Pure premium calculation of rice farm insurance scheme in Indonesia based on the 4-parameter beta mixture distribution

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Abstract. The Indonesian Government introduced rice farm insurance scheme (Asuransi Usaha Tani Padi – AUTP program) to protect rice farm from loss caused by flood, drought and pest and disease infestations. It has been discussed the method to calculate pure premium of the rice farm insurance scheme in Indonesia with assume that the distribution of rice yield data is normal distribution, gamma distribution, or normal mixture distribution. The normal distribution can be used for the case of distribution of rice yield data in the form of symmetry. The gamma distribution can be used for the case of distribution of rice yield data in the form of skewed to the right or positively skewed. In addition, the normal and gamma distributions are categorized as unimodal distributions. It has also been discussed the method of calculating pure premium of the rice farm insurance scheme in Indonesia with the assumption that the rice yield data is normal mixture distribution. The normal mixture distribution can be categorized as multimodal distribution. Characteristic of the normal mixture distribution is suitable for rice yield data in Indonesia that contain rice yield data from several provinces. On the other hand, it is also known that the 4-parameter beta mixture distribution can be applied to rice yield data in Indonesia. This distribution is more flexible than the normal mixture distribution in terms of the tail shape of the distribution. In this paper, pure premium calculation method of the AUTP program is formulated with assume that the distribution of rice yield data is the 4-parameter beta mixture distribution. Monte Carlo simulation is used to evaluate performance of the method. The method is applied to the rice productivity data in several provinces in Indonesia for the period 1970 to 2016.

1. Introduction
The Indonesian Government established rice farm insurance scheme (Asuransi Usaha Tani Padi – AUTP program) to protect rice farm from loss caused by flood, drought and pest and disease infestations. AUTP program began in the planting season of October 2015 - March 2016.

In the United States, Japan and Brazil, agricultural insurance has existed since 1899, 1939 and 1954, respectively [1]. In China, agricultural insurance has existed since 1949 [2], while in India it has been in existence since 1979 [3]. Meanwhile in Mexico and Canada, each has existed since 1961 and 1964 [4]. In Thailand and Malaysia, rice crop insurance had started in 2008 and 2013 respectively.

One important stage in the insurance business process is the determination of the amount of premiums [5]. Several methods of calculating agricultural insurance premiums have been discussed by many researchers. There are three common methods for calculating the amount of agricultural insurance premiums, namely the judgment method, loss ratio, and pure premium [6]. The normal curve method is discussed by Botts and Bales in 1958 in Bharamappanavara et al. [7]. The empirical methods are discussed by Goodwin [8] and Hatt et al. [9]. The methods involving the law of opportunity are discussed
by Babcock et al. [10]. The parametric and nonparametric methods are discussed by Ozaki et al. [11]. The Bayesian method is discussed by Ozaki [12], Ozaki and Silva [13], and Ramadan [14]. The survival analysis model is applied by [2] to design agricultural insurance premiums. The loss Cost Ratio is discussed by Woodard et al. [15]. The technical premium method is discussed by Chakrabarti [16].

The methods for calculating the pure premium of the AUTP program with assume that the distribution of rice yield data is normal and gamma has been discussed by Mutaqin et al. [17] and Mutaqin et al. [18] respectively. Monte Carlo simulation used by Mutaqin [19] to evaluate the performance of the method [17]. The method with assume that the distribution of rice yield data is normal mixture distribution has discussed by Mutaqin [20]. The normal mixture distribution can be categorized as multimodal distribution. Characteristic of the normal mixture distribution is suitable for rice yield data in Indonesia that contain rice yield data from several provinces. On the other hand, Sutarlan et al. [21] discussed the 4-parameter beta mixture distribution that can be applied to rice yield data in Indonesia. This distribution is more flexible than the normal mixture distribution in terms of the tail shape of the distribution. This article aims to formulate the pure premium calculation method for the AUTP program with assume that the distribution of rice yield data is the 4-parameter beta mixture distribution. Monte Carlo simulation will be used to evaluate performance of the method. The method will be applied to rice productivity data in several provinces in Indonesia for the period 1970 to 2016.

2. The AUTP program

The following are some important things related to the AUTP program:

- The insurance participant in this case the farmer has a maximum area of 2 hectares.
- The insured object value is IDR6,000,000/hectare.
- The premium of the AUTP program is 3% of the insured object value or IDR180,000/hectare. The government provides subsidies of 80% or IDR144,000/hectare, while farmer pays 20% or IDR36,000/hectare.
- The types of risks that can be insured are flood, drought and pest and disease infestations.
- The period of insurance coverage is one planting season.
- Farmers who only harvest a maximum of 25% of the planted area will receive full compensation of IDR6,000,000, for other cases depending on the level of damage and planting age [22].

In the planting season of October 2015 to March 2016, the Indonesian government began to run the AUTP program.

3. The 4-parameter beta distribution

Let \( Y \) be a random variable that follows 4-parameter beta distribution. The probability density function of random variable \( Y \) is

\[
f(y; \alpha, \beta, a, b) = \frac{\Gamma(\alpha + \beta)}{\Gamma(\alpha)\Gamma(\beta)} \frac{(y - a)^{\alpha-1}(b - y)^{\beta-1}}{(b - a)^{\alpha+\beta-1}}; a \leq y \leq b, \, \alpha > 0, \beta > 0.
\]

The 4-parameter beta distribution also called Pearson Type I distribution [23]. The cumulative distribution function of random variable \( Y \) is

\[
F(y; \alpha, \beta, a, b) = I_z(\alpha, \beta),
\]

where

\[
z = \frac{y - a}{b - a}.
\]

\( I_z(\alpha, \beta) \) is regularized incomplete beta function

\[
I_z(\alpha, \beta) = \frac{B_z(\alpha, \beta)}{B(\alpha, \beta)}.
\]
where \( B(\alpha, \beta) \) is beta function and \( B_2(\alpha, \beta) \) is incomplete beta function

\[
B(\alpha, \beta) = \int_0^1 t^{\alpha-1}(1-t)^{\beta-1} dt = \frac{\Gamma(\alpha)\Gamma(\beta)}{\Gamma(\alpha+\beta)},
\]

\[
B_2(\alpha, \beta) = \int_0^z t^{\alpha-1}(1-t)^{\beta-1} dt.
\]

The expectation and variance of random variable \( Y \) are

\[
E(Y) = a + (b - a) \left( \frac{\alpha}{\alpha + \beta} \right),
\]

\[
Var(Y) = \frac{(b-a)^2\alpha\beta}{(\alpha + \beta)^2(\alpha + \beta + 1)}.
\]

4. The 4-Parameter beta mixture distribution

4.1. Properties

The probability density function and the cumulative distribution function of random variable \( Y \) that follows the 4-parameter beta mixture distribution are

\[
f(y) = \sum_{j=1}^{k} \omega_j \left( \frac{\Gamma(\alpha_j + \beta_j)}{\Gamma(\alpha_j)\Gamma(\beta_j)} \right) \frac{(y-a)^{\alpha_j-1}(b-y)^{\beta_j-1}}{(b-a)^{\alpha_j+\beta_j-1}} \]  
(1)

\[
F(y) = \sum_{j=1}^{k} \omega_j F_j(y; \alpha_j, \beta_j, a, b) = \sum_{j=1}^{k} \omega_j I_{x_j}(\alpha_j, \beta_j). \]  
(2)

The expectation and variance of random variable \( Y \) are

\[
E(Y) = \sum_{j=1}^{k} \omega_j \left( a + (b-a) \frac{\alpha_j}{\alpha_j + \beta_j} \right), \]  
(3)

\[
V(Y) = \sum_{j=1}^{k} \omega_j \left( \frac{(b-a)^2\alpha_j\beta_j}{(\alpha_j + \beta_j)^2(\alpha_j + \beta_j + 1)} + \left[ a + (b-a) \left( \frac{\alpha_j}{\alpha_j + \beta_j} \right)^2 \right] \right)
- \sum_{j=1}^{k} \omega_j \left[ a + (b-a) \frac{\alpha_j}{\alpha_j + \beta_j} \right]^2. \]  
(4)

4.2. Expectation-maximization algorithm

The Expectation-Maximization Algorithm (EM Algorithm) is used to estimate parameters of the 4-parameter beta mixture distribution. Let given the observed data \( y = \{y_1, ..., y_n\} \), and indicator vector \( z_i = (z_{i1}, z_{i2}, ..., z_{ik}) \), for \( y_i \), such that

\[
z_{ij} = \begin{cases} 
1 & \text{if } y_i \text{ in component } j \\
0 & \text{elsewhere}
\end{cases}
\]

The log-likelihood function for the observed data is

\[
\ell(\Theta; y, z) = \sum_{i=1}^{n} \sum_{j=1}^{k} z_{ij} \ln \left( \omega_j \left( \frac{\Gamma(\alpha_j + \beta_j)}{\Gamma(\alpha_j)\Gamma(\beta_j)} \right) \frac{(y-a)^{\alpha_j-1}(b-y)^{\beta_j-1}}{(b-a)^{\alpha_j+\beta_j-1}} \right).
\]
where $\Theta = \{\omega_1, \omega_k, \alpha_1, \ldots, \alpha_k, \beta_1, \ldots, \beta_k\}$ are parameters which will be estimated while the parameters $a$ and $b$ will be fixed.

**Expectation Step:**
The indicator $z_{ij}$ replaced by its expectation, $E[z_{ij}] = \hat{z}_{ij}$, where

$$\hat{z}_{ij} = \frac{\omega_j \left( \frac{\Gamma(a_j + \beta_j)}{\Gamma(a_j)\Gamma(b_j)} \frac{(y - a)^{a_j-1}(b - y)^{\beta_j-1}}{(b - a)^{a_j+\beta_j-1}} \right)}{\sum_{t=1}^k \omega_t \left( \frac{\Gamma(a_t + \beta_t)}{\Gamma(a_t)\Gamma(b_t)} \frac{(y - a)^{a_t-1}(b - y)^{\beta_t-1}}{(b - a)^{a_t+\beta_t-1}} \right)}$$

(5)

**Maximization Step:**
Maximization step is maximizing the following function

$$E[\ell(\Theta; y, z)] = \sum_{i=1}^n \sum_{j=1}^k \hat{z}_{ij} \left[ \ln \left( \frac{\omega_j \left( \frac{\Gamma(a_j + \beta_j)}{\Gamma(a_j)\Gamma(b_j)} \frac{(y - a)^{a_j-1}(b - y)^{\beta_j-1}}{(b - a)^{a_j+\beta_j-1}} \right)}{\sum_{t=1}^k \omega_t \left( \frac{\Gamma(a_t + \beta_t)}{\Gamma(a_t)\Gamma(b_t)} \frac{(y - a)^{a_t-1}(b - y)^{\beta_t-1}}{(b - a)^{a_t+\beta_t-1}} \right)} \right]$$

(6)

To obtain the estimated parameters $\Theta$ from the mixture distribution using the estimated value of $\hat{z}_{ij}$ in the expectation step. The estimated weighting parameter $\omega_j$ that maximizes the log-likelihood function is

$$\omega_j = \frac{1}{n} \sum_{i=1}^n \hat{z}_{ij}, j = 1, 2, \ldots, k.$$  

(7)

The estimated parameters, $\alpha = (\alpha_1, \ldots, \alpha_k)^T$, and $\beta = (\beta_1, \ldots, \beta_k)^T$ can be obtained from the following equation

$$\sum_{i=1}^n \hat{z}_{ij} \left[ \psi(a_j + \beta_j) - \psi(a_j) + \ln \left( \frac{y_i - a}{b - a} \right) \right] = 0, j = 1, 2, \ldots, k.$$  

(8)

$$\sum_{i=1}^n \hat{z}_{ij} \left[ \psi(a_j + \beta_j) - \psi(b_j) + \ln \left( \frac{b - y_i}{b - a} \right) \right] = 0, j = 1, 2, \ldots, k.$$  

(9)

No closed form expression is obtained for the estimated parameters above based on Equations (8) and (9). One way to get the estimated values of the parameters above is to use numerical methods, for example the Newton-Raphson method. The Fuzzy C-Means [24] will be used to group data into the components. The ICL-BIC (Integrated Classification Likelihood Bayesian Information Criterion) criterion will be used to estimate the number of components.

5. Pure premium formulation of the AUTP program

Let $Y$ be a random variable of the average rice yield per hectare for a farmer, with the probability density function $g(y)$, and expectation $E(Y)$. Mutaqin et al. [17] formulated the amount of indemnity for the AUTP program. Let $I$ be a random variable of the amount of indemnity for the AUTP program (in IDR million), then

$$I = \begin{cases} 6 & ; Y \leq 0.25E(Y), \\ \frac{8}{E(Y)}(E(Y) - Y) & ; 0.25E(Y) < Y < E(Y), \\ 0 & ; Y \geq E(Y). \end{cases}$$


The expectation of random variable $I$ is

$$E(I) = 6P(Y \leq 0.25E(Y)) + E\left[\frac{8}{E(Y)} (E(Y) - Y)|0.25E(Y) < Y < E(Y)\right] \times P(0.25E(Y) < Y < E(Y)).$$

The amount of pure premium for the AUTP program is the amount of expectation above. If the average rice yield follows the 4-parameter beta mixture distribution with a density function as in Equation (1), then the amount of pure premium in this case is

$$E(I) = 6P\left(Y \leq 0.25 \sum_{j=1}^{k} \omega_j \left(a + (b - a) \frac{\alpha_j}{\alpha_j + \beta_j}\right)\right)$$

$$+ \left[8 - \frac{8}{\sum_{j=1}^{k} \omega_j \left(a + (b - a) \frac{\alpha_j}{\alpha_j + \beta_j}\right)}E\left[Y \leq \sum_{j=1}^{k} \omega_j \left(a + (b - a) \frac{\alpha_j}{\alpha_j + \beta_j}\right)\right] \times P\left(0.25 \sum_{j=1}^{k} \omega_j \left(a + (b - a) \frac{\alpha_j}{\alpha_j + \beta_j}\right) < Y < \sum_{j=1}^{k} \omega_j \left(a + (b - a) \frac{\alpha_j}{\alpha_j + \beta_j}\right)\right)\right].$$

The probability value

$$P\left(Y \leq 0.25 \sum_{j=1}^{k} \omega_j \left(a + (b - a) \frac{\alpha_j}{\alpha_j + \beta_j}\right)\right)$$

$$= \sum_{j=1}^{k} \omega_j F\left(0.25 \sum_{i=1}^{k} \omega_i \left(a + (b - a) \frac{\alpha_i}{\alpha_i + \beta_i}\right), \alpha_j, \beta_j, a, b\right),$$

and

$$P\left(0.25 \sum_{j=1}^{k} \omega_j \left(a + (b - a) \frac{\alpha_j}{\alpha_j + \beta_j}\right) < Y < \sum_{j=1}^{k} \omega_j \left(a + (b - a) \frac{\alpha_j}{\alpha_j + \beta_j}\right)\right)$$

$$= \sum_{j=1}^{k} \omega_j F\left(\sum_{i=1}^{k} \omega_i \left(a + (b - a) \frac{\alpha_i}{\alpha_i + \beta_i}\right), \alpha_j, \beta_j, a, b\right) - \sum_{j=1}^{k} \omega_j F\left(0.25 \sum_{i=1}^{k} \omega_i \left(a + (b - a) \frac{\alpha_i}{\alpha_i + \beta_i}\right), \alpha_j, \beta_j, a, b\right).$$

While

$$E\left|Y \leq 0.25 \sum_{j=1}^{k} \omega_j \left(a + (b - a) \frac{\alpha_j}{\alpha_j + \beta_j}\right) < Y < \sum_{j=1}^{k} \omega_j \left(a + (b - a) \frac{\alpha_j}{\alpha_j + \beta_j}\right)\right|$$

$$= \frac{\sum_{j=1}^{k} \omega_j F\left(\sum_{i=1}^{k} \omega_i \left(a + (b - a) \frac{\alpha_i}{\alpha_i + \beta_i}\right), \alpha_j, \beta_j, a, b\right) - \sum_{j=1}^{k} \omega_j F\left(0.25 \sum_{i=1}^{k} \omega_i \left(a + (b - a) \frac{\alpha_i}{\alpha_i + \beta_i}\right), \alpha_j, \beta_j, a, b\right)}{\sum_{j=1}^{k} \omega_j F\left(\sum_{i=1}^{k} \omega_i \left(a + (b - a) \frac{\alpha_i}{\alpha_i + \beta_i}\right), \alpha_j, \beta_j, a, b\right)}.$$
The estimated pure premium can be calculated by substituting the estimated parameters of the 4-parameter beta mixture distribution to the above equation.

6. Simulation study
In this section a Monte Carlo simulation will be conducted to evaluate the performance of the proposed method using the mean absolute error (MAE). Monte Carlo simulations performed 1,000 times the generation of data with a combination of parameter values to be tried are presented in table 1. While the sample size to be tried is \( n = 100, 500, 1,000 \). Based on table 1, it can be seen that there are 4 data cases that will be generated, all of them for data cases that have 4-parameter beta mixture distributions with 2 components. For all data cases, parameter values \( a = 0 \) and \( b = 80 \) are fixed.

| Case | \( w_1 \) | \( w_2 \) | \( \alpha_1 \) | \( \alpha_2 \) | \( \beta_1 \) | \( \beta_2 \) | Information |
|------|-----------|-----------|-------------|-------------|------------|------------|-------------|
| 1    | 0.30      | 0.70      | 25          | 40          | 5          | 10         | Large mean; small variance |
| 2    | 0.60      | 0.40      | 25          | 40          | 10         | 30         | Large mean; large variance |
| 3    | 0.30      | 0.70      | 25          | 40          | 15         | 50         | Small mean; large variance |
| 4    | 0.25      | 0.75      | 25          | 60          | 15         | 60         | Small mean; small variance |

Table 2 presents simulation results for the various data cases that were tried.

| Case | True Premium (IDR) | Mean of Estimated Premium (IDR) | MAE (IDR) | Mean of Estimated Premium (IDR) | MAE (IDR) | Mean of Estimated Premium (IDR) | MAE (IDR) |
|------|---------------------|---------------------------------|-----------|---------------------------------|-----------|---------------------------------|-----------|
| 1    | 241,669             | 247,478                         | 12,975    | 240,114                         | 5,495     | 242,210                         | 4,249     |
| 2    | 503,536             | 513,283                         | 29,253    | 502,365                         | 11,291    | 504,455                         | 10,875    |
| 3    | 662,973             | 653,036                         | 43,067    | 657,077                         | 19,771    | 658,938                         | 16,300    |
| 4    | 444,327             | 454,459                         | 26,197    | 448,517                         | 13,389    | 448,333                         | 9,084     |

Table 3. The application results of the proposed method.

| Sumatera Barat | Lampung | DKI Jakarta | Nusa Tenggara Barat | Nusa Tenggara Timur | Papua |
|----------------|---------|-------------|---------------------|---------------------|-------|
| \( \hat{w}_1 \) | 0.73    | 0.27        | 0.35                | 0.26                | 0.74  | 0.62  |
| \( \hat{w}_2 \) | 0.27    | 0.73        | 0.65                | 0.74                | 0.26  | 0.38  |
| \( \hat{\alpha}_1 \) | 92.24   | 15.35       | 6.90                | 15.84               | 32.69 | 21.24 |
| \( \hat{\alpha}_2 \) | 26.45   | 18.95       | 47.89               | 52.76               | 26.68 | 17.47 |
| \( \hat{\beta}_1 \) | 70.56   | 39.57       | 14.29               | 32.14               | 61.91 | 58.62 |
| \( \hat{\beta}_2 \) | 44.22   | 18.56       | 29.18               | 42.74               | 118.33| 22.12 |

Based on the values in table 2, it can be seen that the accuracy and precision of the estimated pure premiums resulting from the proposed method in this study increase with increasing sample size. This can be seen from the closer average value of the estimated premium to the actual premium value and the smaller average MAE value with increasing sample size.
7. Application
The proposed method of calculating the pure premium for the AUTP program will be applied to rice productivity data in several provinces in Indonesia for the period 1970 to 2016. Table 3 contains the estimated parameters of the distribution of 4-parameter beta mixture and the estimated pure premium for rice productivity data of 6 provinces in Indonesia. The rice productivity data of 6 provinces have distribution of 4-parameter beta mixture with 2-component. It appears that the estimated pure premium is at least IDR606,249/hectare/planting season and a maximum of IDR1,053,582/hectare/planting season.

8. Conclusion
The following are the conclusion of this research:

- A proposed method has been developed to calculate the pure premium of the AUTP program based on rice yield data that has the 4-parameter beta mixture distribution.
- The Monte Carlo simulation results show that the proposed method has higher accuracy and precision when increasing sample size.

The results of the application showed that the rice productivity data in 6 provinces in Indonesia has the 4-parameter beta mixture distribution, namely the provinces of Sumatra Barat, Lampung, DKI Jakarta, Nusa Tenggara Barat, Nusa Tenggara Timur and Papua. Meanwhile the estimated pure premium is IDR606,249/hectare/planting season and a maximum of IDR1,053,582/hectare/planting season.

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