Critical Illness Insurance Pricing Using A Modified Option Approach Under Gamma Process

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***Abstract*—Critical illness insurance protects against complex risks and high medical costs. This study proposes a premium model using a modified call option framework, where benefits are paid if medical expenses exceed a predefined claim limit. We examine two cases based on Indonesia's National Health Insurance regulations: with and without an inpatient care class upgrade. The model employs the Gamma process to represent treatment costs and claim limits while analyzing the impact of parameters on insurance premiums. Results show that premiums increase with the cost-to-claim limit ratio in the non-upgraded model. In contrast, in the upgraded model, premiums rise as the claim limit increases, assuming expected costs exceed the limit.**

***Index Terms*—claim limits, critical illness, Gamma process, insurance premium, option.**

I. INTRODUCTION

ILLNESSES requiring intensive treatment and incurring high costs have been widely acknowledged. The financial burden of treating critical illnesses falls heavily on patients and their families. For example, breast cancer patients, in addition to bearing the costs of routine therapy, also face additional expenses if they experience side effects from the administered cancer treatment [1]. Critical illness insurance protects against these complex risks and significant treatment expenses. As a result, such insurance has become vital in modern life. Determining premiums for critical illness insurance is a key area of interest for researchers, practitioners, and insurance companies looking to develop more effective and sustainable insurance policies. In light of changing circumstances, a meticulous and well-informed approach to setting these premiums is both increasingly important and challenging.

Global and technological developments will significantly impact the future of the insurance industry. Various financial product models will offer new ideas and techniques for designing insurance products. One particularly intriguing approach is the use of derivative financial models in insurance [2]. Options, the most commonly used derivative financial instruments to hedge risk, grant the holder the right to buy or sell the underlying asset at a specified time and price [3]. Beyond derivative finance theory, portfolio investment theory also serves as a foundation for modelling insurance products, particularly in the realm of agricultural insurance [4].

The option approach is commonly used to determine premiums for various types of insurance, including life, catastrophe, deposit, and agricultural insurance. Kirkby and Nguyen [5] utilize the fundamental relationship between insurance contracts and Asian options to analyze the structure and value of equity-linked Guaranteed Minimum Death Benefit (GMDB) plans, where the payoff is determined by periodic Dollar Cost Averaging (DCA) investments in a risky index, with premiums paid regularly. Furthermore, the option approach is used in investment insurance to guarantee a return on capital [6]. Prabakaran [7] applies the Black-Scholes call option approach to calculate premiums for catastrophe insurance. Furthermore, the rainfall index-based barrier option approach can be applied to the agricultural insurance model [8].

In health insurance, the option approach can also be applied effectively. Chicaiza-Becerra and Cabedo [9] explore alternative critical illness reinsurance products using the option approach, highlighting how option coverage can be replicated in insurance. Insurance and option contracts share similar concepts since both are hedging products that require a premium at the beginning of the contract. In addition, both contract types compensate for events or potential risks over a relatively short hedging period. For instance, the Black-Scholes call option approach has been used to make health insurance premiums for ADSE civil servants in Portugal more realistic and adaptable [10].

In Indonesia, most critical illness insurance policies provide a lump sum benefit [11]. Some insurance companies offer an alternative scheme where benefits are paid based on the actual treatment bill, subject to a maximum cost limit. For example, the Social Security Agency on Health in Indonesia, known as BPJS, covers claims by setting specific claim limits. Often, the actual treatment costs exceed these covered cost limits. Therefore, a new insurance scheme is needed to cover medical bills exceeding the sum these existing schemes assured. An alternative insurance solution involves an option approach, where the insurance right is exercisable only if the treatment costs exceed a certain limit (claim limit). This paper introduces a modified option approach to estimate critical illness insurance premiums, with the underlying cost being treatment expenses for critical illnesses. In this study, the treatment cost and claim limit are assumed to be random and follow a Gamma process.

Section II offers a comprehensive and systematic definition of the insurance premium and the algorithm for calculating

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insurance premiums. In Section III, we apply the premium determination model to a critical illness case study and examine the effect of changing the parameters' values on the premium amount. This organization ensures that the developed model is structured and understandable and significantly contributes to the field of insurance modelling.

II. Critical Illness Insurance Premium Using the Modified Option Approach

BPJS Kesehatan is Indonesia's national social health insurance agency. It manages the country's health insurance program and ensures that healthcare services are accessible to the public through a social insurance system. BPJS uses a payment method called capitation and a system known as INA-CBGs (Indonesian Case-Based Groups) to reimburse healthcare providers. The INA-CBGs system categorizes treatment costs based on patient diagnoses and medical procedures, which helps determine how much BPJS will reimburse for each service. For example, breast cancer patients receiving chemotherapy are assigned specific INA-CBG codes: C-4-13-I, C-4-13-II, and C-4-13-III. The last letter in these codes indicates the severity of the disease. Within each severity level, healthcare services are further divided into three classes: Class 1, Class 2, and Class 3.

The Indonesian Ministry of Health has introduced a new Minister of Health Regulation (Permenkes RI No. 3 of 2023) regarding the adjustment of INA-CBG tariffs for patients who want to upgrade their inpatient care class. Patients entitled to Class 1, 2, or 3 inpatient care who wish to upgrade to a class above Class 1 (VIP) are required to pay up to a maximum of 75% of the INA-CBGs tariff for Class 1. However, this payment requirement will not apply if the total cost of inpatient care does not exceed the INA-CBG tariff that corresponds to the patient's current entitlement.

In reality, the total cost of cancer treatment may exceed the BPJS claim limit, primarily due to the exclusion of certain necessary medications or supplementary services from BPJS coverage. These may include multivitamins and supplements that support the chemotherapy process. When treatment costs surpass the claim limit, the excess must be borne by the patient. Conversely, if the costs fall within the limit, they are fully covered by BPJS. Thus, insurance products that provide coverage beyond the BPJS claim limit are both relevant and essential for cancer patients.

This study examines an insurance premium scheme model that covers treatment costs not covered by BPJS. Two models were developed: the insurance premium model without inpatient class upgrading and the insurance premium model with inpatient class upgrading. The premium determination is based on a modified option approach.

An option is a financial product in the form of a contract that grants the holder the right (but not the obligation) to buy (call option) or sell (put option) a specific financial asset at a predetermined price (strike price) within a specified period. One of the primary purposes of an option is to protect the value of the underlying financial asset from price declines. To activate the option, the buyer must pay the seller a premium at the beginning of the contract. The option right remains valid until the maturity date. If the buyer exercises their option right during the contract term, he will be compensated according to the contract terms. For instance, in a put option, the buyer can sell the underlying asset at the strike price, irrespective of the asset's current market price. In contrast, in a call option, the buyer can purchase the underlying asset at the strike price, regardless of the market price. This concept of options can be applied to insurance modelling.

In this insurance model, we replicate the risk coverage pattern of the options as follows:

1) The underlying cost of this insurance model is the total cost of treatment.
2) The insured will not exercise his rights if the total cost of treatment on the maturity date is less than the limit of the BPJS claim. In contrast, if medical bills exceed the limit of the BPJS claim, the insured will only pay the strike price amount. We employ the European call option, allowing the insured to exercise their option rights only at maturity.

The future cost of treatment for critical illness is uncertain and is influenced by various factors, leading to potentially high treatment costs. Consequently, some insurance companies limit their medical coverage to mitigate potential losses resulting from unlimited expenses for treating critical illnesses. This limitation on covered costs forms the foundation of our modified option approach model. The maximum amount of coverage allowed is called the claim limit.

In this modified option approach, on the maturity date or the end of the treatment period, the insured will exercise their insurance right if the total cost of treatment during the treatment period exceeds the BPJS claim limit (B_T), where B_T varies and is not constant. It is assumed that both the total treatment cost (S_T) and the claim limit (B_T) follow a Gamma process.

The Gamma process is utilized to model both the total cost of cancer treatment and the BPJS claim limit, as it effectively captures the positively valued and cumulatively increasing nature of these costs over time. Cancer treatment involves multiple stages—such as diagnosis, surgery, chemotherapy, and follow-up care—and may include repeated therapies and additional treatment for complications. Consequently, treatment costs tend to rise over time. Likewise, the BPJS claim limit is expected to increase accordingly to accommodate these growing expenses.

A. Gamma Process

The Gamma process is a continuous-time stochastic process with stationary and independent increments. For any $0 \leq s \leq t$, the increment of the Gamma process follows a Gamma distribution:

$$X(t) - X(s) \sim \text{Gamma}\left(\kappa(t) - \kappa(s), \theta\right)$$

where $\kappa(t)$ is the shape function, which is an increasing function, and θ is the scale parameter. The Gamma process exhibits several unique properties [12], [13]:

1) $X(0) = 0$,
2) it has stationary and independent increments,
3) it features jumps, reflecting a cumulative process with non-decreasing paths.

Furthermore, if $\{X(t)\}_{t\geq 0}$ represents a Gamma process over the time interval t, it can be expressed as

$$X(t) \sim \text{Gamma}\left(\kappa(t), \theta\right).$$

The Gamma process can be applied in reliability and maintenance modelling, financial mathematics, and insurance. It is widely used in financial mathematics to model jumps in asset prices, cumulative risk assessment, and financial derivatives pricing. In the insurance sector, the Gamma process can be utilized to model medical treatment costs, which serve as the basis for health insurance premium determination. Additionally, the Gamma process can be employed to model cumulative exposure to risk factors, aiding in predicting health outcomes.

B. Insurance Premium Model Without Inpatient Class Upgrading

In this model, the insurance company will provide an insurance benefit equal to the difference between medical bills and the BPJS claim limit. It can be illustrated as follows:

$$IB_{MO,T} = \begin{cases} S_T - B_T, & \text{if } S_T > B_T \\ 0, & \text{if } S_T \leq B_T. \end{cases}$$

Thus, the insurance premium with a maturity date T is the present value of insurance benefits, calculated by

$$P_{MO\_T} = \exp(-rT)E\left[\max(S_T - B_T, 0)\right]. \quad (1)$$

The cost of treatment for critical illnesses, indicated as S_T, is assumed to follow a Gamma process with parameters $\kappa_1(t) > 0$ and $\theta_1 > 0$. It is denoted as $S_T \sim \text{Gamma}(\kappa_1(T), \theta_1)$. The limit of the BPJS claim, B_T, is also assumed to follow a Gamma process and is denoted $B_T \sim \text{Gamma}(\kappa_2(T), \theta_2)$. Since $Y_T = S_T - B_T$ does not directly follow a Gamma distribution or any other common distribution, $E\left[max(S_T - B_T, 0)\right]$ does not have a closed-form solution. Therefore, we use numerical simulation to obtain the insurance premium under this modified option framework.

1) Case 1: ($\theta_1 = \theta_2 = \theta$): In the first case, $\theta_1 = \theta_2 = \theta$ and $\kappa_1 > \kappa_2$ are assumed. The first step in the numerical simulation for this case is to generate M samples of S_T and B_T, which are each distributed as $\text{Gamma}(\kappa_1(T), \theta)$ and $\text{Gamma}(\kappa_2(T), \theta)$, respectively. The premium value is obtained by discounting $E\left[max(S_T - B_T, 0)\right]$, with r being the risk-free interest rate.

Algorithm for calculating insurance premiums using a modified option approach with the assumption that $\theta_1 = \theta_2 = \theta$

```
Set the shape parameter value of S_T (κ1);
Set the shape parameter value of B_T (κ2);
Set the scale parameter value of B_T and S_T (θ);
Set the discount rate (r);
Set the maturity date (T);
For i = 1, ..., M
    Generate S_T ~ Gamma(κ1 T, θ);
    Generate B_T ~ Gamma(κ2 T, θ);
    Set Y[i] = max(S_T[i] − B_T[i], 0);
    Set E[Y] = Σ_{i=1}^{M} Y[i]/M;
end for.
Set P_MO_T = e^{−rT} E[Y].
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If the insurance right can be exercised at the end of the treatment period for n treatment period, then the pure single premium paid at the start of the contract is the sum of the premiums of the n-modified option with a varying maturity date and is stated as

$$P_{MO} = \sum_{T=1}^{n} P_{MO\_T}. \quad (2)$$

2) Case 2: ($\theta_1 \neq \theta_2$): Suppose $S_T \sim \text{Gamma}(\kappa_1(T), \theta_1)$, $B_T \sim \text{Gamma}(\kappa_2(T), \theta_2)$, and $\kappa_1 > \kappa_2$, then the insurance premium with modified option approach is calculated through a numerical simulation based on the following algorithm.

Algorithm for calculating insurance premiums using a modified option approach with the assumption that $\theta_1 \neq \theta_2$

```
Set the shape parameter value of S_T (κ1);
Set the scale parameter value of S_T (θ1);
Set the shape parameter value of B_T (κ2);
Set the scale parameter value of S_T (θ2);
Set the discount rate (r);
Set the maturity date (T);
For i = 1, ..., M
    Generate S_T ~ Gamma(κ1 T, θ1);
    Generate B_T ~ Gamma(κ2 T, θ2);
    Set Y[i] = max(S_T[i] − B_T[i], 0);
    Set E[Y] = Σ_{i=1}^{M} Y[i]/M;
end for.
Set P_MO_T = e^{−rT} E[Y].
```

C. Insurance Premium Model With Inpatient Class Upgrading

In this second insurance premium scheme model, it is assumed that if a BPJS participant wishes to upgrade their inpatient care class, they must pay an amount equal to p times the claim limit. According to the Minister of Health Regulation (Permenkes RI No. 3 of 2023), the maximum value of p is 0.75 or 75% of B_T. However, BPJS participants are not required to pay this amount if S_T is less than B_T. Therefore, the insurance benefits received by the insured under the scheme we have developed are as follows:

$$IB_{MO_u,T} = \begin{cases} pB_T, & \text{if } S_T > B_T \\ 0, & \text{if } S_T \leq B_T. \end{cases}$$

Thus, the insurance premium with a maturity date T is calculated by

$$P_{MO_u\_T} = \exp(-rT)E\left[pB_T\right]\mathbf{1}_{S_T > B_T}, \quad (3)$$

where $0 < p \leq 1$ and $\mathbf{1}_{S_T > B_T}$ is an indicator function.

Algorithm for calculating insurance premiums with inpatient class upgrading using a modified option approach

Set the shape parameter value of S_T (κ_1);
Set the scale parameter value of S_T (θ_1);
Set the shape parameter value of B_T (κ_2);
Set the scale parameter value of S_T (θ_2);
Set the discount rate (r);
Set the maturity date (T);
Set the proportion of benefit paid by insurer ($0 < p \leq 1$);
For $i = 1, \ldots, M$
    Generate $S_T \sim \text{Gamma}(\kappa_1 T, \theta_1)$;
    Generate $B_T \sim \text{Gamma}(\kappa_2 T, \theta_2)$;
    Set an indicator function (1 if $S_T > B_T$, else 0);
    Set $Y[i] = p \times B_T \times$ indicator;
    Set $E[Y] = \sum_{i=1}^{M} Y[i]/M$;
end for.
Set $P_{MO_u\_T} = e^{-rT} E[Y]$.

III. Numerical Simulation

Cancer, particularly breast cancer, is a critical illness and stands out as a significant health concern in Indonesia, with notable increases in the number of patients reported by 2020. According to [14], the three main types of cancer in Indonesia are breast cancer, cervical cancer, and lung cancer. Breast cancer, specifically, represented the highest proportion (16.6) of the 396,914 reported cancer cases in Indonesia in 2020 [15]. Cancer diagnosis is classified into benign and malignant breast cancer. Accurate determination of the breast cancer diagnosis plays a crucial role in guiding patient treatment [16]. Among the various treatments for breast cancer, chemotherapy has become a commonly utilized option in medical practice. This treatment employs chemical agents and medications to target and eliminate abnormal cells in breast tissue and other areas where cancer cells may have spread. Chemotherapy typically follows cycles lasting 21-28 days. Therefore, breast cancer becomes the focus of the numerical simulation of this critical illness insurance model.

The first simulation employs numerical simulation with 10^6 iterations to forecast the price of cancer insurance premiums without inpatient class upgrading assumption, specifically for breast cancer. Furthermore, an analysis is conducted to examine how changes in parameter values affect premium pricing. The premiums are calculated at a risk-free interest rate of 5%, with a maturity period of $T = 1$. The premium values resulting from the first simulation are illustrated in Figure 1 and Figure 2.

Figure 1 illustrates the effect of the shape parameter of S_T (κ_1), the shape parameter of B_T (κ_2), and the ratio of these two shape parameters on the premium values across various scale parameters. It is assumed that $\theta_1 = \theta_2 = \theta$ and $\kappa_1 > \kappa_2$. Figure 1 shows that an increase in κ_1 or θ results in a higher P_{MO_T}. However, an increase in κ_2 decreases the P_{MO_T}. In other words, the higher the average treatment cost for breast cancer, the higher the insurance premium. Conversely, the higher the average BPJS claim limit, the lower the breast cancer insurance premium. It is also evident that as the ratio between the average treatment cost and the BPJS claim limit increases, the insurance premium becomes higher (the higher the value of $\frac{\kappa_1}{\kappa_2}$, the higher the value of P_{MO_T}).

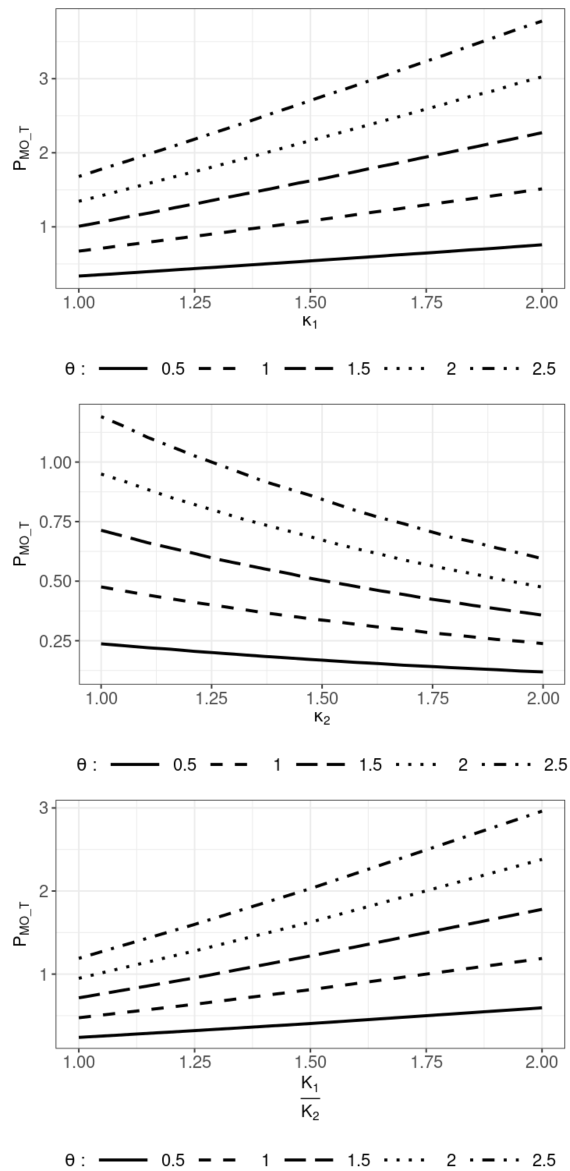

Fig. 1. Effects of κ_1, κ_2, and $\frac{\kappa_1}{\kappa_2}$ in insurance premiums under assumption of $\theta_1 = \theta_2 = \theta$ and $\kappa_1 \geq \kappa_2$

Figure 2 presents the simulation results of premium values under the assumption that $\theta_1 \neq \theta_2$. It is evident from Figure 2 that the P_{MO_T} value increases with higher values of κ_1, $\frac{\kappa_1}{\kappa_2}$, and $\frac{\theta_1}{\theta_2}$. However, there is only a slight increase in premium prices when θ_1 is less than θ_2. Conversely, the P_{MO_T} value decreases as κ_2 increases. This phenomenon indicates that, in cases where $\theta_1 > \theta_2$, a higher average cost of treatment significantly leads to higher breast cancer insurance premiums. Conversely, an increase in the average BPJS claim limit causes the premium price to decrease. Furthermore, the greater the ratio between treatment costs and the BPJS claim limit, the higher the breast cancer insurance premium.

In the second numerical simulation, we assume the insured will receive an upgrade in the inpatient care class. If the medical expenses exceed the claim limit, the insurer will provide benefits amounting to pB_T. The insurance premium is calculated based on a simulation with 10^6 iterations, the proportion of the claim limit paid of 50%, a risk-free interest

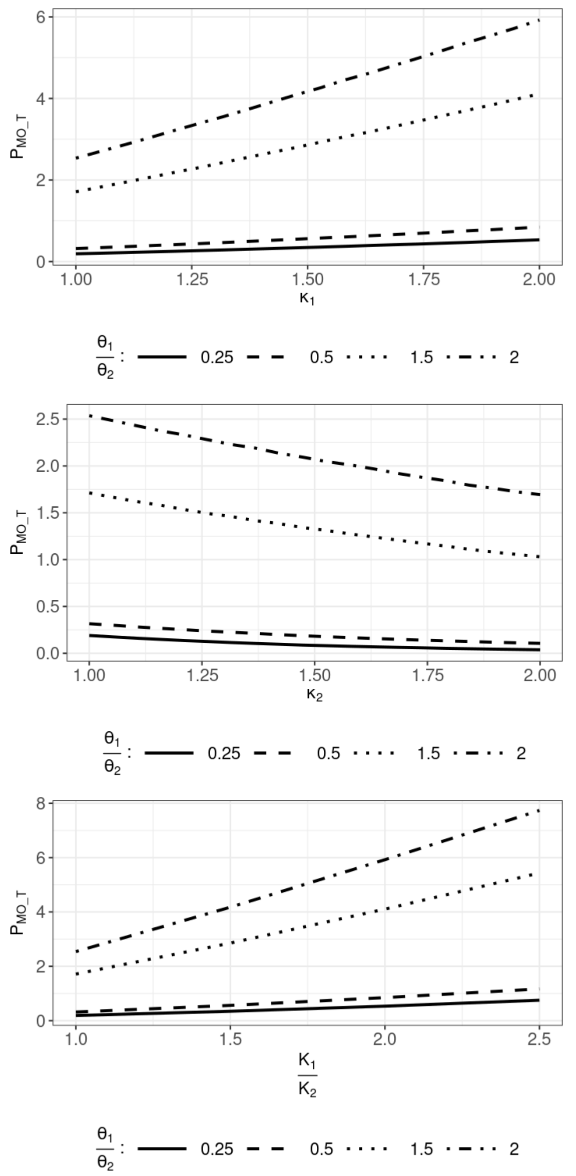

Fig. 2. Effects of κ_1, κ_2, and $\frac{\kappa_1}{\kappa_2}$ in insurance premiums under assumption of $\theta_1 \neq \theta_2$ and $\kappa_1 \geq \kappa_2$

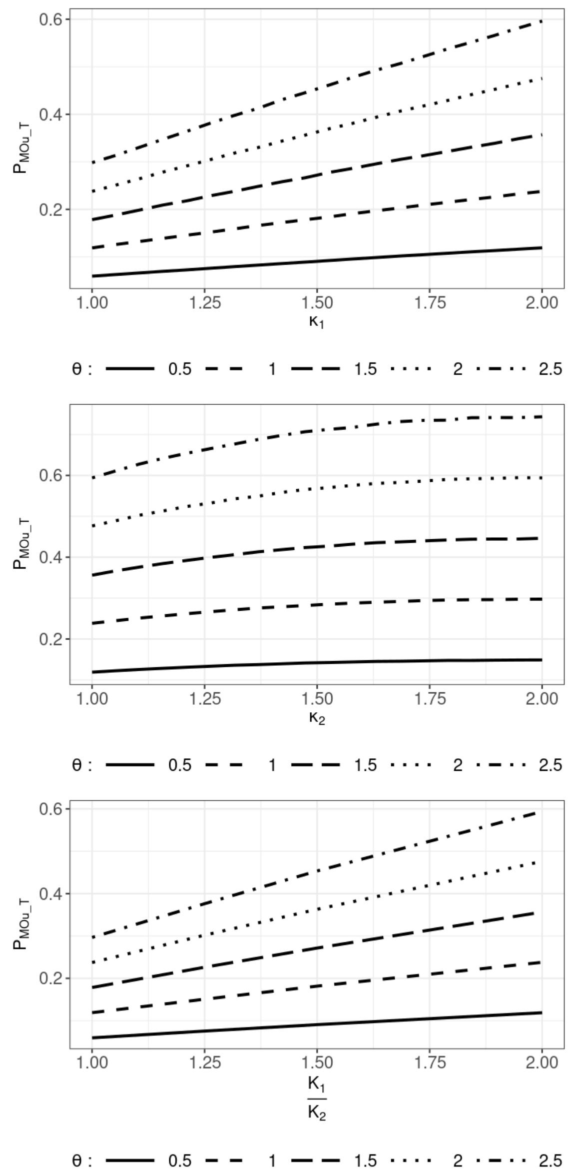

Fig. 3. Effects of κ_1, κ_2, and $\frac{\kappa_1}{\kappa_2}$ in insurance premiums with inpatient class upgrading under assumption of $\theta_1 = \theta_2 = \theta$ and $\kappa_1 \geq \kappa_2$

rate of 5%, and a maturity period of $T = 1$. Figures 3 and 4 illustrate the premium outcomes derived from the second numerical simulation.

Figure 3 demonstrates how κ_1, κ_2, and their ratio $\frac{\kappa_1}{\kappa_2}$ influence the value of $P_{MO_u\_T}$ across different values of θ, assuming that $\theta_1 = \theta_2 = \theta$. As κ_1, κ_2, and $\frac{\kappa_1}{\kappa_2}$ increase, $P_{MO_u\_T}$ also increases. A higher κ_1 enhances the likelihood of $S_T > B_T$, while an increase in κ_2 leads to greater insurance benefits in a health insurance model with inpatient care upgrades, subsequently raising the premium. Moreover, a higher $\frac{\kappa_1}{\kappa_2}$ ratio further increases the probability of $S_T > B_T$. Additionally, Figure 3 shows that increasing θ results in an overall rise in $P_{MO_u\_T}$.

In general, when $\theta_1 \neq \theta_2$, increasing κ_1, κ_2, and the ratio $\frac{\kappa_1}{\kappa_2}$ results in an increase in $P_{MO_u\_T}$ (Figure 4). A significant increase is observed when $\theta_1 > \theta_2$. However, if θ_1 is less than θ_2, increasing κ_2 tends to decrease $P_{MO_u\_T}$ slightly. It occurs because $\theta_1 < \theta_2$ means that the variance of S_T is smaller than that of B_T. Additionally, as κ_2 increases, the B_T value is raised, lowering the chances of S_T being greater than $B - T$. Thus, this results in lower insurance premiums for models with inpatient class upgrades.

IV. Discussion and Concluding Remarks

The option approach with "at-cost" insurance benefits presents an appealing alternative for computing critical illness insurance premiums. This model's simplicity in formulation and interpretation is noteworthy. However, modifications to the conventional call option approach are imperative to shield insurance companies from the potential ramifications of exceptionally high critical illness treatment expenses.

Our study proposes a call option approach model that integrates a modification disguised as an insurance claim limit. Based on real-world regulations regarding the governance and implementation of the National Health Insurance (Jaminan Kesehatan Nasional) in Indonesia, we

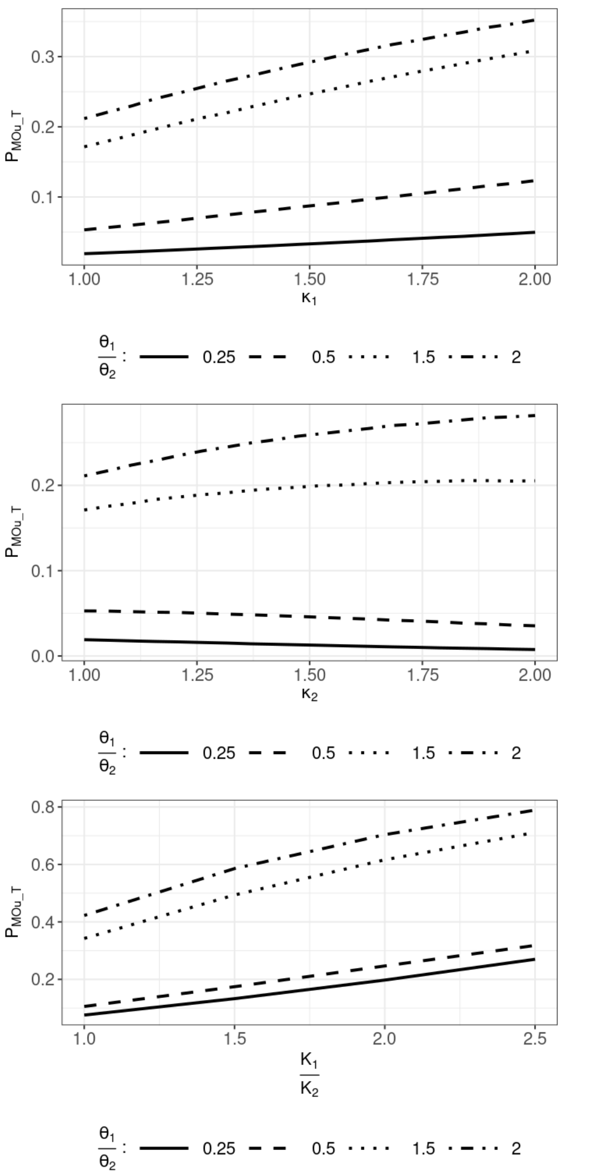

Fig. 4. Effects of κ_1, κ_2, and $\frac{\kappa_1}{\kappa_2}$ in insurance premiums with inpatient class upgrading under assumption of $\theta_1 \neq \theta_2$ and $\kappa_1 \geq \kappa_2$

developed two critical illness insurance premium models: one without an inpatient class upgrade and another with an inpatient class upgrade. We employ the Gamma process to model critical illness treatment costs and claim limits. Nonetheless, it is essential to acknowledge that various other models for estimating critical illness treatment costs are also viable and warrant consideration.

The results of this study indicate that the parameters in the developed model, namely κ_1, κ_2, θ_1, and θ_2, have a significant influence on determining the premium for critical illness insurance. κ_1 and κ_2 represent the shape parameters of the Gamma process, while θ_1 and θ_2 represent the scale parameters of the Gamma process. Additionally, an increase in the average cost of treatment leads to a rise in critical illness insurance premiums. Conversely, increasing the BPJS claim limit reduces critical illness insurance premiums. However, in the insurance model with an inpatient care class upgrade, a higher BPJS claim limit increases the insurance premium. The greater the ratio between treatment costs and the BPJS claim limit, the higher the premium for critical illness insurance. Finally, if θ_1 is smaller than θ_2, changes in the critical illness insurance premium will not be substantial.

The cost of treating critical illnesses, such as cancer, continues to rise in line with advancements in medical technology, inflation, and the increasing complexity of treatments. Periodic adjustments to claim limits and premiums are essential steps that BPJS must undertake in response to the escalating costs of critical illness treatments. Through adaptive policies, BPJS can ensure the sustainability of its programs, improve service accessibility, and maintain long-term participant satisfaction. Furthermore, BPJS could offer rider insurance products for critical illness coverage to enhance service quality and provide more specific benefits. The model we have developed can serve as both a reference and an alternative framework for calculating premiums for such rider insurance. For other insurance companies, this model can also serve as a guide for calculating premiums for insurance with deductible schemes or for covering treatment costs not covered by other insurance.

Due to the limitations of the available data, this study does not address the parameter estimation methods for the model or its application to real-world data. Further research is crucial to deepen theoretical and practical understanding, improve accuracy, and extend the findings to a broader context.

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