Available online at http://iorajournal.org/indx.php/orics/index

Operations Research: International Conference Series

e-ISSN: 2722-0974
p-ISSN: 2723-1739

Vol. 1, No. 4, pp. 118-123, 2020

Price Determination of Agricultural Insurance Premium Based on Rainfall Index With Black-Scholes Model

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Abstract

This article discusses the use of the Black-Scholes model to calculate the price of agricultural insurance premiums based on the rainfall index. The Black-Scholes model is one of the models used to determine option prices. The research method used is studying the material through mathematics books and journals and collecting secondary data. The data used in this study are rainfall data and rice production data in Magelang City from 2019 to 2020. Based on the results and discussion, the quarterly rainfall data that has a strong correlation are quarterly rainfall one and three. For the reference size with the latest rainfall data (319.5 mm) the premium obtained is IDR 3,557,321.00 per hectare, while for the reference size with the average rainfall data (1094,725 mm) the premium obtained is IDR 623,387. ,00 per hectare. Based on the calculation results, the higher the percentile value, the higher the premium value for the two reference sizes.

Keywords: Agricultural Insurance, Rainfall, Rice Production, Black-Scholes Model

1. 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. Rainfall that is too high or too low can disrupt business in the agricultural sector (Sudrajat, 2019).

To reduce farmers' losses due to crop failure caused by excessive rainfall and other causes, agricultural insurance was introduced (Fadhil et al., 2021; Pasaribu, 2010; Shofiyati et al., 2021). 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. The rainfall is represented by a rainfall index which is used as a reference to determine the premium (Smith and Watts, 2019; Meze-Hausken, 2009).

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(Cummins, 1998; Satri et al., 2022). The agricultural insurance scheme is carried out by means of the insurer receiving a premium to provide compensation (compensation, benefits, benefits, sum assured) to the insured due to loss or crop failure. In calculating the premium, the organizers only base it on one cause, such as 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 time period for data formation(Yusuf et al., 2021; Sujarwo, 2017; Dartanto 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 (eg shares) at a certain price and time period. There are two kinds of options, namely European options and American options. European options are exercised only at maturity, while American options are exercised before or at maturity (Johnson and Stulz, 1987; Karatzas, 1998; Geske and Roll, 1984).

Options have two types of contracts, namely call options and put options. 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 time 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 of time (Zhao et al., 2013; Stoll, 1969).

One of the models used to determine option prices is the Black-Scholes model. The equation between the option calculation and the calculation of agricultural insurance premiums causes the Black-Scholes model to be used to determine the price of agricultural insurance premiums based on the rainfall index. The determination of the premium is done by finding the largest correlation between rainfall data and rice production. The rainfall data with the largest correlation was chosen as the rainfall index (Shi and Jiang, 2016; Islam et al., 2018). Thus, the insurance scheme is called rainfall index-based agricultural insurance.

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 geographic area of Magelang. This article uses two reference data, namely the latest data and the overall average rainfall index data. The comparison of the premium size is given as an analysis referring to the use of the two types of reference data

2. Research Methodology

The method used in this research is literature study and secondary data collection. The data used are monthly rainfall and rice production. Data analysis was carried out with the help of Microsoft Excel 2013 and Rstudio. The research steps used are as follows:

1) Collect data on rice production and monthly rainfall in Magelang City from 2019 to 2020;
2) Converting annual rainfall and rice production data into quarterly data;
3) Perform a correlation test to determine the rainfall index;
4) Testing the normality for the natural logarithm of the quarterly data with the rainfall that is the strongest correlated with rice production; and
5) calculate the price of insurance premiums to be paid based on the data obtained.

2.1. Data

The data used in this study is data on rainfall and rice production in Magelang City from 2019 to 2020. The data used are shown in Table 1 and Table 2.

Table 1. Rainfall data for Magelang City in 2019-2020 (mm)

Period	2019	2020
January	875	503
February	437	422
March	328	409.4
April	318	301
May	42	180
June	166	60
July	104	21
August	154	5,85
September	206	121.5
October	3	306
November	211	481
December	379	515

Table 2. Rice production data for the City of Magelang in 2019-2020 (tons).

Period	2019	2020
January	229	198.4
February	225.36	190.96
March	264	194,56
April	182.4	168
May	176.32	176.32
June	186	188.48
July	187.2	187.2
August	188.48	188.48
September	188.48	187.2
October	197.12	168
November	193.44	188.48
December	193.44	176.32

The distribution of rainfall data per quarter is based on seasonal changes, namely the dry season, the rainy season, and the transition season. The start of the rainy season usually starts in January, while the dry season starts from May.

Thus, the transition season is placed from September. Basically, the transition seasons are fairly short, so this grouping is a bit rough, and is only to help in making it easier to understand the division of time into seasons.

Table 3 presents rainfall data calculated every four months (quarterly). The first quarter starts from January 2019 - April 2019. Rainfall in this quarter is the amount of each rainfall in May - August 2019, for the second quarter of 2019 data is the sum of rainfall data for September - December 2019, for the third quarter data 2019 is the sum of the rain data for January – April 2019. Likewise for the data for 2020.

Table 3. Quarterly rainfall data for Magelang City in 2019-2020 (mm)

Period	2019	2020
Quarter one (Dry)	466	319.5
Quarter two (Pancaroba)	799	1423.5
Third Quarter (Rain)	1958	1635.4

It can be seen in the table that in the first quarter the rainfall tends to be low, this is due to the dry season. In the second quarter the rainfall can be high or low, this is because in this month the transition season occurs. The transition season is a transitional period between two seasons, namely the rainy season and the dry season. Meanwhile, in the third quarter the rainfall tends to be high, this is due to the occurrence of the rainy season.

Rice production data is also presented as quarterly rice production data in Magelang City. As in Table 4 below.

Table 4. Quarterly rice production data in Magelang City in 2019-2020 (tons)

Period	2019	2020
Quarter one (Drought)	466	319.5
Quarter two (Transition)	799	1423.5
Third Quarter (Rain)	1958	1635.4

As with the rainfall data, for the first quarter rice production data, namely the number of rice production data from May to August. The second quarter is the amount of data from September to December. While the third quarter is data on rice production from January to April.

2.2. Determination of Rainfall Index

Correlation test is used to determine the relationship between two variables. Insurance based on rainfall index (rainfall/weather) can be applied because there is a strong correlation between rainfall data and losses experienced by farmers. Too little or too much rainfall has the potential to cause crop failure. 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 5.

Table 5. Correlation values of each quarterly rainfall and rice production

Rainfall	Rice production		
	Quarter one (Dry)	Quarter two (transition)	Third Quarter (Rain)
Quarter one (Dry)	-0.9999999999873	1.0000000000000	1.0000000000000
Quarter two (transition)	0.9999999999873	-1.0000000000000	-1.0000000000000
Third Quarter (Rain)	-0.9999999999876	1.0000000000000	1.0000000000000

This correlation test is carried out to find a rainfall index which will then be tested for normality which is then used as a reference for calculating premiums. In Table 5, it can be seen that the rainfall data in the first and third quarters are the most strongly correlated with rice production in the second and third quarters, which is 1.

2.3. Third Quarter Rainfall Data Normality Test

One type of distribution that is often used to determine the amount of premium is the normal distribution. The data normality test was conducted to test whether the natural logarithm of the second quarter rainfall data was normally distributed or not. The normality test was carried out using the Kolmogorov-Smirnov test on the natural logarithm of the rainfall data in the first and third quarters, with the help of Eviews 10. The following is a hypothesis on the normality test:

H0 : Data ln (rainfall in the first and third quarters) is normally distributed

H1 : Data ln (rainfall in the first and third quarters) 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 H0 is accepted, meaning that the rainfall data for the first and third quarters are lognormally distributed. The p-value is greater than 0.650 because the p-value = 0.650 is greater than alpha = 0.05, so the decision taken is H0 is accepted, meaning that the natural logarithm of rainfall in the first and third quarters is normally distributed. Based on these results, the rainfall data for the first and third quarters of Magelang City are lognormally distributed.

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 one year there are three groups of data so that t 3/ 12 0.25 . The first and third quarterly rainfall data based on time are 1958; 466 ; 1635,4; 319.5. From these data, with Equations (3) and (5) obtained:

$$\tilde{\mu} = (\frac{1}{n-1}\ln\frac{R_n}{R_1})t = (\frac{1}{3}\ln\frac{319.5}{1958})0.25 = -0.1510767958$$

Calculatio $\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(u_i - \bar{u})^2}$ (for small data) is done by Equation (4).

The calculation requires the values of u_i and $\bar{u}$ which are calculated by the equation $u_i = \ln\left(\frac{R_j}{R_{j-1}}\right) \forall j, j = 2,3,\dots,n$ dan $\bar{u} = \frac{\sum_{i=1}^{n-1} u_i}{n-1}$ Based on the calculation results obtained = 1.61265 and = t= 0.80632.

2.4. Premium Price Calculation with Black Scholes Model

The calculation of the premium price uses equation (1). The first step in calculating the premium is to calculate the value of d_2 with Equation (2). The value of R_0 was chosen from the rainfall data with the strongest correlation. In this article, two R_0 are used for comparison, namely the latest data and the average rainfall data in the quarter with the strongest correlation. Obtained $R_{0,1}$=319.5 mm (last data) and $R_{0,2}$=1094.725 (mean data). Other data required is the annual risk-free interest rate r = 0.065 and the amount of compensation P = 6,000,000.00 rupiah.

The results of calculating the price of insurance premiums on several percentiles are given in Table 6 and Table 7. In Table 6 and Table 7, respectively, two calculations are presented for two references, namely $R_{0,1}$=319.5 mm (last data) and $R_{0,2}$=1094, 725.

Table 6. The price of agricultural insurance premiums in Magelang City in 2019-2020 with $^{R}{}_{0.1}$ = 319.5 mm.

Persentil		d2	-0,2699	N(-d2)	Premi
0.05	341.475	-0.2699	0.26986	0.6026	3557321
0.1	363.45	-0.3472	0.34721	0.6331	3737372
0.15	385.425	-0.42	0.42001	0.6628	3912699
0.2	407.4	-0.4888	0.48878	0.6844	4040210
0.25	429.375	-0.5539	0.55394	0.7088	4184250
0.3	451.35	-0.6158	0.61584	0.7291	4304087
0.35	525.47	-0.8044	0.80441	0.7881	4652381
0.4	703.88	-1.1669	1.16694	0.877	5177184
0.45	882.29	-1.4471	1.44712	0.9251	5461132
0.5	1060.7	-1.6755	1.67552	0.9525	5622882
0.55	1239.11	-1.8683	1.86833	0.9686	5717925
0.6	1417.52	-2.0352	2.03515	0.9788	5778138
0.65	1595.93	-2.1822	2.18218	0.9854	5817100
0.7	1685.66	-2.25	2.25001	0.9878	5831268
0.75	1731.05	-2.283	2.28297	0.9887	5836581

0.8	1776.44	-2.3151	2.31507	0.9896	5841894
0.85	1821.83	-2.3464	2.34636	0.9904	5846616
0.9	1867.22	-2.3769	2.37688	0.9911	5850749
0.95	1912.61	-2.4067	2.40667	0.9918	5854881
1	1958	-2.4358	2.43576	0.9925	5859013

Table 7. The price of agricultural insurance premiums in Magelang City in 2019-2020 with $R_{0,2}$ = 1094.725.mm.

Persentil		d2	1,2575	N(-d2)	Premi
0.05	341.475	1.25745	-1.2575	0.1056	623387
0.1	363.45	1.1801	-1.1801	0.119	702491
0.15	385.425	1.1073	-1.1073	0.1357	801076
0.2	407.4	1.03853	-1.0385	0.1515	894348
0.25	429.375	0.97337	-0.9734	0.166	979946
0.3	451.35	0.91147	-0.9115	0.1814	1070856
0.35	525.47	0.7229	-0.7229	0.2358	1391995
0.4	703.88	0.36037	-0.3604	0.3594	2121642
0.45	882.29	0.08019	-0.0802	0.4681	2763329
0.5	1060.7	-0.1482	0.14821	0.5557	3280457
0.55	1239.11	-0.341	0.34101	0.6331	3737372
0.6	1417.52	-0.5078	0.50784	0.6915	4082124
0.65	1595.93	-0.6549	0.65486	0.7422	4381420
0.7	1685.66	-0.7227	0.7227	0.7642	4511293
0.75	1731.05	-0.7557	0.75566	0.7734	4565603
0.8	1776.44	-0.7878	0.78776	0.7823	4618142
0.85	1821.83	-0.819	0.81905	0.791	4669501
0.9	1867.22	-0.8496	0.84957	0.7995	4719679
0.95	1912.61	-0.8794	0.87936	0.8078	4768676
1	1958	-0.9084	0.90844	0.8159	4816493

The premium price generated in this study is pure premium because it is only based on field conditions, namely rainfall and rice production. Not added with other costs. The implementation of AUTP stipulates that farmers only need to pay IDR 180.000,00 per hectare per planting season. The use of the reference rainfall data R_0 gives very different results. The smallest reference rainfall data, namely $R_{0,1}$=319.5 mm, resulted in a very high premium. The average rainfall data, namely $R_{0,2}$= 1094.725.mm, gives premium results that are closer to the AUTP premium, especially at the 5th percentile. The choice of percentile is also very influential on the amount 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.

3. Conclusion

The implementation of AUTP stipulates that farmers only need to pay IDR 36,000.00 with government assistance of IDR 144,000.00 so that the total AUTP premium is Rp. 180,000.00 per hectare per growing season. The results showed that the premium price was IDR 3,557,321.00 when the latest rainfall data reference (319.5 mm) was used. When used as a reference for the average overall rainfall data (1094,725 mm) the premium is IDR 623,387.00.

Based on the calculation results, it can be concluded that the selection of the percentile and the reference rainfall of 1094.72 greatly influences the premium. The average rainfall data, namely $R_{0,2}$=1094.725 mm, gives a premium result that is closer to the AUTP premium, especially at the 5th percentile. The higher the percentile value, the higher the premium value for both R_0. Suggestions that can be conveyed by researchers are the use of indices other than rainfall, for example drought index, humidity index, soil fertility level, etc. and try to use complete data without missing values with a longer period of time.

References

Cummins, J. D. (1988). Risk-based premiums for insurance guaranty funds. *The journal of Finance*, *43*(4), 823-839.

Dartanto, T., Halimatussadiah, A., Rezki, J. F., Nurhasana, R., Siregar, C. H., Bintara, H., ... & Soeharno, R. (2020). Why do informal sector workers not pay the premium regularly? Evidence from the National health insurance system in Indonesia. *Applied health economics and health policy, 18*(1), 81-96.

Fadhil, R., Yusuf, M. Y., Bahri, T. S., & Maulana, H. (2021). Agricultural insurance policy development system in Indonesia: a meta-analysis. *Journal of Hunan University Natural Sciences, 48*(2).

Geske, R., & Roll, R. (1984). On valuing American call options with the Black-Scholes European formula. *The Journal of Finance, 39*(2), 443-455.

Islam, M. M., Ahamed, T., & Noguchi, R. (2018). Land suitability and insurance premiums: A GIS-based multicriteria analysis approach for sustainable rice production. *Sustainability, 10*(6), 1759.

Johnson, H., & Stulz, R. (1987). The pricing of options with default risk. *The Journal of Finance, 42*(2), 267-280.

Karatzas, I. (1988). On the pricing of American options. *Applied mathematics and optimization, 17*(1), 37-60.

Meze-Hausken, E., Patt, A., & Fritz, S. (2009). Reducing climate risk for micro-insurance providers in Africa: A case study of Ethiopia. Global Environmental Change, 19(1), 66-73.

Pasaribu, S. M. (2010). Developing rice farm insurance in Indonesia. *Agriculture and Agricultural Science Procedia, 1*, 33-41.

Santri, S. H., Yaswirman, Y., Warman, K., & Fauzi, W. (2022). Accountability answers company insurance life based investing against the risk of failure to pay for policyholders. *Linguistics and Culture Review, 6*, 427-437.

Shi, H., & Jiang, Z. (2016). The efficiency of composite weather index insurance in hedging rice yield risk: evidence from China. *Agricultural Economics, 47*(3), 319-328.

Shofiyati, R., Takeuchi, W., Pasaribu, S. M., & Irawan, Y. R. (2021). Space-based drought analysis to support agricultural insurance facing climate change. In IOP Conference Series: *Earth and Environmental Science, 648*(1), p. 012130.

Smith, V. H., & Watts, M. (2019). Index based agricultural insurance in developing countries: Feasibility, scalability and sustainability. Gates Open Res, 3(65), 65.

Stoll, H. R. (1969). The relationship between put and call option prices. *The Journal of Finance, 24*(5), 801-824.

Sudrajat, I. S. (2019). Farmer Behavior on Facing Production Risk of Organic Rice Farming in Indonesia. *Journal of Economics and Sustainable Development, 10*(8), 1-8.

Sujarwo, S. (2017). Factors Affecting Farmers'acceptability Toward Agricultural Insurance Program In Malang, East Java, Indonesia. *Agricultural Socio-Economics Journal, 17*(3), 97-104.

Yusuf, M. Y., Fadhil, R., Bahri, T. S., & Maulana, H. (2021). Comparison study of agricultural insurance government subsidy and farmers' self-subsistent premium in Indonesia. *Economia agro-alimentare/Food Economy-Open Access*, *23*(2).

Zhao, Y., Ma, L., Xie, G., & Cheng, T. E. (2013). Coordination of supply chains with bidirectional option contracts. *European Journal of Operational Research, 229*(2), 375-381.