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# Price of pure agricultural insurance premiums using the Elliptical Copula Approach

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## Abstract

The study aims to investigate the price of pure agricultural insurance premiums using the Elliptical Copula Approach. Data on rainfall and rice productivity have extreme values, so the assumption of normality cannot be met. The copula is used to identify relationships between variables and determine the value of agricultural insurance premiums. Based on the data used and conducted a simulation study obtained by Gaussian Copula, the Gaussian copula shows a smaller error value. In conclusion, the Gaussian copula is better in modeling dependencies. The price of pure agricultural insurance premiums using the Gaussian copula is smaller than using t-Copula.

**Keywords:** Elliptical copula, Premiums, Agricultural insurance.

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# Precio de las primas de seguros agrícolas puros utilizando el enfoque de cópula elíptica

**Resumen**

El estudio tiene como objetivo investigar el precio de las primas de seguros agrícolas puros utilizando el Enfoque de Cópula Elíptica. Los datos sobre la lluvia y la productividad del arroz tienen valores extremos, por lo que no se puede cumplir el supuesto de normalidad. La cópula se utiliza para identificar relaciones entre variables y determinar el valor de las primas de seguros agrícolas. En base a los datos utilizados y realizó un estudio de simulación obtenido por la cópula gaussiana, la cópula gaussiana muestra un valor de error menor. En conclusión, la cópula gaussiana es mejor para modelar dependencias. El precio de las primas de seguros agrícolas puros que utilizan la cópula gaussiana es menor que el uso de t-Copula.

**Palabras clave:** Cópula elíptica, Primas, Seguro agrícola.

## 1. INTRODUCTION

Revenues in agriculture are very uneven, for example in 1961 and 2011 in Asia and the Pacific they produced greater production, compared to Latin America and the Caribbean, both of which had relatively different rainfall (ALSTON, 2014). According to MAHATO (2014), rainfall and agricultural productivity correlate, meaning agricultural output is influenced by a lot of rainfall. Rice planted in rice fields is very dependent on natural conditions, in the sub-tropical regions water availability is a determining factor in the agricultural sector (JANETOS, 2017). According to a study conducted by MAHATO (2014) mentioning that reduced rainfall intensity is the biggest reason for the decline in crop yields of farmers on dry land in

Dharmaputri, India. The decline in yields caused a decrease in farmers' income. The decline in farmer's income is a short-term impact, while the long-term impact is the end of the dry land farmers' profession (of employment). Reduced rainfall intensity is a major contributing factor to crop yields (AHMAD & AHMAD, 2019; DUNNETT, 2018). Climate variations such as long dry periods have a high impact on the yield of dry land crops.

Climate change has a negative influence on agricultural production (CHATZOPOULOS, PÉREZDOMÍNGUEZ, ZAMPIERI, & TORETI, 2019). Climate change will have an impact on the productivity of agricultural products, i.e. reduced crops or reduced income for farmers. Efforts to minimize losses caused by climate change are to guarantee risks that cause productivity to decline or the existence of agricultural insurance programs and find out the characteristics of the relationship between the observed variables. This strategy is mostly adopted by farmers in developed countries. Agricultural insurance already exists in Latin America (for example, Brazil, Costa Rica, and Mexico) and Asia (for example, India and the Philippines) between the 1950s and 1980s (AHMAD & AHMAD, 2018; NATHANIEL, & CHRISTOPHER, 2017).

Relationship identification methods that are often used are Pearson correlation and OLS (Ordinary Least Square) regression. The method is used if the data meets the assumption of normal distribution (WILLIAMS, 2013). Rainfall data and agricultural productivity have extreme values, so the assumption of normally distributed data is not fulfilled. In this study, the method used to overcome this problem is the copula approach.

The copula is a method for identifying relationships between variables, this method ignores normally distributed data. Copula can show dependency relations of extreme points, the copula is a function of multivariate distribution, each of which has marginal distribution (NELSEN, 2005; AHMAD & SAHAR; 2019). Copula was first introduced by SKLAR (1959) and has been widely used in modeling dependencies. Copula modeling becomes popular as literature in finance and econometrics (FANG & MADSEN, 2013: MARTYNOVA et al, 2019).

In addition to modeling dependencies, in this study copula is used in the insurance field to determine premium prices. When viewed from the risk, the agricultural sector has a large risk of loss. Therefore, the loss factor needs to be considered in modeling the price of agricultural insurance premiums.

## 2. MATERIALS AND METHODS

### *2.1. Copula*

In modeling two or variables that are not independent, copula can be used. In this discussion, some things related to copula will be described. Copula with dimension $n$ denoted by $C$ is a multivariate distribution function $F$ of random variables $X_1, X_2, \dots, X_n$ with distribution marginal $F_1, F_2, \dots, F_n$ with uniform distribution standard, namely,

$$F_i \sim U(0,1); i = 1,2, \dots, n.$$

This copula function is a function that has a domain $[0,1]^n$ and range [0,1], which is represented by $C: [0,1] \rightarrow [0,1]$ (NELSEN, 2005).

*2.2. Elliptical Copula*

Copula elliptical is copula with ellip distribution. If there is d-dimension copula ellip it will have at least $d\,(d-1)\,/\,2$ parameters. The copula type of the ellipse is normal or Gaussian copula and t-copula.

*2.3. Gaussian Copula*

Gaussian Copula is defined as follows,

$$C_\Sigma^G(\boldsymbol{u}; \Sigma) \coloneqq \Phi_\Sigma\left(\Phi^{-1}(u_1), \dots, \Phi^{-1}(u_d)\right) \quad (2)$$

$\boldsymbol{u} \in (0,1)^d$, $\Phi^{-1}$ is the inverse of the marginal distribution used in copula dan $\Phi_\Sigma$ is a standard normal multivariate function with a correlation matrix $\Sigma$ (LIMPERT, STAHEL, & ABBT, 2001).

In general, the normal multivariate distribution is as follows,

$$\Phi_{\mathcal{R}} = \int_{-\infty}^{x_1} \dots \int_{-\infty}^{x_d} f_{d;\mathcal{R}}\,(\mathrm{x})d\mathrm{x}$$

$$f_{d;\mathcal{R}}(\mathrm{x}) = \frac{1}{\sqrt{(2\pi)^d|\mathcal{R}|}} \exp\left(-\frac{1}{2}(x-\mu)'\mathcal{R}^{-1}(x-\mu)\right), \qquad (3)$$

$\mu$ is a location parameter vector and $\mathcal{R}$ is a covariance matrix with element $\sigma_{i,j} = E(X-\mu_i)(X_j-\mu_j)$. Elemen $\mathcal{R}$ has a relationship with the correlation matrix $\Sigma$ as follows

$$\rho_{i,j} = \frac{\sigma_{i,j}}{\sigma_i \sigma_j}$$

*2.4. t-Copula*

Copulates in dimension d have shapes

$$C_t(u;\ \Sigma, v) = t_{\Sigma,\mathrm{v}}\left(t_v^{-1}(u_1), \dots, t_v^{-1}(u_d)\right) \qquad (4)$$

$v$ is a free degree parameter, $t_1^{-1}$ is an inverse function of the marginal distribution used in copula and $t_{\Sigma,\mathrm{v}}$ is a multivariate distribution t with a correlation matrix Σ and degrees of freedom $v$. The density function of the multivariate t is given as follows (BALAKRISHNAN, KOTZ, & JOHSON, 2000)

$$f_{t;D,v}(\mathrm{x}) = \frac{\Gamma\left(\frac{\mathrm{v}+\mathrm{d}}{2}\right)}{\Gamma\left(\frac{v}{2}\right)\sqrt{(\pi \mathrm{v})^{\mathrm{d}}|D|}}\left(1+\frac{\left((\mathrm{x}-\mu)'D^{-1}(\mathrm{x}-\mu)\right)}{v}\right)^{-\frac{v+d}{2}} \quad (5)$$

Γ is a Gamma function. Matrix $D = \frac{(v-2)}{v}cov(\mathrm{X})$ is a definitive positive dispersion matrix and is only defined as $v > 2$.

Because copula is invariant to all monotonous upward transformations of the marginal distribution or random vector component X, then by using equation 5, based on equation 4 the t-Copula form is obtained as follows,

$$C_t(\mathbf{u};\, \Sigma, \mathrm{v}) = \frac{\Gamma\left(\frac{\mathrm{v}+\mathrm{d}}{2}\right)}{\Gamma\left(\frac{v}{2}\right)\sqrt{(\pi \mathrm{v})^{\mathrm{d}}|\Sigma|}} \int_{-\infty}^{t_v^{-1}(u_1)} \cdots \int_{-\infty}^{t_v^{-1}(u_d)} \left(1 + \frac{(\mathrm{x}'\Sigma^{-1}\mathrm{x})}{v}\right)^{-\frac{v+d}{2}} dx \quad (6)$$

From equation 6, we get the t-Copula density

$$c_t(\mathbf{u};\Sigma,\mathrm{v}) = \frac{\mathrm{f}_{\Sigma,\mathrm{v}}\left(t_v^{-1}(u_1),\dots,t_v^{-1}(u_d)\right)}{\prod_{i=1}^{d} f_v\left(t_v^{-1}(u_i)\right)} \qquad (7)$$

*2.5. Copula Transformation to* $U[0,1]$

The data used is transformed into the domain $U[0,1]$. The distribution of the unknown random variable $X_i$ is expressed in equation 4 as follows.

$$F_{x_j}(x_j) = \frac{1}{n+1}\sum_{i=1}^{n} 1(X_j^{(i)} \le x_j); x_j \in R. \qquad (4)$$

Transformation of original data to domain $U[0,1]$ is done by making scatterplot transformations [0,1], by making a rank plot for $X_j$ as in equation 5 below.

$$\left(\left(\frac{R_1^{(i)}}{n+1}\right),\left(\frac{R_2^{(i)}}{n+1}\right),\dots,\left(\frac{R_m^{(i)}}{n+1}\right)\right); 1 \le i \le n \qquad (5)$$

$R_1^{(i)}, R_2^{(i)},\dots,R_m^{(i)}$ is the rank of $X_1, X_2,\dots,X_m$ which was previously changed in matrix form. By the transformation of the copula in equation 6 below.

$$C_n(u_1,\ldots u_m) = \frac{1}{n}\left(\frac{R_1^{(i)}}{n+1} \le u_1, \frac{R_1^{(i)}}{n+1} \le u_2, \ldots, \frac{R_m^{(i)}}{n+1} \le u_m\right) \quad (6)$$

1(.)In equations 4 and 6 are indicator functions, if respectively $X_j^{(i)} \le x_j$and $\frac{R_j^{(i)}}{n+1} \le u_j$ , $i = 1{,}2{,}3, \ldots m$

*2.6. Copula Parameter Estimation*

In this section, we will discuss a method that is often used for copula parameter estimation. The method often used to estimate parameters is to use the maximum likelihood (MLE). N is given vector n dimension random variable from multivariate distribution, $\hat{x}_1, \ldots, \hat{x}_N$, , with $\hat{x}_j = (\hat{x}_{j,1}, \ldots \hat{x}_{j,n}), j \in \{1, \ldots, N\}$ Parametric models for the marginal distribution $F_1, \ldots, F_n$ with parameters $\alpha_1, \ldots, \alpha_n$ and Copula parameter $C$ are θ so we can write the multivariate distribution density $f$ as follows:

$$f(x_1, \ldots, x_n) = c(F_1(x_1;\alpha_1), \ldots, F_d(x_d;\alpha_d);\theta) \prod_{i=1}^{d} f_i(x_i;\alpha_i) \quad (7)$$

With $c$ being the copula density and $f_1, \ldots, f_n$ is the density of the marginal distribution.

The parameters of the marginal distribution, $\alpha_1, \ldots, \alpha_n$ and parameters from copula $\theta$, can be estimated from data using MLE as follows JOE & XU (1996),

$$\arg\max_{\alpha_1,\ldots,\alpha_n,\theta} \sum_{j=1}^{N} \ln(c(F_1(\hat{x}_{j,1};\alpha_1),\ldots,F_n(\hat{x}_{j,n};\alpha_n);$$

$$\theta) \prod_{i=1}^{n} f_i(\hat{x}_{j,i};\alpha_i) \quad (8)$$

*2.7. Correct Copula Determination*

Several methods can be used to determine the appropriate copula include the Method of Graphics, the Goodness of Fit Formal Test, AIC (Akaike Information Criteria), and Root-Mean-Square Error (RMSE). In this study, RMSE is used to determine the appropriate copula.

The value of RMSE shows the amount of error from the theoretical population to copula empirical. If there is more than one copula, then copula which has the smallest RMSE value can be said to be the best to use compared to another copula. Given $C(u,v)$ which is the theoretical population that will be tested for its compatibility, in this case, copula Gaussian and t-copula. The value of RMSE can be obtained by using the following equation:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(C(u_i, v_i) - C_n(u_i, v_i)\right)^2} \quad (9)$$

With $(u_i, v_i)$for $i = 1,2,\cdot\cdot\cdot,n$ is the pairing data and $C_n(u_i, v_i)$ is the empirical copula. Basically, the empirical copula is used to approach the theoretical copula.

*2.8. Agricultural Insurance Premium Model Using Copula*

Agricultural insurance is a transfer of risk to minimize losses. Agricultural insurance premiums in this study are reviewed from the amount of rainfall. If the Rainfall Intensity $(R)$ is less than the specified limit $Q$, then the Policyholder can submit a claim, can be illustrated in Equation (10).

$$H_i = \begin{cases} 0 & R_i > Q_3 \\ C & R_i < Q_1 \\ \frac{C}{2} & Q_1 \le R_i < Q_2 \\ \frac{C}{3} & Q_2 \le R_i < Q3 \end{cases} \quad (10)$$

$H_i$ is the Total loss, $C$ is a theoretical copula calculated using equations (4) and (2), $R_k$ s the rainfall for $k = 1,2, \dots n$ and $Q_j$ is the quartile value, for $j = 1,2,3$. The amount of loss for each quartile is obtained by using the following formula

$$Y_{(i_j)} = H_j P_{(N_j)} P_{(H_j)} v^t M;\ for \quad j = 1,2,3\ ; i = 1,2, \dots, n_j \quad (11)$$

For $n_j$ the number of claims in the j$^{th}$ quartile, $v^t$ is present value with insurance period t (4 months). $H_{i_j}$ is the total loss in the j$^{th}$ quartile, $P_{(N_j)}$ is the probability of the claim occurring in the j$^{th}$ quartile, $P_{H_j}$ is the probability of total losses in the j$^{th}$ quartile and $M$ is the amount of the obtained compensation funds. So pure agricultural insurance premiums can be summarized as follows.

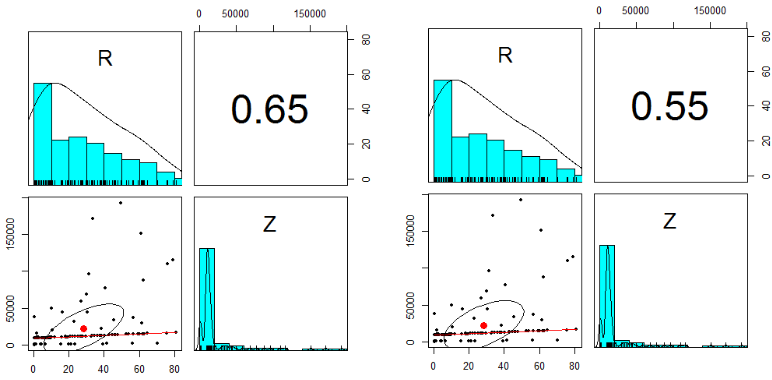
$$P = E\left[Y_{i_j}\right] \quad (12)$$

## 3. RESULTS AND DISCUSSION

### *3.1. Effect of Rainfall on the Area of Harvest*

Rainfall is a parameter of the impact of climate change. The volume of rain every month will affect the growth of rice plants whose irrigation systems depend only on rainwater. In this section, we will explain the effect of rainfall on the area of rice yields.

Rainfall data is expressed by variable R and the area of rice yield is expressed as variable Z. Furthermore, dependencies will be calculated between two variables using copula with the help of software R, resulting in positive correlations between the area of rice yield and wind speed. This shows that the less rain falls to the earth, the wider the yield of rice yields. The results can be summarized in Figure 1.




(1) (2)

Figure 1: Effect of Rainfall on the Area of Harvest, (1) Spearman correlation (2) Kendal correlation

From Fig 1, it can be seen that there is a positive correlation between rainfall and the area of productivity. This shows that the less rainfall falls, the less extensive agricultural productivity. If seen from Figure 1 the pattern of the relationship between rainfall and the area of agricultural productivity shows an irregular pattern with random distribution and shows data not normally distributed (skewed).

*3.2. Distribution Assumption Test*

In this study, the method used for testing distribution assumptions is the hypothesis test using Kolmogorov-Smirnov,

Hypothesis test:

$$H_0\text{: Data is normally distributed}$$

$$H_1\text{: Data is not normally distributed}$$

By using the help of software R obtained the results in Figure 2.

```
        One-sample Kolmogorov-Smirnov test

data:  Data$R
D = 0.15269, p-value = 0.01495
alternative hypothesis: two-sided
```

```
        One-sample Kolmogorov-Smirnov test

data:  Data$Z
D = 0.96744, p-value < 2.2e-16
alternative hypothesis: two-sided
```

Figure 2: Kolmogorov-Smirnov test

From Figure 3. Shows that both variables have ρ-values less than 0.05, this means the data does not follow the normal distribution. This causes Pearson correlation cannot be used because the variable does not meet the assumption of normality, therefore further dependency analysis is done with copula because it can overcome the problem of variables that are not normally distributed.

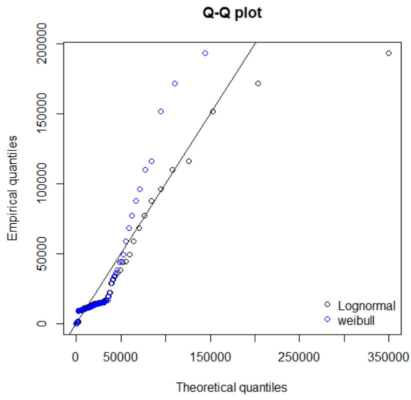



Figure 3: QQ plot

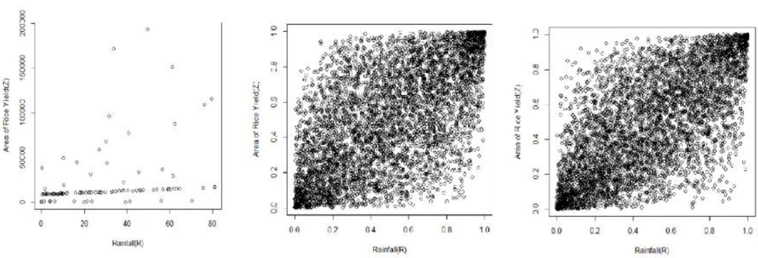
From the QQ graph, the plot in Figure 3 illustrates the lognormal distribution approximating the graph from the sample data. So in this study, a lognormal distribution is used to describe the distribution of rainfall data and the area of agricultural productivity.

### *3.3. Estimated Gaussian Copula Parameters*

Estimation of the elliptical copula family parameters is done using maximum likelihood, by using software R based on equation 5, the Gaussian Copula parameter value $\rho = 0.622$

Simulations are performed to compare observational data and simulation data through the empirical copula distribution. The simulation that is carried out is to build a row of data that follows the

Causa Gaussian Model using parameters obtained in the previous process with the help of software R, the simulation of 5000 data so that the distribution can be more clearly presented in the following scatterplot,




(1) (2) (3)

Figure 4: (1) Scatterplot observation data, (2) Scatterplot t-Copula simulation data (3) Scatterplot Gaussian Copula simulation data

Figure 4. Identifying Gaussian copula scatterplot observational data and Gaussian Copula and t-Copula simulation data. Gaussian Copula simulation data in Figure 2. (3). has a small dependency tail, whereas in Figure 2. (2) t-Copula simulation data has a large dependency tail, meaning that for a small dependency tail the data distribution is centered on its average, while a large tail dependency means the distribution of data is equally. The distribution of simulation results has a good distribution compared to observational data and is assumed to have a linear relationship, so if rainfall is low then the area of agricultural productivity is also low. In the observation data have a distribution that is not good enough and cannot explain the relationship between 2 related variables.

### *3.4. Determination of Appropriate Copula*

Comparing graphs of sample data with graphs of several distributions such as Lognormal and Weibull. It is obtained that the Log-normal distribution is more following the sample data. Furthermore, determining the appropriate copula using RMSE, the value of RMSE shows the magnitude of error from the theoretical population to the empirical copula. If there is more than one copula, then copula money has the smallest RMSE value can be said to be the best to use compared to another copula. Based on equations (9) by using software R, RMSE values for the Gaussian Copula and t-Copula can be seen in Table 1.

Table 1: Copula RMSE Values

| Copula | Gaussian Copula | t-Copula |
|---|---|---|
| RMSE | 0.3230 | 0.3243 |

Based on Table 1, it can be seen that the Gaussian Copula error value is 0.3230, while for t-Copula it is 0.03243. The copula error value is below 5%, Gaussian Copula is still relevant to use. Therefore, Gaussian Copula can be used to model dependencies between rainfall variables and rice yield area.

### *3.5. Pure Agricultural Insurance Premium*

Data published by BMKG on weather and BPS on agricultural productivity, do not provide information about the frequency and magnitude of claims. Based on (10) the frequency and magnitude of claims are measured by the bulk data presented in Table 2,

Table 2: Probability and Frequency of Claims

| | Frequency of Claims | | $P_{N_j}$ | | $P_{H_j}$ | |
|---|---|---|---|---|---|---|
| | t-Copula | Gausian Copula | t-Copula | Gausian Copula | t-Copula | Gausian Copula |
| 1st Quartile ( $R_i < Q_1$ ) | 27 | 26 | 0,247619048 | 0,247619048 | 0,640073294 | 0,633039843 |
| 2nd Quartile ( $Q_1 \leq R_i < Q_2$ ) | 26 | 26 | 0,247619048 | 0,247619048 | 0,246926119 | 0,25997877 |
| 3rd quartile $Q_2 \leq R_i < Q3$ | 27 | 27 | 0,257142857 | 0,257142857 | 0,113000587 | 0,119373937 |
| $R_i > Q3$ | 25 | 26 | 0,238095238 | 0,247619048 | 0 | 0 |

The risk contained in the 1st quantile data has a large enough value, this is due to the very low rainfall in the 1st quintile which results in decreased productivity. With the high risk of causing pure premiums that are expensive. Based on equations (11) and (10), with the amount of the compensation fund determined at IDR 8,000,000, and interest (i) 6%, a pure premium is presented in the following Table 3.

Table 3: Pure Premium

| | Pure Premium | |
|---|---|---|
| | t-Copula | Gausian Copula |
| 1st Quartile ($R_i < Q_1$) | 1,042,967 IDR | 993,303 IDR |
| 2nd Quartile ($Q_1 \le R_i < Q_2$) | 387,452 IDR | 407,933 IDR |
| 3rd quartile $Q_2 \le R_i < Q3$ | 184,129 IDR | 194,514 IDR |
| $R_i > Q3$ | 0 IDR | 0 IDR |

## 4. CONCLUSIONS

Copula an extension of a multivariate distribution whose marginal distribution can come from other distributions. As is known, if there are $F\ (X_1, X_2, \ldots, X_N)$ with multivariate t student distribution, then each $X_i$ is distributed t.

To model variable dependence that is not normally distributed, it cannot use Pearson distribution, using Copula as an alternative method for modeling dependency structures between variables whose marginal distribution can be different. In this study t-Copula is the best model to explain the dependencies of the two related variables.

The higher the risk or the least rainfall, resulting in expensive premiums, compared to agricultural systems that have a low risk.

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