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Application of Black Scholes Method to Determining Premium Insurance in the Potato Agricultural Based on Price Index

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Abstract

Potato is one of the leading horticultural commodities. Potato farming business often experiences price fluctuations that cause losses to farmers. The government is making efforts to minimize the farmers' losses by issuing agricultural insurance programs. This study aims to determine the relationship between potato prices at the provincial level and potato prices at the farmer level and to determine agricultural insurance premiums based on the price index. The data used are potato price data at the West Java Province level and potato price data at the farmer level in Pangalengan District. The correlation between provincial level prices and farmer level prices can be obtained using the Pearson Product Moment correlation method. The price index is calculated using the relative price index method. Determination of the premium to be paid by farmers using the Black-Scholes method. The results of the analysis show that potato prices at the West Java Province level have a very strong correlation with farmer prices in Pangalengan District in October. Based on the Black-Scholes method, the premium value depends on the trigger value obtained with a price range between IDR 9,806,100.00 to IDR 10,267,784.00 for a sum insured of IDR 39,403,000 per one contract period. Various premium values can be a consideration for farmers in choosing an agricultural insurance policy.

Keywords: Agricultural insurance, price index, relative price index method, Black-Scholes.

1. Introduction

The agricultural sector is included in the top three leading sectors contributing to Indonesia's largest Gross Domestic Product (GDP) (Mahul, 2012). One of the leading agricultural sectors is potatoes. Potatoes are vegetables with a large average production, even though the amount of potato production fluctuates each year (Saptana, 2022). According to the Central Statistics Agency (BPS), potato production in Indonesia will reach 1.36 million tonnes in 2021. Not only in terms of production, fluctuations often occur in potato prices on the market. These price fluctuations can be a risk of threat of loss when the harvest fails.

The government offers a solution by presenting an agricultural insurance program. The existence of agricultural insurance can help overcome losses experienced by farmers when crop failure occurs. The agricultural insurance analyzed in this study is index-based agricultural insurance. The index used is the price index. Based on this, a study was conducted on the determination of agricultural insurance premiums based on the provincial price index.

Research on index-based agricultural insurance was previously conducted by Gemech et al. (2011), who researched the relationship between international coffee prices and farmer-level prices and the determination of agricultural insurance premiums based on price indexes. This research was conducted in Bali using the Black-Scholes method in determining insurance premiums. The difference between this research and previous research is in determining the object of research and the price index used. The difference lies in the selection of agricultural types and the price index. In this study, data on agricultural prices for potatoes from Pangalengan District and West Java Province were used as price indexes at the provincial level of West Java.

The initial stage of the research was carried out by determining the provincial-level price index using the relative price index method based on provincial-level price data. The relative price index method is a method commonly used in determining the price index without taking into account the weight of the object. Based on provincial price index values, agricultural insurance premiums are calculated using the Black-Scholes method. The results of this study can be a general description for farmers, insurance companies, and related institutions for the development of price index-based agricultural insurance.

2. Literature Review

2.1 Insurance and Agricultural Insurance

Based on the Kitab Undang-Undang Hukum Dagang (KUHD) of the Republic of Indonesia, insurance or coverage is an agreement, with an insurer binding himself to an insured, by receiving a premium, to provide compensation to him due to a loss, damage or loss of expected profits, which may suffer due to an unspecified event. In Indonesia, there are various types of insurance including life insurance, health insurance, vehicle insurance, agricultural insurance and so on.

According to the Law of the Republic of Indonesia Number 19 of 2013, agricultural insurance is an agreement between farmers and insurance companies to commit themselves to farm business risk coverage. Agricultural insurance is one of the government's efforts to protect farmers. Seeing the risks and problems that occur in farming, insurance is one of the right solutions to overcome this condition.

2.2 Correlation Analysis

Let X and Y are random variables with covariance σ_{XY} which have standar deviations σ_X and σ_Y, respectively. Determining the covariance of σ_{XY} using equation (1)

$$\sigma_{XY} = E(XY) - E(X)E(Y). \tag{1}$$

Standar deviations of σ_X and σ_Y using equation (2) and (3)

$$\sigma_X = \sqrt{(E(X^2) - \big(E(X)\big)^2} \tag{2}$$

$$\sigma_Y = \sqrt{E(Y^2) - \big(E(Y)\big)^2}. \tag{3}$$

The correlation coefficient of X and Y is defined by the equation (4)

$$\rho_{XY} = \frac{\sigma_{XY}}{\sigma_X \sigma_Y} = \frac{E(XY) - E(X)E(Y)}{\sqrt{E(X^2) - \big(E(X)\big)^2}\sqrt{E(Y^2) - \big(E(Y)\big)^2}} \tag{4}$$

where $E(X) = \frac{\sum X_i}{n}$, equation (4) can be written as an equation (5)

$$\rho_{XY} = \frac{n\sum X_i Y_i - \sum X_i \sum Y_i}{\sqrt{n\sum X_i^2 - (\sum X_i)^2}\sqrt{n\sum Y_i^2 - (\sum Y_i)^2}}. \tag{5}$$

The value of the correlation coefficient is $-1 \leq \rho_{XY} \leq 1$. If there is a perfect linear relationship between X and Y then $\rho_{XY} = \pm 1$; +1 if the links are unidirectional and −1 if the links are opposite. If there is no linear relationship between X and Y then ρ_{XY} = 0. This correlation coefficient is referred to as the Pearson Product Moment correlation coefficient (Lane, 2003).

2.3 Normality Test

The Black-Scholes model assumes that the data is lognormally distributed. Therefore, before determining the premium price using the Black-Scholes model, it is necessary to test the lognormal distribution of provincial price data. The Kolmogorov-Smirnov test functions to examine data of size n from a continuous population with a cumulative distribution of F(x) (Chakravarti et.al., 1967). The Kolmogorov-Smirnov test is carried out by comparing the value of D with D_{tabel}. The value of D is calculated using equation (6),

$$D = \text{maks}|F_0(x) - S_n(x)| \tag{6}$$

where $F_0(x)$ is cumulative frequency distribution and $S_n(x)$ is cumulative frequency distribution of observational scores.

2.4 Relative Price Index Method

The price index is a number that shows changes in the prices of goods, both for one type of goods and for various types of goods in a certain period of time (Foster, 2012). Relative price index, namely the amount of prices of goods and services in a certain year which in this study is the price of potatoes at the provincial level with a base year without giving commodity weights. The relative price index, $P_{\frac{n}{0}}$, is shown by equation (7)

$$P_{\frac{n}{0}} = \frac{P_n}{P_0} \times 100 \tag{7}$$

where P_n is provincial level potato prices in the n^{th} year and P_0 is provincial level potato prices base year.

2.5 Black-Scholes Method

In Ariyanti et al. (2020) the price of the European type put option determined by the Black-Scholes formula is as follows:

$$P = Ke^{-rT}N(-d_2) - S_0N(-d_1) \tag{8}$$

with,

$$d_1 = \frac{\ln\left(\frac{S_0}{K}\right)+\left(r+\frac{\sigma^2}{2}\right)T}{\sigma_T\sqrt{T}} \tag{9}$$

$$d_2 = \frac{\ln\left(\frac{S_0}{K}\right)+\left(r-\frac{\sigma^2}{2}\right)T}{\sigma_T\sqrt{T}} = d_1 - \sigma_T\sqrt{T} \tag{10}$$

where P is put option price, S_0 is initial stock price, K is option strike price, r is annual risk-free interest rate, σ_T is standar deviation of stock price, T is time until maturity, $N(-d_1)$ is standar normal cumulative distribution function of d_1, and $N(-d_2)$ is standar normal cumulative distribution function of d_2.

There are several similarities between option pricing and index insurance. Therefore, index insurance can be formulated the same as the option price. In determining the price of index insurance using the Black-Scholes method, the following can be considered:

a) The benchmark value for index insurance is C_T.
b) The payment structure for index insurance is one at a time.
c) The index follows a Lognormal distribution.

By analogy with equation (10), the agricultural insurance premium value can be calculated by first finding the cumulative distribution value d_2 with equation (11),

$$d_2 = \frac{\ln\left(\frac{C_0}{C_T}\right)+\left(r-\frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}} \tag{11}$$

where C_0 is lowest price value, C_T is benchmark value (price selected as index), σ is standar deviation of price index, r is risk free interest rate, and T is time.

Equation (12) can be used in determining price index-based agricultural insurance premiums,

$$\text{Premium} = Pe^{-r(T)}N(-d_2) \tag{12}$$

where P is the value of coverage, $N(-d_2)$ is the probability that the price index is less than the trigger value, r is risk free interest rate, and T is time.

3. Materials and Methods

3.1. Materials

The object of this study is the determination of the potato agricultural insurance premium based on the price index at the West Java Province level. The data used in this study were obtained from the Agriculture Office of West Java Province and the Pangalengan District Agriculture Extension Center. The data is the price of potatoes in West Java Province and Pangalengan District, Bandung Regency. To facilitate calculations assisted by Python programming. Thus, it will minimize the error in the calculation.

3.2. Methods

The steps taken to determine the value of agricultural insurance premiums based on the price index at the provincial level using the Black-Scholes method are as follows:

a) Collect price data at the West Java Province level and farmer level prices in Pangalengan District for potato commodities through the West Java Provincial Agriculture Service and the Pangalengan District Agricultural Extension Center.
b) Calculating descriptive statistics and plotting price data at the West Java Province level and farmer level prices in Pangalengan District.
c) Calculating the correlation of provincial level prices to farmer level prices. The relationship between provincial-level prices and farmer-level prices can be identified through the value of the correlation coefficient. According to Lane (2003) the Pearson Product Moment correlation coefficient is determined by the equation (5). The month with the strongest correlation coefficient can be used as an index reference in determining price index-based insurance premiums.
d) Perform a normality test. The normality test is used to determine whether the data population is lognormally distributed or not. In this study, the Kolmogorov-Smirnov test will be used using a significance level of 0.05 referring to the equation (6).
e) Determining of price index, exit, and trigger value. The determination of the price index referred to in this study uses the relative price index method. Determination of the price index using equation (7).
f) Determining the cost of agricultural insurance coverage. The determination of the sum insured is based on production costs during one harvest season. Production costs include the cost of potato seeds, fertilizers (organic

fertilizers and NPK fertilizers), and labor costs for land preparation starting from land preparation to post-harvest.

g) Determine the price of agricultural insurance premiums using the Black-Scholes method by referring to the equation (12).

4. Results and Discussion

4.1 Calculate Descriptive Statistics and Plot Data

This research is presented in the form of descriptive statistics to provide an overview of the quantitative data used. As for the calculation of the presentation of descriptive statistical data in this study using Python programming assistance. The results of the descriptive statistics can be seen in Table 1.

Table 1: Descriptive statistics of provincial and farmer price data

Parameters	Provincial Price	Farmer Price
Mean	7684.625	7543.520833
Median	7732.5	7535.5
Maximum	9959	10170
Minimum	4564	4050
Standar deviation	1154.256	1326.650413
Varians	1332307	1760001.319
Kurtosis	0.551003	0.060618541
Skewness	-0.50795	-0.44086849

The graph of price data for the province of West Java and farmers in Pangalengan District from January 2018 to December 2021 can be seen in Figure 1.

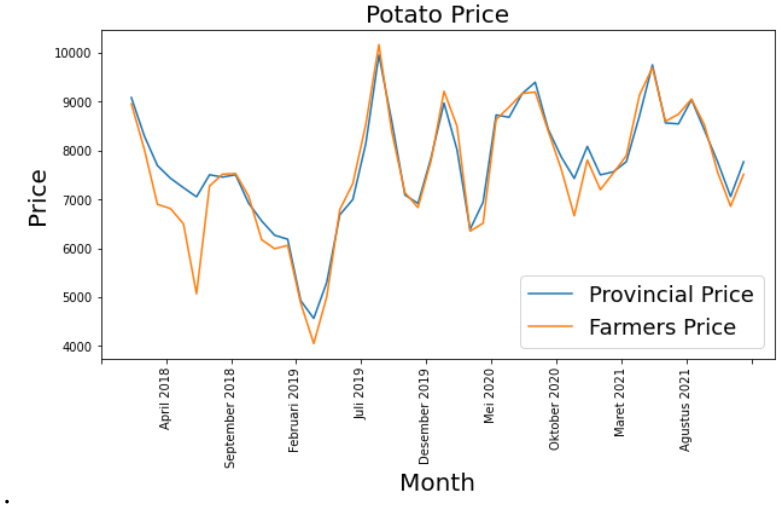

Figure 1: Graph of Provincial and Farmer Price Data

Based on Figure 1 it can be seen that farmer prices and provincial prices have almost the same graphs. Price charts tend to fluctuate and some time experienced quite extreme decreases and increases.

4.2 Determine the Correlation Between Provincial and Farmer Level Prices

The relationship between provincial-level (x) and farmer-level (y) potato prices is a guarantee for insurance companies in insuring the risk of fluctuations in provincial potato prices. The correlation between provincial and farmer-level potato prices was carried out for each month. Provincial and farmer price correlations can be calculated using the Pearson Product Moment correlation referring to equation (5). Correlation results can be seen in Table 2.

Table 2: Provincial and farmer price correlation coefficient

Month	Correlation Coefficient	Interpretation
January	0.99102	Very strong
February	0.98055	Very strong
March	0.96678	Very strong
April	0.97481	Very strong
May	0.97098	Very strong
June	0.83522	Very strong
July	0.95018	Very strong
August	0.98797	Very strong
September	0.96236	Very strong
October	0.99918	Very strong
November	0.61795	Strong
December	0.99301	Very strong

Table 2 shows the degree of relationship between provincial and farmer-level potato prices, namely strong and very strong. The highest correlation was found in October at 0.99918. Provincial potato prices in October are further analyzed to determine agricultural insurance premiums based on provincial price indexes.

4.3 Lognormal Distribution Test

Normality in provincial price data is a requirement in implementing the Black-Scholes method. The hypothesis in the provincial price data normality test is as follows:

H_0 : Provincial price data is lognormal distribution

H_1 : Provincial price data is not lognormal distribution.

The test statistic used in the Kolmogorov-Smirnov test is that H_0 is rejected if $D > D_{tabel}$. Testing was carried out with the help of EasyFit software with the following results:

Table 3: Provincial price data normality test

Lognormal [#41]					
Kolmogorov-Smirnov					
Sample Size	48				
Statistic	0.1179				
P-Value	0.48101				
Rank	27				
α	0.2	0.1	0.05	0.02	0.01
Critical Value	0.1513	0.17302	0.19221	0.21493	0.23059
Reject?	No	No	No	No	No

The results of the lognormal distribution test on provincial price data showed that the value of $D = 0.1179$ was smaller than $D_{table} = 0.19221$. Based on the decision rule, it can be concluded that H_0 is accepted and the provincial price data is lognormal distribution.

4.4 Determining Price Index

The price index is determined using the relative price index method based on provincial potato price data. January 2018 is used as the base year month index. The index calculation refers to the equation (7). Previously it was known that October has the strongest correlation value. Therefore, the index that will be used in determining the premium is only based on the price index for October 2018 to 2021, as can be seen in Table 4..

Table 4: October 2018-2021 price index

Year	Price Index
2018	76.205
2019	78.054
2020	86.627
2021	85.549

Trigger are determined by looking for percentiles of the provincial price index for October 2018-2021. Percentiles are values that divide data into 100 equal parts. The results of calculating the trigger value with predetermined percentiles can be seen in Table 5.

Table 5: Trigger of Price Index

Percentile	Trigger
20	77.314
30	77.869
40	79.553
50	81.801
60	84.050

4.5 Determining of Insurance Coverage

The price of agricultural insurance coverage is based on the cost of producing potatoes in one hectare including capital costs and operational costs. Based on capital costs and operational costs, the insured price for potato farming is 39,403,000/Ha.

4.6 Determine the Price of Agricultural Insurance Premiums

Descriptive statistics of the price index to calculate the premium can be seen in Table 6.

Table 6: Descriptive statistics of price index

Parameters	Value
Mean	81.609
Standar deviation	4.5429
Varians	20.6379
Maximum	86.6277
Minimum	76.2051

The premium calculation using the Black-Scholes method uses the minimum provincial price (C_0), which is 4564. The trigger value used for each percentile is C_T. The selected time period is $T = 0.25$ and the risk interest rate is $r = 0.06$. The standard deviation of the calculated price index is $\sigma = 4.5429$. Using equation (11) d_2 calculation for C_T = 77.314 is as follows:

$$d_2 = \frac{\ln\left(\frac{C_0}{C_T}\right) + \left(r - \frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}}$$

$$d_2 = \frac{\ln\left(\frac{4564}{77.314}\right) + \left(0{,}06 - \frac{(4.5429)^2}{2}\right)0.25}{4.5429\left(\sqrt{0.25}\right)}$$

$$d_2 = 0.6662$$

$$N(-d_2) = N(-0.6662) = 0.2526$$

Based on the cumulative function calculation results of $(-d_2)$ for C_T = 77.314, namely 0.2526, so using equation (12) the calculation of the premium to be paid is as follows:

$$\begin{aligned}\text{Premium} &= Pe^{-rT}N(-d_2)\\ &= 39{,}403{,}000\left(e^{-0.06(0.25)}\right)(0.2526)\\ &= \text{IDR } 9{,}806{,}100\end{aligned}$$

So, the price of premium that must be paid when choosing trigger $C_T = 77.314$ is IDR 9.806.100. The premium to be paid for other trigger values can be seen in Table 7.

Table 7: Amount of premium to be paid

Percentile	Trigger	Price Coverage (IDR)	Premium (IDR)
20	77.314	39,403,000	9,806,100
30	77.869	39,403,000	9,845,199
40	79.553	39,403,000	9,962,640
50	81.801	39,403,000	10,116,683
60	84.050	39,403,000	10,267,784

Table 7 shows the premium price depending on the trigger value obtained, the lowest trigger value is 77.314 and the largest trigger is 84.050. The premium range is between IDR 9,806,100 and IDR 10,267,784. The results of the premium calculation are used as a reference in determining the price of agricultural insurance premiums that must be paid by farmers. The premium price must be paid by farmers every planting season, with a planting area of 1 ha. The trigger value of the price index and various price premiums can be used as a consideration for buying insurance.

5. Conclusion

The correlation value of potato price data at the provincial level and farmers was determined by calculating the correlation of provincial and farmer price data, where October had a very strong correlation of 0.99918. Furthermore, the price index in the month with the strongest correlation, namely October 2018-2021 is used as an index in considering the calculation of agricultural insurance premiums. The results of the calculation of the potato commodity agricultural insurance premium based on the price index of West Java Province obtained the lowest premium price with a trigger price index of 77.314 and the sum insured of IDR 39,403,000.00 is IDR 9,806,100.00, while the highest premium price with a trigger price index of 84.05 and a sum insured of IDR 39,403,000.00 is IDR 10,267,784.00. The calculation results show that the greater the price index trigger value, the greater the premium payment

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