the D'Agostino-Pearson normality test returns p-values < 0.05 for every scenario. However, the test's high sensitivity with $n = 10,000$ is mostly to blame for this rejection. The standard actuarial assumption of normality is supported by the very tiny skewness and kurtosis values, which practically show that premium distributions can be well-approximated by a normal distribution.

3.7. Convergence Test for Monte Carlo Simulation

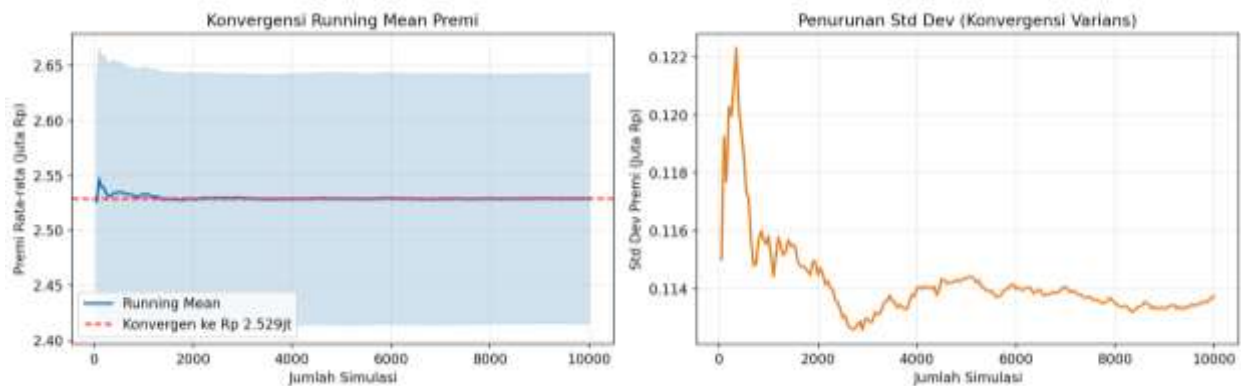


Figure 8. Convergence Test: Male, Age 35, 20-Year Term, Running Mean (left) and Standard Deviation Reduction (right)

The convergence analysis for a 35-year-old male with a 20-year term is shown in Figure 8. The running mean of premiums as the number of simulations rises is displayed in the left panel, and the decrease in the mean estimate's standard deviation is displayed in the right panel.

After about 3,000 iterations, the running mean of premiums stabilizes and varies very little around the converged value of IDR 2,529,043, indicating a clear convergence. According to the premise that the standard error of the mean diminishes according to $\frac{1}{\sqrt{n}}$, the gray shaded area (± 1 standard deviation) narrows as the number of simulations grows.

The standard deviation's monotonic decline is confirmed by the right panel. This study's 10,000 simulations result in a standard error of the mean of roughly $SE = 113,743 / 10,000 \approx 1,137$ IDR or around 0.045% of the average premium. This degree of accuracy is more than sufficient for premium settings in actuarial practice, where error limits often don't go over 1% to 2%.

3.8. Analysis of Results and Consequences

3.8.1. Benefits of the Stochastic Interest Rate Method

In contrast to traditional deterministic methods, this study shows that the Vasicek stochastic interest rate model offers a more realistic framework for Monte Carlo simulations. The stochastic approach produces a complete distribution of premiums, including confidence intervals, which are extremely useful for managing insurance risk, while a deterministic approach with a fixed interest rate (e.g., 6.5%) only produces a single premium value without any information on uncertainty.

There is a lot of useful information about premium distributions, especially the standard deviation and confidence intervals. The upper bound of the 95% CI can be used by insurance companies to create technical reserves that are more resilient to changes in the market or as a foundation for gross premiums with more conservative loading.

3.8.2 Consequences for the Life Insurance Sector in Indonesia

The results have a number of significant ramifications for the Indonesian life insurance market, including:



1. The need for frequent monitoring and recalibration of interest rate parameters is highlighted by the high sensitivity to θ_0 , particularly during times of major changes in Bank Indonesia's monetary policy.
2. The official Indonesian mortality standard, TMI IV mortality statistics, supports the consistent gender-based premium differentiation (males 25–50% more expensive), which should be upheld in underwriting procedures.
3. In the context of the Risk-Based Capital (RBC) framework required by the Otoritas Jasa Keuangan (OJK), the simulation findings can be used as a standard for solvency stress testing.

3.8.3. Research Restrictions

There are a number of limitations to this study that should be noted. First, although a minimum of 0.1% was required for execution, the Vasicek model theoretically permits negative interest rates. On the other hand, the Cox-Ingersoll-Ross (CIR) model may be a better option since it inherently guarantees non-negative rates. Second, operating costs, agent commissions, and profit loadings—all important factors in real-world premium calculations—are not taken into account in the study's use of net premiums. Third, the Vasicek parameters were established based on overall market conditions rather than being properly calibrated using historical Indonesian interest rate data. The accuracy of the model would be significantly increased by doing a formal calibration on historical BI Rate data using either the Generalized Method of Moments (GMM) or Maximum Likelihood Estimation (MLE).

CONCLUSION

This study successfully develops a term life insurance premium model by incorporating stochastic interest rates using the Vasicek model and Monte Carlo simulation. The results demonstrate that the net premium is strongly influenced by entry age, coverage duration, and gender, where higher age and longer terms lead to significantly higher premiums. Male policyholders consistently have higher premiums than females due to higher mortality risk reflected in the TMI IV mortality table.

The Monte Carlo simulation results indicate that premium distributions are approximately normal, with relatively small skewness and kurtosis, allowing for practical actuarial interpretation. However, the variability of premiums increases with longer coverage periods, highlighting the impact of interest rate uncertainty on long-term insurance products.

Sensitivity analysis shows that the long-term mean interest rate parameter is the most influential factor in determining premium levels, while volatility mainly affects the dispersion of premium values rather than their expected value. This finding emphasizes the importance of accurate calibration of interest rate parameters in actuarial modelling.

Overall, the stochastic modeling approach provides a more realistic and informative framework compared to deterministic methods, as it captures both the expected premium and its uncertainty. The results of this study can support better pricing strategies, risk management, and solvency assessment in the life insurance industry, particularly in the Indonesian context.



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