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## ENDOWMENT LIFE INSURANCE CALCULATION MODELING WITH DARA UTILITY FUNCTION AND STOCHASTIC INTEREST

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### ABSTRACT

In this research, a 10-year endowment life insurance's premium will be calculated with a DARA function according to principle of utility equivalence. The calculation results will be performed using a Vasicek interest-based model, among male and female policyholders within the age range of 20-80 years old, and over varying benefit levels. Indonesian Mortality Table IV 2019 is used as reference for mortality data. Stochastic interest is modeled using the Vasicek Model derived through Ordinary Least Square Method (OLS) Method from BI-Rate in the volatile September 2022 - August 2024 period with a monthly step time, which yields the following parameters:  $\theta = 0.060626$ ,  $c = 0.288230$ ,  $\sigma = 0.184573$ , resulting in a 95% confidence interval  $CI = 0.060626 \pm 0.043496$  with standard error  $SE = 0.022192$ . This  $CI$  indicated high uncertainty in the interest modelling. The results showed that premium rate is heavily affected by this volatility in the interest rates. Premium value is higher for male than female policyholders and it increases faster at higher entry age due to an increase of the mortality rate. The relation between the DARA coefficient and premium value is non-linear despite a slight increase in premium when a larger coefficient is chosen. An increase of benefit rate is followed by a nearly proportional increase of the premium rate. Further research on this topic could analyze the impact of policy horizon and wealth on the premium rate or compare the results with another stochastic model (e.g. CIR model).

**Keywords :** Endowment Life Insurance, Vasicek Model, Ordinary Least Square, Principle of Utility Equivalence, Indonesian Mortality Table IV.

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### PRELIMINARY

For life insurance policies, the principle of equivalence utility stated that both the insurer and insured would act to minimize losses or the goal is to achieve the loss value:

$$L = 0 \tag{1}$$

Based on this principle, a utility function could be used to analyze the utility value of a policy (Handamari, Sa'adah, Widhiatmoko, & Nabili, 2023). The usage of DARA function for this purpose could be justified as the initial risk-averse attitude of the insurer decreases once capital requirements are examined (Veronika, 2025). Furthermore, recent events like COVID-19 has been shown to cause risk-preference among the insured to become risk-

averse when crisis hits before the level decreases again after adaptation to the changed situation (Saraf & Baser, 2024; Schachat, Walker, & Wei, 2021; Tsutsui & Tsutsui-Kimura, 2022). Previous research on insurance premium calculation by using utility functions have been performed by Venter (1983), Nielsen (2005), Supitra (2008), Gharakhani, Nasiri, & Alizadeh (2016), Mongrut & Chang (2017), and Wang (2018). Among the inadequacies found in these previous research, Supitra (2008) stated a limitation of DARA function's application to only discrete calculation models with constant interest rates (Handamari, Sa'adah, Widhiatmoko, & Nabili, 2023) and the limited capability of programs used (e.g. Excel and R) in simulating the calculation with large-valued parameters (Mongrut & Chang, 2017).

The endowment life insurance combines pure endowment with term life insurance in its mechanism, where the kind of benefit paid would depend on whether the policyholder lives past a given term. Survival benefit at endowment rate will only be received if the policyholder survived past the term's maturity, otherwise a death benefit would be received at term life insurance rate. On one hand, the survival benefit offers an advantage for the family of the insured since it provides a a long-term financial plan to secure funds, while on the other hand the death benefit offers protection to the policyholder before maturity (Fikri, Muhartini, Sharoni, Febrianti, & Mahuda, 2022). To determine maturity period, Yunita, Widana, & Harini (2018) showed that a life insurance policy should have at least a 10-year long term to provide substantial utility to the insured regardless of the interest model used in the calculation. Therefore, all premium calculation in this research will use a 10-year period.

Based on the expositions above, the objective of this research is set to develop a life insurance premium calculation model by using a utility function which would simulate the uncertainty of lifetime through the policyholder's mortality rate and market uncertainty with a variable interest rate given by a stochastic interest model. This model is expected to become a useful reference for modeling policies that could adjust the pricing for everchanging market conditions and meet policyholders' need for an insurance policy despite existing volatility.

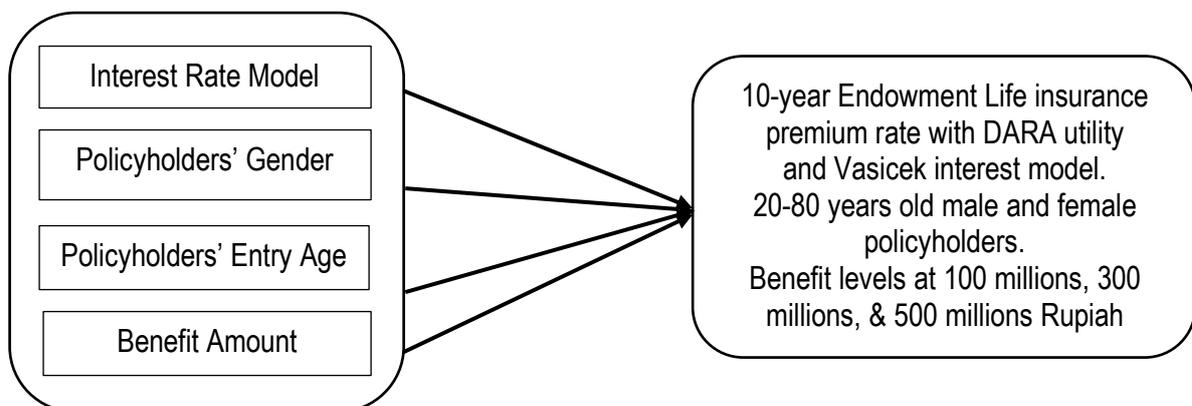
To achieve this objective, on this research several models will be developed to calculate endowment life insurance premium rate with a 10-year period by using DARA utility function where the Vasicek interest model will be applied in the calculation process. A comparative analysis will be performed to study how the mortality rate of the policyholder and benefit level might affect the premium rate.

In determining stochastic interest rates that will be used in premium calculations, the parameters will be based on BI-Rate data in the period of September 2022–August 2024, a

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yearly interest rate which is adjusted by Bank Indonesia on a monthly basis. The interest rates in this interval is characterized by high volatility, where the rate increased from 4.25% to 6.25% within a short span of 24 months brought by worldwide market uncertainty in the post-pandemic period, despite a history of low interest rates in preceding the period (Dwijaya, Azis, Fitrianiingsih, & Apriani, 2024). The usage of this volatile data can be justified by the fact that some research have indicated that similar situation might happen again in the very near future due to the macroeconomic effects of international geopolitical changes (Lebreton & Argou, 2024) or climatic changes (Bertrand, Coqueret, McLoughlin, & Mesnard, 2024) which would require life insurers to continuously adapt to high-volatility periods. To analyze the effect of volatility, the Vasicek rate calculations will be performed within 95% confidence interval through the mean and standard error of the Vasicek model.

Furthermore, effects of the policyholders' entry age and gender on the premium rate will be analyzed as well in this study. Finally, the results will be compared on different benefit levels (in Rupiah). These limitations of the study are illustrated in the following figure:



**Figure 1.** Limitations of the Study

Since a Vasicek stochastic model would yield interest values that fluctuate continuously over time, the premium calculations would require the usage of continuous distributions as well. Definitions on several important statistical and actuarial concepts will be explained in the following expositions before moving on to the calculation methods used in this research.

### Important variables and notations

First of all let we define important variables and notations that are used in this paper:

$E[X]$ : Expected value of a random variable  $X$

$a(w)$ : risk aversion

$u(w)$ : utility function

$w$ : wealth (in Rupiah)

$d$ : chosen positive coefficient for utility function

$L$ : Loss variable

$E(L)$ : Expected loss

$x$ : age of the policyholder (in years)

$l_x$ : size of population at age  $x$

$q_x$ : probability of death by age  $x + 1$  for a person at age  $x$

$p_x$ : probability of survival to age  $x + 1$  for a person at age  $x$

${}_nq_x$ : probability of death by age  $x + n$  for a person at age  $x$

${}_np_x$ : probability of survival to age  $x + n$  for a person at age  $x$

$t$ : period (yearly)

$v$ : present value of life annuity at period  $t$

$r(t)$ : interest rate at period  $t$

$\delta$ : discount value at period

$\bar{a}_x$ : whole life annuity starting at age  $x$  (in Rupiah)

$\bar{a}_{x:\overline{n}|}$ :  $n$ -year life annuity starting at age  $x$  (in Rupiah)

$A_{x:\overline{n}|}^1$ :  $n$ -year pure endowment present value starting at age  $x$  (in Rupiah)

$A_{x:\overline{n}|}$ :  $n$ -year endowment present value starting at age  $x$  (in Rupiah)

$\bar{P}(A_{x:\overline{n}|}^1)$ :  $n$ -year pure endowment premium starting at age  $x$  (in Rupiah)

$\bar{P}(A_{x:\overline{n}|})$ :  $n$ -year endowment premium starting at age  $x$  (in Rupiah)

$b$ : benefit value of the policy (in Rupiah)

$z$ : present value of the benefit (in Rupiah)

$\theta$ : long-term mean of interest rate (found through OLS)

$c$ : speed of reversion of the interest rate back to the mean value  $\theta$  (found through OLS)

$\sigma$ : volatility of the interest rate (found through OLS)

$W(t)$ : Wiener Process, Which simulates randomness of market risk at period  $t$

### **Continuous random variable**

Given a set  $B$  of real number values. If for a real number  $X$  there exists a non-negative function  $f(x)$  defined for every  $X \in (-\infty, \infty)$  with

$$P\{X \in B\} = \int_B f(x)dx \quad (2)$$

where  $P\{X \in B\}$  is the probability of  $X$  being included in  $B$ ,  $f(x)$  a probability density function. Then  $X$  is a continuous random variable (Sutikno & Ratnaningsih, 2019).

### Continuous expected value

According to Sutikno & Ratnaningsih (2019), given  $X$  a continuous random variable with probability density function  $f(x)$ , then the expectation value of  $X$  is given by:

$$E[X] = \int_{-\infty}^{\infty} xf(x)dx \quad (3)$$

For a new random variable  $g(X)$  which is dependent on  $X$ , then

$$E[g(X)] = \int_{-\infty}^{\infty} g(x)f(x)dx \quad (4)$$

### DARA Function

Venter (1983) stated that The DARA utility function has its foundations on the principle of *Absolute Risk Aversion* (Handamari, Sa'adah, Widhiatmoko, & Nabili, 2023) where the risk aversion ( $a(w)$ ) applies, given by:

$$a(w) = -\frac{u''(w)}{u'(w)} > 0 \quad (5)$$

Supitra (2008) stated that the value of  $u''(w)$  and  $u'(w)$  in this equation should both be positive to allow it to be defined as a utility function (Handamari, Sa'adah, Widhiatmoko, & Nabili, 2023, p. 7). The requirement of  $a(w) > 0$  depicted in (5) is necessary to model the risk-averse behavior in a concave function to show that the risk-aversion of the insurer is given by a positive value (Nielsen, 2005). This will result in a concave function for the utility function  $u(w)$  which caused the customer's utility function to lie at  $u'(w)$  when there is no insurance coverage bought, or remain at  $u(w)$  with insurance coverage (Gharakhani, Nasiri, & Alizadeh, 2016).

Moreover, according to Handamari, Sa'adah, Widhiatmoko, & Nabili (2023) for creating a utility function where risk aversion is decreasing as  $w$  is increasing, the utility function could be assumed to have an exponential form given by:

$$u(w) = 1 - e^{-\sqrt{\frac{w}{d}}} \quad (6)$$

From this equation a function  $u(w)$  is defined, which would become more sensitive toward fluctuations when the value of  $d$  chosen is bigger or smaller.

### Equivalency principle and the principle of utility equivalency

As stated by Rakhman & Effendie (2019), it could be assumed that any insurer would strive to avoid losses while determining insurance premium rate, which could be written as:

$$E(L) = 0 \quad (7)$$

Equation (7) defined the equivalency principle, with  $L$  representing acquired loss for the insurer and  $E(L)$  representing the expected loss. Supitra (2008) postulated that by applying risk-aversion on the equivalency principle (Handamari, Sa'adah, Widhiatmoko, & Nabili, 2023, p. 8), the following equation is found:

$$E(u(w)) = E(u(w - L)) \quad (8)$$

By substituting Equation (5) on Equation (7), then:

$$E\left[1 - e^{-\sqrt{\frac{w}{d}}}\right] = E\left[1 - e^{-\sqrt{\frac{w-L}{d}}}\right] \quad (9)$$

$$E\left[e^{-\sqrt{\frac{w}{d}}}\right] = E\left[e^{-\sqrt{\frac{w-L}{d}}}\right] \quad (10)$$

According to Supitra (2008) this equation could be interpreted as the balance between premium rate and risk for minimizing losses to the insurer, which fulfills (1). (Handamari, Sa'adah, Widhiatmoko, & Nabili, 2023).

### Mortality

To evaluate the risk of mortality for the insured, the insurer may take several approaches, one of which is by using a mortality table (Prabowo, Ardhiani, & Syahwa, 2024). This table contains values  $q_x$  which represent the risk of death by age  $x + 1$  for a person at age  $x$ . Given a population  $l_x$  of people at age  $x$ , then  $q_x$  or risk of death by  $x + 1$  is given by

$$q_x = \frac{l_x - l_{x+1}}{l_x} = 1 - \frac{l_{x+1}}{l_x}, \quad 0 \leq q_x \leq 1 \quad (11)$$

and the population of people at age  $x + 1$  is

$$l_{x+1} = (1 - q_x)l_x = p_x l_x, \quad 0 \leq p_x \leq 1 \quad (12)$$

where  $p_x = 1 - q_x$  defines the probability that a person at age  $x$  would live to reach  $x + 1$  (Rakhman & Effendie, 2019).

Then the population of people at age  $x + n$  is

$$l_{x+n} = p_{x+n-1}l_{x+n-1} = \prod_{i=0}^{n-1} p_{x+i} l_x = {}_n p_x l_x \quad (13)$$

From here, the probability of death by  $x + n$  for a person at age  $x$  could be derived:

$${}_n q_x = \frac{l_x - l_{x+n}}{l_x} = 1 - \frac{l_{x+n}}{l_x} \quad (14)$$

By substituting  $l_{x+n}$  on equation (14) the following formula is acquired:

$${}_nq_x = 1 - \prod_{i=0}^{n-1} p_{x+i} = 1 - {}_np_x \tag{15}$$

**Continuous life annuity**

Due to the usage of stochastic modeling in this research, a continuous life annuity model is necessary for calculating the premium rate. In this model, the whole life annuity is given by

(Rakhman & Effendie, 2019)

$$\bar{a}_x = \int_0^{\infty} v^t {}_tp_x dt \tag{16}$$

and the  $n$ -year life annuity is given by

$$\bar{a}_{x:\overline{n}|} = \int_0^n v^t {}_tp_x dt \tag{17}$$

with the present value of life annuity defined as

$$v = e^{-\delta} \tag{18}$$

where  $\delta$  is the discount value, given by

$$\delta = \int_0^t r(t) dt \tag{19}$$

**$n$ -year pure endowment life insurance**

A pure endowment life insurance with  $n$ -year term is a form of life insurance policy where the present value of the benefit received is:

$$z = bv^n, \quad b \geq 0 \tag{20}$$

This benefit is received only if the policyholder survived the  $n$ -years term's maturity. The premium paid is represented by  $\bar{P}(A_{x:\overline{n}|}^1)$ , with the loss function given by (Rakhman & Effendie, 2019)

$$L = \begin{cases} -\bar{P}(A_{x:\overline{n}|}^1)\bar{a}_t, & t < n \\ bv^n - \bar{P}(A_{x:\overline{n}|}^1)\bar{a}_n, & t \geq n \end{cases} \tag{21}$$

$$L = -\bar{P}(A_{x:\overline{n}|}^1)\bar{a}_t + bv^n - \bar{P}(A_{x:\overline{n}|}^1)\bar{a}_n \tag{22}$$

In accordance with the equivalency principle defined in (7), then:

$$E[-\bar{P}(A_{x:\overline{n}|}^1)\bar{a}_t + bv^n - \bar{P}(A_{x:\overline{n}|}^1)\bar{a}_n] = 0 \tag{23}$$

$$E[bv^n] - \bar{P}(A_{x:\overline{n}|}^1)E[\bar{a}_n + \bar{a}_t] = 0 \tag{24}$$

with the present value of the  $n$ -year pure endowment given by

$$A_{x:\overline{n}|}^1 = v^n {}_np_x = E[v^n] \tag{25}$$

Then, the actuarial  $n$ -year pure endowment premium acquired is defined as

$$\bar{P}(A_{x:\bar{n}}^1) = \frac{A_{x:\bar{n}}^1}{\bar{a}_{x:n}} \quad (26)$$

**n-year endowment life insurance**

For a  $n$ -year endowment life insurance, the present value of the benefit received is:

$$z = bv^s, \quad b \geq 0, s \geq n \quad (27)$$

if the policyholder passed away in year  $s \geq n$  the term's maturity. The pure endowment benefit rate ( $z = bv^n$ ) would only be received if the policyholder survived the  $n$ -year term's maturity. Rakhman & Effendie (2019) stated that the insurance premium paid here is given by  $\bar{P}(A_{x:n})$ , with the loss function:

$$L = \begin{cases} bv^t - \bar{P}(A_{x:\bar{n}})\bar{a}_t, & t < n \\ bv^n - \bar{P}(A_{x:\bar{n}})\bar{a}_n, & t \geq n \end{cases} \quad (28)$$

$$L = bv^t - \bar{P}(A_{x:\bar{n}})\bar{a}_t + bv^n - \bar{P}(A_{x:\bar{n}})\bar{a}_n \quad (29)$$

In accordance with the equivalency principle defined in (7), then:

$$E[bv^t - \bar{P}(A_{x:\bar{n}})\bar{a}_t + bv^n - \bar{P}(A_{x:\bar{n}})\bar{a}_n] = 0 \quad (30)$$

$$E[bv^t] + E[bv^n] - \bar{P}(A_{x:\bar{n}})E[\bar{a}_n + \bar{a}_t] = 0 \quad (31)$$

with the present value of the  $n$ -year endowment given by

$$A_{x:\bar{n}} = \int_0^n v^t {}_t p_x \mu_x dt + v^n {}_n p_x = \bar{A}_{x:\bar{n}}^1 + A_{x:\bar{n}}^1 \quad (32)$$

where  $\mu_x$  is the rate of mortality, given by

$$\mu_x = \frac{\frac{d}{dt} {}_t q_x}{{}_t p_x} \quad (33)$$

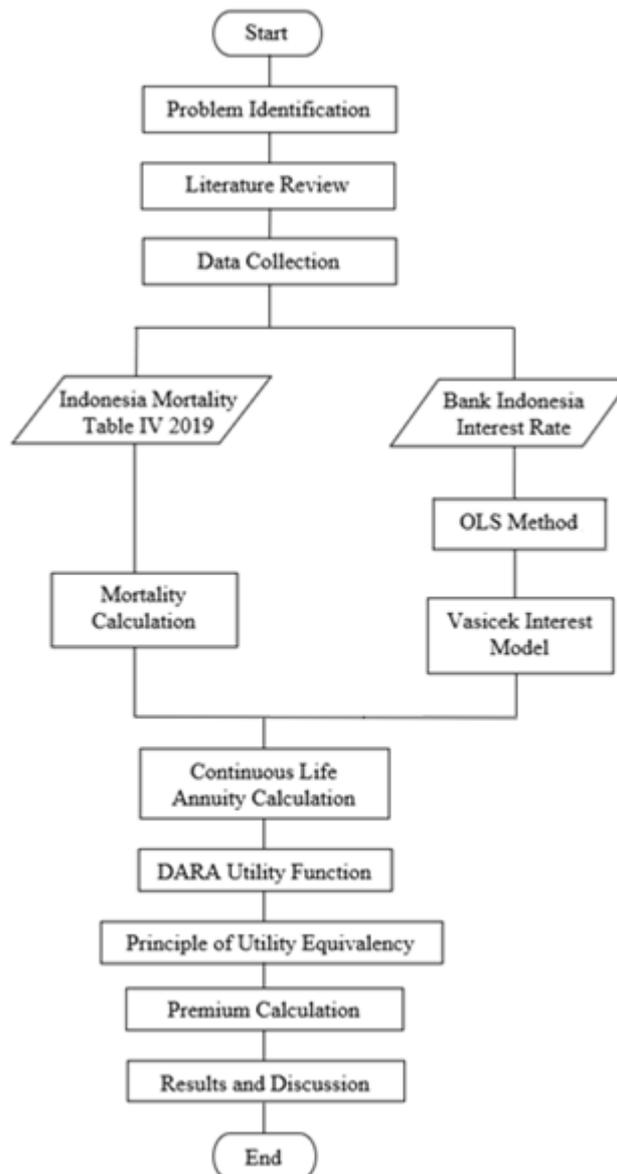
Then the actuarial  $n$ -year endowment premium acquired is defined as

$$\bar{P}(A_{x:\bar{n}}) = \frac{A_{x:\bar{n}}}{\bar{a}_{x:n}} \quad (34)$$

**METHODS**

**Research process**

In order to implement this research, there are several steps taken starting from collecting data to acquiring premium rate results. Each step of this research is illustrated by the figure below:



**Figure 2.** Research Flowchart

Details on several components of this research will be explained below.

### Research data

This research is done through a quantitative approach with purpose sampling. The following secondary data are used here:

a. Indonesian Mortality Table IV

The Indonesian Mortality Table IV 2019 or abbreviated as TMI IV 2019 has a steady increase of mortality normalized within the age range 0-111 years which is useful for showing how policyholder mortality rate increases with age (Wulandari, Fauziah, & Fitriyati, 2023). This data is collected by Indonesian Association of Life Insurance (Asosiasi Asuransi Jiwa Indonesia or abbreviated as AAJI) based on insurance company mortality calculation results using the Makeham law (Asosiasi Asuransi Jiwa

Indonesia, 2019). In this research, the TMI IV 2019 will be used to calculate the risk of mortality among policyholders. The data contains two mortality risk groups separated by gender, namely male and female groups, where the data from both groups within the age range of 20-80 years will be used in calculations.

b. BI-Rate Interest Data

The interest rate for the period September 2022–August 2024 is given below:

**Table 1.** BI-Rate Interest in September 2022–August 2024 (%)

sep/22	4,25	sep/23	5,75
okt/22	4,75	okt/23	6
nov/22	5,25	nov/23	6
dec/22	5,5	dec/23	6
jan/23	5,75	jan/24	6
feb/23	5,75	feb/24	6
mrt/23	5,75	mrt/24	6
apr/23	5,75	apr/24	6,25
mei/23	5,75	mei/24	6,25
jun/23	5,75	jun/24	6,25
jul/23	5,75	jul/24	6,25
aug/23	5,75	aug/24	6,25

Source: <https://www.bi.go.id/id/statistik/indikator/bi-rate.aspx>

The data from BI-Rate in this period is used to find the Vasicek parameters through Ordinary Least Square (OLS) method. Explanation on the calculation of these parameters will be discussed in the subchapter on OLS Method below.

Based on the research flowchart (Fig. 2), the following processes will be performed in this research:

**1. Mortality calculation**

The probability of a person at age  $x$  to survive until  $x + 1$  is defined as (Rakhman & Effendie, 2019)

$$p_x = 1 - q_x, \quad x \in \{20,21,22,\dots,80\} \tag{35}$$

The mortality  $q_x$  in this research will be taken from TMI IV 2019 for male and female in the age range of 20-80 years. Given a period of  $t$  years, the probability that a person would survive to age  $x + t$  is defined as:

$${}_t p_x = \prod_{i=0}^{t-1} p_{x+i}, \quad x \in \{20,21,22,\dots,80\} \tag{36}$$

**2. Ordinary Least Square (OLS) method**

In this research, the Vasicek parameters  $\theta, \sigma, c$  are computed through the *Ordinary Least Square* (OLS) based on the BI-Rate data in the period of September 2022–August

2024. In the OLS method, the formula for computing the three parameters are (Anita, Rosita, & Arsita, 2023)

$$\theta = \frac{(m-1) \sum_{i=1}^{m-1} r_{i+1} - \sum_{i=1}^{m-1} \frac{r_{i+1}}{r_i} \sum_{i=1}^{m-1} r_i}{(m^2 - 2m + 1 + \sum_{i=1}^{m-1} r_{i+1} \sum_{i=1}^{m-1} \frac{1}{r_i} - \sum_{i=1}^{m-1} r_i \sum_{i=1}^{m-1} \frac{1}{r_i} - (n-1) \sum_{i=1}^{m-1} \frac{r_{i+1}}{r_i})} \quad (37)$$

$$c = \frac{m^2 - 2m + 1 + \sum_{i=1}^{m-1} r_{i+1} \sum_{i=1}^{m-1} \frac{1}{r_i} - \sum_{i=1}^{m-1} r_i \sum_{i=1}^{m-1} \frac{1}{r_i} - (m-1) \sum_{i=1}^{m-1} \frac{r_{i+1}}{r_i}}{(m^2 - 2m + 1 - \sum_{i=1}^{m-1} r_i \sum_{i=1}^{m-1} \frac{1}{r_i}) \Delta i} \quad (38)$$

$$\sigma = \sqrt{\frac{1}{m-2} \sum_{i=1}^{m-1} \left( \frac{r_{i+1} - r_i}{\sqrt{r_i}} - \frac{\theta}{\sqrt{r_i}} + c\sqrt{r_i} \right)^2} \quad (39)$$

where:

$r_i$ : the BI-Rate at month  $i \in \{1,2,3, \dots, 24\}$ . from  $i = 1$  at September 2022,  $i = 2$  at October 2022, and so on to  $i = 24$  or August 2024

$m$ : the number of interest data in BI-Rate in September 2022–August 2024,  $m = 24$

$\Delta i$ : monthly time step

### 3. Vasicek model

Reuvers (2021) stated that the Vasicek model, which yields a differential of interest rate  $dr(t)$  on the interval  $dt$  with a short rate  $r(t)$  that has a tendency to approach the mean value, is given by the following equation:

$$dr(t) = c(\theta - r(t))dt + \sigma dW(t) \quad (40)$$

Where the parameters  $\theta$ ,  $c$ ,  $\sigma$  are determined by OLS Method in (37), (38), and (39).

The analytic solution of this equation is provided below (Ambagaspitiya & Ford, 2023):

$$r(t) = r(0)e^{-ct} + \theta(1 - e^{-ct}) + \sigma e^{-ct} \int_0^t e^{cs} dW(s) \quad (41)$$

with the initial interest rate  $r(0) = r_0$  which is deliberately set at the mean value of the BI-rate data, given by (Santosa, 2023):

$$r_0 = \frac{\sum_{i=1}^m r_i}{m}, m \in \mathbb{N} \quad (42)$$

with  $m = 24$  the length of the monthly BI-rate data and  $r_i$  the  $i$ -th interest BI-rate data,  $i \in \{1,2,3, \dots, 24\}$ .

For any period  $t$ , the Vasicek interest rate  $r(t)$  has a mean value of

$$\text{mean} = r(0)e^{-ct} + \theta(1 - e^{-ct}), \quad t \geq 0 \quad (43)$$

and the variance of

$$var = \frac{\sigma^2}{2c} (1 - e^{-2ct}), \quad t \geq 0 \quad (44)$$

#### 4. Confidence interval & standard error

Since a Vasicek interest model is normally distributed (Galea, Molina, & Beaudry, 2025), a confidence interval based on the mean and standard error of the Vasicek model is used to depict the volatility in the data. The formula for the confidence interval is given below (Santosa, 2023):

$$CI = mean \pm Z * SE \quad (45)$$

where the *mean* is given by (41),  $Z = 1.96$  for the 95% confidence interval, and the standard error *SE* is defined as (Metzler, 2022):

$$SE = \sqrt{\frac{var}{k}}, k \in \mathbb{N} \quad (46)$$

With *var* defined in (44) and  $k = 120$  the amount of discrete Vasicek rate data that is updated monthly over a 10-year period.

#### 5. Trapezoidal rule

The cumulative trapezoidal rule from Python's *scipy* library will be used in aligning the discrete mortality and interest data to continuous formulas used in life annuity and premium calculations that will be discussed in the next sections. For an interval  $[a, b]$ , the mathematical formula of the approximation is (Rahayu & Hindasyah, 2023):

$$\int_a^b f(x)dx \approx \frac{h}{2} (f_0 + 2(f_1 + f_2 + \dots + f_{k-1}) + f_k) \quad (47)$$

where  $f_0, f_1, f_2, \dots, f_{k-1}, f_k$  the values of  $f(x)$  for each  $x \in \{0,1,2, \dots, k\}$ ,  $k$  is the discrete data size, and  $h = b - a$ .

The asymptotic error for the cumulative trapezoidal is (Saha & Santosh, 2024):

$$\varepsilon = -\frac{h^3}{12} f''(x), \quad a \leq x \leq b \quad (48)$$

where the  $f''(x)$  used follows the maximum value of the second derivative.

#### 6. Life annuity calculation

For calculating a continuous endowment life insurance premium, the continuous whole life annuity  $\bar{a}_x$  and the continuous 10-year life annuity  $\bar{a}_{x:\overline{10}|}$  will be required. The formula for whole life annuity is given by (16), which become:

$$\bar{a}_x = \int_0^{\infty} v^t {}_t p_x dt, \quad x \geq 0 \quad (49)$$

The formula for a 10-year life annuity follows (17), which become:

$$\bar{a}_{x:\overline{10}|} = \int_0^{10} v^t {}_t p_x dt, \quad 20 \leq x \leq 80 \quad (50)$$

The value of  ${}_t p_x$  is defined in (34), which is a discrete model. The formula for  $v$  is defined in (18), with  $\delta$  from (19) substituted becomes:

$$v = e^{-\int_0^t r(u) du}, \quad t \geq 0 \quad (51)$$

the Vasicek model defined in (40) will be used as the interest rate  $r(t)$  in (51), which also gives discrete values. In relation to the variability of the Vasicek interest data and the fact that there are 12 monthly interest values for each year over the 10 year period, in practice for (50) the value of  $r(t)$  will be calculated deterministically based on the yearly mean value and the corresponding confidence interval defined in (45). In regard to the whole life annuity in (49), according to (43) as  $t$  approaches  $\infty$  the *mean* should converge to  $\theta$  as defined in (37) while  ${}_t p_x$  should approach 0 since the mortality  $q_x$  in TMI IV reaches 1 at the end of the table.

## 7. 10-year endowment life insurance premium calculation with utility function

The calculation of premium  $\bar{P}(A_{x:\overline{10}|})$  in this research does not depend directly on the actuarial definition given in (34), but instead it will be influenced by the utility equivalence defined in (10). By substituting the loss equation in (28) on (10), from which the following equation is acquired:

$$E \left[ e^{-\sqrt{\frac{w-L}{d}}} \right] = \int_0^{10} {}_t p_x e^{-\sqrt{\frac{w-bv^t + \bar{P}(A_{x:\overline{10}|}) \bar{a}_t}{d}}} dt + \int_{10}^{\infty} {}_t p_x e^{-\sqrt{\frac{w-bv^{10} + \bar{P}(A_{x:\overline{10}|}) \bar{a}_{10}}{d}}} dt \quad (52)$$

When the goal to minimize loss as defined in (1) is reached in (53), it resulted in:

$$E \left[ e^{-\sqrt{\frac{w}{d}}} \right] = \int_0^{10} {}_t p_x e^{-\sqrt{\frac{w-bv^t + \bar{P}(A_{x:\overline{10}|}) \bar{a}_t}{d}}} dt + \int_{10}^{\infty} {}_t p_x e^{-\sqrt{\frac{w-bv^{10} + \bar{P}(A_{x:\overline{10}|}) \bar{a}_{10}}{d}}} dt \quad (53)$$

Equation (53) denotes the expected utility of the premium value. In this research the trapezoid rule given by (47) will be used to compute (53). Since both  ${}_t p_x$  and  $r(t)$  are discrete data, the trapezoid rule in (46) will be used to calculate the continuous values in (53).

## RESULT AND DISCUSSION

### Results for the Vasicek interest rate

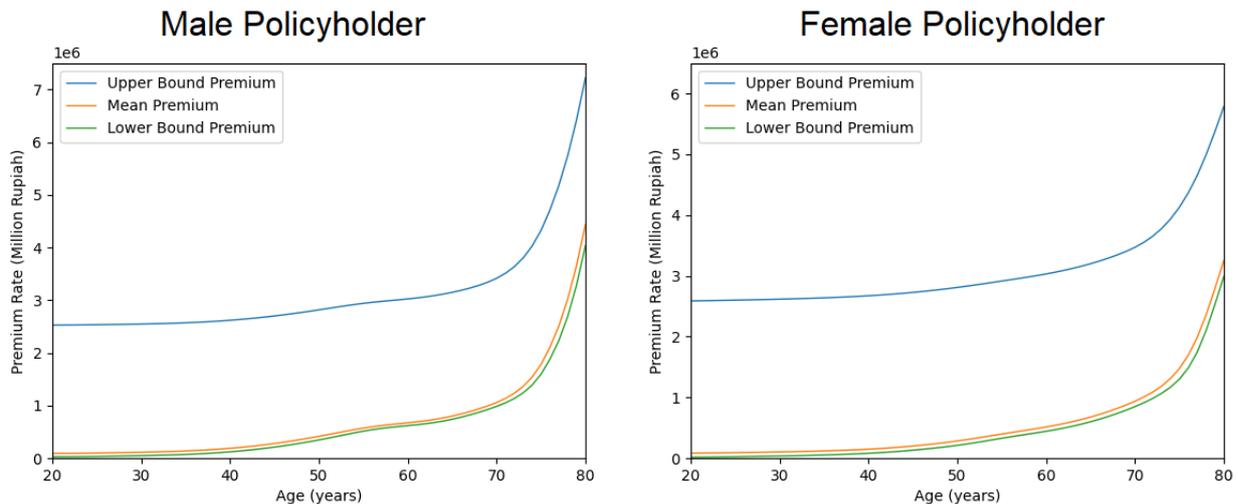
The parameters  $\theta$ ,  $\sigma$ ,  $c$  determined from BI-Rate in September 2022 – August 2024 with the OLS method as given by equation (37), (38), and (39), yielded the following

values:  $\theta = 0.060626$ ,  $c = 0.288230$ ,  $\sigma = 0.184573$ . For initiating the Vasicek model, the starting rate is set at the mean value of BI-rate given in (42), with  $r_0 = 0.057813$ .

In accordance with (43), (44), and (45), the normally distributed interest rate for period  $t = 10$  has  $mean = 0.060626$ ,  $var = 0.059098$ , and  $SE = \sqrt{\frac{0.059098}{120}} = 0.022192$ . This shows that the *mean* for this period has converged to the value of  $\theta$ . The resulting 95% interval defined in (45) is  $CI = 0.060626 \pm 0.043496$  for the Vasicek model, which implies a lower bound of 0.017130 (1.71%) and an upper bound of 0.104122 (10.41%). This forms a wide interval attributed to the volatility in the BI-Rate data. The *mean* of the Vasicek rate is slightly higher than the BI-Rate average  $r_0$ , however as the value of the latter still falls within the *CI* of the Vasicek model it is not statistically significant.

**Application of Vasicek interest on premium calculation with utility function**

The following figure showed the results of premium calculation with utility equivalence defined in (53) in consideration of the 95% confidence interval of the Vasicek interest rate. The calculation is based on policyholder wealth at  $w = 1 \cdot 10^9$  and DARA coefficient  $d = 10^7$ . The results showed the effect of uncertainty in interest rates on



Source: Data processed with Python 3.8 on PyCharm Community Edition 2024.1.1  
**Figure 3.** Graphic for 10-year term annual endowment premium rate for Vasicek-based model with DARA Utility function, 20-80 years old male and female policyholders,  $b = 1 \cdot 10^8$ ,  $w = 1 \cdot 10^9$ ,  $d = 1 \cdot 10^7$

The results showed a large divergence for the upper and lower bounds of the premium rate. This pattern indicated that volatility in the interest data affected premium calculation significantly. Following (51), a higher interest rates would cause lower present value  $v$  and therefore lower premium rate  $\bar{P}(A_{x:\overline{10}|})$ . This means that the lower bound of

the premium calculation is produced from using the upper bound of the interest rate's confidence interval and vice versa. The numerical results of the premium rate in select entrance ages 25, 35, 45, 55, 65, and 75 are shown in the following table:

**Table 3.** Values for 10-year term endowment premium rate for Vasicek-based model with DARA utility function, male and female policyholders at age 25, 35, 45, 55, 65, and 75,  $b = 1 \cdot 10^8$ ,  $w = 1 \cdot 10^9$ ,  $d = 1 \cdot 10^7$

Entrance Age (Years)	10-Year Endowment Annual Premium Rate (Rupiah)					
	Male Policyholders			Female Policyholders		
	Lower Bound	Mean	Upper Bound	Lower Bound	Mean	Upper Bound
25	35.484.67	99.723.81	2.535.347.30	26.997.42	91.177.43	2.527.793.55
35	73.811.20	139.236.20	2.572.017.01	542.88.70	118.711.06	2.552.341.20
45	213.702.82	282.121.15	2.701.174.17	131.156.67	197.396.91	2.623.799.64
55	516.280.13	574.469.18	2.940.443.83	322.380.76	385.983.38	2.784.260.14
65	741.362.49	801.985.99	3.149.788.50	584.339.92	649.580.48	3.021.034.31
75	1.596.186.92	1.781.587.78	4.324.563.33	1.247.260.20	1.388.943.05	3.848.074.30

Source: Data processed with Python 3.8 on PyCharm Community Edition 2024.1.1

The results as depicted in Fig. 3 and Table 3 showed that the premium rate increased as the policyholder's entrance age increased, where it increased faster at higher entrance age. The premium rate for male policyholders is overall higher than for female policyholders as well, both of which could be attributed to their higher mortality data in TMI IV. The error formula in (48) is used to analyze error in premium calculation given in (53), which yields the following results for premium in select entrance ages 25, 35, 45, 55, 65, and 75:

**Table 4.** Values for asymptotic error of 10-year term endowment premium rate for Vasicek-based model with DARA utility function, male and female policyholders at age 25, 35, 45, 55, 65, and 75,  $b = 1 \cdot 10^8$ ,  $w = 1 \cdot 10^9$ ,  $d = 1 \cdot 10^7$

Entrance Age (Years)	Asymptotic Error for 10-Year Endowment Annual Premium (Rupiah) on Each Premium Rate					
	Male Policyholders			Female Policyholders		
	Lower Bound Rate	Mean Rate	Upper Bound Rate	Lower Bound Rate	Mean Rate	Upper Bound Rate
25	1.62	11.10	34.45	1.17	8.18	25.58
35	3.63	28.53	92.13	2.48	18.30	58.09
45	10.31	79.12	254.01	6.15	47.43	152.44
55	22.91	139.45	416.56	14.69	97.94	301.83
65	36.69	237.85	726.79	28.69	195.06	605.13
75	141.62	1291.56	4334.77	89.97	769.64	2545.48

Source: Data processed with Python 3.8 on PyCharm Community Edition 2024.1.1

**Sensitivity of DARA utility coefficient over premium rate**

Premium calculation with different DARA utility coefficients at  $d = 0.5 \cdot 10^7$ ,  $d = 1 \cdot 10^7$ , and  $d = 2 \cdot 10^7$  over the mean Vasicek rate showed the following results for male and female policyholders in select entrance ages 25, 35, 45, 55, 65, and 75 years old:

**Table 5.** Values for 10-year term endowment premium with DARA utility function over mean Vasicek rate, male and female policyholders at age 35, 55, 45, 55, 65, and 75, different DARA utility coefficient values, and  $b = 1 \cdot 10^8$ ,  $w = 1 \cdot 10^9$

Entrance Age (Years)	10-Year Endowment Annual Premium Rate (Rupiah)					
	Male Policyholders			Female Policyholders		
	$d = 0.5 \cdot 10^7$	$d = 1 \cdot 10^7$	$d = 2 \cdot 10^7$	$d = 0.5 \cdot 10^7$	$d = 1 \cdot 10^7$	$d = 2 \cdot 10^7$
25	99.718.59	99.723.81	99.757.61	91.172.63	91.177.43	91.208.59
35	139.229.04	139.236.20	139.282.05	118.704.90	118.711.06	118.750.66
45	282.107.43	282.121.15	282.205.83	197.387.00	197.396.91	197.459.39
55	574.443.74	574.469.18	574.614.93	385.965.16	385.983.38	386.093.37
65	801.950.38	801.985.99	802.197.50	649.550.96	649.580.48	649.757.48
75	1.781.507.17	1.781.587.78	1.782.172.02	1.388.881.35	1.388.943.05	1.389.355.52

Source: Data processed with Python 3.8 on PyCharm Community Edition 2024.1.1

A comparison between premium rates at  $d = 0.5 \cdot 10^7$  and  $d = 1 \cdot 10^7$  where  $d$  is 2 times larger, showed that as age increases, the ratio between the two rates decreases. For examples, for male and female policyholders in select entrance ages 35, 55, and 75:

$$\bar{P} \left( A_{35:\overline{10}|} \right) \text{ ratio is } \frac{139.236.20}{139.229.04} = 1.000051 \text{ for male and } \frac{118.711.06}{118.704.90} = 1.000052 \text{ for female.}$$

$$\bar{P} \left( A_{55:\overline{10}|} \right) \text{ ratio is } \frac{574.469.18}{574.443.74} = 1.000044 \text{ for male and } \frac{385.983.38}{385.965.16} = 1.000047 \text{ for female.}$$

$$\bar{P} \left( A_{75:\overline{10}|} \right) \text{ ratio is } \frac{1.781.587.78}{1.781.507.17} = 1.000045 \text{ for male and } \frac{1.388.943.05}{1.388.881.35} = 1.000044 \text{ for female.}$$

While a comparison between premium rates at  $d = 1 \cdot 10^7$  and  $d = 2 \cdot 10^7$  where  $d$  is 2 times larger, showed the following results:

$$\bar{P} \left( A_{35:\overline{10}|} \right) \text{ ratio is } \frac{139.282.05}{139.236.20} = 1.000329 \text{ for male and } \frac{118.750.66}{118.711.06} = 1.000334 \text{ for female.}$$

$$\bar{P} \left( A_{55:\overline{10}|} \right) \text{ ratio is } \frac{574.614.93}{574.469.18} = 1.000254 \text{ for male and } \frac{386.093.37}{385.983.38} = 1.000285 \text{ for female.}$$

$$\bar{P} \left( A_{75:\overline{10}|} \right) \text{ ratio is } \frac{1.782.172.02}{1.781.587.78} = 1.000328 \text{ for male and } \frac{1.389.355.52}{1.388.943.05} = 1.000297 \text{ for female.}$$

The results showed slight sensitivity from premium rate toward  $d$ , which is more apparent for a higher  $d$  value. Still, overall the relation between  $d$  and  $\bar{P} \left( A_{x:\overline{10}|} \right)$  is non-linear.

**Sensitivity of benefit amount over premium rate**

Premium calculation at different benefit levels  $b = 1 \cdot 10^8$ ,  $b = 3 \cdot 10^8$ , and  $b = 5 \cdot 10^8$ , over the mean Vasicek rate showed the following results for male and female

policyholders in select entrance ages 35, 45, 55, 65, and 75 years:

**Table 6.** Values for mean 10-year term endowment premium rate with DARA utility function over mean Vasicek rate with differing benefit levels, male policyholders at age 35, 55, and 75,  $w = 1 \cdot 10^9$ ,  $d = 1 \cdot 10^7$

Entrance Age (Years)	10-Year Endowment Annual Premium Rate (Rupiah)					
	Male Policyholders			Female Policyholders		
	$b = 1 \cdot 10^8$	$b = 3 \cdot 10^8$	$b = 5 \cdot 10^8$	$b = 1 \cdot 10^8$	$b = 3 \cdot 10^8$	$b = 5 \cdot 10^8$
25	99.723.81	299.292.00	499.422.46	91.177.43	273.642.73	456.622.85
35	139.236.20	417.875.53	697.294.93	118.711.06	356.276.08	594.508.35
45	282.121.15	846.692.66	1.412.810.40	197.396.91	592.424.74	988.548.51
55	574.469.18	1.724.047.60	2.876.643.12	385.983.38	1.158.393.58	1.932.887.68
65	801.985.99	2.406.833.94	4.015.776.03	649.580.48	1.949.463.85	3.252.731.45
75	1.781.587.78	5.346.523.61	8.919.508.72	1.388.943.05	4.168.253.09	6.954.143.50

Source: Data processed with Python 3.8 on PyCharm Community Edition 2024.1.1

A comparison between premium rates at  $b = 1 \cdot 10^8$  and  $b = 3 \cdot 10^8$  where  $b$  is 3 times larger, showed that as age increases, the ratio between the two rates has a slight decrease.

For examples, for male and female policyholders in select entrance ages 35, 55, and 75:

$$\bar{P}(A_{35:\overline{10}|}) \text{ ratio is } \frac{417.875.53}{139.236.20} = 3.001199 \text{ for male and } \frac{356.276.08}{118.711.06} = 3.001203 \text{ for female.}$$

$$\bar{P}(A_{55:\overline{10}|}) \text{ ratio is } \frac{1.724.047.60}{574.469.18} = 3.001111 \text{ for male and } \frac{1.158.393.58}{385.983.38} = 3.001149 \text{ for female.}$$

$$\bar{P}(A_{75:\overline{10}|}) \text{ ratio is } \frac{5.346.523.61}{1.781.587.78} = 3.000988 \text{ for male and } \frac{4.168.253.09}{1.388.943.05} = 3.001025 \text{ for female.}$$

While a comparison between premium rates at  $b = 3 \cdot 10^8$  and  $b = 5 \cdot 10^8$  where  $b$  is 5/3 times larger, showed the following results:

$$\bar{P}(A_{35:\overline{10}|}) \text{ ratio is } \frac{697.294.93}{417.875.53} = 1.668667 \text{ for male and } \frac{594.508.35}{356.276.08} = 1.668673 \text{ for female.}$$

$$\bar{P}(A_{55:\overline{10}|}) \text{ ratio is } \frac{2.876.643.12}{1.724.047.60} = 1.668540 \text{ for male and } \frac{1.932.887.68}{1.158.393.58} = 1.668593 \text{ for female.}$$

$$\bar{P}(A_{75:\overline{10}|}) \text{ ratio is } \frac{8.919.508.72}{5.346.523.61} = 1.668282 \text{ for male and } \frac{6.954.143.50}{4.168.253.09} = 1.668359 \text{ for female.}$$

These ratios showed that when a higher value of  $b$  is chosen, it results in a higher premium rate, where an increase of  $b$  is followed by an almost proportional increase for  $\bar{P}(A_{x:\overline{10}|})$ .

## CONCLUSION

From this research it could be concluded that:

1. The application of Vasicek model yielded a wide confidence interval  $CI = 0.060626 \pm 0.043496$  caused by volatility in BI-Rate data which indicated high uncertainty in the interest modelling. In long term the mean converges to  $\theta = 0.060626$ .

2. Volatility in the interest data caused a large divergence between the upper and lower bounds of the premium value. Premium shows an exponential relation to the policyholder's entrance age as it increases faster at higher entrance age. The premium rates for male policyholders are constantly higher than for female policyholders, which can be confirmed by higher mortality rate among the male population in TMI IV data.
3. Premium rates showed slight sensitivity toward change in DARA utility coefficient  $d$ , which is more noticeable when a higher  $d$  value is chosen, e.g.  $d = 2 \cdot 10^7$ . Overall results showed a non-linear relation between  $d$  and premium rate.
4. Premium rates showed an almost proportional relation to the benefit rate  $b$ . A slight deviation in proportionality become more apparent at lower entrance age.

Further research on this topic could apply a different interest data with lower volatility to achieve stable premium rates. It could also analyze the impact of wealth on the premium rate, where wealth is seen as a function of time which could increase or decrease depending on the policyholder's income and expenses. Another factor that can be studied further is the effect of policy horizon on premium rates. Finally, a comparative analysis of the resulting premium rate can be performed between the Vasicek model and other stochastic models such as Cox-Ingersoll-Ross model on policyholders spanning various age groups.

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