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Insurance Premium Formulation for Agricultural Commodity Prices

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Abstract

This research develops the appropriate formula to determine insurance premiums on agricultural commodity prices that provide coverage to policyholders for losses caused by falling prices. The price component is assumed to follow the Brownian Geometric motion in determining the insurance premiums for agricultural commodity prices. So, through the $It\hat{o}$ process, a target price can be selected and is used as a reference to determine whether a claim can be made or not at harvest time. The approach of the Black-Scholes model is used to construct an appropriate model to determine insurance premiums of agricultural commodity prices due to a decrease in prices from the expected price. A simulation study is carried out using daily price data for red chili commodities in the Jambi province in 2020 with several assumptions made based on literature studies and farmers' common habits in Jambi. The simulation results indicate that the average return is -0.001069649, and the standard deviation is 0.07297269. Thus, the expected estimated value of the profit rate is -0.001069649, and the estimated volatility value is 0.07297269. Furthermore, using the target price value, the red chili price insurance premium for a one-planting period with an area of one hectare is Rp. 1,527,088.

Keywords: agriculture insurance; Black-Scholes model; European option; $It\hat{o}$ process.

Abstrak

Penelitian ini mengembangkan formula yang sesuai untuk menetapkan harga premi asuransi harga komoditas hasil pertanian yang memberikan pertanggungan kepada nasabah atas kerugian yang disebabkan oleh turunnya harga. Dalam menentukan premi asuransi harga komoditas hasil pertanian, komponen harga diasumsikan bergerak mengikuti Gerak Brownian Geometrik. Sehingga melalui proses $It\hat{o}$ *dapat ditentukan target harga yang akan dijadikan acuan untuk menentukan klaim atau tidaknya nasabah pada saat panen. Pendekatan model Black-Scholes digunakan untuk mengkonstruksi model yang sesuai untuk menentukan premi asuransi harga komoditas hasil pertanian yang disebabkan karena turunnya harga komoditas dari harga yang diharapkan. Simulasi dilakukan menggunakan data harga harian komoditas cabe merah di Provinsi Jambi tahun 2020 dengan beberapa asumsi yang dibangun berdasarkan kajian literatur dan kebiasaan umum petani di Provinsi Jambi. Hasil simulasi menunjukkan bahwa rata-rata return adalah* -0.001069649 *dan standar deviasi* 0.07297269. *Sehingga diperoleh nilai estimasi tingkat keuntungan yang diinginkan sebesar* -0.001069649, *dan nilai estimasi volatilitas sebesar* 0.07297269. *Selanjutnya, menggunakan nilai target harga diperoleh premi asuransi harga cabe merah untuk 1 periode tanam dengan luas lahan 1 hektar sebesar Rp*. 1.527.088.

Kata Kunci: *asuransi pertanian; model* Black-Scholes; *opsi eropa; proses* $It\hat{o}$.

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1. INTRODUCTION

Agriculture is a type of business with high risk and uncertainty. Sources of risk and uncertainty that are external to agriculture (cannot be controlled by farmers) come from the socio-economic environment, especially those related to market behavior of farming's input and output; the dynamics

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of business links between the agricultural and non-agricultural sectors; inconsistency in economic policies, social conflicts, and the natural environment, particularly climate, natural disasters, or the explosion of plant-disturbing organisms.

In dealing with risks, farmers have implemented various strategies, such as *production strategy* (i.e., choosing a farm with flexible financing and production management), *marketing strategy* (i.e., selling crops gradually), *financial strategy* (i.e., making cash flow projections based on estimates of production costs, production selling prices, and realistic productions), *utilization of informal credit* (i.e., borrowing money or basic necessities from other parties - traders, individual capital owners), and *agricultural insurance* participants (i.e., becoming participants of formal agricultural insurance to cover part or all of the losses that are expected to occur). Farmers mostly adopt these strategies in developing countries [1] [2].

The farmers' ability to minimize the risks is constrained by capital, technological mastery, and market access. Conventional approaches applying one or a combination of product strategy, marketing, financial, and informal credit utilization are less effective. This is worsened by the instability of agricultural commodity prices, which have fluctuated significantly in recent years. It makes the actual commodity prices far below the prices expected by the farmers, resulting in a loss for farmers. If this condition is allowed to continue, agricultural stability may be disrupted. Therefore, a systematic formal protection system is required. In this context, developing a formal agricultural insurance system is worth considering, particularly for crucial commodities. In addition, it should be normatively positioned as an integral part of the long-term agricultural development strategy.

Empirically, agricultural insurance in developed countries, such as the US, Japan, and several European countries, is growing rapidly and effectively protecting farmers. Government policies significantly affect the stability of agricultural commodity prices in many countries [3], such as Canada, Australia [4], Germany [5], Turkey [6], China [7], Japan, and Thailand [8]. Implementing agricultural insurance has become one of the strategies to adapt to price instability. This condition is in contrast to what happens in developing countries. The development of agricultural insurance varies and has not shown satisfactory results. In Taiwan, agricultural insurance is well-developed. On the other hand, countries like India, Bangladesh, and the Philippines show slow development, while Thailand is less developed.

In Indonesia, agricultural insurance has not yet been achieved, although, from 1982-1992, the Working Group for the Development of Harvest Insurance was formed three times (1982, 1984, and 1985). In 1999, the development of agricultural insurance was re-launched. A serious discussion has been carried out. But to move to the implementation stage, careful consideration is needed. Various inputs are required to formulate policies, strategies, programs, pilots, and institutional instruments that align with the development strategies [2].

Basically, agricultural insurance cannot be used to cover the overall risks of farming. This is related to difficulties securing actual data or potential bankruptcy of insurance institutions due to the very high insurance value that must be paid. For example, crop failure in a very large area is potentially very vulnerable to catastrophic natural disasters. In this paper, we develop a new approach to determine the agricultural insurance premium model for the risk of loss caused by falling agricultural commodities prices by adopting the Black-Scholes model. Therefore, the negative impact of the instability of agricultural commodity prices can be minimized, leading to agricultural and economic stability in Indonesia.

2. METHODS

This research consists of two stages. The first stage is a literature study obtained from official sources, such as books and scientific journals, and through discussion with experts. The second stage is to study the case using real-world data. The data needed in this research are data on land area and agricultural products retrieved from the Central Bureau of Statistics (BPS) and the Ministry of Agriculture, Republic of Indonesia. In addition, the data for agricultural commodity prices are also collected from traditional markets or farmers.

To answer the research questions in this study, the authors studied the agricultural literature from books and journals, including papers [9] [2] that described the development of insurance system implementation for agriculture in Indonesia, and agricultural issues in Indonesia are elaborated in the LEMHANNAS RI (2013) research journal [10]. Other literature [9] discussed agricultural insurance and premiums. Yasin [11] elaborated on coordinating agricultural insurance premium payments between the central and local governments. The legal basis of agricultural insurance implementation in Indonesia was described in Bramantia [12]. A direct interview with farmers was conducted to strengthen further and complete the author's understanding.

Furthermore, the author strengthened the theory by studying articles from previous research and the corresponding literature [13] [14] [15]. Next, an analysis of the potential variables was carried out to form the model, based on a study of the agricultural theory of copula [16] [17], a science of uncertainty [18] [19], vulnerability [20], index insurance benefits [20] [21], and direct information from insurance premium design [22] [23] [24]. Besides that, we also do some interviews with the farmers to get the primary data. As for the data obtained, data processing was carried out using the R program with further analysis adjusted to the characteristics of the collected data.

3. RESULTS AND DISCUSSION

3.1. Insurance Premium Model

The expected value of a payment in the event of an agricultural insurance claim can generally be determined by the function

$$v(n,f) = \int_0^z (z-x)^n f(x)dx, \tag{1}$$

where z is the benefit target, price target, or revenue target; x is the associated random variable, and $f(x)$ is the probability density function. The function for $n=0$ indicates the probability of payment, for $n=1$, shows the expected value of a payment, and for $n=2$ indicates a semi-variance depreciation.

In general, agricultural insurance differs from general insurance. It relates to agricultural products that are not produced throughout the year. In agriculture, there are seasonal periods, such as planting, maintenance, and harvest seasons. The harvest season is the time when farmers carry out loss assessments. Thus, the only reasonable time for a claim to occur is right after the harvesting season. Especially agriculture insurance insures agriculture commodities

The price will be set in insurance as a target price (Z_p). The target price is determined based on equation (1) as price insurance with boundary conditions $E[Max(Z_p - P, O)]$. This policy provides compensation equal to the difference between the targeted price and the market price at harvest time, depending on which is greater. In price insurance, compensation is usually paid based on the average long-term yields (Y) and on current yields. Therefore, the premium value per hectare is given by $YE[Max(Z_p - P, O)]$. In contrast to agricultural insurance, crop yields are observed annually, and cash prices are observed at the beginning of the planting year. Thus, the possibility for the price at harvest time will fall below the targeted price depending on the initial price (price at planting). This issue requires an evaluation from time to time, considering these kinds of possible changes [25].

An equation is then formed to determine the insurance value of agricultural commodity prices. Since compensation is only paid if there is a deficiency in price, then only the cost of price insurance is required to be calculated (e.g., rupiah/kg) [26]. Afterward, the insurance cost of agricultural commodity prices is multiplied by the average total production per hectare (for a one-time harvest) to obtain the agricultural insurance value per hectare. To calculate the insurance cost per unit, it is assumed that there is no issue related to the market [26]. For analysis purposes, let P be the market price and f be the later price for each period. Thus, an equation can be formed as follows

$$P = f. \tag{2}$$

The later price changes (df) are assumed to follow a geometric Brownian motion explained by the following $Itô$ prosses

$$df = \alpha_f f dt + \sigma_f f dZ_f, \tag{3}$$

where α_f is the rate of expected deviation on $Itô$ process, σ_f is the rate of annual standard deviation for *f*; and dZ_f is the Wiener process ($dZ_f = \epsilon_t \sqrt{dt}$, where ϵ_t is a random variable following a normal distribution with mean 0 and variance 1). Since $\epsilon_t \sim N(0,1)$, which means that $E(\epsilon_t) = 0$ and $Var(\epsilon_t) = 1$. By using $dZ_f = \epsilon_t \sqrt{dt}$ then

$$E(dZ_f) = E(\epsilon_t \sqrt{dt}\,) = \sqrt{dt}\, E(\epsilon_t) = \sqrt{dt}\,(0) = 0,$$

and

$$Var(dZ_f) = Var(\epsilon_t \sqrt{dt}\,) = dt\, Var(\epsilon_t) = dt\,(1) = dt,$$

thus, $dZ \sim N(0, dt)$.

Equation (3) can be expressed as $P(f, t)$. By applying the lemma $Itô$, then

$$dP = P_f df + P_t dt + \frac{1}{2} P_{ff} (df)^2, \tag{4}$$

where subscripts f, ff, and t indicate partial derivatives. Since $P_t = P_{ff} = 0$ and $P_f = 1$, then the $Itô$ process on Equation (2) describes the dynamics of market prices given by

$$dP = df,$$

or

$$dP = \alpha_f f dt + \sigma_f f dZ_f. \tag{5}$$

From this, the expected value of dP can be calculated as follows

$$\begin{aligned} E[dP] &= E\left[\alpha_f f dt + \sigma_f f dZ_f\right] = E\left[\alpha_f f dt\right] + E\left[\sigma_f f dZ_f\right] \\ &= E\left[\alpha_f f dt\right] + E\left[\sigma_f f\ \epsilon_t \sqrt{dt}\right] = \alpha_f f dt + \sigma_f f\ E[\epsilon_t]\ \sqrt{dt}. \end{aligned}$$

Since $E[\epsilon_t] = 0$, then $E[dP] = \alpha_f f dt + \sigma_f f\ (0)\ \sqrt{dt} = \alpha_f f\ dt.$
Next, the variance of dP is

$$\begin{aligned} Var[dP] &= Var\left[\alpha_f f dt + \sigma_f f dZ_f\right] = Var\left[\alpha_f f dt + \sigma_f f\ \epsilon_t \sqrt{dt}\right] \\ &= Var\left[\alpha_f f dt\right] + Var\left[\sigma_f f\ \epsilon_t \sqrt{dt}\right] \\ &= Var\left[\sigma_f f\ \epsilon_t \sqrt{dt}\right] \\ &= {\sigma_f}^2 f^2 dt\ Var[\epsilon_t]. \end{aligned}$$

Since $Var[\epsilon_t] = 1$, then $Var[dP] = {\sigma_f}^2 f^2 dt(1) = {\sigma_f}^2 f^2\ dt.$

The dynamics of market prices are fully explained by the expected value and the variance from the underlying future contract (if any). This allows the use of an option pricing model. There are five variables influencing the price of insurance premiums with the Black-Scholes model, i.e., commodity prices, targeted prices, the time until harvest, interest rates, and return volatility of the commodity prices. Thus, a formula to determine the insurance premium of agricultural commodity prices is expressed as follows

$$V_P = e^{-rt}[Z_P N(-d_2) - P N(-d_1)], \tag{6}$$

where

$$d_1 = \frac{\ln\left({P_0}/{Z_P}\right) + rt + 0{,}5{\sigma_f}^2 t}{\sigma_f \sqrt{t}}, \tag{7}$$

$$d_2 = \frac{\ln\left({P_0}/{Z_P}\right) + rt - 0{,}5{\sigma_f}^2 t}{\sigma_f \sqrt{t}}, \tag{8}$$

and V_P is the premium price, P_0 is the commodity price at time $t = 0$, Z_P is the targeted price, t is the time until harvest, r is the interest rate of the Bank of Indonesia, $N(x)$ is the cumulative value from a standard normal distribution, and σ_f is the return volatility of the commodity prices. The formula to determine the insurance premium of agricultural commodity prices in equation (6) with d_1 and d_2 as in equations (7) and (8), is obtained from the following explanation.

Overall, the insurance premium of agricultural commodity prices with the Black-Scholes models can be written in the form

$$V_P = e^{-rt}\ E\left[Max\left(Z_p - P, O\right)\right], \tag{9}$$

where Z_p is the targeted price, P is the commodity price at time t, and $E\left[Max\left(Z_p - P, O\right)\right]$ indicates the expected value from the profit function (claim) received by policyholders, e^{-rt} is the discounted value with r is the interest rate of Bank of Indonesia, and t is the time until harvest. In the Black-Scholes models, the commodity prices are assumed to follow a lognormal distribution, so that $\log P \sim N\left(\mu_f, {\sigma_f}^2\right)$. Variable P has a lognormal distribution and $ln(P)$ is normally distributed; thus, the density function of P is given by

$$g(p) = \begin{cases} \frac{1}{p\sqrt{2\pi}\sigma_f} exp\left(-\frac{1}{2}\left(\frac{\ln p-\mu_f}{\sigma_f}\right)^2\right), & p > 0, \\ 0 & , \quad p \leq 0. \end{cases} \quad (10)$$

Daily changes in agricultural commodity prices (P) follow a geometric Brownian motion, i.e.,

$$P = P_0 \, exp\left(\left(r - 0{,}5{\sigma_f}^2\right)t + \sigma_f W(t)\right), \quad (11)$$

with $W(t) \sim N(0, t)$. Thus, equation (11) can be written as

$$\ln P = \ln P_0 + \left(r - 0{,}5{\sigma_f}^2\right)t + \sigma_f W(t). \quad (12)$$

From equation (12), the expectation and variance of $\ln P$ are given by

- $E(\ln P) = E\left(\ln P_0 + \left(r - 0{,}5{\sigma_f}^2\right)t + \sigma_f W(t)\right)$
  $= \ln P_0 + \left(r - 0{,}5{\sigma_f}^2\right)t + E\left(\sigma_f W(t)\right)$
  $= \ln P_0 + \left(r - 0{,}5{\sigma_f}^2\right)t + \sigma_f E(W(t))$
  $= \ln P_0 + \left(r - 0{,}5{\sigma_f}^2\right)t + \sigma_f(0)$
  $= \ln P_0 + \left(r - 0{,}5{\sigma_f}^2\right)t$
- $Var(\ln P) = Var\left(\ln P_0 + \left(r - 0{,}5{\sigma_f}^2\right)t + \sigma_f W(t)\right)$
  $= Var\left(\sigma_f W(t)\right)$
  $= {\sigma_f}^2 \, Var(W(t))$
  $= {\sigma_f}^2 t.$

Note that

$$\frac{\ln P - E(\ln P)}{\sqrt{Var(\ln P)}} = \frac{\ln P - \left(\ln P_0 + \left(r - 0{,}5{\sigma_f}^2\right)t\right)}{\sqrt{{\sigma_f}^2 t}} = \frac{\ln P - \left(\ln P_0 + \left(r - 0{,}5{\sigma_f}^2\right)t\right)}{\sigma_f\sqrt{t}} = Z \sim N(0{,}1),$$

then $\ln P = z\,\sigma_f\sqrt{t} + \left(\ln P_0 + \left(r - 0{,}5{\sigma_f}^2\right)t\right)$.

Next, the expected value of the benefit function (claim) received by policyholders is given by

$$E\left[Max\left(Z_p - P, O\right)\right] = \int_0^{Z_p}\left(z_p - p\right) g(p)dp = Z_p \int_0^{Z_p} g(p)dp - \int_0^{Z_p} pg(p)dp.$$

$$E\left[Max\left(Z_p - P, O\right)\right] = V_A - V_B. \quad (13)$$

where $V_A = Z_P \int_0^{Z_p} g(p)dp$ and $V_B = \int_0^{Z_p} pg(p)dp$. Therefore, the insurance premium of agricultural commodity prices can be written in the following form

$$V_p = e^{-rt}\left[Z_p \int_0^{Z_p} g(p)dp - \int_0^{Z_p} pg(p)dp\right]. \quad (14)$$

Furthermore, for ease of expression, V_A and V_B are elaborated separately as follows

- Elaboration of $V_A = Z_p \int_0^{Z_p} g(p)dp$

$$\int_0^{Z_p} g(p)dp = P_r\left(0 \le P \le Z_p\right) = P_r\left(-\infty \le \ln P \le \ln Z_p\right)$$
$$= P_r\left(-\infty \le \ln P_0 + \left(r - 0{,}5{\sigma_f}^2\right)t + \sigma_f W(t) \le \ln Z_p\right)$$
$$= P_r\left(-\infty \le \left(r - 0{,}5{\sigma_f}^2\right)t + \sigma_f W(t) \le \ln Z_p - \ln P_0\right). \quad (15)$$

from equation (15), let $A = \left(r - 0{,}5{\sigma_f}^2\right)t + \sigma_f W(t)$, then

$$E(A) = E\left(\left(r - 0{,}5{\sigma_f}^2\right)t + \sigma_f W(t)\right) = \left(r - 0{,}5{\sigma_f}^2\right)t + E\left(\sigma_f W(t)\right)$$
$$= \left(r - 0{,}5{\sigma_f}^2\right)t + \sigma_f\, E\left(W(t)\right) = \left(r - 0{,}5{\sigma_f}^2\right)t + \sigma_f(0) = \left(r - 0{,}5{\sigma_f}^2\right)t,$$

and

$$Var(A) = Var\left(\left(r - 0{,}5{\sigma_f}^2\right)t + \sigma_f W(t)\right) = Var\left(\sigma_f W(t)\right) = {\sigma_f}^2\, Var(W(t)) = {\sigma_f}^2 t.$$

So that,

$$Z = \frac{A - E(A)}{\sqrt{Var(A)}} = \frac{\left(r - 0{,}5{\sigma_f}^2\right)t + \sigma_f W(t) - \left(r - 0{,}5{\sigma_f}^2\right)t}{\sqrt{{\sigma_f}^2 t}} = \frac{\left(r - 0{,}5{\sigma_f}^2\right)t + \sigma_f W(t) - \left(r - 0{,}5{\sigma_f}^2\right)t}{\sigma_f\sqrt{t}} = \frac{W(t)}{\sqrt{t}} \sim N(0,1).$$

Next,

$$\int_0^{Z_p} g(p)dp = P_r\left(-\infty \le Z \le \frac{\ln Z_P - \ln P_0 - \left(r - 0{,}5{\sigma_f}^2\right)t}{\sigma_f\sqrt{t}}\right)$$
$$= P_r\left(-\infty \le Z \le \frac{\ln\left({Z_p}/{P_0}\right) - \left(r - 0{,}5{\sigma_f}^2\right)t}{\sigma_f\sqrt{t}}\right)$$
$$= P_r\left(-\infty \le Z \le \frac{\ln\left({Z_p}/{P_0}\right) - rt + 0{,}5{\sigma_f}^2 t}{\sigma_f\sqrt{t}}\right)$$
$$= P_r\left(-\infty \le Z \le -\left(\frac{\ln\left({P_0}/{Z_p}\right) + rt - 0{,}5{\sigma_f}^2 t}{\sigma_f\sqrt{t}}\right)\right)$$
$$= N\left(-\left(\frac{\ln\left({P_0}/{Z_p}\right) + rt - 0{,}5{\sigma_f}^2 t}{\sigma_f\sqrt{t}}\right)\right).$$

Let $d_2 = \frac{\ln\left({P_0}/{Z_p}\right) + rt - 0{,}5{\sigma_f}^2 t}{\sigma_f\sqrt{t}}$, then

$$\int_0^{Z_p} g(p)\, dp = N(-d_2). \quad (16)$$

So,

$$V_A = Z_P N(-d_2). \tag{17}$$

- Elaboration of $V_B = \int_0^{Z_p} pg(p)dp$.

$$\int_0^{Z_p} pg(p)dp = \int_0^{Z_p} p \frac{1}{p\sqrt{2\pi}\sigma_f} exp\left(-\frac{1}{2}\left(\frac{\ln p - \mu_f}{\sigma_f}\right)^2\right) dp$$
$$= \int_0^{Z_p} p \frac{1}{p\sqrt{2\pi}\sigma_f\sqrt{t}} exp\left(-\frac{1}{2}\left(\frac{\ln p - \left(\ln P_0 + \left(r - 0{,}5\sigma_f{}^2\right)t\right)}{\sigma_f\sqrt{t}}\right)^2\right) dp$$
$$= \int_0^{Z_p} \frac{1}{\sqrt{2\pi}\sigma_f\sqrt{t}} exp\left(-\frac{1}{2}\left(\frac{\ln p - \left(\ln P_0 + \left(r - 0{,}5\sigma_f{}^2\right)t\right)}{\sigma_f\sqrt{t}}\right)^2\right) dp.$$

Let $Z = \frac{\ln P - \left(\ln P_0 + \left(r - 0{,}5\sigma_f{}^2\right)t\right)}{\sigma_f\sqrt{t}}$ and $Z_p{}^* = \frac{\ln Z_p - \left(\ln P_0 + \left(r - 0{,}5\sigma_f{}^2\right)t\right)}{\sigma_f\sqrt{t}}$. Then,

$$dZ = d\left(\frac{\ln P - \left(\ln P_0 + \left(r - 0{,}5\sigma_f{}^2\right)t\right)}{\sigma_f\sqrt{t}}\right) = \frac{1}{p\,\sigma_f\sqrt{t}}dp \;\rightarrow\; dp = p\sigma_f\sqrt{t}dZ.$$

Further,

$$\int_0^{Z_p} pg(p)dp = \int_{-\infty}^{Z_p{}^*} \frac{1}{\sqrt{2\pi}\sigma_f\sqrt{t}} exp\left(-\frac{1}{2}Z^2\right) p\sigma_f\sqrt{t}dZ = \int_{-\infty}^{Z_p{}^*} \frac{1}{\sqrt{2\pi}} exp\left(-\frac{1}{2}Z^2\right) p\, dZ.$$

Since $Z = \frac{\ln P - \left(\ln P_0 + \left(r - 0{,}5\sigma_f{}^2\right)t\right)}{\sigma_f\sqrt{t}}$, then $\ln P = Z\,\sigma_f\sqrt{t} + \left(\ln P_0 + \left(r - 0{,}5\sigma_f{}^2\right)t\right)$. Consequently,

$$P = exp\left(Z\,\sigma_f\sqrt{t} + \left(\ln P_0 + \left(r - 0{,}5\sigma_f{}^2\right)t\right)\right). \tag{18}$$

Next, based on equation (18), then

$$\int_0^{Z_p} p\, g(p)\, dp = \int_{-\infty}^{Z_p{}^*} f(Z) exp\left(Z\,\sigma_f\sqrt{t} + \left(\ln P_0 + \left(r - 0{,}5\sigma_f{}^2\right)t\right)\right) dZ.$$

Note that

$$f(Z) exp\left(Z\,\sigma_f\sqrt{t} + \left(\ln P_0 + \left(r - 0{,}5\sigma_f{}^2\right)t\right)\right) = f(Z) exp\left(Z\,\sigma_f\sqrt{t} + \left(\ln P_0 + rt - 0{,}5\sigma_f{}^2 t\right)\right)$$
$$= \frac{1}{\sqrt{2\pi}} exp\left(-\frac{1}{2}Z^2\right) P_0 e^{rt} exp\left(Z\,\sigma_f\sqrt{t} - \frac{1}{2}\sigma_f{}^2 t\right)$$
$$= P_0 e^{rt} exp\left(-\frac{1}{2}Z^2 + Z\sigma_f\sqrt{t} - \frac{1}{2}\sigma_f{}^2 t\right)\frac{1}{\sqrt{2\pi}}$$
$$= P_0 e^{rt} exp\left(-\frac{1}{2}\left(Z^2 - 2Z\sigma_f\sqrt{t} + \sigma_f{}^2 t\right)\right)\frac{1}{\sqrt{2\pi}}$$
$$= P_0 e^{rt} exp\left(-\frac{1}{2}\left(Z - \sigma_f\sqrt{t}\right)^2\right)\frac{1}{\sqrt{2\pi}}$$

$$= P_0 e^{rt} \int_{-\infty}^{Z_p{}^*} \frac{1}{\sqrt{2\pi}} exp\left(-\frac{1}{2}\left(Z - \sigma_f\sqrt{t}\right)^2\right) dZ$$

Assuming $y = Z - \sigma_f\sqrt{t}$, then $dy = dZ$. Thus,

$$f(Z) exp\left(Z\,\sigma_f\sqrt{t} + \left(\ln P_0 + \left(r - 0{,}5{\sigma_f}^2\right)t\right)\right) = P_0 e^{rt} \int_{-\infty}^{Z_p{}^* - \sigma_f\sqrt{t}} f(y) dy$$

$$= P_0 e^{rt} P_r\left(-\infty \le y \le Z_p{}^* - \sigma_f\sqrt{t}\right)$$

$$= P_0 e^{rt} P_r\left(-\infty \le y \le \frac{\ln Z_p - \left(\ln P_0 + \left(r - 0{,}5{\sigma_f}^2\right)t\right)}{\sigma_f\sqrt{t}} - \sigma_f\sqrt{t}\right)$$

$$= P_0 e^{rt} P_r\left(-\infty \le y \le \frac{\ln Z_p - \left(\ln P_0 + \left(r - 0{,}5{\sigma_f}^2\right)t\right) - {\sigma_f}^2 t}{\sigma_f\sqrt{t}}\right)$$

$$= P_0 e^{rt} P_r\left(-\infty \le y \le \frac{\ln Z_p - \ln P_0 - rt + 0{,}5{\sigma_f}^2 t - {\sigma_f}^2 t}{\sigma_f\sqrt{t}}\right)$$

$$= P_0 e^{rt} P_r\left(-\infty \le y \le \frac{\ln\left({Z_p}/{P_0}\right) - rt - 0{,}5{\sigma_f}^2 t}{\sigma_f\sqrt{t}}\right)$$

$$= P_0 e^{rt} P_r\left(-\infty \le y \le -\left(\frac{\ln\left({P_0}/{Z_p}\right) + rt + 0{,}5{\sigma_f}^2 t}{\sigma_f\sqrt{t}}\right)\right)$$

$$= P_0 e^{rt} N\left(-\left(\frac{\ln\left({P_0}/{Z_p}\right) + rt + 0{,}5{\sigma_f}^2 t}{\sigma_f\sqrt{t}}\right)\right).$$

Let $d_1 = \frac{\ln\left({P_0}/{Z_p}\right) + rt + 0{,}5{\sigma_f}^2 t}{\sigma_f\sqrt{t}}$, then

$$\int_0^{Z_p} p g(p) dp = P_0 e^{rt} N(-d_1),$$

or

$$\int_0^{Z_p} p g(p) dp = PN(-d_1). \quad (19)$$

Thus,

$$V_B = PN(-d_1). \quad (20)$$

According to equations (17) and (20), then $E\left[Max\left(Z_p - P, O\right)\right] = Z_p N(-d_2) - PN(-d_1)$. So that the formula to determine the insurance premium of agricultural commodity prices is obtained as follows

$$V_p = e^{-rt}\left[Z_p N(-d_2) - PN(-d_1)\right]. \tag{21}$$

where $d_1 = \frac{\ln\left(P_0/Z_p\right)+rt+0,5\sigma_f{}^2 t}{\sigma_f\sqrt{t}}$ and $d_2 = \frac{\ln\left(P_0/Z_p\right)+rt-0,5\sigma_f{}^2 t}{\sigma_f\sqrt{t}}$.

The expected value of the compensation given in equation (21) is the expected benefit gross value received by policyholders at the price of 1 kilogram of a commodity. The insurance premium for agricultural commodity prices for a one-time harvest is given by

$$V_p{}^* = P_a e^{-rt}\left[Z_p N(-d_2) - PN(-d_1)\right], \tag{22}$$

where P_a is the average production for a one-time harvest.

For plants that can be harvested multiple times, the insurance premium of agricultural commodity prices is determined by accumulating the V_p of each harvest and multiplying it by the average production for a one-time harvest. If farmers only pay a partial amount (e.g., δ = 33%), the benefit received is $(1-\delta)V_p{}^*$. Thus, farmers will receive an income equivalent to the benefit of 67% of the premium.

This illustrates the conditions where farmers (policyholders) do not have to pay 100% of the specified premium price. In other words, farmers are able to choose the desired coverage level (k). Of course, the number of benefits expected to be received by the farmers in case of a claim will depend on the selected coverage level. Suppose farmers (policyholders) select a coverage level at 75%, then the benefit received in the case they experience losses due to falling price is $0{,}75 \times loss \times average\ of\ production$. Therefore, a formula to determine the insurance premium can be formed according to the selected coverage level, i.e.,

$$V_p{}^{**} = k\ P_a e^{-rt}\left[Z_p N(-d_2) - PN(-d_1)\right]. \tag{23}$$

3.2. Simulation

A simulation is performed using a daily price of red chili in Jambi province from 1st January to 31st December 2020 (Pusat Informasi Harga Pangan Strategis Nasional). Several assumptions are considered in the simulation study [27], namely

a. A policyholder buys an insurance policy during the planting season.
b. The first harvest period is at the age of 90 days after planting.
c. The harvest time interval is four days for two months. Thus, harvesting time is carried out 16 times in one planting period, i.e., on days 90, 94, 98, 102, 106, 110, 114, 118, 122, 126, 130, 134, 138, 142, 146, and 150 after planting.
d. The planting period is two times a year.
e. The average harvested production is determined based on red chili production in Jambi province in 2017, i.e., 160.449 kg per harvest for 1 hectare of red chili land area. It is calculated according to data on harvested land area and red chili production shown in Table 1.

Table 1. Harvested land area and agricultural commodity production in Jambi Province in 2017

Harvested Area (Ha)	Production (Kw)	Productivity (Kw/Ha)	Productivity from the one-time planting period (Kg/Ha)
7776	399241	51.34272	160.44600

Source: Central Bureau of Statistics and Directorate General of Horticulture

The simulation results show that the average red chili price return in Jambi province is -0.001069649 with a standard deviation of 0.07297269. The estimate for the expected benefit rate is equal to $\alpha_p = -0.001069649$, and the estimated volatility of red chili prices is $\sigma_f = \sigma_p = 0.07297269$. The change in red chili prices per day is given by equation (5), so that

$$dP = \alpha_f f dt + \sigma_f f \epsilon_t \sqrt{dt}. \quad (24)$$

To determine the target price at harvest time, a simulation for red chili prices is performed using equation (25). The resulting simulation of the target price is summarized in Table 2.

$$Target\ Price\ [1+i] = Target\ Price[i] + dP\ [i], \quad (25)$$

where i is the red chili target price on the day after planting ($i = 1$ indicates the price on the first day after planting).

Table 2. Target price of red chili

Day $[i]$	Target Price
90	57334.99
94	57334.25
98	57333.82
102	57334.49
106	57332.95
110	57330.76
114	57331.51
118	57328.54
122	57327.60
126	57327.43
130	57323.64
134	57323.67
138	57322.19
142	57322.50
146	57324.29
150	57322.75

Using equation (21), the insurance premium of red chili prices per kilogram for a one-time planting period is Rp. 9.517,77, and Rp. 1.527.088 for a one-time planting period with a land area of one hectare.

4. CONCLUSIONS

This paper examines the insurance premium model for agricultural commodity prices using the Black-Scholes model. The stage of determining the target price is crucial and determines the number of premium prices. The target price is the price agreed upon at the beginning to be the benchmark price whether the claim can be made or not at the harvest time. The resulting model in this paper is suitable for the condition in Indonesia. The instability factor in agricultural commodity prices caused by the government's weak intervention strengthens this argument. In addition, the issue of instability prices, as the focus of this paper, is a major factor causing farmers' losses in Indonesia.

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