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Actuarial Estimation of Unit-Linked Insurance Benefits Using the Point-to-Point Method with De Moivre's Law

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Abstract
Unit-linked insurance is a life insurance product that combines elements of protection and investment. Hence, the value of the benefits received by policyholders depends on the performance of the underlying investment asset. This study aims to estimate the benefits of a dual-purpose life insurance (endowment) unit-linked policy using the Point-to-Point method and De Moivre's Law. The Point-to-Point method determines investment results based on changes in stock prices from the beginning to the end of the contract period. At the same time, De Moivre's Law is applied to calculate the insured's chances of life and death to determine actuarial benefits. The data used are daily share prices of PT Bank Negara Indonesia Tbk for the period July 2024-June 2025, assuming a risk-free interest rate of 5,25%. The results showed that the stock volatility of 0,378 reflected a moderate level of risk, while the endowment life insurance benefit obtained of 1,43061 resulted in a single premium of IDR 66.809.378. The investment benefits received by the heirs are calculated based on the benefit structure with a minimum warranty limit and a predetermined maximum value (cap). These findings show that the Point-to-Point method provides a transparent, easy-to-understand estimate of benefits and can be a relevant alternative for calculating the value of unit-linked endowment insurance products in Indonesia.
Keywords: Unit link insurance, Point-to-Point, De Moivre's Law, Endowment Life Insurance, Investments.

1. INTRODUCTION

Insurance is one of the financial instruments that can help individuals and companies reduce financial risks from unexpected events such as natural disasters, accidents, or property loss [2]. Insurance can refine risk management methods, account for the characteristics of claim distribution, and formulate more effective mitigation strategies [9]. The presence of insurance allows individuals and families to obtain financial security in the event of unexpected events, thereby avoiding excessive economic burdens. In its development, insurance is divided into various types, one of which is life insurance. Life insurance has multiple forms, including term life insurance, which protects for a specific period of time with relatively affordable premiums, whole life insurance, which provides lifetime protection as well as cash value as long-term savings, endowment insurance, which combines life protection with savings benefits, and unit-linked life insurance, which is a hybrid product with protection benefits as well as investment benefits.

Unit-linked insurance is a form of insurance product that combines life protection benefits with investment functions. Some of the premiums are allocated to investment instruments to build funds that will benefit policyholders in the future, such as pension funds [12]. However, because there is an element of investment, the financial risks that arise are the policyholder's responsibility, either in whole or in part. Unit-linked life insurance products are a significant innovation in the insurance industry because they offer investment opportunities alongside life protection. In the last two decades, this product has grown rapidly in Indonesia and has become one of the main contributors of premiums in the national life insurance industry [4]. Unit-linked premiums still account for the dominant portion of total life insurance premiums. However, the high popularity of unit links is inseparable from various problems, such as limited public understanding of the cost structure, uncertainty about investment returns, and disputes between customers and insurance companies over product transparency. This condition prompted regulators to issue POJK Number 5 of 2022 concerning Insurance Products Linked to Investment (PAYDI) to strengthen consumer protection [14].

Determining the value of a unit-linked investment requires the correct calculation method to ensure the benefits received by customers comply with applicable regulations. Some commonly used methods for calculating the performance of unit-linked investments include the Point-to-Point method, the Annual Ratchet method, and the High-Water Mark method [1]. The high-water mark method calculates returns based on the ratio of the index's highest value over a given period to the initial value, while the Annual Ratchet method is an indexing method based on the level of participation evaluated from year to year. The Point-to-Point method calculates returns by comparing the initial and final values of an index or investment asset over a given period. According to Hardy (2003), the Point-to-Point method has advantages over the Annual Ratchet and High-Water Mark methods because it uses a simpler basis for index calculation, comparing index values at the beginning and end of the contract period. This relatively lower calculation basis allows for higher participation rates than ratcheting-based methods, which generally require a decrease in participation rates due to the use of maximum values or periodic value-setting mechanisms. In addition, the Point-to-Point method is more transparent and easier to understand. It better reflects investment performance because it does not involve a ratcheting mechanism or value-setting during the contract period. The novelty of this study lies in the quantitative analysis that specifically positions the Point-to-Point method as the primary focus in evaluating the benefits and risks of unit-linked products. In contrast to previous studies that tend to focus on the Annual Ratchet or High-Water Mark approach, this study offers an alternative perspective on the implications of the Point-to-Point method for the characteristics of the benefits produced, thereby enriching the literature on the performance and risk analysis of unit-linked products. In this study, the focus is on an endowment-type unit-linked product that combines life protection, guaranteed benefits at the end of the contract, and potential investment returns. The selection of unit link endowment is intended so that the analysis not only emphasizes the investment aspect, but also pays attention to the characteristics of certainty of benefits that distinguish it from other types of unit link. However, academic studies in Indonesia on the application of the Point-to-Point method in unit-linked products, especially endowment products, remain limited, so further research is needed to provide a deeper quantitative understanding.

This research is essential because the valuation method not only affects the amount of benefits customers receive but also affects insurance companies' risk management strategies and the effectiveness of regulatory oversight. Therefore, the study of unit-linked insurance with the application of the Point-to-Point method, especially in endowment products, is relevant to provide a more comprehensive picture of the balance between potential benefits and risks, as well as contribute to the development of academic literature, industry practices, and regulatory policies in building a healthy, transparent, and sustainable insurance industry.

2. METHODOLOGY

This section describes the methodological approach adopted in the study, beginning with the formulation of the Stock Price Model to capture asset price dynamics. It then details the computation of Investment Value, followed by the application of De Moivre's Law within the actuarial framework. The premium calculation using the Point-to-Point method is also presented. Collectively, these methods establish a coherent and rigorous framework for the quantitative analysis conducted in this research.

2.1 Stock Price Model

Stock prices are determined by the demand and supply mechanisms in the stock market. However, according to Campbell, Lo, and MacKinlay (1997), in the financial world, investors are more likely to use data on returns (rates of return) rather than the stock's price [3]. This is because returns can provide a more comprehensive picture of investment performance and have statistical characteristics that make them easier to analyze and understand. For example, S_t is the price of the stock at time t. Based on Tsay (2010), return data can be defined as follows [13]:

$$R_t = ln\left(\frac{S_t}{S_{t-1}}\right) \tag{2.1}$$

The mean return value can be obtained from:

$$\bar{R}_t = \frac{\sum_{t=1}^{n} R_t}{n} \tag{2.2}$$

Meanwhile, annual volatility (σ) can be calculated by dividing the standard deviation of the stock price's log return (s) by the period of time in a year (τ) or it can be written as follows:

$$\sigma = \frac{s}{\sqrt{\tau}} \tag{2.3}$$

Volatility is a measure of the spread rate or variability of stock returns in a specific period. The higher the volatility, the greater the risk for investors, as stock prices tend to fluctuate sharply. The time frame in a year is the proportion of the observation time relative to one year, used to convert the standard deviation of daily returns to annual volatility. The value of τ is calculated as the inverse of the number of active trading days in a year (T), which is generally assumed to be 252. A value of τ is defined as:

$$\tau = \frac{1}{T} \tag{2.4}$$

The value of s can be calculated by the formula:

$$s = \sqrt{\frac{1}{n-1}\sum_{t=1}^{n}(R_t - \bar{R}_t)^2} \tag{2.5}$$

with n being the number of observation days +1.

2.2 Investment Value

Investment value is the economic value of funds invested in an asset or portfolio, which can change over time in response to market conditions (Hull, 2018) [8]. In unit-linked insurance products, the investment value comes from a portion of the premiums allocated to financial instruments. Market fluctuations mean the benefits received by policyholders in unit-linked insurance products depend on investment performance, so there is a risk that one party could suffer losses. Insurance companies risk losing money if the share price increases significantly at the time of the claim, while the insured may be harmed if the share price drops sharply at that time. To reduce these risks, benefits are usually limited by a minimum warranty and a maximum value (cap), thereby protecting both the insurance company and the insured from extreme losses. According to Hardy (2003) the minimum warranty, (G_k) can be determined using the percentage of premium return (β), the interest rate of the warranty (g), and the index of the annual time period (k), as follows formula [5]:

$$G_k = \beta(1+g)^k \tag{2.6}$$

According to Gaillardetz, P., & Lakhmiri (2011), the maximum value (cap) can be determined by using the cap (c) interest rate and the annual time period index (k), as in the following formula [6]:

$$C_k = (1+c)^k \tag{2.7}$$

The investment value of the benefit structure can be obtained from the function of the standard normal cumulative distribution (Φ), participation rate (α), risk-free interest rate (r), annual time period index (k), minimum guarantee (G_k), and maximum value (C_k), defined as follows:

$$\begin{aligned}\Pi(k) \quad = \quad & \alpha[\Phi(\delta)-\Phi(\kappa)] + e^{-rk}[\beta(1+g)^k] - \Phi(\xi)[\beta(1+g)^k-(1-\alpha)] \\ & +\Phi(v)[(1+c)^k-(1-\alpha)]\end{aligned} \tag{2.8}$$

with

$$\delta = \sigma\sqrt{k} + \frac{\left(r-\frac{1}{2}\sigma^2\right)k - \ln\left(\frac{\beta(1+g)^k-(1-\alpha)}{\alpha}\right)}{\sigma\sqrt{k}},$$

$$\xi = \delta - \sigma\sqrt{k},$$

$$\kappa = \sigma\sqrt{k} + \frac{\left(r-\frac{1}{2}\sigma^2\sigma\right)k - ln\frac{(1+c)^k-(1-\alpha)}{\alpha}}{\sigma\sqrt{k}},$$

and

$$v = \kappa - \sigma\sqrt{k}$$

2.3 De Moivre’s Law

De Moivre's law is a fundamental model in actuarial science used to estimate the probabilities of death or survival at a given age, based on a simplified assumption about the distribution of ages at death. Compared with actual mortality tables, such as the Indonesian Mortality Table (TMI) or the Commissioners Standard Ordinary (CSO) Table, De Moivre's law has limitations because it does not fully capture empirical mortality patterns, which are generally nonlinear, particularly at advanced ages, nor does it account for variations in mortality risk arising from demographic characteristics and population heterogeneity. Consequently, the resulting estimates of survival and death probabilities are less adequate for realistic risk assessment. Therefore, in this study, De

Moivre's law is employed as a conceptual approach and a model simplification to explain the fundamental mechanisms of actuarial calculations, rather than as a representation of actual mortality levels. According to Neill (1977), De Moivre's law assumes that the force of mortality increases linearly with age beyond a threshold, leading to a simplified linear representation of survival probabilities across ages [11]. Despite its simplicity, this model remains appropriate because it provides a transparent, easily interpretable analytical framework that enables focused analysis of the relationship between mortality assumptions and actuarial outcomes. Its structural simplicity has also led to its widespread use as a baseline model in various actuarial applications, such as the valuation of life annuities and the calculation of life insurance premiums, as well as a reference point for the Development and evaluation of more complex mortality models. According to Miguel (2009), De Moivre's Law assumes that death is uniformly distributed during the death interval, with the probability density function being $f(x) = \frac{1}{\omega}$ for $0 \leq x \leq \omega$, so that the life chance for a person of x age can survive to the age of $x + t$ years is as follows [10]:

$$ {}_t p_x = \frac{\omega - x - t}{\omega - x} \tag{2.9} $$

And the chances of a person of age x dying are less than the age of $x + t$ years, as follows:

$$ {}_t q_x = \frac{t}{\omega - x} \tag{2.10} $$

2.4 Premium

Endowment insurance policies provide benefits in both death and survival. If the policyholder dies during the n-year coverage period, the heirs will receive the sum insured. Conversely, if the insured is still alive until the end of the coverage period, then the benefit will also be paid to the policyholder [7]. Benefits are provided if the policyholder dies within n years or survives to n years.

$$
\begin{aligned}
A_{x:\overline{n|}} &= A^1_{x:\overline{n|}} + A_{x:\overline{n|}}{}^{1} \\
&= \sum_{k=0}^{n-1} v^{k+1}\ {}_k p_x\, q_{x+k} + v^n\ {}_n p_x \\
&= \sum_{k=0}^{n-1} E\left[b_{k+1} e^{-r(k+1)}\right] {}_k p_x q_{x+k} + E\left[b_n e^{-rn}\right] {}_n p_x \\
&= \sum_{k=0}^{n-1} \Pi(k+1)\ {}_k p_x q_{x+k} + \Pi(n)\ {}_n p_x \\
&= \Pi(1)\ {}_0 p_x q_x + \Pi(2)\ {}_1 p_x\, q_{x+1} + \cdots + \Pi(\mathrm{n})\ {}_{n-1} p_x\, q_{x+k-1} + \Pi(\mathrm{n})\ {}_n p_x \\
&= \sum_{k=1}^{n} \Pi(k)\,{}_{k-1} p_x q_{x+k-1} + \Pi(\mathrm{n})\ {}_n p_x
\end{aligned} \tag{2.11}
$$

The calculation of a single premium for endowment insurance products can be obtained by multiplying the actuarial present value of endowment benefits by the initial share price, (S_0). and the number of shares (u), as shown in the following equation:

$$ P = A_{x:\overline{n|}}\, S_0\, u \tag{2.12} $$

2.5 Point-to-Point Method

Investment performance is determined by the difference between the stock price at maturity and the stock price at the beginning of the policy contract, so the change in stock price that occurs between the two time points is not taken into account. This approach provides policyholders with protection against a decline in share prices during the contract period. The investment results obtained at time t with the Point-to-Point method can be defined as follows:

$$H_t = \frac{S_t - S_0}{S_0} \tag{2.13}$$

After obtaining the minimum warranty value and maximum value (cap), the structure of the investment benefit received by the policyholder at the time of claiming in the year 10 can be calculated as follows:

$$b_k = maks[\min[1 + \alpha H_t, (1+c)^k], \beta(1+g)^k] \tag{2.14}$$

3. RESULT & DISCUSSION

This section presents the analysis results and discusses the findings based on the applied methodology.

3.1 Data

The profile of policyholders and investments is assumed as shown in Table 3.1 below:

Table 3.1 Policyholder and Investment Profile

Assumptions	***Values***
Premium return percentage (β)	80%
Guaranteed interest rate (g)	4%
Cap interest rate (c)	10%
Risk-free interest rates (r)	5,25%
Participation rate (α)	80%
Age (x)	35
Coverage period (n)	30
Initial stock price (S_0)	Rp 4.670
Number of shares (u)	10.000

3.2 Stock Price Model

In financial theory, stock prices are influenced by both fundamental and technical factors. One approach often used to assess stock prices is to focus on the benchmark interest rate. Changes in interest rates affect the cost of capital and the expected rate of return for investors. The higher the interest rate, the higher the risk-free rate, which can suppress investor interest in stocks. Therefore, the interest rate used in this calculation is the annual risk-free interest rate, denoted by r, equal to the official benchmark interest rate issued by Bank Indonesia at 5.25% per annum.

Table 3.2 The closing price of PT Bank Negara Indonesia Tbk

t	Date	Closing Price (Rp)
0	8 July 2024	4.670
1	9 July 2024	4.860
2	10 July 2024	4.820
⋮	⋮	⋮
229	26 Juny 2025	4.120
230	30 Juny 2025	4.120

Table 3.2 shows the closing price of PT Bank Negara Indonesia Tbk on several observation dates. PT Bank Negara Indonesia Tbk shares were chosen as the object of research because they are one of the state-owned banks with a large market capitalization and high liquidity levels in the Indonesian capital market. In addition, the availability of consistent historical stock price data and its role as a representative stock in the banking sector make this stock suitable to illustrate the application of the modeling methods and frameworks used in this study. This study employs a single asset, allowing a more focused examination of the proposed methodology while limiting the generalizability of the results to other stocks or sectors. Therefore, the results obtained are specific to the assets being analyzed and are not intended to represent the overall market behavior. The data used in this study covered a one-year observation period. The use of relatively short data periods allows for a more focused analysis of stock price dynamics under homogeneous market conditions, making it easier to identify volatility characteristics and model short-term responses to price changes. This approach also reduces the potential for distortions due to long-term structural changes, such as regulatory changes or extreme macroeconomic conditions. However, limited observation periods yield period-specific results and may introduce temporal bias. Future research should extend the observation period and incorporate multiple assets or portfolio-based approaches to increase the robustness and generalizability of the results. From the Table, it can be seen that stock prices fluctuate over time. For example, on July 8, 2024, the closing price was at IDR 4,670, then increased to IDR 4,860 the day after, before dropping again to IDR 4,820 on July 10, 2024. This price change will later become the basis for calculating daily stock returns.

Stock return is the level of profit or loss that investors get from a stock investment in a specific period. The return can be calculated from day-to-day changes in closing price, allowing daily stock performance to be obtained. Using equation (2.1), the following results are obtained:

Table 3.3 Calculation of the value of stock return

t	Date	Closing Price (Rp)	Return (R_t)
0	8 July 2024	4.670	
1	9 July 2024	4.860	0,039879
2	10 July 2024	4.820	-0,008265
⋮	⋮	⋮	⋮
229	26 Juny 2025	4.120	0,002430
230	30 Juny 2025	4.120	0,000000

Next, calculate the stock's volatility, which describes the level of risk in its price movements. This volatility measures how much the daily return deviates from its average, providing an idea of a stock's stability or instability over the observation period. Based on the calculation results, the stock volatility is 0,378. This value represents the standard deviation of PT Bank Negara Indonesia

Tbk's daily returns around their mean. In other words, the level of fluctuations in stock prices is relatively moderate, so the risk borne by investors is neither too high nor completely stable.

3.3 Invesment Value

The minimum warranty and cap value determine the lower and upper limits of the investment value, providing investors with protection against losses and an overview of potential profits. Based on the calculations using equations (2.6) and (2.7), the minimum warranty and stamp value for each period can be seen in the following Table 3.4:

Table 3.4 Minimum Warranty and Cap Value

k	G_k	C_k
0	0,8000	1,0000
1	0,8320	1,1000
2	0,8653	1,2100
⋮	⋮	⋮
75	15,1562	1.271,8954
76	15,7625	1.399,0849

After determining the minimum warranty value and cap value, the calculation proceeds with determining the additional parameters required to obtain the investment value. The parameters used include $\delta, \xi, \kappa,$ and v, each representing a component of a probability distribution-based stock price model. The calculation subsequently applies these values to the standard normal cumulative distribution function $\Pi(k)$, in accordance with the valuation model's theoretical assumptions. The analysis employs the normality assumption to simplify the model and facilitate analytical derivations. However, it should be noted that stock return distributions in practice often deviate from normality and exhibit time-varying behavior. Consequently, the use of the standard normal distribution may be less effective at capturing extreme risk events, and the resulting valuations should be interpreted in light of these modeling limitations.

Table 3.5 Standard Normal Distribution Parameter Values and Functions

k	δ	ξ	κ	v	$\Phi(\delta)$	$\Phi(\xi)$	$\Phi(\kappa)$	$\Phi(v)$
0								
1	0,9508	0,5723	0,0168	-0,3617	0,8291	0,7164	0,5067	0,3588
2	0,8083	0,2731	0,0283	-0,5069	0,7905	0,6076	0,5113	0,3061
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
75	1,9468	-1,3310	0,5913	-2,6865	0,9742	0,0916	0,7228	0,0036
76	1,9595	-1,3400	0,5961	-2,7034	0,9750	0,0901	0,7244	0,0034

From Table 3.5, it can be seen how the parameter values change as the period k increases. The cumulative distribution value $\Pi(k)$ indicates the probability of each parameter, which is then used to calculate the probability of $\Pi(k)$ at the next stage. The next step is to calculate the likelihood or weight used to determine the investment's final value. The value of $\Pi(k)$ is obtained from the results of the previous parameter using equation (2.8) and serves as a multiplier in calculating the expected investment value in the period.

Table 3.6 Investment Expected Value

k	$\Pi(k)$
0	
1	0,9314
2	0,9321
⋮	⋮
75	13,8321
76	14,5232

With the acquisition of $\Pi(k)$ value, all components of the investment calculation are available. Furthermore, these values can be used to determine the final investment value, the main goal of this stock price model. This final value will represent the fair price of the instrument, taking into account the volatility, minimum warranty, cap value, and probability distribution.

3.4 De Moivre's Law

In this section, De Moivre's Law is used to calculate the value of endowment life insurance benefits. The calculation of the value of endowment insurance requires information about a person's life expectancy and the probability of death at a given age, both of which can be obtained using De Moivre's Law. Before determining the benefits of endowment life insurance, the benefits of term and pure endowment life insurance will be calculated first using equation (2.11). Table 3.7 presents the results of calculating the benefits of term life insurance.

Table 3.7 Calculation Results of Term Life Insurance Benefits

k	${}_{k-1}p_x$	q_{x+k-1}	$\Pi(k)$	$\Pi(k)\ {}_{k-1}p_x\ q_{x+k-1}$
1	1,00000	0,01316	0,93143	0,01226
2	0,98684	0,01299	0,93210	0,01195
⋮	⋮	⋮	⋮	⋮
29	0,63158	0,00962	1,70743	0,01037
30	0,61842	0,00952	1,77124	0,01043
Total				0,31762

Based on the calculation, the benefit of term life insurance is 0,31762. Furthermore, the benefit of pure endowment life insurance is calculated using the equation $\Pi(n),\ {}_np_x,$ and yields a result of 1,11299. Thus, the total benefits of endowment life insurance are 1,43061. The total value of the benefits is then used in the premium calculation stage, as per equation (2.12). In this process, initial data included an initial share price of 4.670 and 10.000 shares, and an endowment benefit value of 1,43061. Based on these parameters, a premium of IDR 66.809.378 was obtained.

After determining the premium value, the analysis continues by assessing the benefits the insured or heirs will receive under the investment benefit structure. In this illustration, it is assumed that the insured died in the 10th year. The investment yield obtained at $k = 10$ with the Point-to-

Point method is 0,09208. Based on this value, the investment benefit can be calculated using the benefit structure (b_k), with equation (2.14). For $k = 10$ is obtained:

$$\begin{aligned} b_{10} &= \text{maks}(\min[71.730.668, 173.286.320], 79.115.360) \\ &= \text{maks}(71.730.668, 79.115.360) \\ &= 79.115.360 \end{aligned}$$

So, the unit link endowment life insurance benefit received by the heirs if the insured dies in the 10th year of the contract is IDR 79.115.360. The amount of unit-linked endowment life insurance benefits received by heirs in the 10th year, IDR 79.115.360, reflects the accumulation of the protection and investment components, calculated under the mortality and rate-of-return assumptions used in the model. From an actuarial perspective, this benefit value indicates a relatively moderate level of benefit adequacy, in which the amount of protection is determined not only by the risk of death but also by investment performance during the contract period. The benefit structure describes the balance between claims obligations and investment risk exposure for insurance companies, making asset-liability management an essential factor in maintaining the company's solvency and financial stability. For policyholders, the benefits received in the 10th year provide medium-term financial protection and exposure to investment returns, with benefit levels that are sensitive to the assumed return and market volatility. The results of this valuation emphasize the importance of policyholders' understanding of the characteristics of unit-linked products, especially the trade-off between premiums paid, investment risks, and benefits obtained.

4. CONCLUSION

This study shows that the application of the Point-to-Point method with De Moivre’s Law approach can be used effectively to estimate the benefits of endowment life insurance unit link. The Point-to-Point method provides simple, transparent, and easy-to-understand investment calculation results for customers because it considers only the change in stock prices between the beginning and end of the contract period, without accounting for price fluctuations in the middle of the period. Based on daily share price data for PT Bank Negara Indonesia Tbk from July 2024 to June 2025, a volatility of 0,378 was obtained, indicating that the investment risk is in the moderate category. The calculation of the benefits of endowment life insurance, using De Moivre's Law, resulted in a benefit value of 1.430,61 and a single premium of IDR 66.809.378 for 10,000 shares with an initial price of IDR 4.760. Suppose the insured dies in the 10th year of the contract. In that case, the investment benefit received by the heirs is calculated according to the benefit structure, which takes into account the minimum warranty (floor) and the maximum value (cap) to protect both insurance companies and policyholders from extreme risks.

Overall, this study confirms that the Point-to-Point method and De Moivre's Law can be a relevant and applicable quantitative approach for determining benefits and premiums fairly and has the potential to support the development of valuation and risk management models in the life insurance industry in Indonesia.

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