Determination of Agricultural Insurance Premium Prices Based on Rainfall Index with the Black-Scholes Model

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Abstract: *This article discusses the use of the European put option formula to calculate agricultural insurance premium prices based on the rainfall index. The data used in this study is data on rainfall and rice production in Banjarnegara Regency from 2014 to 2019 which are arranged in quarterly form. The research was completed by literature study and online secondary data searching. From the results of the research, rainfall data that has a strong correlation is rainfall in the tenth month (October) so that rainfall data on October is used as a rainfall index. From the calculation results, at the 5th percentile, the October rainfall is 2.2 mm. For this rainfall, a premium price of IDR 2,515,549.00 is obtained, if the trigger data for the last rainfall (2.2 mm) is used. When used as a reference, the average overall rainfall data (9.92 mm) obtained a premium of IDR 562,664.00. These results show that the selection of references gives very different results. The calculation results also show that the high and low percentiles affect the price of agricultural insurance premiums in Banjarnegara Regency. The higher the percentile value, the more rainfall will increase, and the premium price will increase.*

INTRODUCTION

Agriculture is one of the businesses with high risk and uncertainty so that rice production can decrease. One of the factors that can threaten the decline in rice production is rainfall (Putri et al., 2017). Excess rainfall results in flooding, and too little rainfall results in drought (Prabowo, 2019; Prabowo et al., 2019). Both floods and droughts have an impact on crop failure (Babcock et al., 2004).

To reduce farmers' losses due to crop failure caused by excessive rainfall, drought, and other causes, agricultural insurance was introduced (Goodwin, 1994; Muttaqin et al, 2016). In this case, it is agricultural insurance based on the rainfall index. Index-based insurance is a form of insurance in which the losses incurred are based on a factor such as rainfall (Bharamappanavara et al., 2010).

The rainfall is represented by a rainfall index which is used as a reference to determine the premium.

The insurance premium is the obligation of the insured party to the insurer in the form of payment of money in a certain amount, all at once or periodically. The agricultural insurance scheme is carried out using the insurer obtaining a premium to provide compensation (compensation, benefits, benefits, sum assured) to the insured due to loss or crop failure (Ozaki et al., 2008). Harvest failures for which compensation can be claimed include, among others, pests, climate, natural disasters, rainfall, and others (Woodard et al., 2011). However, in calculating the premium, the organizers only base it on one cause, for example, rainfall, so it is called agricultural insurance based on the rainfall index. In addition, the amount (price) of the premium also depends on the amount (large) of the insured value and other factors such as interest rates and the period for data formation (Sukono et al., 2020).

Similar to insurance, an option is a contract or agreement between two parties, namely one party gives the other the right to buy or sell an asset (e.g. shares) at a certain price and period. There are two kinds of options, namely European and American. European options are exercised only at maturity, while American options are exercised before or at maturity.

Options have two types of contracts, namely call and put. A put option is a type of contract that gives the option buyer the right to sell (put) a certain number of shares to the option seller at a certain price and period. Meanwhile, a call option is a type of contract that gives the option buyer the right to buy (call) from the option seller a certain number of shares at a certain price within a certain period.

One of the methods (models) used to determine option prices is the Black-Scholes model (Prabowo et al., 2020). The equation between the option calculation and the calculation of agricultural insurance premiums causes the Blacks-Scholes model to be used to determine the price of agricultural insurance premiums based on the rainfall index. Premium calculation is based on rainfall index, not rainfall. This means that not all of the rainfall is used as data in determining the amount of the premium, but only part of the rainfall data. Determination of rainfall data that is used as a reference for calculating the premium is done by looking for the largest correlation between rainfall data and rice production (Erfianan et al., 2020). The rainfall data with the largest correlation was chosen as the rainfall index (Prabowo et al., 2020). Thus, the insurance scheme is called rainfall index-based agricultural insurance.

In the calculation of the option price, the stock price becomes the underlying asset and the stock option price becomes the derivative. That is, the price of the option is affected by the stock price. In the calculation of agricultural insurance premiums, the rainfall index becomes the underlying asset and the premium price becomes the derivative (Prabowo et al., 2020). That is, the rainfall index determines the premium price.

Based on the explanation above, this study was conducted to calculate the price of agricultural insurance premiums based on the rainfall index using the European type cash-or-nothing call option formula derived from the Black-Scholes model using secondary data from the Banjarnegara geographical area.

The purpose of this study was to determine agricultural insurance premiums using the Black-Scholes model. Researches relevant to the theme of the discussion in this article have been carried out by Wendra (2015), Putri et al. (2017), Prabowo et al. (2020) and Filiapuspa et al. (2019). The factor that distinguishes this research is the data. The data used by Wendra (2015) is data for the Jambi region. While Putri et al. (2017) used rainfall data for the Bali region from 1998 to 2015. Meanwhile, Filiapuspa et al. (2019) using data from the Province of Banten from 2005 to 2015.

In this study, data on rainfall and rice production were maintained in the form of monthly data. Whereas in previous studies the data was converted into quarterly data by referring to the length of the rice growing season which was four months (Erfiana et al., 2020). The use of monthly data in this study is due to the absence of differences between the premiums for each growing season. Beside those, Wendra (2015), Putri et al. (2017), and Filiapuspa et al. (2019) use the latest rainfall index data as reference data, while in this article two reference data are used, namely the latest data and the overall average rainfall index data. The comparison of premium size is given as an analysis referring to the use of the two types of reference data.

METHODS

For insurance premiums based on the rainfall index, the premium calculation is modeled using the European type of cash-or-nothing put option formula. The price of insurance premiums is calculated by

$$premium = Ke^{-rt}N(-d_2), \tag{1}$$

where $N(-d_2)$ is the cumulative normal distribution, K is the payoff (the amount of compensation that will be received by farmers in the event of a claim), r is the interest rate per year, and t is time (yearly).

The interest rate r is calculated annually. If we assume r is the risk-free interest rate, then $r = \mu$. If the time period t is not annual, then r adjusts the time period.

Payoff from index-based insurance can be paid if the actual rainfall R_0 is less than the triggered measurement R_T (Choudhury et al., 2016). The payoff odds are

$$d_2 = \frac{\ln\frac{R_0}{R_T} + \mu t}{\sigma\sqrt{t}}, \tag{2}$$

where R_0 is the latest rainfall data (recent); R_T is a triggered measurement (calculated by percentile data), namely rainfall data used to trigger (determine) the amount of premium; μ is the annual expected rate of return of the stock price; σ is volatility (annual standard deviation of stock price changes). The rainfall data used as R_0 is not always the last data (R_n), but can also be the rainfall mean, median, mode, or the first data (R_1).

In this case μ and σ, respectively, are the mean and standard deviation of the lognormal distribution. The procedure for determining μ and σ parameters in a lognormal distribution is as follows. Suppose the rainfall data is expressed by R_j, $j = 1,2,3,\ldots,n$.

1. Calculate the average return of rainfall data (Filipiapusa, 2019) as follows
$$\mu = \frac{1}{n-1}\ln\frac{R_n}{R_1}. \tag{3}$$
2. Calculate the return value of rainfall data:
$$u_j = \ln\frac{R_j}{R_{j-1}}, \forall j, j = 1,2,3,\ldots,n.$$
3. Calculate your mean return:
$$\bar{u} = \frac{\sum_{j=1}^{n-1} u_j}{n-1}.$$
Filiapuspa (2019) using the sample mean:
$$\bar{u} = \frac{\sum_{j=1}^{n} R_j}{n}.$$
4. Calculate the annual unbiased standard deviation for small data as follows

$$\sigma = \sqrt{\frac{1}{n}\sum_{j=1}^{n}\left(u_j - \bar{u}\right)^2}. \quad (4)$$

If the time period t is not years, then $\tilde{\mu} = \mu t$ and $\tilde{\sigma} = \sigma\sqrt{t}$.

RESULTS AND DISCUSSION

Data

The data used in this study is data on rainfall and rice production in Banjarnegara Regency from 2014 to 2019 (BPS, 2019). The data used are shown in Tables 1 and 2.

Table 1. Rainfall data for Banjarnegara Regency from 2014 to 2019 (in mm)

Period	2014	2015	2016	2017	2018	2019
January	-	14.9	8.3	15.5	17.4	18.8
February	-	16.4	13.9	24	21.6	12.9
March	-	12.8	24	17.6	12.2	10.5
April	11.8	18.6	12.4	16.1	9	-
May	8.8	9.8	15.5	11.7	3.4	-
June	8.2	2.4	16.4	7.3	1.2	-
July	8.1	0.5	7.3	1	0	-
August	4.4	0.2	4.2	0.1	0.1	-
September	0.2	0.2	18.2	8.5	1.1	-
October	4.4	4.4	18.3	20.3	2.2	-
November	17.7	17.7	16.2	24.1	11.8	-
December	25.8	25.8	20.1	18.3	21.4	-

Table 1 presents rainfall data per month (in mm) from April 2014 to March 2019. Although other data for 2014 and 2019 are available, they are not shown in Tables 1 and 2. This is related to the way the data is compiled quarterly. The first, second, and third quarters are April to July, August to November, and December to March.

Table 2. Rice production data for Banjarnegara Regency from 2014 to 2019 (in ton)

Period	2014	2015	2016	2017	2018	2019
January	-	1,866.0	1,134.8	5,454.4	4,301.5	4,235.7
February	-	5,384.0	4,331.2	14,624.6	14,869.0	7,818.6
March	-	23,631.0	21,075.0	24,374.5	20,810.0	14,708.1
April	30,019.0	32,411.0	26,453.0	18,461.8	24,608.0	-
May	14,289.0	15,848.0	14,263.0	10,724.2	11,671.0	-
June	6,140.3	6,737.0	4,800.0	8,884.7	7,015.0	-
July	3,827.7	5,825.0	4,630.0	10,799.1	14,296.0	-
August	11,936.0	14,954.0	19,348.0	18,934.8	19,132.0	-
September	29,210.0	22,462.0	19,552.0	22,219.9	18,157.0	-
October	10,944.0	13,853.0	10,337.0	6,800.3	8,757.3	-
November	3,896,0	3,274.0	4,143.9	4,813.9	6,184.4	-
December	3,586,0	3,518.0	3,305.9	5,736.4	4,484.1	-

Table 2 presents production data per month (in tons) from April 2014 to March 2019. The data is managed by dividing it per quarter as shown in the rainfall data in Table 1.

Determination of Rainfall Index

The data in Table 1 and Table 2 are grouped into monthly data. The results are provided in Table 3. Furthermore, the data in Table 3 is used to determine the rainfall that will be used as an index in calculating rice insurance premiums.

Table 3. Rainfall (in mm) and rice production (in ton) data for Banjarnegara Regency from 2014 to 2019

	Apr 14-18	May 14-18	Jun 14-18	Jul 14-18	Aug 14-18	Sep 14-18	Oct 14-18	Nov 14-18	Dec 14-18	Jan 15-19	Feb 15-19	Mar 15-19
Rainfall	11.8	8.8	8.2	8.1	4.4	0.2	4.4	17.7	25.8	14.9	16.4	12.8
	18.6	9.8	2.4	0.5	0.2	0.2	4.4	17.7	25.8	8.3	13.9	24.0
	12.4	15.5	16.4	7.3	4.3	18.2	18.3	16.2	20.1	15.5	24.0	17.6
	16.1	11.7	7.3	1.0	0.1	8.5	20.3	24.1	18.3	17.4	21.6	12.6
	9.0	3.4	1.0	0.0	0.1	1.1	2.2	11.8	21.4	18.8	12.9	10.5
Rice Production	30019.0	14289.0	6140.3	3827.7	11936.0	29210.0	10944.0	3896.0	3586.0	1866.0	5384.0	23631.0
	32411.0	15848.0	6737.0	5825.0	14954.0	22462.0	13853.0	3274.0	3518.0	1134.8	4331.2	21075.0
	26453.0	14263.0	4800.0	4630.0	19348.0	19552.0	10337.0	4143.9	3305.9	5454.4	14624.6	24374.5
	18461.0	10724.2	8884.7	10799.1	18934.8	22219.9	6800.3	4813.9	5736.4	4301.5	14869.0	20810.0
	24608.0	11671.0	7015.0	14296.0	19132.0	18157.0	8757.3	6184.4	4484.1	4235.7	7818.6	14708.1

Rainfall index-based insurance can be applied because there is a strong correlation between rainfall data and losses experienced by farmers (Choudhury et al., 2016). Too little or too much rainfall has the potential to cause crop failure (Prabowo et al., 2019). Likewise, irrigation management is not optimal (Sukono et al., 2018).

Soil fertility and looseness are factors that also determine the productivity of plants growing on the land, such as rice. As a result, the low productivity of rice can be used as a representation of the losses experienced by farmers. Since rainfall is related to loss of soil looseness which leads to rice productivity, insurance based on the rainfall index can be linked to rice productivity.

The determination of the rainfall index is based on the quarterly rainfall which has the strongest correlation with rice production. The results of calculating the correlation value with the help of Microsoft Excel 2013 can be seen in Table 4.

Table 4: Correlation value between rainfall and rice production per quarter (sig.2-tailed)

Rainfall	Rice Production											
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Apr	0,077	0,274	0,386	-0,238	-0,103	0,096	0,316	-0,629	0,152	-0,407	0,003	0,291
May	-0,038	0,308	-0,321	-0,630	0,153	0,019	0,108	-0,613	-0,215	0,277	0,585	0,827
Jun	-0,118	0,134	-0,557	-0,572	0,170	0,061	-0,123	-0,295	-0,292	0,536	0,646	0,773
Jul	0,253	0,334	-0,674	-0,732	-0,381	0,528	0,108	-0,365	-0,530	0,105	0,123	0,759
Aug	0,314	0,398	-0,767	-0,740	-0.377	0,442	0,175	-0,364	-0,617	0.132	0.109	0.740
Sep	-0,382	-0,099	-0.364	-0.204	0.618	-0.413	-0.299	-0.035	-0.049	0.795	0.866	0.464
Oct	-0.659	-0.359	0.142	-0.074	0.556	-0.218	-0.527	-0.060	0.389	0.661	0.939	0.448
Nov	-0.450	-0.237	0.556	-0.178	-0.026	0.342	-0.314	-0.367	0.532	-0.022	0.455	0.468
Dec	0.931	0.790	-0.368	-0,534	-0.877	0,588	0.853	-0.561	-0.686	-0.881	-0.924	0.176
Jan	-0.797	-0.872	0.244	0.618	0.566	-0.309	-0.917	0.850	0.577	0.763	0.580	-0.381
Feb	-0.451	-0.153	-0.187	-0.332	0.395	-0.073	-0.382	-0.180	0.090	0.650	0.870	0.654
Mar	0.626	0.794	-0.296	-0.527	-0.201	-0.040	0.814	-0.769	-0.532	-0.451	-0.277	0.367

This correlation test is carried out to find the rainfall index which will then be tested for normality which is then used as a reference for calculating premiums. In Table 3 it can be seen that the rainfall data for October is the most strongly correlated with rice production, which is 0.939. The rainfall data for October was selected as the rainfall index. A positive sign means that rainfall is very influential on the amount of rice production or rainfall that has minimal impact on decreasing rice production. A negative sign means that excessive rainfall poses a risk of crop failure, or that minimal rainfall results in abundant harvests.

Rainfall Data for October Normality Test

One type of distribution that is often used to determine the amount of premium is the normal distribution (Prabowo, et al., 2019). The data normality test was conducted to test whether the natural logarithm of the rainfall data for October was normally distributed or not. The normality test was carried out using the Kolmogorov-Smirnov test on the natural logarithm of the rainfall data for October, with the help of Minitab 2016. The following is the hypothesis on the normality test.

H_0: data in (tenth month (October) rainfall) is normally distributed,

H_1: data in (tenth month (October) is not normally distributed.

The level of significance used in the data normality test is 5% with a decision if the p-value ≥ alpha, then H_0 is accepted. This means that the second quarter rainfall data has a lognormal distribution.

One-Sample Kolmogorov-Smirnov Test

		October Rainfall
N		5
Normal Parameters[a]	Mean	9.920
	Std. Deviation	8.6387
Most Extreme Differences	Absolute	.339
	Positive	.339
	Negative	-.234
Kolmogorov-Smirnov Z		.757
Asymp. Sig. (2-tailed)		.615

a. Test distribution is Normal.

Figure 1. Output from SPSS for October rainfall in Banjarnegara Regency 2014 to 2018

In Figure 1, from five data points in the tenth month (October), the p-value is 0.615. Because p-value = 0.615 is greater than alpha = 0.05, the decision taken, namely H_0 is accepted, meaning that the natural logarithm data of the second quarterly rainfall is normally distributed. Based on these results, the rainfall data for the second quarter of Banjarnegara Regency has a lognormal distribution.

The calculation of μ is done annually. In this case, the observation data is rainfall data with the highest correlation to rice production in the quarterly period. Because the data classification is done every four months, in 1 year there are twelve data groups so that $t = 12/12 = 1$. The rainfall data for the second quarter in a row is 4.4, 4.4, 18.3, 20.3, and 2.2. From these data, with equations (3) and (5) obtained

$$\mu = \frac{1}{n-1}\ln\frac{R_n}{R_1} = \frac{1}{4}\ln\frac{2.2}{4.4} = -0.17329$$

and

$$\tilde{\mu} = \mu \times 1 = -0.17329.$$

The calculation of $\sigma = \sqrt{\frac{1}{n}\sum_{j=1}^{n}\left(u_j - \bar{u}\right)^2}$ (for small data) is done by equation (4). The calculation requires the values of u_i and $\bar{u}$, which are calculated using the equations $u_j = \ln\left(\frac{R_j}{R_{j-1}}\right), \forall j, j = 1,2,3, \dots, n$, and $\bar{u} = \frac{\sum_{j=1}^{n-1} u_j}{n-1}$, respectively. Based on the calculation results, $\sigma = 1.31087$ and $\tilde{\sigma} = \sigma\sqrt{t} = 1.31087$ are obtained.

Premium Price Calculation with Black-Scholes Model

Rice Farming Business Insurance/*Asuransi Usaha Tani Padi* (AUTP) calculates the premium (price) for one hectare of land per planting period of 3% of the maximum benefit value of IDR 6,000,000.00 (Prabowo et al., 2019). With a total premium of IDR 180,000.00, the farmer only pays 20% or IDR 36,000.00. While the remaining premium of IDR 144,000.00 is borne by the government.

The premium price calculation uses equation (1). The first step in calculating the premium is to calculate the value of d_2 with equation (2). The R_0 value was chosen from the rainfall data with the strongest correlation. In this article, two R_0s is used for comparison, namely the latest data and the average rainfall data in the quarter with the strongest correlation. Obtained $R_{0,1} = 2.2$ (last data) and $R_{0,2} = 9.92$ (mean). Other data required is the annual risk-free interest rate $r = 0.065$ and the amount of compensation $P = 6{,}000{,}000.00$ IDR.

An example of calculating the premium for the 5th percentile with rainfall data of 2.2 mm. By using a risk-free interest rate of 6.5% per year and for $t = 1$ and $R_{0,1} = 2.2$, equation (2) obtained $d_2 = -0.13219$ and $N(-d_2) = N(0.13219) = 0.447415$. From equation (1), the amount of premium $6{,}000{,}000 \cdot e^{-0.065\cdot 1} \cdot 0.447415 = 2{,}515{,}549$ is obtained.

In the same way, the results of calculating the price of insurance premiums on several percentiles are given in Table 5. In Table 5, two calculations are presented for two references, namely $R_{0,1} = 2.2$ and $R_{0,2} = 9.92$.

Table 5. The price of agricultural insurance premiums in Banjarnegara Regency 2014 to 2018

Percentile	Rainfall R_T	$R_{0,1} = 2.2$			$R_{0,2} = 9.92$		
		$-d_2$	$N(-d_2)$	Premium (IDR)	$-d_2$	$N(-d_2)$	Premium (IDR)
5%	2.2	-0.13219	0.447415	2,515,549	-1.28112	0.100075	562,664
6%	2.2	-0.13219	0.447415	2,515,549	-1.28112	0.100075	562,664
7%	2.2	-0.13219	0.447415	2,515,549	-1.28112	0.100075	562,664
8%	2.2	-0.13219	0.447415	2,515,549	-1.28112	0.100075	562,664
9%	2.2	-0.13219	0.447415	2,515,549	-1.28112	0.100075	562,664
10%	2.2	-0.13219	0.447415	2,515,549	-1.28112	0.100075	562,664
15%	2.2	-0.13219	0.447415	2,515,549	-1.28112	0.100075	562,664
20%	2.64	0.006890	0.502749	2,826,656	-1.14204	0.126719	712,466
25%	3.30	0.177115	0.570291	3,206,407	-0.97181	0.165572	930,912
30%	3.96	0.316200	0.624075	3,508,800	-0.83273	0.202499	1,138,531
40%	4.40	0.396574	0.654159	3,677,948	-0.75235	0.225919	1,270,209
50%	4.40	0.396574	0.654159	3,677,948	-0.75235	0.225919	1,270,209
60%	12.74	1.207594	0.886398	4,983,690	0.058666	0.523391	2,942,716
70%	18.70	1.500359	0.933239	5,247,049	0.351431	0.637368	3,583,538
80%	19.90	1.547806	0.939165	5,280,369	0.398878	0.655008	3,682,722

90%	20.30	1.562988	0.940972	5,290,527	0.414059	0.660585	3,714,074
100%	20.30	1.562988	0.940972	5,290,527	0.414059	0.660585	3,714,074

The implementation of AUTP stipulates that farmers only need to pay 36,000.00 IDR per hectare per growing season, with government assistance of 144,000.00 IDR, so that the total AUTP premium is 180,000.00 IDR. The calculation results show that the AUTP premium is lower.

From Table 5, the choice of percentile also greatly influences the size of the premium. The premium increases as the percentile increases. This is due to the higher risk of failure or loss in the agricultural sector. Still referring to Table 5, the use of reference rainfall data gives very different results. The smallest reference rainfall data, namely $R_{0,1} = 2.2$, produces a very high premium. The smallest, average and latest rainfall data gives a result those are not in line with the AUTP premium, especially at the 5th percentile.

Conclussion

The implementation of AUTP stipulates that farmers only need to pay 36,000.00 IDR with government assistance of 144,000.00 IDR, so the total AUTP premium is 180,000.00 IDR per hectare per planting season. The results showed that the premium price was 3,671,910.00 IDR if the last rainfall data reference was used (2.2 mm). When used as a reference, the average overall rainfall data (9.92 mm) obtained a premium of 562,664.00 IDR. The calculation results obtained in this study show that the AUTP premium is lower. From the calculation results, it can be concluded that the choice of percentile and rainfall reference R_0 greatly influences the premium.

Suggestions that can be conveyed are the use of an index other than rainfall, for example in East Nusa Tenggara which never rains and is evenly dry every month then the drought index can be chosen. In addition, the humidity index, soil fertility level, and others can be used.

The results of this study have weaknesses in the illustrations provided. Rice plants require 4 months of planting time, while in this article data processing is carried out per month. However, the results of this study can be implemented for insurance that targets premium payments per month, or for plants whose planting period is 1 month.

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