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TERM LIFE INSURANCE RESERVES USING THE EXTENDED VASICEK INTEREST RATE MODEL WITH FACKLER AND FULL PRELIMINARY TERM METHODS

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Abstract. Term life insurance reserve calculations are strongly influenced by interest rate uncertainty, which affects the present value of long-term liabilities. This study estimates term life insurance reserves using a stochastic interest rate approach based on the Extended Vasicek model, chosen for its mean-reverting property and analytical tractability, which allow it to capture interest rate dynamics in a stable and interpretable manner. The model parameters are estimated using the Jackknife resampling method to improve stability. The data used consist of the annual average BI Rate from 2010 to 2025 and the Indonesian Mortality Table 2019 (TMI 2019). The results suggest that the Jackknife-based Extended Vasicek model produces stable mean-reverting projections of interest rates. These projections are then applied to reserve calculations using the Fackler and Full Preliminary Term (FPT) methods. The findings indicate that the Fackler method generates a gradual reserve pattern that peaks mid-term before declining to zero. In contrast, the FPT method yields zero reserves in the first year, followed by higher accumulation in subsequent years. Overall, this approach provides relatively stable and realistic reserve estimates under stochastic interest rate conditions. From a practical perspective, the Extended Vasicek model may be considered an alternative framework for actuaries to model interest rate uncertainty in reserve calculations. Future research could further examine its performance under different economic scenarios or compare it with other stochastic interest rate models to better understand its applicability and limitations.

Keywords: Extended Vasicek, Fackler, Full Preliminary Term, Jackknife, Term Life Insurance, Reserve.

A. Introduction

Insurance is defined as an agreement between the insurer and the insured, in which the insurer, in exchange for a premium, commits to providing compensation for losses, damages, or failure to achieve expected profits arising from uncertain events (Marisa, 2025). Consequently, the calculation of premium reserves in term life insurance becomes a fundamental aspect in maintaining financial stability and ensuring the sustainability of insurance company operations (Sitanggang et al., 2024). In this context, the valuation method not only affects the amount of benefits received by policyholders but also influences insurance companies' risk management strategies and the effectiveness of regulatory oversight (Marisa et al., 2026). Therefore, accuracy and prudence in reserve calculations are essential elements of actuarial practice. However, one of the main challenges in premium reserve formation is reliance on interest rate projections, as the present value of claim payments is susceptible to the discount rate applied. Fluctuations and uncertainty in interest rates may lead to significant deviations in insurers' estimates of long-term liabilities (Cocozza & Di Lorenzo, 2006).

In this context, the stochastic approach is seen as better at realistically representing interest rate dynamics than the conventional deterministic approach. One of the most widely used stochastic models is the Extended Vasicek model, which captures mean rate reversion, in which interest rates fluctuate around their long-term average. However, the accuracy of this model is highly dependent on parameter estimation accuracy, as misestimation errors can introduce bias with a significant impact on interest rate projections and premium reserve calculations.

To overcome this problem, this study integrates the Jackknife resampling method into the parameter estimation of the Extended Vasicek model. The Jackknife method is known to improve the stability of estimates and reduce potential bias, especially when using historical data with a limited sample size. The data used in this study are the Bank Indonesia benchmark interest rate (BI Rate) for the period 2010-2025, which reflects the dynamics of domestic interest rates during this period (Triastuti et al., 2023).

The resulting interest rate parameters are then used to calculate term life insurance premium reserves using two approaches: the Fackler method and the Full Preliminary Term (FPT) method. The Fackler method was chosen because it accommodates a stochastic approach to reserve formation, resulting in estimates that are more adaptable to changes in interest rates and market risks. Meanwhile, the Full Preliminary Term (FPT) method is widely used in actuarial practice because it allocates acquisition costs in full in the first year of the policy and begins forming reserves in subsequent years. This approach provides a more realistic picture of the company's financial condition, especially on new policies, and helps reduce high initial financial burdens such as agent commissions and administrative costs (Hasriati et al., 2024).

By combining the Fackler and Full Preliminary Term methods, this study not only considers the stochastic aspect of interest rates in the formation of premium reserves, but also reflects the actual operational conditions of insurance companies more comprehensively. This approach is considered relevant, especially for new insurance products that do not yet have stable historical claim data. Conceptually, this research contributes to the development of modern actuarial methodologies that are in line with risk management principles, and is expected to support the implementation of risk-based solvency frameworks such as Risk-Based Capital (RBC) and IFRS 17, as well as becoming a reference for practitioners, regulators, and academics in improving the quality of decision-making in the field of life insurance.

B. Research Method

1. Descriptive Statistical Analysis

Data analysis was conducted using a descriptive statistical approach to provide a preliminary picture of the variables' characteristics. Descriptive statistics serve as a tool to organize the data that has been obtained to make it easier to understand, through processes such as collection, classification, presentation in the form of tables or graphs, as well as the calculation of statistical measures such as mean, median, mode, and spread size (Chattamvelli & Shanmugam, 2023).

2. Classic Assumption Test

Classical assumptions are applied to ensure that the regression model used meets the criteria of statistical validity (Marisa & Ratam, 2025). The tests conducted include normality, multicollinearity, heteroscedasticity, and autocorrelation tests. The normality test assesses whether the residuals follow a normal distribution, while the multicollinearity test identifies high linear correlation among independent variables. Furthermore, heteroscedasticity and autocorrelation tests were performed to detect residual heteroscedasticity and autocorrelation, respectively (Nuryanti et al., 2025). All of this testing is necessary to ensure that the regression model is free of violations of classical assumptions, so that the resulting estimates and inferences can be interpreted accurately and scientifically.

3. Extended Vasicek

The Extended Vasicek one-factor model is an extension of the classic Vasicek model designed to describe the behavior of short-term interest rates. The main feature of this model is its mean-reverting nature, the tendency of interest rates to revert to their long-term average despite short-term fluctuations (Jermann & Yue, 2018). In addition, the model offers analytical tractability, allowing closed-form solutions for bond pricing, and is relatively simple to implement compared to more complex interest rate models. Its flexibility in capturing the term structure of interest rates also makes it useful for practical applications in financial modeling and risk management. This model is formulated in the form of a stochastic differential Equation as follows:

$$dr(t) = [\theta(t) - a\, r(t)]dt + \sigma\, dW(t) \tag{2.1}$$

with

$r(t)$: The interest rate at time t
$\theta(t)$: The long-term average value that is the target of interest rate movements
a : a positive constant parameter representing the speed of adjustment of the interest rate toward its long-term mean
σ : Volatility
$W(t)$: Wiener process or Brown's motion.

This model allows the value of $\theta(t)$ to change over time, making it more flexible than the standard Vasicek model. This flexibility enables the capture of more complex and realistic economic dynamics. Based on research conducted by (Hadiono & Kusnadi, 2024), the solution of the Extended Vasicek interest rate model is as follows:

$$r(t) = r(0)e^{-at} + e^{-at}\int_0^t \theta(t)\, e^{au} du + \sigma e^{-at}\int_0^t e^{au}\, \sigma dW(u) \tag{2.2}$$

For numerical implementations, the model is then converted into a discrete form using the Euler approach, resulting in the following Equation (Ratam & Marisa, 2025):

$$r(t_{i+1}) = r(t_i)(1 - a\Delta t) + \theta\Delta t + \sigma\Delta W_i \tag{2.3}$$

4. Jackknife

The basic principle of the Jackknife method is to estimate parameters by removing one data point from the sample at a time, then repeating the process as many times as there are data points. This Jackknife procedure estimates parameters via a leave-one-out approach (Sprent, 1989). One of the main advantages of this method is its simplicity and ease of implementation, as it does not require strong distributional assumptions. In addition, the Jackknife method is useful for reducing bias and estimating variance, making it a practical tool for statistical inference, especially when dealing with small to moderate sample sizes. The initial step is to take a random sample of size $n - 1$, then, for each iteration, one data point is removed from the sample, and the parameter estimate is calculated based on the remaining data (Sprent, 1989).

The ith parameter, $\hat{\beta}^i$, can be estimated using the least-squares method to minimize the sum of squared errors. Suppose, y^i it is a matrix of data-bound variables that have been omitted from the ith row of measures $(n-1) \times 1$ and X^i is the matrix of the data-free variable that has been omitted by the ith row, which is measured $(n-1) \times (j+1)$, then, $\hat{\beta}^i$ can be stated as follows:

$$\hat{\beta}^i = \left(X^{i\prime}X^i\right)^{-1}X^i y^i \tag{2.4}$$

Furthermore, the estimation of the Jackknife parameter can be obtained by looking for the average of each parameter as follows:

$$\hat{\beta} = \sum_i^n \frac{\hat{\beta}^i}{n} \tag{2.5}$$

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5. Commutation Symbols

Investment Commutation symbols are symbols used in performing long arithmetic calculations (Naila Muthiah et al., 2024). Commutation symbols are used to simplify the calculation of premiums, reserves, and other insurance values.

1. The symbol $\boldsymbol{D_x = v^x l_x}$, with $\boldsymbol{l_x}$ expresses the number of individuals still alive at the $\boldsymbol{x}$ years and $\boldsymbol{v = \frac{1}{1+i}}$ expresses the discount factor.
2. The symbol $\boldsymbol{N_x = D_x + D_{x+1} + \cdots + D_{w-1}}$, where $\boldsymbol{w}$ is the maximum age in a cohort.
3. The symbol $\boldsymbol{C_x = v^{x+1} d_x}$, with $\boldsymbol{v^{x+1}}$ declare the discount factor for year-end payments to $\boldsymbol{x+1}$ and $\boldsymbol{d_x = l_x - l_{x+1}}$ indicates the number of individuals who died between the age of $\boldsymbol{x}$ years, before reaching the age $\boldsymbol{x+1}$ years.
4. The symbol $\boldsymbol{M_x = C_x + C_{x+1} + \cdots + C_{w-1}}$, where $\boldsymbol{w}$ is the maximum age in a cohort.

6. Life Annuity

A term life annuity provides periodic payments for a fixed period. The cash value of the annuity paid at the beginning of each year, for life insurance participants of age x with an n-year payment period, can be expressed using the following commutation symbol (Futami, 1993):

$$\ddot{a}_{x:\overline{n}|} = \frac{N_x - N_{x+n}}{D_x} \tag{2.6}$$

7. Term life Insurance Premiums

In term life insurance, a single premium for a person x years old with a coverage period of n years and a sum insured of 1 paid at the end of the policy year, is denoted as $A^1_{x:\overline{n}|}$, namely (Faturachman et al., 2022)

$$A^1_{x:\overline{n}|} = \frac{M_x - M_{x+n}}{D_x} \tag{2.7}$$

Meanwhile, the annual premium for term life insurance for n years at age x, with a benefit of 1 paid at the end of the policy year, is the value to be paid annually during the coverage period, as follows (Saragih et al., 2024):

$$P^1_{x:\overline{n}|} = \frac{M_x - M_{x+n}}{N_x - N_{x+n}} \tag{2.8}$$

8. Fackler Method

David Parks Fackler, an actuary from the United States, first developed the Fackler method. This method is an adaptation of the basic formula for retrospective reserves, so, in principle, it is used to calculate reserve values under the retrospective approach. Before applying this method, it is essential to understand the basic concept of retrospective backups, as Fackler's formula is derived from a general one. In the retrospective approach, the final reserve is defined as the difference between the accumulated premiums paid (including interest) and the cash value of the benefits previously collected. Mathematically, the basic formula of retrospective reserves for benefits of Rp1 can be expressed as (Zakirah et al., 2024):

$$_tV = P.\ _tu_x - \ _tk_x \tag{2.9}$$

with

$_tV$: the premium reserve at the end of year t
P : the annual net premium

${}_t u_x$: The total accumulated value of premiums paid, including interest, from year x to year t, before policy issuance

${}_t k_x$: the present value of insurance benefits, including interest, calculated from year x to year t

9. Full Preliminary Term Method

FPT is an actuarial approach to calculating premium reserves that aims to modify the premium structure in the first year to be as low as possible without causing negative reserves. In this method, the net premium for the first year is used solely to cover claims for deaths that occurred during that year, so the reserve at the end of the first year is set to zero. For subsequent years, the reserve calculation is carried out assuming that the new policy is issued one year after the original policy, to the insured who is one year older, with a reduced premium payment period of one year, but with the policy maturity date remaining the same as the original policy. Therefore, the net premium from the second year onwards is equivalent to the net premium for new policies issued at one year older, with a shorter duration of premium payments.
In general, the reserve in the t year of term life insurance with the FPT method, with premium payments for m years with a coverage period of n years, namely (Menge & Fischer, 1965)

$$ {}^{m}_{t}V^{F}_{x:\overline{n}|} = A^{1}_{x+t:\overline{n-t}|} - {}_{m-1}P^{1}_{x+1:\overline{n-1}|}\, \ddot{a}_{x+t:\overline{m-t}|} \quad (2.10) $$

C. Result and Discussion

1. Descriptive Statistical Analysis

The data used in this study consists of the average BI Rate from 2010 to 2025 and the Indonesian Mortality Table (TMI) 2019

Table 1 The Average BI Rate

Year	Average BI Rate (%)	Year	Average BI Rate (%)
2010	6,50	2018	5,10
2011	6,58	2019	5,63
2012	5,77	2020	4,25
2013	6,48	2021	3,52
2014	7,54	2022	4,00
2015	7,52	2023	5,81
2016	6,00	2024	6,10
2017	4,56	2025	5,27

Based on **Table 1**, the average BI Rate during 2010-2025 shows a dynamic pattern from year to year. A relatively high interest rate characterized the initial period of observation, then decreased in the following few years before increasing again in the final period of observation. This fluctuating pattern reflects Bank Indonesia's monetary policy response to changes in domestic and global economic conditions, thereby providing an overview of long-term interest rate dynamics.

Table 2. Descriptive Statistical Analysis

BI Rate	N	Maximum	Minimum	Mean	Std. Deviation
	16	7,54	3,52	5,67	1,1709

Table 2 presents a summary of descriptive statistics from the BI Rate data. During the observation period, the average BI Rate was 5,78% with a standard deviation of 1,1709, indicating moderate variation around the average. The range of BI Rate values, between 3,52%

and 7,54%, suggests that the interest rate data is not extreme and is relatively stable statistically. These characteristics meet the basic assumptions for modeling using stochastic interest rate models, specifically the Extended Vasicek model, at a later stage of analysis.

2. Classic Assumption Test

2.1 Heteroscedasticity Test

Heteroscedasticity testing evaluates whether the variance of residuals is constant (homoscedasticity) or variable (heteroscedasticity) across observations [20]. If the residual variance is continuous, the homoskedasticity assumption holds. On the other hand, if the residuals' variances vary, there is evidence of heteroscedasticity. Based on the heteroscedasticity test using the Breusch–Pagan method, the p-value of 0,2154 is greater than the 5% significance level. This shows that there is no indication of heteroscedasticity in the BI Rate data, so the residual variance can be considered constant during the observation period. Thus, the assumption of homogeneous heteroscedasticity is satisfied, and the BI Rate data are feasible for modeling stochastic interest rates at a later stage.

2.2 Multicollinearity Test

This test is used to determine whether there is a strong correlation between the independent variables in the regression model. Multicollinearity occurs when two or more independent variables are strongly linearly correlated, which can affect the stability of parameter estimation. However, because in this study there is only one independent variable, multicollinearity testing is not required.

2.3 Normality Test

Normality tests are used to determine whether residual data are typically distributed. Residual normality is one of the critical assumptions in regression. Based on the Shapiro-Wilk normality test, the p-value of 0,7975 indicates that the data are not significantly non-normal. A p-value greater than 5% means that the BI Rate data are typically distributed. Thus, the assumption of normality is satisfied, and the data are suitable for modeling stochastic interest rates, especially the Extended Vasicek model, in the next stage of analysis.

2.4 Autocorrelation Test

The Ljung-Box test is used. To detect autocorrelation (serial correlation) in residuals, the Ljung-Box test is used. Based on the test results, a p-value of $0{,}018 < 0{,}05$ was obtained, so the null hypothesis was rejected, and it can be concluded that the residual model still contains autocorrelation. The presence of this autocorrelation reflects the characteristics of the time series in the interest rate data, indicating inter-period dependence. This condition is not considered a violation of the model. Instead, it reinforces the relevance of stochastic interest rate modeling, especially the Extended Vasicek model, for more realistically representing interest rate dynamics.

3. Jackknife Estimation for the Extended Vasicek Interest Rate Model

The Extended Vasicek interest rate is a stochastic model with parameters a, θ, and σ estimated using the Jackknife method. The Python estimation yields the following parameter values: $a = 0{,}3539$, $\theta = 1{,}9315$, and $\sigma = 0{,}8406$. Using Equation (2.3) with an initial interest rate of 6,50%, the resulting Extended Vasicek interest rate model is given as follows:

$$r(t_{i+1}) = r(t_i)(1 - 0{,}3539\Delta t) + 1{,}9315\Delta t + 0{,}8406\Delta W_i$$

The following is a comparison of the BI Rate interest rate with Extended Vasicek:

Figure 1 Comparison of BI Rate and Extended Vasicek Interest Rates

Case Study

Ria, who is currently 45 years old, is enrolled in a term life insurance program with a 15-year coverage period. In this program, if there is a risk of death during the coverage period, a benefit of IDR 250.000.000 will be provided.

Some important information from this case illustration includes: the initial age of the insurance participant (x) is 45 years old, the maximum age used in the calculation (w) is 111 years, coverage period (n) lasts for 15 years, sum assured (R) of IDR 250.000.000, and the interest rate (i) is obtained from the Jackknife method estimate of the annual average data of the BI Rate from 2010 to 2025.

The first step in completing this case study is to calculate the discount factor v using the Jackknife method from the estimated interest rate. After that, the required commutation values are calculated, namely, D_x, C_x, M_x, and N_x, based on the 2019 Indonesian Mortality Table (TMI). With this approach, the calculation results can be systematically obtained, as shown in the **Table 3**.

Table 3 Commutation Value

Year	x	Interest rate (%)	v	D_x	C_x
1	45	6,5	0,94	5730,78	10,06
2	46	6,13	0,94	6299,34	12,41
3	47	5,89	0,94	6582,43	14,30
4	48	5,74	0,95	6649,92	15,91
5	49	5,64	0,95	6568,59	17,22
6	50	5,58	0,95	6392,03	18,47
7	51	5,53	0,95	6157,91	19,55
8	52	5,51	0,95	5892,73	20,55
9	53	5,49	0,95	5613,13	21,44
10	54	5,48	0,95	5330,00	22,33
11	55	5,47	0,95	5049,71	23,12
12	56	5,47	0,95	4776,24	23,73
13	57	5,46	0,95	4512,46	24,09
14	58	5,46	0,95	4259,01	24,27
15	59	5,46	0,95	4017,06	24,23

The next step is to calculate the insurance reserve using the Fackler Method using **Table 3** the premium recommendations are obtained as follows:

Table 4 Insurance Reserves with the Fackler Method

t	${}_tV_{45:\overline{15}\vert}$	t	${}_tV_{45:\overline{15}\vert}$
1	Rp391.994,71	9	Rp2.089.319,80
2	Rp736.437,98	10	Rp2.017.679,45
3	Rp1.052.500,43	11	Rp1.842.458,80
4	Rp1.340.580,13	12	Rp1.556.168,22
5	Rp1.597.857,23	13	Rp1.156.399,01
6	Rp1.811.842,72	14	Rp637.809,54
7	Rp1.973.085,72	15	Rp0,00
8	Rp2.069.143,93		

Based on **Table 4**, the value of term life insurance reserves calculated using the Fackler method shows an initial increase in the early to mid-coverage period, followed by a decrease in the final period until it reaches zero at the end of the contract. Reserves in the early years were relatively small because part of the premium was still allocated to cover the policy's initial cost, and the risk was still low, so reserve accumulation was not significant. Over time, the reserves increased and reached their maximum in the 9th year, reflecting conditions in which the accumulation of premiums has been optimal while the future benefit obligations are still quite large. After reaching this maximum point, the value of reserves begins to decline, as seen in the 10th to 15th years. This decrease in reserves occurs because the remaining coverage period is shorter, thereby reducing the current value of future benefit obligations. In addition, the reserves formed in the previous period are gradually used to cover the obligation to pay benefits that are approaching their realization. At the end of the coverage period, the reserve value is zero, indicating that the insurance company's obligations have been fulfilled and that no liabilities remain. This reserve pattern shows that Fackler's method produces a consistent, rational, and actuarial estimate of reserves for representing term life insurance obligations.

The next step is to calculate the insurance reserve using the Full Preliminary Term Method using **Table 3** The premium recommendations are obtained as follows:

Table 5 Insurance Reserves with the Full Preliminary Term Method

t	${}^{10}_{t}V^{F}_{45:\overline{15|}}$	t	${}^{10}_{t}V^{F}_{45:\overline{15|}}$
1	Rp0.00	9	Rp5.380.957,72
2	Rp743.170,04	10	Rp5.913.203,17
3	Rp1.454.143,80	11	Rp5.041.366,73
4	Rp2.151.165,94	12	Rp4.021.372,68
5	Rp2.840.885,37	13	Rp2.846.688,11
6	Rp3.516.328,93	14	Rp1.507.662,05
7	Rp4.171.262,85	15	Rp0.00
8	Rp4.795.723,17		

Based on **Table 5**, term life insurance reserves calculated using the Full Preliminary Term (FPT) method show that the reserves in the first year were worth zero, then increased significantly to reach a maximum value of Rp5.913.203,17 in the 10th year. The value of the reserves that are zero at the beginning of the coverage period reflects the characteristics of the FPT method, in which the entire first-year premium is allocated to cover initial acquisition costs, so that reserves have not yet been formed. In the following years, the reserves increased along with the accumulation of premiums and the large number of future benefit obligations. After reaching the maximum value, the reserve begins to decrease to zero at the end of the coverage period ($t = 15$). This decline is due to the shorter remaining policy period and the use of reserves formed to meet benefit payment obligations. This study examines the use of the Full Preliminary Term method in estimating reserves for term life insurance. The findings suggest that the method provides a systematic, actuarially consistent representation of reserve patterns, particularly in the early policy years, resulting in more stable estimates. In practice, this method may be considered an alternative to reserve calculation while still accounting for key assumptions such as interest rates, mortality, and premium structures. Future research could compare its performance with other valuation approaches under different scenarios.

D. Conclusion

This study shows that term life insurance reserves calculated using interest rates estimated from the Extended Vasicek model with the Jackknife method produce consistent and actuarially sound results. The Fackler method generates a gradual reserve pattern, increasing to a mid-term peak before declining to zero at the end of the coverage period, reflecting a balanced allocation of premiums over time. In contrast, the Full Preliminary Term method yields zero reserves in

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the first year due to full allocation of initial acquisition costs, followed by a sharper accumulation and a higher mid-term reserve level before declining toward zero at maturity. Overall, both methods adequately represent term life insurance obligations, with the Fackler method offering greater reserve stability and the Full Preliminary Term method emphasizing early cost recovery.

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