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Model estimation of claim risk and premium for motor vehicle insurance by using Bayesian method

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Abstract. Risk models need to be estimated by the insurance company in order to predict the magnitude of the claim and determine the premiums charged to the insured. This is intended to prevent losses in the future. In this paper, we discuss the estimation of risk model claims and motor vehicle insurance premiums using Bayesian methods approach. It is assumed that the frequency of claims follow a Poisson distribution, while a number of claims assumed to follow a Gamma distribution. The estimation of parameters of the distribution of the frequency and amount of claims are made by using Bayesian methods. Furthermore, the estimator distribution of frequency and amount of claims are used to estimate the aggregate risk models as well as the value of the mean and variance. The mean and variance estimator that aggregate risk, was used to predict the premium eligible to be charged to the insured. Based on the analysis results, it is shown that the frequency of claims follow a Poisson distribution with parameter values λ is 5.827. While a number of claims follow the Gamma distribution with parameter values p is 7.922 and θ is 1.414. Therefore, the obtained values of the mean and variance of the aggregate claims respectively are IDR 32,667,489.88 and IDR 38,453,900,000,000.00. In this paper the prediction of the pure premium eligible charged to the insured is obtained, which amounting to IDR 2,722,290.82. The prediction of the claims and premiums aggregate can be used as a reference for the insurance company's decision-making in management of reserves and premiums of motor vehicle insurance.

Keywords: Poisson distribution, Gamma distribution, Bayesian method, aggregate claims, premium calculation

1. Introduction

Motor vehicle insurance is one of the important branches of non-life insurance type. Even in many countries, motor vehicle insurance is the largest total premium revenue earner. Indonesia is included in the country that gets the largest total insurance premium, from motor vehicle insurance. One of the driving factors causing the auto insurance industry to grow rapidly is the increasing number of motor vehicles in Indonesia every year. As a risk taker and recipient institution, insurance companies must be able to anticipate the risks if there are many claims. Because otherwise, would cause losses that could make the insurer bankrupty [11]. In risk management, insurance companies must know the character of the risk. The purpose is to predict the losses event in the future [4].

In modeling the claim loss there are two important measures to be considered, namely the frequency of claims and the amount or severity of claims. The frequency of claims, as usual is properly modelled by using discrete distributions, including binomial, geometric, negative binomial and Poisson. Whereas, claim severity represent a large loss of an insurance claim, which is generally modelled by using a non-negative continuous distribution. For example the exponential and Pareto distributions, as well as the attached traits such as tail and quartile properties [4,1]. To carry out the distribution parameter estimation of claims frequency and claims severity, according Jaroengeratikun [10] and Bolstad [3], the Bayesian method can be applied to estimate the parameters of a model of the distribution of losses. The advantage of the Bayesian method is that the prior information of the parameters involved in the risk model needs to be determined first, then the sample data is observed to produce a posterior distribution. Similar studies ever undertaken include Migon et al. [13] and Sukono et al. [16], conducting a risk analysis of health insurance claims, where the model parameter estimation uses the Bayesian method approach. Meanwhile, Eliasson [6] applied the Bayesian method for the estimation of the credibility parameters for non-life insurance pricing on historical data of individual claims. In the analysis of non-life insurance, the risk distribution model of loss is an important concern for insurance companies. The risk distribution model is very useful in determining the premium to be paid by the insured to the insurer.

Based on the previous explanation, this paper intends to apply how to assess a collective risk models in non-life insurance using Bayesian methods. The Bayesian method is used to estimate the parameters of the claim frequency model and the amount of the claim, in order to be used in the calculation of risk, and also to determine the premiums the insured must pay to the insurer.

2. Methology

In this section the aims is to discuss the methodology, which includes the discussion of: collective risk model, parameter estimation, and principle of premiums calculation. We begin with a discussion of the collective risk model as follows.

2.1 Collective risk model

This section aims to discuss the collective risk model. If we let the total frequency of claims for an insurance portfolio in the time period t is denoted by N_t, then a large number of aggregate claims S_t is as follows [9]:

$$S_t = \sum_{i=1}^{N_t} X_{t,i} \ . \tag{1}$$

where $X_{t,i}$ is the *i*-th amount of claim which occurred during the time period t, or so-called amount of individual claims [4,5].

The assumptions used in this model are:

- Amount of claim $X_{t,i}$ is a non-negative random variables that are independent and identically distributed.
- Claim frequency N_t is a random variable and independent toward the *i*-th amount of claim $X_{t,i}$.

An important thing to do is to evaluate the frequency distribution model of claims, as well as the appraisal of the large distribution model of claims. After the estimator of the calim frequency distribution model and the estimator of the amount of claim distribution model have been obtained, it can then be used to determine the expected value $E(S_t)$ and variance $Var(S_t)$. The expected value and the variance are the measures to estimate the total loss in the collective risk model. In the collective risk model, the expected and variance magnitude of total loss can be calculated using the following equation [12,14]:

$$E(S_t) = E[E(S_t \mid N_t)] = E[E(X_1 + X_2 + ... + X_N)] = E[N.E(X)]$$

$$= E(X)E(N). \tag{2}$$

$$Var(S_t) = E[Var(S \mid N)] + Var[E(S \mid N)] = E[N.Var(X)] + Var[N.E(X)]$$
$$= E(N)Var(X) + [E(X)]^2 Var(N). \tag{3}$$

2.2 Maximum Likelihood and Bayesian methods

This section aims to discuss the maximum likelihood and Bayesian estimation methods. Maximum Likelihood is one of the most commonly methods used for performing an estimation of parameters. Assumed that $X_1, X_2, ..., X_n$ are random sample of the population with a probability density function $f(x \mid \theta_1, \theta_2, ...\theta_k)$, likelihood function of the random sample is expressed by [4]:

$$l(\theta \mid x) = l(\theta_1, \theta_2, ..., \theta_k \mid x) = \prod_{i=1}^{n} f(x_i \mid \theta_1, \theta_2, ...\theta_k). \tag{4}$$

Furthermore, estimation of parameter θ is performed which gives the maximum value of (4). The estimation of these parameters in this paper is done by using Bayesian method. According to Boldstad [3] and Gill [8], the Bayesian method is one of the parameter estimation methods that uses preliminary information on parameters θ, or so-called as the prior distribution, and information from the observed data that has been obtained. After the sample information is taken, and the prior has been determined, the posterior distribution is determined by multiplying the prior with the sample information obtained from the likelihood. Where this prior is independent of its likelihood, and the posterior distribution is given by:

$$f(\theta \mid x) = \frac{f(\theta, x)}{f(x)} = \frac{f(\theta)l(x \mid \theta)}{\int_0^{\infty} f(\theta)l(x \mid \theta)d\theta} \propto f(\theta)l(x \mid \theta),$$

with posterior distribution $f(\theta \mid x)$, prior distribution $f(\theta)$, and Likelihood function $l(x \mid \theta)$.

2.3 Parameters estimation of claim frequency model

This section aims to discuss the parameters estimation of the claim frequency model. Assumed that frequency of claim N is a discrete random sample that Poisson distributed with mean λ. The probability density function of the Poisson distribution is expressed as follows [2,4]:

$$p(n) = \frac{e^{-\lambda}\lambda^n}{n!},\ n = 1,2,3,...$$

Therefore, the likelihood function of the sample data which following the Poisson distribution is expressed by:

$$l(n_i \mid \lambda) = \frac{e^{-t\lambda}\lambda^{\sum_{i=1}^{t} n_i}}{\prod_{i=1}^{t} n_i!}.$$

According to Ntzoufras [15], the frequency of claims N which Poisson distributed, has a prior conjugate that Gamma-distributed with a probability density function expressed by:

$$f(\lambda) = \frac{\beta_\lambda{}^{\alpha_\lambda}\lambda^{\alpha_\lambda - 1}e^{-\lambda\beta_\lambda}}{\Gamma(\alpha_\lambda)}, 0 \le \lambda < \infty.$$

Posterior of parameter λ can be expressed by multiplication between likelihood $l(n_i \mid \lambda)$ with prior $f(\lambda)$. If the equation which not related to the parameter λ is neglected, the proportional posterior equation is obtained as follows:

$$f(\lambda \mid n_1, n_2, ..., n_t) \propto \lambda^{\alpha_\lambda + \sum_{i=1}^{t} n_i - 1} e^{-\lambda(\beta_\lambda + t)}.$$

So it can be said that posterior of the parameter λ also Gamma distributed as expressed as [3,7]:

$$\lambda \mid n_i \sim Gamma(\alpha_\lambda + \sum_{i=1}^{t} n_i, \beta_\lambda + t).$$

Therefore, if the posterior of the parameter λ is Gamma Distributed, then the mean or expected value is obtained, expressed by:

$$E(\lambda \mid n_i) = \hat{\mu}_\lambda = \frac{\alpha_\lambda + \sum_{i=1}^{t} n_i}{\beta_\lambda + t},$$

while the variance of the posterior is expressed by:

$$Var(\lambda \mid n_i) = \hat{\sigma}_\lambda{}^2 = \frac{\alpha_\lambda + \sum_{i=1}^{t} n_i}{(\beta_\lambda + t)^2}.$$

2.4 Parameters estimation of claim amount model

In this section it is intended to discuss about the parameters estimation of the claim amount model. In this paper the amount of claim X is assumed to be a continuous random sample that Gamma distributed with parameter p and θ. The probability density function that follows the Gamma distribution is expressed by [2,4]:

$$f(x) = \frac{\theta^p x^{p-1} e^{-x\theta}}{\Gamma(p)}.$$

Furthermore, the likelihood function of sample data of claim amount which follows Gamma distribution is expressed by:

$$l(x_i \mid p, \theta) = \frac{\theta^{pn}}{\Gamma(p)^n} \left(\prod_{i=1}^{n} x_i{}^{p-1} \right) e^{-\theta \sum_{i=1}^{n} x_i}.$$

According to Ntzoufras [15], amount of claims which is Gamma distributed has a prior conjugate that Gamma distributed with a hyperparameter α_θ and β_θ. The probability density function is expressed as follows:

$$f(\theta) = \frac{\beta_\theta{}^{\alpha_\theta} \theta^{\alpha_\theta - 1} e^{-\theta\beta_\theta}}{\Gamma(\alpha_\theta)}, 0 \le \theta < \infty.$$

Posterior to parameter θ can be expressed by multiplication between likelihood $l(x_i \mid p, \theta)$ to prior $f(\theta)$. If the equation which not related to the parameter θ is neglected, the proportional posterior equations are obtained as [4], [7]:

$$f(\theta \mid p, x) \propto \theta^{pn + \alpha_\theta - 1} e^{-\theta(\sum_{i=1}^{n} x_i + \beta_\theta)}.$$

So it can be said that posterior $f(\theta \mid p, x)$ is Gamma distributed with parameter $\alpha_{\theta,1} = pn + \alpha_\theta$ and $\beta_{\theta,1} = \sum_{i=1}^{n} x_i + \beta_\theta$.

Because of the posterior parameter θ is Gamma distributed then the mean can be obtained, expressed by:

$$E(\theta \mid x_i) = \hat{\mu}_\theta = \frac{pn + \alpha_\theta}{\sum_{i=1}^{n} x_i + \beta_\theta},$$

while the variance of the posterior is expressed by:

$$Var(\theta \mid x_i) = \hat{\sigma}_\theta^{\,2} = \frac{pn + \alpha_\theta}{\left(\sum_{i=1}^{n} x_i + \beta_\theta\right)^2}.$$

2.5 Premium calculation models

This section aims to discuss the principles of premium calculation. Premiums are calculated on the basis of the principle of equality, or the principle of premium calculation. There are several principles used for the calculation of premiums, namely [4,16]:

a. Pure Premium Principle
   The calculation of pure premium principle is done by using following equation:

$$p(t) = E(S), \tag{5}$$

   where $E(S) = \frac{E(S_t)}{t}$.

b. Expectation Value Principle
   The premium calculation of Expectation Value Principle is done by using following equation:

$$p(t) = (1+\theta)E(S_t), \tag{6}$$

   where $\theta > 0$ represents a premium loading factor.

c. Variance Principle
   The premium calculation of Variance Value principle is done by using following equation:

$$p(t) = E(S) + \alpha Var(S), \tag{7}$$

   where $Var(S) = \frac{Var(S_t)}{t}$ and $\alpha > 0$ represents a premium loading factor

d. Standard Deviation Principle
   The premium calculation of Standard Deviation Principle is done by using equations:

$$p(t) = E(S) + \alpha\sqrt{Var(S)}, \tag{8}$$

   where $\alpha > 0$.

3. Results and discussion

In this section the aims is to study the results and discussions that include: analyzed data, an estimation of the claims frequency distribution model, the estimation of the claims amount distribution model, and the calculation of insurance premiums. It starts with a discussion of the claims frequency distribution, as follows.

3.1 Analyzed data

The data used in this study, is the data of motor vehicle insurance claims on non-life insurance company PT. "X" with periods of 2015 to 2016. Data are grouped into claims frequency and claim amount. A summary of claims data is presented in Table 1.

Table 1. Data of claim amount and frequency of claim

No	Interval	Frequency
1	1,978,435 - 3,121,754	6
2	3,121,755 - 4,265,074	13
3	4,265,075 - 5,408,393	20
4	5,408,395 - 6,551,712	12
5	6,551,713 - 7,695,031	8
6	7,695,031 - 8,838,351	4
7	8,838,352 - 9,981,670	7
Total	392,307,367	70

Furthermore, based on claims frequency data and the claims amount in Table 1, the most suitable or fit distribution is determined by using *Easyfit 5.6* software, and it is tested statistically by using a goodness of fit test.

3.2 Estimating of the claim frequency distribution model

In this section it aims to estimate the claim frequency distribution model. The steps include: identification of the distribution model, the estimation of the distribution model, and testing the significance of the distribution estimator.

- ***Identification of the claim frequency data distribution model***

Identification of the claim frequency data distribution model is done by using statistical *software EasyFit 5.6*. The result of curve matching can be seen in Figure 1.

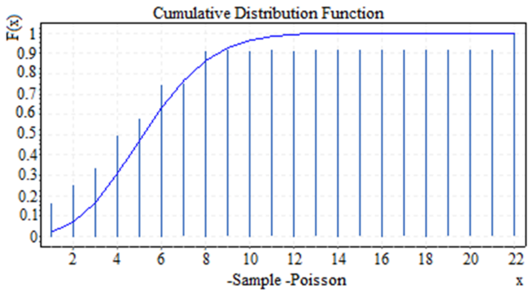

Figure 1 Histogram and cumulative distribution function curve of claims frequency data

Based on the results of curve fitting using *Easyfit 5.6* software, the suitable model for the frequency of claims is obtained, that is the Poisson distribution. Estimated parameters using the maximum likelihood method $\lambda = 5{,}8333$. To determine the most suitable distribution, the *Kolmogorov-Smirnov* test was used on the Poisson distribution by using *EasyFit 5.6* software. Based on the *Kolmogorov-Smirnov* test, the most suitable model for the claims frequency data is the Poisson distribution.

- ***Parameters estimating of the claim frequency distribution model***

Based on Figure 2, the selected prior value is $\alpha_\lambda = 0.001$ and $\beta_\lambda = 0.001$, because the Bayesian estimation approximates the likelihood estimation of the parameter λ.

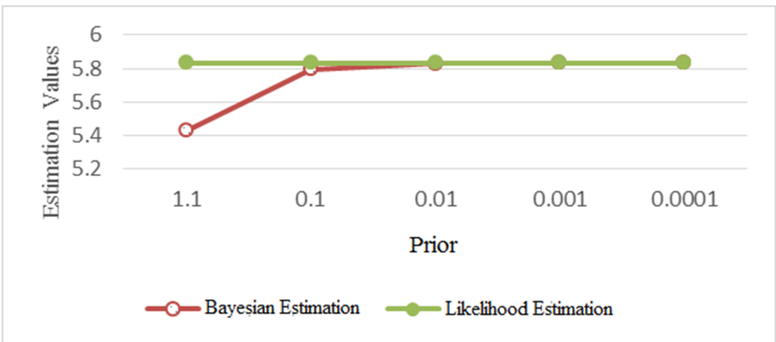

Figure 2 Comparison of parameter λ by estimation of Likelihood and Bayesian

Because the claim frequency data is known, and the values of α_λ and β_λ have been determined, then the posterior distribution of the parameters λ can be expressed by: $\lambda \mid n_i \sim Gamma(70.001,\ 12.001)$. The statistical summary of the mean and variance of parameter λ which was observed over the twelve months expressed in Table 2.

Table 2. Statistical summary of Bayesian estimation of parameter λ which is obtained manually

Parameter	Posterior α_λ	Posterior β_λ	Mean	Variance	Standard Deviation
λ	70.001	12.001	5.832931	0.486037	0.697163

The OpenBUGS program is used to obtain a statistical summary of parameters λ, by simulating the sample data from the posterior distribution in several iterations. In this study, the three chains are used to simulate the posterior distribution of samples, wherein each chain was observed to test the convergence of the parameters visually by using trace plot. The iteration performed on each chain is 10,000 iterations. The statistical summary with the OpenBUGS program yields Bayesian parameter estimation λ, which comprises the mean and standard deviations expressed in Table 3.

Table 3. Statistical summary of Bayesian estimation of parameter λ which is obtained by OpenBUGS program

Parameter	Mean	Standard Deviation	2.5% Percentil	97.5 % Percentil
λ	5.827	0.6985	4.544	7.276

3.3 Estimating of the claims amount distribution model

In this section the purpose is to evaluate the distribution model of the severity of the claim. The steps include: identification of the distribution model, the estimation of the distribution model, and testing the significance of the distribution estimator.

- ***Identification of the claim amount data distribution model***

Identification of the distribution model of the claims amount made by using statistical *software Easyfit 5.6.* The result of curve fitting can be seen in Figure 3.

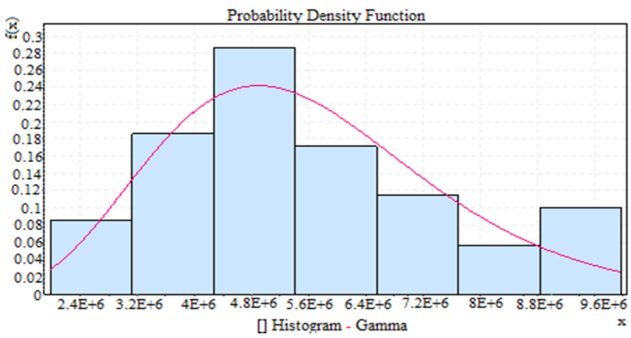

Figure 3. Histogram and density function of claims severity data

Based on the results of curve fitting using *Easyfit 5.6* software, the obtained distribution model which suitable for amount of claims that Gamma distributed with parameters $p = 7.9216$ and $\theta = 1.41437 \times 10^{-6}$. To determine the most suitable distribution, *Kolmogorov-Smirnov* test was used on the Gamma distribution by the help of *EasyFit 5.6* software. Based on the *Kolmogorov-Smirnov* test, the most suitable model for amount of claim data is Gamma distribution.

- ***Parameter estimating of the claim amount data distribution model***

Based on Figure 3, the selected prior value is $\alpha_\theta = 0.001$ and $\beta_\theta = 0.001$, since the Bayesian estimated value is close to the likelihood estimate of the parameter θ.

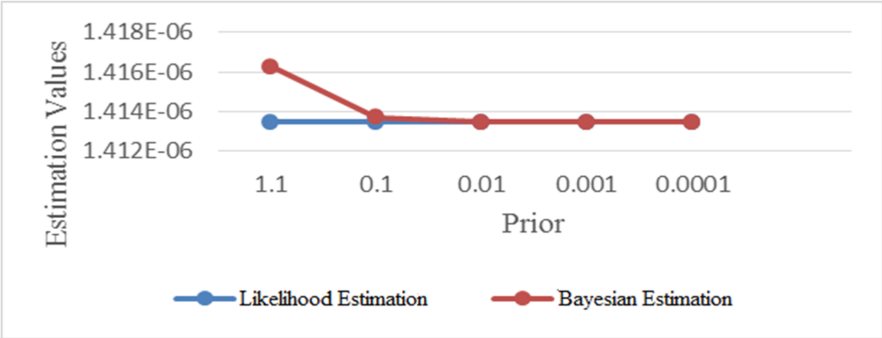

Figure 4. Comparison of parameter estimation of θ by using likelihood and Bayesian

Based on Equation (14), the known value of each hyperparameter α_θ and β_θ are:

$$\alpha_{\theta,1} = pn + \alpha_\theta = (7.9216)(70) + 0.001 = 554.513$$

$$\beta_{\theta,1} = \sum_{i=1}^{n} x_i + \beta_\theta = 392{,}307{,}367 + 0.001 = 392{,}307{,}367.001$$

A statistical summary of the mean and variance of parameter θ, which was observed over the twelve months expressed in Table 4.

Table 4. Statistical summary of Bayesian estimation parameter θ which is obtained manually

Parameter	Posterior α_θ	Posterior β_θ	Mean	Variance	Amount of Claim
θ	554.513	392,307,367.001	1.41×10^{-6}	3.60×10^{-15}	5,604,380.85

The posterior distribution explains the confidence level of the parameters contained in the sample data. Statistical summary of posterior parameter θ shown in Table 5, which consists of the mean and standard deviation. These results are obtained by using statistical software OpenBUGS of three parallel chains and the iterations are done of 10,000 times.

Three parallel chains with an iteration of 10,000 times in each chain are used to test the convergence of parameter θ, which is checked visually by using *trace* plot. Convergence test is done by observe whether the three chain are overlapping each other or not in the *trace* plot.

Table 5. Statistical summary of Bayesian estimation parameter θ which is obtained by OpenBUGS program

Parameter	$E(\theta)$	Standard Deviation	2.5% Percentil	97.5 % Percentil	*E(X)*
θ	1.413×10^{-6}	6.028×10^{-8}	1.298×10^{-6}	1.534×10^{-6}	5,606,227.884

Based on Table 5, it is obtained that the mean of claims approved by the insurance company to be paid to the insured amounting to IDR5,606,227,884.

3.4 Estimating of the collective risk model

This section the purpose is to estimate the collective risk model. Collective risk model is used for the calculation of premiums. Based on equation (1) the obtained number of aggregate claims is $S_t = 392{,}307{,}367$. Based on equation (2) the obtained expectation of collective risk model is $E(S_t) = (5.827)(5{,}606{,}227.884) = 32{,}667{,}489.88$.

While based on equation (3) the obtained variance of collective risk model is:

$Var(S_t) = (5.827)(3,967,610,000,000) + (5,606,227.884)^2(0.4879) = 38,453,900,000,000.$

The expected value and the variance of the previous collective risk model, can be used to predict the premium to be paid by the insured.

3.5 The Calculating of Premium

In this section the intention is to make a calculation of premiums amount to be paid by the insured to the insurance company. The amount of premium depends on the value of the claim frequency and amount of the aggregate claim (collective). In this study, the assumed charge factor at a premium for θ is 0.1 and α is 0.1.

- By using equation (17), the obtained calculation of pure premium is: $p(t) = 2,722,290.823$.
- By using equation (6), the obtained calculation of the expected value premium principles is: $p(t) = 2,994,519.906$.
- By using equation (7), the obtained calculation of variance premium principles is: $p(t) = 320,452,000,000$.
- By using equation (8), the obtained calculation of standard deviation premium principles is: $p(t) = 2,901,301.783$.

4. Conclusions

In this paper, we discussed the estimation of claims risk model and motor vehicle insurance premiums by using Bayesian methods approach. Based on the data processing, the frequency of claims is Poisson distributed with the value of estimated parameter $\lambda = 5,827$, and total claim amount of Gamma distributed with estimated parameter $p = 7,9216$ and $\theta = 1,41347 \times 10^{-6}$. By using both distribution estimators the aggregate claim distribution was formed, then the aggregate claim is obtained on non-life insurance companies amounting to IDR32,667,489.88 with a variance of IDR38,453,900,000,000.00. The value of these expectations and variance is used by the insurance company as a reference in determining the premium value. In this paper, the prediction of the pure premium to be paid by the insured to the insurance company is IDR2,722,290.82, the prediction of the expectation premium is IDR2,994,519.91, the prediction of the variance premium is IDR320,450,000,000.00, and the prediction of standard deviation premium is IDR2,901,301.78. Based on some predictions of such premiums amount, the insurance company can determine the yearly reasonable and affordable premium amount for the insured.

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