Coffee prices behavior in the Indonesian market and its implication to derivatives pricing

N Binatari¹, A Latip²,

¹ Department of Mathematics Education, Faculty of Mathematics and Natural Science, Yogyakarta State University, Jl Colombo No.1 Depok Karangmalang Sleman Yogyakarta Indonesia
² Department of Mathematics and Statistics, Prince of Songkla University, Songkhla 90110, Thailand

² ade.latif@yahoo.com

Abstract. Indonesia is one of the main producers of agricultural commodities including coffee. Whereas the physical market of coffee in Indonesia, as a commodity, has been existed for centuries, the derivative market of coffee has just begun to appear recently as the result of demand growth for local market and export purpose. The paper market emerges as the outcome of the need of the producers, suppliers, and buyers to hedge against the risk of the availability and the prices volatility of coffee. In this growing commodity derivative market, it is important to examine the regular pattern and behavior of the coffee price for pricing purpose of its derivatives, especially in the specific case for the Indonesian market. This paper analyses the spot, futures, and option of coffee in Indonesia. The coffee spot price process is presented along with the parameters and its implication to derivatives pricing.

1. Introduction
The geological and climate condition of Indonesia that has a micro-climate is ideal for the growth and production of coffee. Not only provide a potential for large-scale production, but this benefits also resulting in quality coffee with its rich, full body and mild acidity coffee. Accordingly, Indonesian coffee industry has experienced a significant growth in the 21st century as well, where the exports value is reached an all-time high in 2012. On the other hand, domestic consumption is also quickly growing well beyond its exports each year. With the recent growing market of the coffee, the risk of availability of the coffee, and price volatility are subjects to concern. These are the main reason for the existence of derivatives market such as futures, forward and options. Additionally, some investors have also been increasingly attracted towards speculative investment in some commodities due to the benefits of diversification and perceived underperformance in other asset classes.

In general, agricultural commodities are well known to have a physical form, except electricity, and in large extent influenced by its supply and demand. These properties lead its price to have different properties compared to other financial asset classes. One of most important empirical property among these is the mean reversion property in commodity price process. Mean reversion property means commodity price tend to go back to its mean drifted by convenience yields. Working, Kaldor, and Geman quantify convenience yields as the advantage of the physical commodity holder to take short-term profit from the inventory [1], [2], [3]. Basically, this means that in the absence of any spot price movement, the commodity holder still expect the economic value of a commodity to appreciate or
depreciate. The study about the mean-reverting property of commodity has turned into numerous theories and models such as the three different commodity spot price models from Schwartz [4]. In this research, our model setup for coffee spot price implements the mean-reverting property directly in the price process by means of an Ornstein-Uhlenbeck (OU) process.

The other important empirical feature of coffee price is a seasonal pattern. Coffee price clearly shows the seasonal pattern of its price level induced by its supply and demand. The coffee supply in Indonesia is subject to harvesting circle which varies depending on the region of the plantation. Most producers in Temanggung, Central Java harvest on May while it happens on November in Tanah Gayo, Aceh. During the harvesting period, the supply will rise that force the price to decrease. Along with that, their demand is also subject to the increase of the need during peak season. Seasonal pattern of the underlying price shall be incorporated in the model to accurately calculate the fair value of the option contract. In this research, we focus to adapt the seasonal component on price process as deterministic trigonometric functions with a frequency of one year. This approach is similar to the approach proposed in [5], [6], [7], [8].

Indonesia is the fourth largest coffee producer and exporter in the world according to the International Coffee Organization’s report in 2018 [9]. This achievement is mainly the result of the geographic landscape and also a long historical development of coffee in Indonesia. Coffee produced from Indonesia has strong recognition for Arabica coffees such as Tanah Gayo, Sumatera Mandheling and its specialty coffees such as Kopi Luwak. It has achieved international appeal with its distinctive taste depending on the region in which it is planted as the specific soil type, altitude, coffee variety, processing, and aging affects its characteristics. The Robusta Coffee also play a big role in the Indonesian coffee industry as it is the main production and consumption in size. The exports value for both Robusta and Arabica coffee is reached an all-time high at USD1.5 billion in 2012, indicating its high international appeal. Along with that, the rising domestic consumption is quickly growing well beyond its exports each year at 24 CAGR (Compound Annual Growth Rate) from 2010 to 2013. Coffee consumption in Indonesia has nearly doubled in the past 10 years as the local coffee market is growing both for big scale (corporation) and retails market.

In spite of the physical market of coffee is already existed for centuries as it appears in the Multatuli's book in 1868 [10], the derivative market of coffee just be presented in 2013. The demand of the market participant drives to materialize of the legal regulation of some commodity futures including coffee. The producer, supplier, and buyer need the derivatives instruments to hedge against the risk of price volatility and adverse supply. PT. Bursa Berjangka Jakarta with its exchange namely Jakarta Futures Exchange (JFX) is the main exchange that facilitates the paper market of coffee in Indonesia. JFX offers two products for coffee futures, Robusta coffee futures (RCF) and Arabic coffee futures (ACF). Both are sold base on for six delivery months, January, March, May, July, September, and November. One lot RCF is for five tons where one lot ACF is two tons.

The understanding of the coffee price behavior is important for its derivatives pricing purpose as the coffee’s paper market is growing. Thus, this paper is set to analyze the behavior of coffee price and its implication for derivatives valuation in the Indonesian market by taking into account the mean-reverting and the seasonal pattern. This paper is also handy for the practical purpose for other commodities as the method used for the parameter estimation is quite simple.

We organize this paper as follows. The coffee market in Indonesia is explained in section 2. The details of commodity price process and its implication for derivatives valuation are presented in Section 3. It is followed by the parameter estimation of the price process, the numerical results, and sensitivity analysis. Finally, section 5 provides the conclusion of this work.

2. Research method
This section covers the method and data collection of the research.
2.1. Method
This research emphasizes measurement, and the mathematical and numerical analysis of the coffee prices data collected from the market. Our research uses a quantitative method where we first presume the coffee spot price process to follow a certain stochastic process based on the coffee price pattern. Non-linear least square methods are used to obtain the parameter of the coffee price process. The probabilistic approach is the main ingredient of the measurement technique while the numerical analysis focuses on the implication and sensitivity of the derivative prices to the parameters change.

2.2. Data collection
The data is secondary data collected from the BappepTI Indonesia from 2014 to 2017. The coffee spot price is available for the delivery in Medan, North Sumatera according to the data from BappepTI [11].

3. Research and Discussion
In the following we discuss the results of our study. We first explore the coffee price data in the context of its pattern. Stochastic model for the coffee price is presented after while its parameter estimation and sensitivity analysis of the derivatives price are following.

3.1. Casual interpretation from coffee price
Figure 1 shows the casual look of the price behavior of the spot price of coffee in Indonesia from 2014 to 2017. At first casual look at Figure 1, we can see that the coffee price tends to go back to its mean value in level 54,083. This behavior is the mean reverting process of the coffee price that also well-known for general commodity price process.

![Figure 1. Coffee spot prices pattern in Indonesia from 2014 to 2017 and its mean (straight line).](image)

The seasonal pattern is defined as the systematic, although not necessarily regular, the intra-year movement caused by the changes of the weather, the calendar, and timing of decisions, directly or indirectly through the production and consumption decisions made by agents of the economy [12]. The seasonal pattern of coffee price in Indonesia can be seen from simple inspection in Figure 2.

We note an immediate conclusion from this casual inspection; the mean reverting process and seasonality appear on the coffee spot price in Indonesia.
3.2. Coffee price - 1 factor model with mean reverting and seasonality component

A large class of commodity, including coffee, is widely observed to exhibit mean-reverting property and seasonal pattern on its spot price due to the heavy interaction between supply and demand influenced by production and consumer behavior. There are several alternatives to implement the mean-reverting process in the literature. Some of the most popular are the work from Schwartz in [4] who offers 3 different commodity price models, namely model 1, model 2 and model 3. Model 1 is one factor model of the log-spot price process that directly implements the means reverting to the price process, model 2 has two factors that implement the mean reverting to its subordinate process by means the volatility process and model 3 has three factors models that implement the mean-reverting process to its subordinate volatility and interest rate process. Those three models differ with respect to the long-term equilibrium price assumptions of the commodity price process considered. Model 1 has long-term equilibrium price is assumed to be deterministic, while model 2 and model 3 may have a stochastic long-term equilibrium [13]. This paper focuses to implement the mean-reverting process by adapted the 1 factor model of OU process proposed [4] and incorporate the deterministic seasonality in trigonometric function as it is proposed in one factor model of log-spot price model by [5].

Let us agree to the assumptions that the coffee price is following the mean-reverting process and incorporated seasonality and consider coffee spot price at time t is denoted by \( S_t \) under probability space \( (\Omega, \mathcal{F}, \mathbb{Q}) \) where \( g(t) \) stands for the deterministic seasonality. The price process is directly set under risk-neutral measure \( \mathbb{Q} \) and defined by

\[
\ln S_t = g(t) + y_t
\]

with the initial value \( S_0 = s_0 \). The mean-reverting is assigned in the OU process \( y_t \) as follow
\[ dy_t = -\kappa y_t dt + \sigma dW_t^Q \]  

(2)  

as \( \kappa \) denotes the speed of mean-reverting with initial value \( y_{t_0} = 0 \). We prefer to direct implementation of risk-neutral measure \( Q \) rather than its equivalent physical measure as it is stated in [13]. They argue that the market price of risk can only be estimated with very low precision from derivatives data, thus a change of measure is dispensable.

We now aim to extract information from the coffee price process for its derivatives pricing purpose. Make the use of Ito’s lemma on equation (1) we obtain

\[ dS_t = \left( \frac{1}{2} \sigma^2 - \kappa y_t + g'(t) \right) dt + \sigma S_t dW_t^Q \]  

(3)  

We have the following equation (4) by add and subtract \( \kappa g(t) S_t dt \) to equation (3)

\[ dS_t = \kappa (\theta(t) - \ln S_t) S_t dt + \sigma S_t dW_t^Q \]  

(4)

where \( \theta(t) = \frac{\sigma^2/2 + g(t)}{\kappa} + g(t) \). As seen from equation (4) the drift term of SDE on coffee price process is non-homogeneous i.e. time-dependent where the volatility is independent of the coffee price. We need the transition probability density function (abbreviated by p.d.f) of the coffee price to perform a valuation of the coffee’s derivatives. The transition p.d.f determines the laws of which the coffee price move from one state to another in a specified time period.

We transform the price process in equation (4) into the explicit OU process to get the transition p.d.f of coffee price by taking the logarithm of the price process. Consider \( X_t = \ln S_t \), then apply Ito’s lemma to equation (4) we obtain

\[ dX_t = \kappa (\hat{\theta}(t) - X_t) dt + \sigma dW_t^Q \]  

(5)

with \( X_{t_0} = x_0 \) and \( \hat{\theta}(t) = g(t) + \frac{g''(t)}{2\kappa} \). We need the Ito’s lemma to the process \( e^{\kappa t} X_t \) to obtain the explicit form of equation (5) as follow

\[ d(e^{\kappa t} X_t) = \left( \kappa e^{\kappa t} X_t + e^{\kappa t} \kappa (\hat{\theta}(t) - X_t) \right) dt + e^{\kappa t} \sigma dW_t^Q \]  

(6)

Hence integrating both sides through \( t_0 \) to \( t \), we obtain

\[
\int_{t_0}^{t} d(e^{\kappa t} X_t) = \int_{t_0}^{t} \left( \kappa e^{\kappa s} X_s + e^{\kappa s} \kappa (\hat{\theta}(s) - X_s) \right) ds + \int_{t_0}^{t} e^{\kappa s} \sigma dW_s^Q
\]

\[
X_t = x_0 e^{-\kappa (t-t_0)} + \kappa \int_{t_0}^{t} e^{-\kappa(s-t_0)} \hat{\theta}(s) ds + \int_{t_0}^{t} e^{\kappa s} \sigma dW_s^Q
\]  

(7)

Thus we arrive in the well-known normally distributed of OU process \( X_t \) [14], i.e., \( X_t \sim N(m_X(t|x_0,t_0),\nu_X(t|x_0,t_0)) \) with

\[
m_X(t|x_0,t_0) = x_0 e^{-\kappa(t-t_0)} + \kappa \int_{t_0}^{t} e^{-\kappa(s-t_0)} \hat{\theta}(s) ds
\]  

(8)

\[
\nu_X(t|x_0,t_0) = \frac{\sigma^2}{2\kappa} (e^{-\kappa(t-t_0)})
\]  

(9)

Therefore the transition p.d.f of \( X_t \) can be expressed as

\[
f_X(x,t|x_0,t_0) = \frac{1}{\sqrt{2\pi \nu_X(t|x_0,t_0)}} \exp \left( \frac{(x-m_X(t|x_0,t_0))^2}{2\nu_X(t|x_0,t_0)} \right)
\]  

(10)

### 3.3. Derivatives Pricing

The transition probability density function is essential for the pricing purpose since the value of any derivative must be the expected value, under the risk-neutral measure, of its payoffs, discounted to the
valuation date at the risk-free rate, which we assume to be constant. The value at time zero of a futures contract on the spot price maturing at the time $T$ must be:

$$ v_{t_0}(S, T) = e^{-r(T-t)}E^Q[S_T - F_t] $$

(11)

Since we the value of the futures at the valuation date $t_0$ should be zero, we have the following formula for the futures price

$$ e^{-r(T-t)}E^Q[S_T - F_t] = 0 $$

(12)

Thus we have

$$ F_t = e^{-r(T-t)}E^Q[S_T] $$

(13)

With the same argument, the put option price at time $t$ is:

$$ P_t(S, T, K) = e^{-r(T-t)}E^Q[\max(S_T - K, 0)] $$

(14)

where we can make the use of option put-call parity to evaluate the call price.

### 3.4. Parameters Estimation

For the purpose of the parameters estimation, we implement the seasonality component $g(t) = \eta \sin(\zeta t)$ where $\eta$ and $\zeta$ are parameters to control seasonality amplitude and period respectively. The value of $\kappa$, $\sigma$, $\eta$ and $\zeta$ are estimated using non-linear least square method (LSM). Then, we simulate the log-price process base on the analytic solution of the OU process from [14]

$$ X_t = x_0 e^{-\kappa(t-t_0)} + \kappa \int_{t_0}^{t} e^{-\kappa(t-s)} \tilde{\theta}(s) ds + \int_{t_0}^{t} e^{\kappa t} \sigma dW_t^Q $$

$$ = x_0 e^{-\kappa(t-t_0)} + \kappa \int_{t_0}^{t} e^{-\kappa(t-s)} \tilde{\theta}(s) ds + \frac{\sigma e^{-\kappa t}}{\sqrt{2\kappa}} W_{e^{2\kappa t-1}} $$

(15)

where $W_{e^{2\kappa t-1}}$ is a random variable that follows the normal distribution with zero mean and variance $e^{2\kappa t} - 1$.

### 3.5. Numerical analysis

For the numerical implementation, we use the data from Bappepi coffee spot price from Jan 2014 to December 2017 [11]. We perform non-linear LSM on the average of daily price from the four years data. We obtain the parameters $\kappa = -0.00001$, $\sigma = 0.01$, $\eta = -0.06$, and $\zeta = 0.02$. The parameters obtained shows that the expectation of coffee price in a year term agrees with the mean value from historical price 54,083.

We analyze the behavior of the coffee price through its transition density. The transition p.d.f of process $X_t$ shows the law of the coffee log-price shift from one state to another. We plot the example on how the coffee log-price behaves in the manner of its transition p.d.f using the parameter obtained.

![Figure 3. Transition p.d.f behavior of coffee log-prices from the state $X_{t_0} = \log 51,143$ to the various price states at time $T = 230$](image)
From the figure 3, the red line shows that the coffee price has the most likeliness to move from level 51,143 to 50,000 while the blue line shows that the coffee price has the least likeliness to move to level 65,000 in the given period.

3.6. Sensitivity Analysis

One of our main concern is the impact of coffee price behavior on the value of its derivatives. We check the sensitivity of the value of the derivatives in respect to the change of the value of its parameter. Firstly we fixed the parameters, $\sigma = 0.01$, $\eta = -0.06$, $\zeta = 0.02$ and the initial coffee price at 51,143, then compute with different values of $\kappa$ as seen in table 1. We use negative values of mean-reverting parameter $\kappa$ as the coffee price, from the data, reverts to the higher value than its initial state.

Table 1. Derivatives price sensitivity to $\kappa$

| $\kappa$ | Futures Price | European Put Price |
|----------|---------------|--------------------|
| -0.00001 | 5479.1        | 679.6              |
| -0.00002 | 5618.2        | 586.0              |
| -0.00003 | 5761.1        | 498.6              |
| -0.00005 | 6059.1        | 345.7              |
| -0.00009 | 6706.7        | 136.6              |
| -0.0003  | 11609.8       | 0                  |

Table 2. Derivatives price sensitivity to $\sigma$

| $\sigma$ | Futures Price | European Put Price |
|----------|---------------|--------------------|
| 0.01     | 5479.1        | 679.6              |
| 0.03     | 6008.4        | 1086.7             |
| 0.05     | 7225.2        | 1407.0             |
| 0.07     | 9527.8        | 1648.4             |
| 0.09     | 13777.9       | 1833.7             |
| 0.1      | 17151.2       | 1910.5             |

Table 1 shows that both futures and European put option values are sensitive to the change of the parameter $\kappa$. A slick change of the speed of mean-reverting $\kappa$ will impact the derivatives value drastically.

Secondly, we fixed the parameters $\kappa = -0.00001$, $\eta = -0.06$, $\zeta = 0.02$ and the initial coffee price at 51,143, then compute with different values of $\sigma$ as seen in table 2. The parameter coffee price volatility $\sigma$ represents the risk of the coffee price to change from one state to another. The market participant will expect the higher premium from higher volatility risk. Table 2 shows that our result is consistent with that, as the higher the value of $\sigma$ then the value of both futures and European put option also get higher.

We then study the sensitivity of the derivatives price to the seasonality parameters. We fixed the parameters $\kappa = -0.00001$, $\sigma = 0.01$, $\zeta = 0.02$ and the initial coffee price at 51,143, then compute with different values of $\sigma$ as seen in table 3. The parameter $\eta$ represents the seasonality amplitude of the coffee price. The sign of the value of $\eta$ will take effect in the direction of the seasonality amplitude. From this case we understand that the expected coffee price at time $T$ will increase as the amplitude $\eta$ get higher (in negative sign), so does the futures price as seen in table 3. However, the European put option gets lower as the value of amplitude $\eta$ gets higher (in negative sign).

Table 3. Derivatives price sensitivity to $\eta$

| $\eta$ | Futures Price | European Put Price |
|--------|---------------|--------------------|
| -0.01  | 5344.6        | 778.1              |
| -0.03  | 5398.0        | 738.2              |
| -0.06  | 5479.1        | 679.6              |
| -0.1   | 5589.8        | 604.6              |
| -0.3   | 6173.4        | 295.2              |
| -0.5   | 6818.8        | 111.5              |
| -1     | 8742.9        | 2.5                |

Table 4. Derivatives price sensitivity to $\zeta$

| $\zeta$ | Futures Price | European Put Price |
|---------|---------------|--------------------|
| 0.01    | 5438.15       | 708.859            |
| 0.02    | 5161.83       | 922.992            |
| 0.05    | 5180.24       | 907.869            |
| 0.1     | 5184.78       | 904.160            |
| 0.5     | 5471.10       | 685.291            |
| 1       | 5220.72       | 875.024            |
| 2       | 5475.23       | 682.371            |
We fixed the parameters $\kappa = -0.00001$, $\sigma = 0.01$, $\eta = -0.06$ and initial coffee price 51,143, then compute with different values of $\sigma$ as seen in table 3. The parameter $\zeta$ represents the seasonality period of the coffee price. We can see from table 4 that there is no similar pattern with previous parameters of the futures and European put option price as the level of $\zeta$ increase as we understand that the expected coffee price at time $T$ has also varied as the $\zeta$ increase.

4. Conclusion
This article presents the study of the coffee spot price behavior in the Indonesian market. We use the main characteristics of the general commodity that has mean reverting process governing by its large extend to supply and demand. Our theoretical assumption of a seasonal pattern of coffee price also agrees to casual look from the real price data. Thus we make a use one factor model of the OU process with seasonality component as our coffee price process. We then study this behavior for the implication to its derivatives pricing. The parameters are obtained from the historical data and simple estimation. Using the exact formula of the coffee prices, we explore the sensitivity of the parameters changes to its derivatives price.

Based on our study results, we can conclude that the coffee price in Indonesia is experiencing mean reverting with speed of $\kappa = -0.00001$ and volatility $\sigma = 0.01$. The coffee price in Indonesia also incorporates seasonality with magnitude and period parameters are $\eta = -0.06$ and $\zeta = 0.02$ respectively. We also conclude that the coffee derivatives have a certain degree of sensitivity to the change of the speed of mean reverting, volatility and seasonal parameters change.

References
[1] Working H 1949 The Theory of Price of Storage The American Economic Review vol 39(6) pp 1254-62.
[2] Kaldor N 1939 Speculation and Economic Stability The Review of Economic Studies vol 7 pp 1-27.
[3] Geman H, Smith W O 2013 Theory of storage, inventory and volatility in the LME base metals Resources Policy vol 33(1) pp 18-28.
[4] Schwartz E S 1997 The stochastic behavior of commodity prices: implication for valuation and hedging J. finance 52(3) pp 923-73.
[5] Lucia J J and Schwartz 2002 Electricity prices and power derivatives: evidence from The Nordic Power exchange Review of derivatives research vol 5(1) pp 5-50.
[6] Elliot R, Gordon and Stein M 2003 Modelling electricity price risk.
[7] Sorensen C 2002 Modelling seasonality in agricultural commodity futures J. Futures Mark. 22(5) pp 393-426
[8] Richter M and Sorensen 2002 Stochastic volatility and seasonality in commodity futures and options: the case of soybeans.
[9] I C Organization, "http://ico.org/trade_statistics.asp," [Online]. [Accessed September 2018].
[10] Dekker E D and Multatuli 1868 Max Havelaar: or the coffee auctions of the Dutch trading company Edinburg: Edmonston & Douglas.
[11] Bappepti, "http://bappebti.go.id/harga_komoditi_bursa," Bappepti, October 2018. [Online]. Available: http://bappebti.go.id/harga_komoditi_bursa. [Accessed 2018].
[12] Hylleberg S 1992 Modelling seasonality Modelling seasonality Oxford University Press.
[13] Back J, Prokopczuk M and Rudolf M 2013 Seasonality an dthe valuation of commodity options . J. Bank. Finance 37 273-290.
[14] Doob J L 1942 The Brownian movement and stochastic equations Annals of Mathematics 43(2) 351-369.