Available online at http://www.iorajournal.org/index.php/ijgor/index

International Journal of Global Operations Research

e-ISSN: 2722-1016
p-ISSN: 2723-1739

Vol. 2, No. 2, pp. 80-87, 2021

Determining Agricultural Premium Insurance in Malang City using Black Scholes Model

Herlia Widi*, Dea Nisa Rahma Lani dan Faridatul Hasanah

Department of Mathematics, Universitas Islam Negeri Sunan Gunung Djati Bandung

**Corresponding author mail:* herliawidi7@gmail.com

Abstract

This study examines the determination of rainfall-based agricultural insurance premium prices using the Black-Scholes model. The Black-Scholes model was originally used to determine the price of European-type options. The research method used is a literature study with secondary data collection. The data used in this study are rainfall data and rice production results in the city of Malang from 2015 to 2020. Based on the results and discussion, rainfall which is strongly correlated with rice production results is in quarter 2. The premium results obtained are different according to the desired percentile. In addition to percentiles, taking R_0 also affects the premium price. When R_0=322, the premium price tends to be cheaper than R_0=271.

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

1. Introduction

Agriculture is a sector that plays an important role in human life (Gracino et al., 2021). Food needs can be adequate by agriculture. In reality, agriculture has various risks that can reduce the quality or quantity of agricultural production, such as rainfall that is too high or too low, attacks by pests or plant diseases, and various other factors. This risk is certainly unavoidable but can be overcome with agricultural insurance (Alam et al., 2020; Wang et al., 2011).

Insurance is a challenge that provides compensation due to agricultural business losses (Irianingsih et al., 2020; Bhise et al., 2007; Jain, 2004). The premium is the payment of a certain amount of money by the insured to the insurer (Dafny et al., 2012; sari et al., 2020). One of the ways to determine premiums is the Black-Scholes model. The Black-Scholes model was introduced by Fisher Black and Myron Scholes in 1973 to estimate the price of a European option over time (Zubedi et al., 2020). European type options are options that can only be exercised at maturity. With an option which is an agreement between the two parties, insurance is also an agreement between two agricultural parties, namely the insurer (insurance) and the insured (farmer). The Black-Scholes model in agricultural insurance premiums is carried out by looking at the rainfall factor.

The black scholes model has application in insurance and finance such as crop insurance pricing (Filiapuspa et al. 2019), pricing of index insurance (Okine, 2014), natural disaster insurance premiums (Sukono et al., 2020), pricing of palm-oil futures (Okaro et al., 2018), estimating high-cost illness insurance (Chicaíza and Cabedo, 2009), field of weather derivatives (Botoş and Ciumaş, 2012), increased market volatility from hedging strategies (Ronnie Sircar and Papanicolaou, 1998), Micro-insurance product for medical insurance (Magero. 2018).

Based on the description above, we have presented the price of agricultural insurance premiums based on rainfall using the Black-Scholes model. This study uses case studies in Malang City with a range of years from 2015 to 2020.

2. Materials and Methods

The method used in this research is a literature study, namely by studying and understanding books and various related journals that have been published. The data collection process is carried out on a secondary basis, obtained from the BPS (Badan Pusat Statistik) website page. The data used are rainfall data (mm) and rice production (tons/ha) in Malang City from 2015 to 2020.

All the data will then be made into quarterly data and processed using Microsoft Excel and Minitab. Furthermore, it will be plotted to see the movement of rainfall that occurs every year. Then determine the correlation value between the two, how much influence rainfall has on rice production. To make it clearer, the steps taken in general are as follows (Erfiana et al., 2020):

1. Collecting data on rice production and monthly rainfall in Malang City from 2015 to 2020;
2. Converting annual rainfall and rice production data into quarterly data (4 months);
3. Make a plot of quarterly rainfall data and quarterly rice production data in Malang City from 2015 to 2020;
4. Determine the correlation test between rainfall data and production data to find the rainfall index;
5. Perform normality test for the natural logarithm of quarterly data with rainfall which is the strongest correlated with rice production;
6. Determine the price of agricultural insurance coverage; and
7. Calculating the price of insurance premiums to be paid based on the data obtained using the Black-Scholes (BS) model.

3. Results and Discussion

3.1 Data

In this study, the data used are data on rainfall and rice production in Malang City in 2015-2020. Rainfall data in millimeters (mm) is shown in Table 1.

Table 1. Malang City Rainfall Data in 2015-2020 (mm)

Month	2015	2016	2017	2018	2019	2020
January	73	140	140	435	283	191
February	261	683	377	449	518	572
March	496	387	307	163	375	479
April	281	194	422	215	-	231
May	186	246	84	59	131	205
June	46	279	25	72	-	56
July	-	65	20	-	14	21
August	-	77	-	-	-	40
September	-	69	21	8	-	2
October	-	195	53	-	-	152
November	93	675	532	142	110	170
December	533	294	342	437	199	448

(Source: Badan Pusat Statistik)

Furthermore, data on rice production in tons per hectare (tons/ha) is shown in Table 2. (Source: Badan Pusat Statistik). The data obtained from the website is in tons and hectares, so this data is a calculation of tons divided by hectares.

Table 2. Malang City Rice Production Data in 2015-2020 (ton/ha)

Month	2015	2016	2017	2018	2019	2020
January	0.220	0.980	0.782	2.045	0.993	0.727
February	1.386	-	1.199	2.494	1.426	1.154
March	0.865	-	1.260	0.722	1.252	1.561
April	2.378	-	1.159	0.577	0.555	1.152
May	0.858	-	0.770	0.524	1.121	0.694
June	1.394	-	0.958	1.706	1.148	0.742
July	0.597	-	1.868	1.169	1.801	1.053
August	0.897	-	1.762	0.826	0.773	1.575
September	1.308	-	0.882	0.748	0.628	1.214
October	3.100	-	0.410	0.725	1.007	1.133
November	1.331	-	0.581	0.926	0.809	0.792
December	0.520	-	1.071	1.086	1.108	0.711

3.2 Rainfall Data Plot

The rainfall data shown in Table 1, will be converted into quarterly data. One year is divided into 3 quarters. Quarter 1 starts from January to April 2020; Quarter 2 starts from May to August 2020; and Quarter 3 starts from September to December 2020. Each quarter is totaled and will be shown in Table 3.

Table 3. Malang City Quarterly Rainfall Data in 2015-2020 (mm)

Period	2015	2016	2017	2018	2019	2020
Quarter 1	1111	1404	1246	1262	1176	1473
Quarter 2	232	667	129	131	145	322
Quarter 3	626	1233	948	587	309	772

Furthermore, this quarterly rainfall data will be plotted using Microsoft Excel.

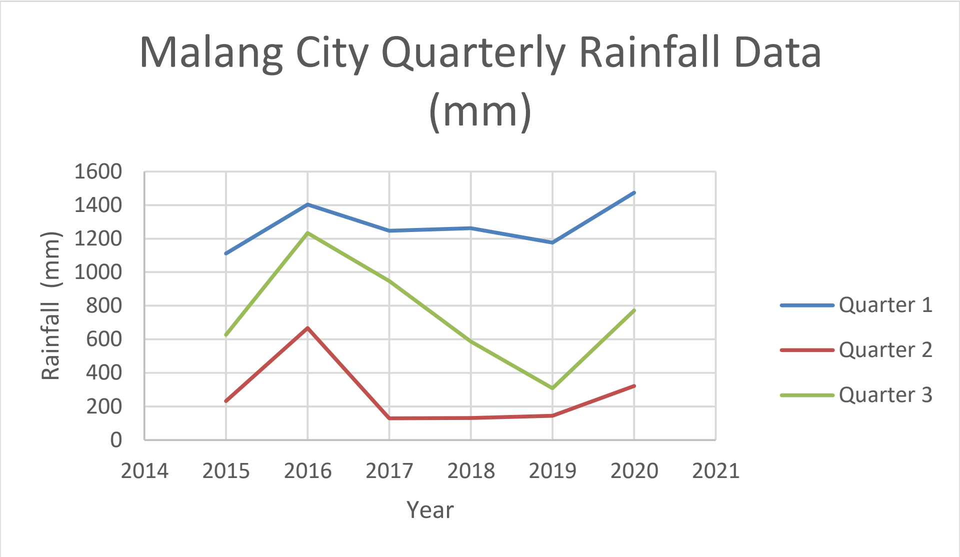

Figure 1. Plot of Malang City Quarterly Rainfall Data 2015-2020

Based on Figure 1, the first quarter rainfall is always the highest throughout 2015 to 2020. This means that every January to April there is a rainy season. And the second quarter rainfall is always the lowest throughout 2015 to 2020. This means that every May to August there is a dry season. The highest rainfall is in the 1st quarter of 2020, meaning that from January 2020 to April 2020 it rains quite often during that month. While the lowest rainfall was in the second quarter of 2017, meaning that from May 2017 to August 2017, it rarely rained during that month.

3.3 Rice Production Data Plot

Table 2 shows production yield data in tons per hectare. This data will also be converted into the same quarter as Table 3. Where quarter 1 starts from January to April, quarter 2 starts from May to August and quarter 3 starts from September to December will be shown in Table 4.

Table 4. Malang City Quarterly Rice Production Data in 2015-2020 (tons/ha)

Period	2015	2016	2017	2018	2019	2020
Quarter 1	4,848881	0.980132	4,399048	5,837827	4,226274	4,594418
Quarter 2	3,74597	0	5,357979	4,224892	4,843891	4,065002
Quarter 3	6,258337	0	2,943708	3,485116	3,551586	3,850636

Furthermore, the production data per quarter will be plotted using Microsoft Excel.

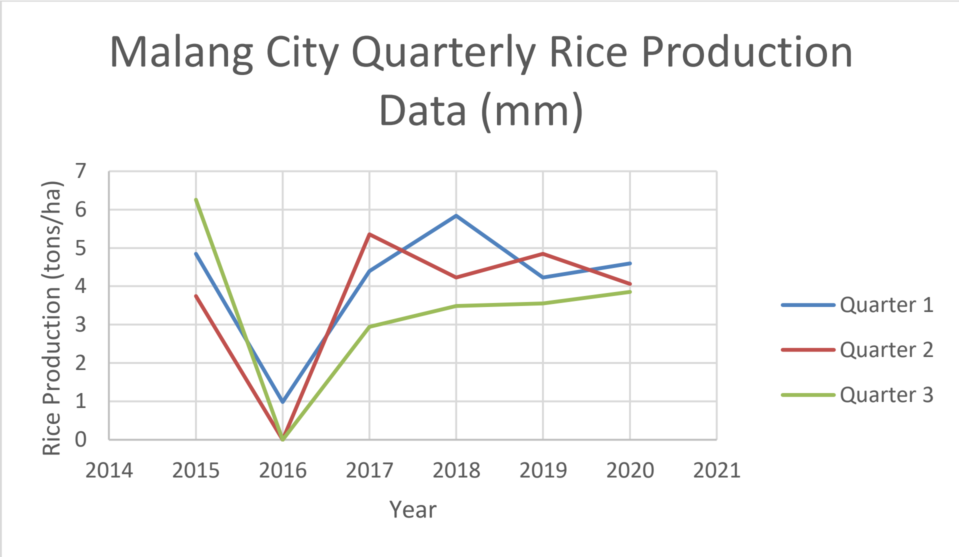

Figure 2. Data Plot of Quarterly Rice Production Results in Malang City 2015-2020

Based on Figure 2, rice production in 2016 had the lowest yield due to missing data from February to December. The highest production results were in the 3rd quarter of 2015, meaning that from September to December 2015 the results of rice production in Malang City were very abundant.

3.4 Determination of Rainfall Index

The rainfall index will be determined by looking at the strongest correlation between rainfall and rice production. For this reason, we will look for the correlation of each quarter with X as rainfall and Y as rice production using Microsoft Excel. The correlation results will be shown in

Table 5. Correlation of Rainfall (X) and Rice Production (Y) quarterly

Correlation of Rainfall and Rice Production (X and Y)		Y (Rice Production)		
		Quarter 1	Quarter 2	Quarter 3
X (Rainfall)	Quarter 1	-0.42	-0.45	-0.60
	Quarter 2	-0.90	**-0.96**	-0.67
	Quarter 3	-0.71	-0.67	-0.67

The negative correlation result means that there is an opposite relationship between X and Y. It means that when the rainfall (X) is high, the production yield (Y) is decreasing. The closer to 0, the weaker the correlation, while the closer to 1 or -1, the stronger the correlation. Table 5 shows that the strongest correlation is -0.96, so the rainfall in the second quarter will be used to determine the premium.

3.5 Second Quarter Rainfall Data Normality Test

Normality test is used to test whether the population is normally distributed or not. In this study, the normality test will be used using the Kolmogorov-Smirnov test with Minitab software. The hypotheses in this normality test are:

H_0 = Quarter 2 rainfall data is normally distributed

H_1 = Quarter 2 rainfall data is not normally distributed

By taking the significant level $= 5\% = 0.05$, if the p-value is greater than then accept H_0. The Minitab output will be shown in Figure 3.

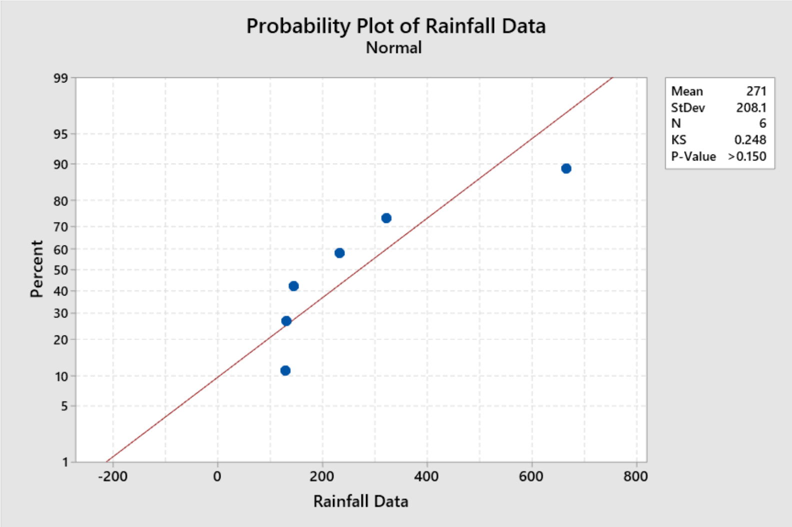

Figure 3. Plot of Rainfall Probability of Malang City Quarter 2

From Minitab's output, p-value > 0.150 is obtained, which means it is greater than 0.05. So, accept H_0 or quarterly 2 data with normal distribution.

3.6 Pricing for Agricultural Insurance Coverage

The determination of the insured price is based on the input costs of rice production including the cost of rice seeds, fertilizers (organic fertilizers and NPK fertilizers), labor costs, and tractor rental[2]. In this study, the insured value of AUTP (Padi Farmer Business Insurance) is Rp. 6,000,000.00 per hectare .

3.7 Determination of Premium Pricing with the Black-Scholes Model

To determine the premium price with the Black-Scholes model as follows (Ariyanti et al., 2020).

$$Premium = K \cdot e^{-rt} \cdot N(-d_2) \tag{1}$$

Information

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

with

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

R_0 : the latest rainfall data (recent)
R_T : triggered measurement (calculated with data percentile), i.e. rainfall data that used to trigger (determine) the amount of premium
μ : annual expected rate of stock price return, and
σ : volatility (annual standard deviation of stock price changes).

Table 6. Rainfall Data for Quarter 2 Malang City 2015-2020

	R_1	R_2	R_3	R_4	R_5	R_6
Quarter 2	232	667	129	131	145	322

After knowing the rainfall data to be used, we will look for $\mu = \frac{1}{n-1} ln \frac{R_n}{R_1}$. Since t is not annual, we will use $\tilde{\mu} = \left(\frac{1}{n-1} ln \frac{R_n}{R_1}\right) t$ where $t = \frac{3}{12} = 0{,}25$ and $n = 6$.

$$\tilde{\mu} = \left(\frac{1}{6-1} \ln \frac{R_6}{R_1}\right) 0{,}25 = \left(\frac{1}{5} \ln \frac{322}{232}\right) 0{,}25 = 0{,}016$$

Next, we will search for $\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(u_i - \bar{u})^2}$ with $u_i = ln\left(\frac{R_i}{R_{j-1}}\right) \forall j, j = 1,2,3, \dots, n$ and $\bar{u} = \frac{\sum_{i=1}^{n-1} u_i}{n-1}$. By using the help of Microsoft Excel. The rainfall data for quarter 2 Malang city 2015-2020 can be seen in Table 6.

After obtaining $\tilde{\mu} = 0{,}016$ and $\sigma = 0{,}86$. The R_T value will be searched according to the desired percentile for the second quarterly rainfall data. The percentiles used in this study are $5\%, 6\%, 7\%, 8\%, 9\%, 10\%, 20\%, 30\%, 40\%, 50\ \%, 60\%, 70\%, 80\%, 90\%$ and 100%. The R_0 value to be used is the average value from R_1 to R_6 and the R_0 value from the last data, namely R_6. So R_0 to be used is R_0=271 and R_0=322. After obtaining R_T and R_0, then the value of d_2 will be searched by formula (2). One example of calculating d_2 with $R_0 = 271$, and $R_T(5\%) = 129.5$

$$d_2 = \frac{\ln\frac{R_0}{R_T} + \tilde{\mu} \cdot t}{\sigma\sqrt{t}} = \frac{\ln\frac{271}{129{,}5} + 0{,}016\ \cdot 0{,}25}{0{,}86\sqrt{0{,}25}} = 1{,}7263$$

Next, look for the value $(-d_2)$ in the normal distribution table. The $N(-1.7263) = 0.0421$ will be used to find premium with formula (1). The value of $K = 6{,}000{,}000$ is the insured value, the value of $r = 3.5\% = 0.035$ is the risk-free interest rate issued by Bank Indonesia for August 2021. So, the premium price for $R_0 = 271$ with a 5% percentile is

$$Premium = K \cdot e^{-rt} \cdot N(-d_2) = 6.000.000 \times e^{(-0{,}035 \times 0{,}25)} \times 0{,}0421 = Rp. 250664{,}80$$

To facilitate the calculation, Microsoft Excel is used and the premium results are shown in Table 7 with $R_0 = 271$ and Table 8 with $R_0 = 322$.

Table 7. Premium Prices for Agricultural Insurance in Malang City with $R_0 = 271$

Percentile	R_T	d_2	$(-d_2)$	$N(-d_2)$	Premium
5%	129.5	1.7263	-1.7263	0.0421	250664.8
6%	129.6	1.7245	-1.7245	0.0423	251625.9
7%	129.7	1.7227	-1.7227	0.0425	252589.2
8%	129.8	1.7209	-1.7209	0.0426	253554.8
9%	129.9	1.7192	-1.7192	0.0428	254522.6
10%	130	1.7174	-1.7174	0.0430	255492.6
20%	131	1.6995	-1.6995	0.0446	265315.8
30%	138	1.5785	-1.5785	0.0572	340345.6
40%	145	1.4635	-1.4635	0.0717	426256.9
50%	188.5	0.8535	-0.8535	0.1967	1169840
60%	232	0.3708	-0.3708	0.3554	2113841
70%	277	-0.0414	0.0414	0.5165	3072036
80%	322	-0.3914	0.3914	0.6522	3879319
90%	494.5	-1.3887	1.3887	0.9175	5457300
100%	667	-2.0844	2.0844	0.9814	5837340

Table 8. Premium Prices for Agricultural Insurance in Malang City with $R_0 = 322$

Percentile	R_T	d_2	$(-d_2)$	$N(-d_2)$	Premium
5%	129.5	2.1272	-2.1272	0.0167	99334.26
6%	129.6	2.1254	-2.1254	0.0168	99778.34
7%	129.7	2.1236	-2.1236	0.0169	10022.,8
8%	129.8	2.1218	-2.1218	0.0169	100670.6
9%	129.9	2.1200	-2.1200	0.0170	101118.7
10%	130	2.1183	-2.1183	0.0171	101568.2
20%	131	2.1004	-2.1004	0.0178	106138.2
30%	138	1.9794	-1.9794	0.0239	142060.4
40%	145	1.8644	-1.8644	0.0311	185179.4
50%	188.5	1.2544	-1.2544	0.1048	623604.8
60%	232	0.7717	-0.7717	0.2202	1309435
70%	277	0.3595	-0.3595	0.3596	2138858
80%	322	0.0095	-0.0095	0.4962	2951260
90%	494.5	-0.9878	0.9878	0.8384	4986493
100%	667	-1.6836	1.6836	0.9539	5673339

Based on Table 7 and Table 8, different premium results are obtained according to the desired percentile. R_T value indicates rainfall, where there are 4 types in rainfall

1. Low (0-100mm)
2. Medium (100-300mm)
3. High (300-500mm)
4. Very High (>500mm)

The value of the second quarter rainfall is in the range of 129 to 667, which means it is in the medium to very high rainfall. From a small R_T value, it has a low premium price too. Assume that for 129.5 rainfall with $R_0 = 271$, the premium is IDR $250.664{,}80$. Meanwhile, for 667 rainfalls with $R_0 = 271$, the premium is IDR $5.837.340{,}00$. For $R_0 = 322$ with 129.5 rainfall, the premium is IDR $5.673.339{,}00$. It can be seen that R_0 and R_T affect the problem of premium prices. The lower the rainfall, the lower the premium price.

4. Conclussion

Based on the research that has been done, it can be concluded that the rainfall index which has the strongest correlation with rice production in Malang City from 2015 to 2020 occurs in quarter 2 where the correlation of rainfall with rice production is inversely proportional, meaning that the higher If it rains, the rice production will decrease. Based on this rainfall index, the premium value of an agricultural insurance can be calculated. By using the Black-Scholes model, the premium prices for $R_0 = 271$ and $R_0 = 322$ are obtained which vary according to the desired percentile. The bigger the percentile, the bigger the premium. When $R_0 = 322$, the premium price tends to be cheaper than $R_0 = 271$.

It is hoped that this premium price can be used as a determination of insurance in accordance with the rainfall in the city of Malang. Calculations with the Black-Scholes model only look at the rainfall index. So as a suggestion from the author, it is hoped that the determination of premiums can use other methods or models that look at various other factors.

References

Ariyanti, D., Riaman, R., & Irianingsih, I. (2020). Application of Historical Burn Analysis Method in Determining Agricultural Premium Based on Climate Index Using Black Scholes Method. JTAM *(Jurnal Teori dan Aplikasi Matematika)*, *4*(1), 28-38.

Alam, A. F., Begum, H., Masud, M. M., Al-Amin, A. Q., & Leal Filho, W. (2020). Agriculture insurance for disaster risk reduction: A case study of Malaysia. *International Journal of Disaster Risk Reduction*, *47*, 101626.

Bhise, V. B., Ambhore, S. S., & Jagdale, S. H. (2007). *Performance of agriculture insurance schemes in India* (No. 686-2016-47134).

Botoş, H. M., & Ciumaş, C. (2012). The use of the Black-Scholes model in the field of weather derivatives. *Procedia Economics and finance*, *3*, 611-616.

Chicaíza, L., & Cabedo, D. (2009). Using the Black-Scholes method for estimating high-cost illness insurance premiums in Colombia. *Innovar*, *19*(33), 119-130.

Dafny, L., Duggan, M., & Ramanarayanan, S. (2012). Paying a premium on your premium? Consolidation in the US health insurance industry. *American Economic Review*, *102*(2), 1161-85.

Erfiana, D., Prabowo, A., Tripena, A., & Riyadi, S. (2020). Penentuan Harga Premi Asuransi Pertanian Berbasis Indek Curah Hujan Dengan Model Black-Scholes. *Prosiding*, *10*(1), 95-107

Filiapuspa, M. H., Sari, S. F., & Mardiyati, S. (2019, November). Applying Black Scholes method for crop insurance pricing. In *AIP Conference Proceedings* (Vol. 2168, No. 1, p. 020042). AIP Publishing LLC.

Gracino, M. A., Priyanti, E., & Azijah, D. N. (2021). Collaborative Governance: Re-Enactment Share Understanding in the Process of Agricultural Food Management in Karawang Regency. *International Journal of Business, Economics, and Social Development*, *2*(1), 18-23.

Irianingsih, I., Susanti, D., & Kartiwa, A. (2020). The Estimated Value of Losses and Insurance Due to Citarum River Flooding. *International Journal of Business, Economics, and Social Development*, *1*(1), 13-23.

Magero, E. N. (2018). *Pricing of Micro-insurance Product for Medical Insurance in Kenya Using Black-scholes Model* (Doctoral dissertation, University of Nairobi).

Jain, R. C. A. (2004). Challenges in implementing agriculture insurance and re-insurance in developing countries. *The Journal*, *2004*, 14-23.

Okaro, C. S. O., Okeke, C. K., & Uzondu, C. S. (2018). Efficiency of the black-scholes option pricing model in the pricing of palm-oil futures in Nigeria's Physical Market. *International Journal of Academic Management Science*, *2*(9), 83-92.

Okine, A. N. (2014). Pricing of Index Insurance Using Black-Scholes Framework: A Case Study of Ghana. *Masterr theisie, Ilinois State University*.

Ronnie Sircar, K., & Papanicolaou, G. (1998). General Black-Scholes models accounting for increased market volatility from hedging strategies. *Applied Mathematical Finance*, *5*(1), 45-82.

Sari, W. P., Rosalina, D., & KS, I. L. (2020). The Impact Of Premium Income On Asset Growth: A Case Of Indonesia Sharia Insurance. *Accounting and Business Journal*, *2*(1), 53-60.

Sukono, S. S., Mamat, M., & Bon, A. T. (2020). Model for Determining Natural Disaster Insurance Premiums in Indonesia Using the Black Scholes Method. *Proceedings of the International Conference on Industrial Engineering and Operations Management*, Detroit, Michigan, USA, August 10 - 14, 2020

Wang, M., Shi, P., Ye, T., Liu, M., & Zhou, M. (2011). Agriculture insurance in China: History, experience, and lessons learned. *International Journal of Disaster Risk Science*, *2*(2), 10-22.

Zubedi, F., Oroh, F. A., & Aliu, M. A. (2020). Penentuan Harga Call Opsi Eropa Dengan Menggunakan Model Black-Scholes, Antithetic Variate Dan Binomial. *Jurnal Riset Dan Aplikasi Matematika* 4(2), 74-81.