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DETERMINING AGRICULTURAL INSURANCE PREMIUMS USING THE BLACK-SCHOLES APPROACH BASED ON LINEAR REGRESSION OF POTATO PRODUCTION AND PRICES

Sri Purwani [1*], Sarah Sutisna [2], Rayyan Al Muddatstsir Fasa[3]

[1,2,3] Department of Mathematics, Faculty of Mathematics and Natural Sciences, Universitas Padjadjaran, Jl. Raya Bandung-Sumedang km 21 Jatinangor, Sumedang 45363. Indonesia
*Corresponding author's e-mail: * **sri.purwani@unpad.ac.id***

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ABSTRACT

Price fluctuations, which often occur in the agricultural sector, cause farmers to experience losses when selling prices are not balanced with production costs. The government is trying to minimize farmers' losses by issuing an agricultural insurance program. One of the problems with agricultural insurance is determining the premium that farmers must pay so as not to disadvantage the insurance company. This paper explores the price of insurance premiums associated with potato cultivation in West Java, Indonesia. In addition, this research analyzes the factors that influence prices by focusing on the relationship between potato production levels and market prices. Therefore, a comprehensive data set of potato production data and associated prices is used. Regression analysis, as a statistical technique, is used to model the relationships. The Black-Scholes method then uses the obtained result to determine insurance premiums. This method is used due to a theoretical framework for pricing options that allows selecting an option's fair price using a structured, defined methodology that has been tried and tested. The premium values that depend on the trigger value are then obtained with a range of prices between IDR 5,687,670 and IDR 18,067,953 for an insured amount of IDR 39,403,000 per contract period. The premium price range allows farmers to choose the right agricultural insurance policy. It also allows insurance companies to determine insurance premiums for potato cultivation.

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1. INTRODUCTION

The agricultural sector is the third largest contributor to the Gross Domestic Product (GDP), which helps food security in Indonesia [1]. The potato commodity is one of the agricultural sub-sectors that can support food security. However, potato farming often faces fluctuations in prices and production [2]. Price fluctuations result in a mismatch between selling prices and production costs experienced by farmers at the farm level [3]. This affects potato farmers, having a risk of threat of loss when the crop fails. Therefore, this threat requires efforts to minimize the risk of loss. Agricultural insurance is an alternative risk management that is worth considering.

The problem with the insurance scheme is determining the premium amount, which does not burden farmers but does not disadvantage insurers. The calculation of the premium price is similar to the calculation of the European-type put option [4]. One of the mathematical models commonly used to determine European-type options is the Black-Scholes model. The model can be used for European or American option pricing [5], [6], [7], [8]. It can also be used to determine the price-based agricultural insurance premiums. The premium amount is determined by looking for the most significant correlation between the price data and potato production. Price data, the most critical correlation, determines insurance premiums. Thus, the insurance scheme is called price-based agricultural insurance.

Many studies were carried out using the Black-Scholes model to determine premium prices. Qosim et al. [9] used a stochastic weather generator model to simulate price data. The simulation results were then used to determine agricultural insurance premium prices. Aggraeni et al. [10] used the Historical Burn Analysis method to calculate a temperature value. Using the Black-Scholes method, this value was used as a reference for determining the premium value. Chicaiza and Cabedo [11] used the Black-Scholes method to estimate high-cost disease insurance premiums in Colombia, with the estimated premium value being similar to that obtained using an actuarial method. Prabowo et al. [12] determined the price of agricultural insurance premiums based on the correlation between potato production and the price index in Banjarnegara Regency. Roji [13] determined the value of agricultural insurance premiums in the city of Bogor using the Black-Scholes method by previously determining the exit and trigger values using the Historical Burn Analysis method. The Black-Scholes method determined agricultural insurance premium prices based on the rainfall index [14]. Hidayat and Sembiring used the Historical Burn Analysis method to calculate the rainfall index to determine crop insurance premiums using the Black-Scholes method [15]. Togatorop et al. [16] determined agricultural insurance premium prices for the commodities of cayenne pepper based on prices in Salatiga. In addition, Golbabai et al. [17] numerically analyzed a model of time fractional Black–Scholes European option pricing, which arises in the financial market.

This study aims to determine the strongest correlation between the independent and dependent variables, meanly potato production and potato prices, and to determine the agricultural insurance premium using the Black-Scholes model. The determined premium allows farmers and insurance companies to take advantage in deciding their future strategies.

2. RESEARCH METHODS

The following steps describe the overall stages involved in accomplishing the research:

1. Collect price and production data.
2. Determine the price data that has the strongest correlation with potato production.
3. Determine a linear regression model with the strongest correlation between the price data and potato production in the month.
4. Conduct a correlation test between price predictions and potato production.
5. Perform a normality test on the reference price.
6. Determine σ and μ.
7. Determine premiums using the Black-Scholes method.

Table 1 shows the data used in this study, which consists of monthly potato prices and monthly potato production in West Java, Indonesia, from 2018 to 2021, obtained from the Food Crops and Horticulture Office of West Java Province. The monthly price is presented in IDR/Kg, whereas the monthly production is in Kg for 2018-2021.

Table 1. Monthly Potato Prices and Production in West Java Indonesia

Month	2018		2019		2020		2021	
	Price (IDR/Kg)	Production (Kg)	Price (IDR/Kg)	Production (Kg)	Price (IDR/Kg)	Production (Kg)	Price (IDR/Kg)	Production (Kg)
Jan	9087	24254100	6185	21987900	8975	13142000	7504	24771700
Feb	8299	26372000	4929	23078500	8018	20019200	7566	23182000
Mar	7695	27446700	4564	25767200	6389	19190800	7775	24923300
Apr	7435	25254600	5305	25764400	6944	20293100	8708	20805100
May	7240	28758800	6686	25811200	8730	17693100	9757	28250100
Jun	7055	23036000	7001	26511300	8684	23298400	8568	24081000
Jul	7506	21648900	8150	20190000	9167	18083500	8549	22005000
Aug	7459	19312400	9960	19609400	9400	16628000	9045	17419300
Sep	7505	19147600	8587	14641400	8438	11622500	8414	15490500
Oct	6925	18010800	7093	14701100	7871	11761300	7774	14286400
Nov	6561	18075100	6920	16612300	7430	11939100	7059	12831400
Dec	6267	14218900	7847	10743400	8086	13185300	7772	12435900

2.1 Black-Scholes Method

The price of a European put option determined by the Black-Scholes formula is as follows [18]:

$$\text{Premium} = P \times e^{-rt} \times N\left(-d_2\right) \tag{1}$$

where P is the payoff (amount of compensation that will be received by farmers if a claim occurs), r is the interest rate per year, t is time (yearly), and $N\left(-d_2\right)$ is the standard normal cumulative distribution function of d_2 or the probability that the price is less than the trigger value.

The payoff value P is based on the capital and operational costs of potato farming. The payoff from price-based insurance can be paid if the actual (last) price R_0 is less than the triggered measurement R_T. Furthermore, the conditions related to the payoff (compensation) that can be paid are:

$$d_2 = \frac{\ln\left(\frac{R_0}{R_T}\right) + \mu.t}{\sigma\sqrt{t}} \tag{2}$$

where R_0 is the latest (recent) price prediction on the price prediction data obtained from the simple linear regression equation between the price and potato production, R_T is the triggered measurement, namely the prediction of the potato price, which is used to trigger (determine) the amount of the premium, calculated as a percentile of the predicted price, μ is annual expected rate of return predicted price, and σ is volatility (annual standard deviation of the price prediction return).

In this study, the price prediction returns are lognormally distributed [19] which is a condition that must be met when using the Black-Scholes model. The values μ and σ are the mean and standard deviation of the price prediction data, respectively. For example, the price prediction data are denoted by R_j ; $j = 1, 2, 3, \ldots, n$, then to calculate the average return of potato price prediction data is given as follows:

$$\mu = \frac{1}{n-1} \ln \frac{R_n}{R_1} \tag{3}$$

The annual unbiased standard deviation is formulated as follows:

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

where

$$u_j = \ln\left(\frac{R_j}{R_{j-1}}\right), \quad j = 2,3,\cdots,n \tag{5}$$

is the return prediction of potato prices, and

$$\bar{u} = \frac{1}{n-1}\sum_{j=2}^{n} u_j \tag{6}$$

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

3. RESULTS AND DISCUSSION

Determination of the price data is based on the price that has the strongest correlation with potato production because the highest correlation value (in absolute value) implies a perfect linear dependence between the variables with all data points lying on a line. The price data having the strongest correlation with potato production will be used to determine the insurance premium. The results of calculating the Pearson correlation values can be seen in **Table 2**.

Table 2. Correlation Coefficient of Potato Price and Production

Month	Correlation Coefficient
Jan	-0.3496
Feb	0.0959
Mar	0.1404
Apr	-0.6016
May	-0.1673
Jun	-0.4264
Jul	-0.6930
Aug	-0.2186
Sep	-0.8188
Oct	-0.8482
Nov	-0.9215
Dec	-0.6435

Table 2 shows that November's price data has the strongest correlation, in absolute value, with potato production, namely -0.921. The high absolute value of -0.921 indicates that the data points lie almost perfectly on a monotonically decreasing line with a negative sign. November's price data from 2018 to 2021 are then selected as the price data used to construct a linear regression model.

3.1 Linear Regression between November's Potato Price and Potato Production

The relationship between the potato price and production is then expressed as a simple linear regression equation, in which the independent variable x is potato production and the dependent variable y is potato prices. The data pairs used to create a linear regression model can be seen in **Table 3**.

Table 3. Data Pairs for Building a Simple Linear Regression Model

November's data	Year			
	2018	2019	2020	2021
Price (IDR/Kg)	6561	6920	7430	7059
Potato production (Kg)	18075100	16612300	11939100	12831400

Performing the linear regression method on data in Table 3, results in an equation as follows:

$$y = 8662.5 - 0.000112x \tag{7}$$

The linear regression model (7) has the coefficient of determination $R^2 = 0.8492$ which means that the model fits the real data points perfectly. From another perspective, as Equation (7) is a linear least square approximation, it is the best linear fit for the data points, as it has the smallest average least squares errors amongst other linear polynomials approaching the data points. With the linearity assumption, the regression model (7) is used to predict potato prices for each month, the results of which are given in Table 4.

Table 4. Monthly Predictions of Potato Prices from 2018-2021

Month	2018		2019		2020		2021	
	Prediction Price (IDR/Kg)	Production (Kg)	Prediction Price (IDR/Kg)	Production (Kg)	Prediction Price (IDR/Kg)	Production (Kg)	Prediction Price (IDR/Kg)	Production (Kg)
Jan	5947	24254100	6201	21987900	7192	13142000	5889	24771700
Feb	5710	26372000	6079	23078500	6421	20019200	6067	23182000
Mar	5589	27446700	5778	25767200	6514	19190800	5872	24923300
Apr	5835	25254600	5778	25764400	6391	20293100	6333	20805100
May	5443	28758800	5773	25811200	6682	17693100	5499	28250100
Jun	6083	23036000	5694	26511300	6054	23298400	5966	24081000
Jul	6239	21648900	6402	20190000	6638	18083500	6199	22005000
Aug	6501	19312400	6467	19609400	6801	16628000	6713	17419300
Sep	6519	19147600	7024	14641400	7362	11622500	6929	15490500
Oct	6646	18010800	7017	14701100	7346	11761300	7063	14286400
Nov	6639	18075100	6803	16612300	7326	11939100	7226	12831400
Dec	7071	14218900	7460	10743400	7187	13185300	7271	12435900

Table 4 shows the prediction of potato prices using the linear regression model (7), both in terms of interpolation and extrapolation, meanly inside and outside the modeling range. Regarding extrapolation, a linear regression model can be the best fit because higher degree least squares approximation quickly diverges outside the modeling range, except when using orthogonal polynomials such as Legendre or Chebyshev polynomials as a basis. Regression modeling using orthogonal polynomials provides a stable system of linear equations, resulting in an accurate solution to the regression model. Therefore, the linear regression model is used to model the price data inside and outside the modeling range.

3.2 Pearson Correlation Values of Regression Result Data

Calculation of the Pearson correlation values using regression results from Table 4 is presented in Table 5.

Table 5. Correlation Coefficients of Prediction Price and Production

Month	Correlation coefficient
Jan	-1
Feb	-1
Mar	-1
Apr	-1
May	-1
Jun	-1
Jul	-1
Aug	-1
Sep	-1
Oct	-1
Nov	-1
Dec	-1

Table 5 shows that the price prediction data as a whole has a very strong or perfect correlation (in absolute value) with potato production, which is equal to -1. This means that all data points lie perfectly on a monotonically decreasing line. Therefore, the selection of price data can be freely determined. In this study, November was chosen as the final price, which will be used to determine the premium.

3.3 Month's Price Data Normality Test of the Strongest Correlation (Regression Case)

The Black-Scholes model assumes that the price data is normally distributed logically. Hence, the data normality test was conducted to test whether the natural logarithm of November's price data is normally distributed. The normality test was carried out by using the Kolmogorov-Smirnov test. A significance level of 0.05 was used. The formulation of the hypothesis for the normality test is as follows:

H_0: ln (November's price data) is normally distributed.
H_1: ln (November's price data) is not normally distributed.

Table 6. Normality Test (Kolmogorov-Smirnov)

Statistic	0.24187				
p-Value	0.86885				
Rank	8				
α	0.2	0.1	0.05	0.02	0.01
Critical Value	0.44698	0.50945	0.56328	0.62718	0.66853
Reject?	No	No	No	No	No

In **Table 6**, a *p*-value of 0.869 is obtained and the value is greater than $\alpha = 0.05$. The decision taken is that H_0 is accepted, meaning that the natural logarithm data from November's price data are normally distributed.

3.4 Determination of μ and σ

Potato farming is seasonal farming, which is usually harvested once every four months. Hence, the time t = 3/12 = 0.25. Calculation of the mean μ using **Equation (3)** is performed on predicted price data of potatoes, namely 6639, 6802, 7326, and 7226, as is required when applying the Black-Scholes model. Applying **Equation (3)** on those data results in:

$$\mu = \frac{1}{n-1}\ln\frac{R_n}{R_1} = \frac{1}{3}\ln\frac{7226}{6639} = 0.02824\,, \quad n = 4$$

and $\tilde{\mu} = \mu \times t = 0.00706$.

The value of σ is calculated according to **Equation (4)** which requires some numbers as shown in **Table 7**.

Table 7. Calculation Steps of σ

j	R_j	u_j	$\bar{u}$	$(u_j - \bar{u})^2$
1	6639	-	0.02824	-
2	6802	0.02425		0.0000159201
3	7326	0.07421		0.0021132409
4	7226	-0.01374		0.0017623204

From **Table 7** it is obtained that the average return is $\bar{u} = 0.02824$. Then, calculating σ **Equation (4)** gives the following values:

$\sigma = 0.03591$ and $\tilde{\sigma} = \sigma\sqrt{t} = 0.01795$.

3.5 Premium Price Calculation Using the Black-Scholes Method

With the values μ and σ determined in Section 3.4, the premium price (1) can be calculated by first calculating the value of d_2 using **Equation (2).** The R_0 value is the last potato price prediction data, namely $R_0 = 7226$. Suppose the risk-free interest rate used is $r = 0.063$. It is known that the sum insured is the sum of the capital costs and operational costs of potato farming, i.e., P = IDR 39,403,000. For example, calculating the premium for the 60*th* percentile with predicted potato prices of 7141 and $R_0 = 7226$ and first applying Equation (2) results in $d_2 = 1.05096$ and $N(-d_2) = N(-1.05096) = 0.14663$ from the standard normal cumulative distribution function of d_2. Then, using **Equation (1)** gives the amount of the premium as follows:

$$\text{Premium} = \text{IDR}\,39,403,000 \times e^{-0.063\times 0.25} \times 0.14663$$
$$= \text{IDR}\,5,687,670$$

In the same way, the prices for other percentiles can be obtained as shown in **Table 8**.

Table 8. Potato Agricultural Insurance Premium Prices

Percentile	Prediction Price (IDR)	d_2 (2)	$N(d_2)$	Premium
60	7141	1.05096	0.14663	IDR 5,687,670
65	7205	0.55700	0.28876	IDR 11,200,345
70	7236	0.31627	0.37589	IDR 14,580,070
75	7251	0.20090	0.42038	IDR 16,305,641
80	7266	0.08577	0.46582	IDR 18,067,953

Table 8 shows that with an insured amount of IDR 39,403,000, the premium price is in the range of IDR 5,687,670 to IDR 18,067,953, in which the relationship between predicted prices and premium is illustrated in **Equation (1)** and **Equation (2)**. The results can be used to determine the price of agricultural insurance premiums that must be paid every planting season with a planting area of 1 *ha*. The trigger value of the price and various premium price values can be used to consider purchasing insurance. Full payment of the loss, which is equal to the sum insured, is made if the price that occurs is lower than the insured price (triggered during the insured period).

4. CONCLUSIONS

The agricultural insurance premium value is calculated using the Black-Scholes method. The calculation of the price-based-potato-agricultural insurance premium results in the lowest premium price with a trigger price of 7141 and the sum insured of IDR 39,403,000.00 is IDR 5,687,670, whereas that resulting in the highest premium price with a trigger price of 7266 and an insured amount of IDR 39,403,000.00 is IDR 18,067,953. The results show that the greater the trigger price value is, the greater the premium payment is.

Future research regarding reference price data in determining premium prices might be better not to use the latest data but to use the average, median, or mode as reference data. In addition, in selecting the model for determining the premium, copula can also be used to be more adaptable to conditions in the field. Furthermore, some implications and practical uses of the results may be investigated in future work.

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