Determination of Earthquake Insurance Premiums Using the Bayesian Method

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Abstract

Earthquake is an unpredictable disaster. It made a lot of damage and loss. Other than that, Indonesia is surrounded by three world tectonic plates which makes it more likely to happen. Therefore, we have to be preventive. One of solution that can be applied is to insure our assets to the insurance company as earthquake insurance. However, insurance company has to calculate premium amount which has to be paid by the clients. The aim of this research is to calculate the amount of premium using estimated loss of previous earthquake. This research uses Bayesian method to estimate the loss amount which then used to calculate the premium. The result of this research is premium which is calculated using two principles, expected value principle and standard deviation principle. Premium that is calculated using expected value principle is lower than standard deviation principle. However, the result is not absolute since there is still so many factors that are not included or other premium principles.

Keywords:
Earthquake insurance, loss, insurance, premium, Bayesian method.

1. Introduction

Indonesia is a disaster-prone country. This is because Indonesia is surrounded by three tectonic plates in the world, namely the Indo-Australian Plate, the Eurasian Plate, and the Pacific Plate. The Indo-Australian Plate collides with the Eurasian Plate off the coast of Sumatra, Java, and Nusa Tenggara. Meanwhile, the Pacific Plate is located in northern Papua and North Maluku (Madjid, 2018). Around the location of these plates, there is an accumulation of energy that collides to a point where the earth's layers are no longer able to withstand the pile of energy, and eventually, this energy will be released in the form of an earthquake (Tejakusuma, 2008; Kalfin et al., 2020; Suyudi et al., 2017).

Earthquakes are natural disasters that are difficult to predict. There were several earthquakes recorded in Indonesia that caused huge losses, including the 2004 Aceh earthquake with a magnitude of 9.4 on the Richter Scale/*Skala Richter* (SR), the 2006 Pangandaran earthquake with a magnitude of 6.8 SR, and the 2009 West Sumatra earthquake with a magnitude of 7.6 SR, the 2018 Lombok earthquake with a magnitude of 7.0 SR, and the

2018 Central Sulawesi earthquake with a magnitude of 7.4 SR. The losses caused by the earthquake were various, such as damage to buildings, roads, and even casualties. But in reality, almost all of the material losses suffered by the community are borne by the government. According to Law Number 24 of 2007 in Indonesia concerning Disaster Management, the implementation of natural disaster management is the responsibility of the government (Tejakusuma, 2008; Sukono et al., 2014). Natural disaster management activities, including protection of the community from the impact of disasters, recovery of conditions from the impacts of disasters, and allocation of disaster management budgets in the State Budget (APBN). Even though it has been reserved, the disaster management fund is limited to cover the total loss and damage caused by the disaster (Nota Keuangan (Financial Note), 2017). Considering the magnitude of the losses from the earthquake that must be borne by the government, a system should be established that can ease the burden on the government. One solution is through transferring risks to the private sector through earthquake insurance (Sukono et al., 2018.a; Sidi et al., 2018).

Earthquake insurance is insurance that covers loss or damage to the insured property and or interests which are directly caused by earthquakes, volcanic eruptions, fires, and explosions that follow an earthquake or volcanic eruption, and tsunami. The insurer, which in this case is an insurance company, needs to determine the value of the premiums that must be paid by earthquake insurance consumers so that consumers get benefits and the insurer does not suffer losses (Sidi et al., 2017.a; 2017.b). One way to calculate the premium value is to use previous observational data in the form of losses caused by earthquakes. This data is used to estimate the value of losses that may occur in the future. The Bayesian method is used to estimate losses, while the premium is calculated using the expectation value principle and the standard deviation principle.

2. Research Method

The method used in this research is the Bayesian method. This method is used to estimate the parameters of the unknown Pareto distribution, namely the shape parameter θ. The Pareto distribution is an assumption of the distribution of the estimated loss model in this study.

2.1. Likelihood function

The likelihood function of the earthquake loss model is assumed to have a Pareto distribution with the probability density function (PDF) as follows

$$p(x) = \begin{cases} \theta \dfrac{x_m^{\theta}}{x^{\theta+1}}, & x \geq x_m; \theta > 0, \\ 0, & \text{another } x. \end{cases} \tag{1}$$

The likelihood function is derived from the above equation and the following equation is obtained

$$L(\theta | X_1, X_2, X_3, \ldots, X_n) = \theta^n x_m^{n\theta} \prod_{i=1}^{n} x_i^{-\theta-1}. \tag{2}$$

2.2. Prior Distribution

Because the loss data model is Pareto distributed, the conjugate prior $p(\theta)$ is proportional to the Gamma distribution (Fink, 1997; Sukono et al., 2018.b; 2017). The PDF of the Gamma distribution with hyperparameters a and b is as follows

$$p(\theta) = \begin{cases} \dfrac{1}{\Gamma(a) b^a} \theta^{a-1} e^{-\frac{\theta}{b}}, & \theta \geq 0; a, b > 0. \\ 0, & \text{another } \theta. \end{cases} \tag{3}$$

2.3. Posterior Distribution

Since the prior distribution is a conjugation for likelihood, the posterior distribution is proportional to the multiplication of the likelihood function and the prior distribution (Paudel et al., 2013; Bolstad and Curran, 2016), namely

$$p(\theta | x) = L(\theta | X) p(\theta). \tag{4}$$

To get the estimate from the loss model ($\hat{\theta}$), the following equation is used

$$p(\theta | x) \propto \frac{\theta^{\alpha-1} e^{-\left(\frac{\theta}{\beta}\right)}}{\beta^{\alpha} \Gamma(\alpha)}. \tag{5}$$

with $\alpha = a + n$ and $\beta = \frac{1}{\frac{1}{b} + \ln\left(\prod_{i=1}^{n} x_i - n.\ln(x_m)\right)}$. After the prior distribution parameter is obtained, the shape parameter θ is estimated using the following equation

$$\hat{\theta} = E[\theta|x] = \int_{-\infty}^{\infty} \theta \, p(\theta|x) \, d\theta. \quad (6)$$

2.4. Earthquake Loss Estimator

The estimated loss value for a particular chance of damage is calculated using the inverse PDF of the Pareto distribution as follows

$$x = \left(\frac{\hat{\theta} {x_m}^{\hat{\theta}}}{f(x)}\right)^{\frac{1}{\hat{\theta}+1}}. \quad (7)$$

where x is the estimated loss per house, $\hat{\theta}$ the estimated loss as a whole, x_m is the minimum loss value, and $f(x)$ is the probability of damage to the house whose value is a random real number with the interval $0 < f(x) \leq 1$ (Riaman et al., 2018; Lahcene, 2020).

2.5. Principles of Premium Calculation

The principle of calculating the premium used in this study is the principle of the expectation value and the principle of standard deviation. The following is the equation of the expectation value principle

$$P = L_i(1 + w). \quad (8)$$

where P is the premium value, L_i represents the estimated loss of data to the i-th, and $w > 0$ which states the load factor or risk avoidance coefficient of insurance companies such as administration, taxes, etc. which is assumed to be 0.02 or 2%.

For the standard deviation principle, the following equation is used

$$P = L_i + w\left(\sqrt{Var(L)}\right), \quad (9)$$

where P is the premium value, L_i is the estimated loss from the i-th data, $w > 0$ represents the load factor, and $\sqrt{Var(L)}$ represents the standard deviation of the estimated total loss (Saputra et al., 2018).

3. Results and Discussion

The data used in this study is data on house damage in six districts/cities of West Nusa Tenggara that was caused by the 2018 earthquake. The districts/cities used in this research are East Lombok Regency, North Lombok Regency, Central Lombok Regency, Mataram City, Sumbawa Regency, and West Sumbawa Regency. The data compiles minor damage to houses with an assumed loss of 20,000,000 IDR for information I and 10,000,000 IDR for information II. After the data is known, the prior distribution parameters are estimated using EasyFit software, and $a = 5.4994$ and $b = 30389$ are obtained (Martín and Pérez, 2009; Napitupulu et al., 2018). The prior distribution parameters are used to estimate the posterior distribution parameters using equation (5) and the parameters, mean, and variance are obtained as presented in Table 1.

Table 1. Summary of parameter statistics θ

Parameter	α	β	Expectation/mean	Variance	Standard Deviation
θ	11.4994	0.2626	3.0197	0.7930	0.8905

Based on the posterior distribution function in equation (6), the estimated value of θ which is the estimated loss value is $\hat{\theta} = 3.0197$. The $\hat{\theta}$ value is an estimate of the shape parameters of the Pareto distribution (Casadei et al., 2017; Gamerman, et al., 2006). This parameter estimate is the estimated loss from an earthquake. The mean, variance, and standard deviation of these parameters can be seen in Table 2.

Table 2. Summary statistics of estimated losses in Pareto distribution

Parameter	Average/Mean (Million IDR)	Variance (Million IDR)	Standard Deviation (Million IDR)
$\hat{\theta}$	81619	4742369534	68864.8643

Meanwhile, to see the value of losses based on a certain chance of damage, it is necessary to calculate using equation (7). The calculation of estimated losses for a certain probability of damage with a Pareto distribution is presented in Table 3.

Table 3. Estimated losses due to the earthquake against the chance of damage

No.	Chance of Damage	Loss
1	0.210962701	9492.681964
2	0.330268395	8491.063688
3	0.712663783	7012.403922
4	0.532375158	7540.123449
5	0.893994818	6627.885065
6	0.414202874	8025.942993
7	0.197936465	9644.394884
8	0.651517714	7170.654649
9	0.941011481	6543.909157
10	0.032715984	15092.41043

From Table 3, it can be seen that the losses will be greater if and only if the chance of damage is small. This means that the relationship between the chance of damage and loss is inversely proportional. Furthermore, the premium value is calculated using the expectation value principle and the standard deviation principle based on the losses in Table 3. The premium value is presented in Table 4.

Table 4. The calculation results of the premium per damaged house

No.	Loss (Million IDR)	Principles of Premium Calculation	
		Expectation (Million IDR)	Standard Deviation (Million IDR)
1	9492.681964	9682.535603	10869.97925
2	8491.063688	8660.884962	9868.360974
3	7012.403922	7152.652000	8389.701208
4	7540.123449	7690.925918	8917.420735
5	6627.885065	6760.442766	8005.182351
6	8025.942993	8186.461853	9403.240279
7	9644.394884	9837.282782	11021.69217
8	7170.654649	7314.067742	8547.951935
9	6543.909157	6674.787340	7921.206443
10	15092.41043	15394.25864	16469.70772

Based on Table 5, it can be seen that the insurance premium value with the expectation principle is smaller than the premium value calculated using the standard deviation principle. This makes it easier for the insured party, but the insurer needs to review whether the premium value with this expectation principle is also beneficial for his party or even the principle of standard deviation is more mutual. Therefore, it is necessary to recalculate the various factors so that neither party is disadvantaged.

4. Conclusion

Based on the assumption, information II on the earthquake loss model is Pareto distribution with the parameter scale $x_m = 40810$ and an unknown shape θ. The value of the shape parameter θ was estimated using the Bayesian method and the value of $\hat{\theta} = 3.0197$ was obtained. The insurance premium in this study is calculated based on the estimated loss and chance of damage to the house due to the earthquake. The premium obtained from the principle of expected value has a smaller value but it is not necessarily beneficial for both parties. Therefore, it is necessary to re-examine the premium which is more effectively used for earthquake insurance by taking into account other factors.

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