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Use of ARIMA-GARCH Model to Estimating Value-at-Risk in Gudang Garam (GGRM) Stock

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Abstract

Stocks are one of the best-known forms of investment and are still used today. In stock investment, it is necessary to know the movement and risk of loss that may be obtained from the stock investment, so that investors can consider the possible losses. One way to calculate risk is to use Value-at-Risk (VaR). Since the stock movement is in the form of a time series, a model can be formed to predict the movement of the stock, which can then be used for VaR calculations using time series analysis. The purpose of the study was to determine the Value-at-Risk value of Gudang Garam Tbk.'s (GGRM) shares using time series analysis. The data used for this research is the daily closing price of shares for three years. At the time series analysis stage, the models used in predicting stock movements are Autoregressive Integrated Moving Average (ARIMA) for the mean model and Generalized Autoregressive Conditional Heteroscedasticity (GARCH) for the volatility model. The average and variance values obtained from the model are then used in calculating the VaR of GGRM shares. Based on the results of the study, it was found that the GGRM stock has a VaR of 0.069598. In other words, if an investment of IDR 1,000,000.00 is made for GGRM shares for 37 days (5% of 747 days), the investment period with a 95% confidence level, the maximum loss that may be borne by the investor is IDR 69,598.00.

Keywords: time series analysis, ARIMA, GARCH, Value-at-Risk

1. Introduction

Investment, in general, is the investment of assets or funds by a party for a certain period to gain profits or benefits in the future. One of the most well-known forms of investment and is still being carried out today is stock investment, or rather share ownership rights.

Shares are proof of ownership of the share capital of a limited liability company that entitles them to dividends and others according to the size of the paid-up capital; or rights that people (shareholders) have over the company due to the surrender of a share of capital so that it is considered a share in ownership and control (Big Indonesian Dictionary 18th edition, 2014).

Every investment has its advantages and risks, stocks are no exception. To make a profit, it is necessary to consider the benefits obtained from the return price of the stock with the existing risks. Stocks themselves have price movements that tend to be difficult to ascertain, making stocks have their risks compared to other forms of stock.

The risk of stock investment makes investors need to know the seasonal variance and price movements. There are several ways to estimate risk in investment, such as volatility and Value-at-Risk. This study will use the Value-at-Risk method in analyzing stock risk with a time series model.

These models are widely used for time series analysis of various types of data. Following are some previous studies regarding the use of the ARIMA-GARCH model. The first study was entitled "Forecasting Inflation in Kenya Using ARIMA-GARCH Models" by Uwilingiyimana et al. (2015). This research was motivated by the inflation rate in Kenya which at that time became out of control. This study aims to develop a model that can explain Kenya's inflation rate from 2000 to 2014 using time series analysis. Data analysis used the least-squares method and Auto-Regressive Conditional Heteroscedastic (ARCH). After being analyzed separately through the ARIMA model and the GARCH model, it was found that the ARIMA (1,1,12) model formed forecasts based on stationarity tests and data patterns that were more accurate than the GARCH(1,2) model. It can be concluded that the ARIMA(1,1,12)-GARCH(1,2) model produces the most accurate estimation when compared to other models.

In addition, there is also a study entitled "Estimated Value-at-Risk (VaR) on a stock portfolio with Copula" by Iriani et al. (2013). This research is motivated by the risk of investment in the form of shares which tend to be high. One method of determining investment risk is Value-at-Risk (VaR). The purpose of this study was to determine the VaR return of several stocks from 2005 to 2010 using the Copula method. The study used the ARMA-GARCH model to obtain the residual GARCH (1,1) which was then used for copula modeling and VaR estimation. The copulas used are several Archimedean copulas, including Clayton, Frank, and Gumbel. The study showed that Clayton copula modeling as the best copula model was able to capture heavy tail better based on the resulting VaR.

In this study, the model used is the ARIMA-GARCH model to estimate the Value-at-Risk on Gudang Garam Tbk. shares (GGRM). The purpose of this study is to apply the ARIMA-GARCH model in the estimation of Value-at-Risk on GGRM stock data. The purpose of this study is to determine the characteristics of the analyzed stock data, to estimate the ARIMA-GARCH model from historical stock data, and to determine the value-at-risk of stock data based on the ARIMA-GARCH model. This study uses the help of Microsoft Excel and Eviews 7 applications to chart the size of the data and to estimate the stock model.

2. Literature Review

2.1. Stock

Stock is one form of investment that is considered the most promising because it has the opportunity to provide relatively large profits. However, these benefits also need to be compared with the risks involved. To analyze the stock data itself, the return value is usually used which is formulated as follows (Dowd, 2002)

$$r_t = \left(\frac{P_t - P_{t-1}}{P_{t-1}}\right), \tag{1}$$

where r_t is the value of the data return at time t, P_t is the value of data at time t, and P_{t-1} is the value of data at time $t-1$ (1 previous time).

For stock return value analysis, usually to make the data stationary, the data is derived or differentiated with the analyzed data calculated using (Dowd, 2002)

$$r_t = \ln\left(\frac{P_t}{P_{t-1}}\right), \tag{2}$$

2.2. Normality test

The normality test has a purpose to determine whether the tested data is normally distributed. The data for the normality test in this study is the residual data return model where the normality test uses the Jarque-Berra test. The test uses the following hypothesis.

H_0: The tested data is normally distributed.

H_1: The tested data is not normally distributed.

The test statistic used has the following equation (Jarque and Bera, 1980)

$$JB = n\left(\frac{\varsigma^2}{6} + \frac{(k-3)^2}{24}\right), \tag{3}$$

where n is the sample size, ς is skewness, and k is kurtosis. The test criteria is that H_0 is rejected if $JB \geq \chi^2$.

2.3. Mean Model

In this section, we will discuss ARMA and ARIMA models for research. The ARMA time series model is used to briefly describe weak stationary stochastic processes, namely autoregression and moving average. This model was popularized in 1970 by Box and Jenkins. As the name implies, this model combines the AR model and the MA model to forecast time series data over a certain period. This model is denoted by ARMA(p,q) where p is ordered AR and q is ordered MA. The equation of the ARMA(p,q) model is as follows

$$W_t = \beta_0 + \varepsilon_t + \sum_{i=1}^{p} \beta_i W_{t-i} + \sum_{i=1}^{q} \theta_i \varepsilon_{t-i}, \tag{4}$$

where W_t is the data at time t, β_0 is a constant, β_i is the AR model parameter coefficient which depends on the lag limit, θ_i is the MA model parameter coefficient which depends on the lag limit, and ε_t is the error data at time t.

To select good p and q, PACF is used to determine p and ACF is to determine q. In addition, AIC can also be used.

The ARIMA model is a generalization of the ARMA model. This model is used as a tool to explain the analyzed time series and predict the value of the data in the future (forecasting). This model is denoted by ARIMA(p,d,q) where p is the order for the AR process, d is the degree of data integration so that the data is stationary (the number of times the data value is different from the previous data), and q is the order for the MA process with p, d, and q are non-negative integers respectively (Uwilingiyimana et al., 2015). Process $\{W_t\}$ is ARIMA(p,d,q) if $\Delta^d W_t = (1-L)^d W_t$ is ARMA(p,q). In general, the model is written as follows

$$\beta(L)(1-L)^d W_t = \theta\varepsilon_t; \{\varepsilon_t\} \sim WN(0,\sigma^2), \tag{5}$$

with ε_t following the white noise (WN).

Suppose, L is the lag operator where $L^k W_t = W_{t-k}$ where the autoregressive operator and moving average are defined as follows

$$\begin{aligned} \beta(L) &= 1 - \beta_1(L) - \beta_1(L^2) - \cdots - \beta_p(L^p), \\ \theta(L) &= 1 - \theta_1(L) - \theta_1(L^2) - \cdots - \theta_p(L^q). \end{aligned} \tag{6}$$

The functions β and θ are autoregressive polynomials and moving averages with orders p and q in the variable L, $\theta(L) \neq 0$ if $|\theta| < 1$, $\{W_t\}$ is stationary if and only if $d = 0$, which makes the model ARMA (p,q) (Charline et al., 2015).

For estimating this model, the steps that need to be done are estimating the shape of the model using a correlogram, selecting the best shape, then testing the verification and validation of the model, as well as a diagnostic test (Uwilingiyimana et al., 2015).

2.4. Volatility Model

This section discusses the ARCH and GARCH models for research. The ARCH model is a statistical model that describes the variance of the analyzed time series residuals. This model is used when the error variance in the model follows the autoregressive (AR) form.

To model the time series using the ARCH(p) process, ε_t is used which denotes the residual return from the model mean, as follows

$$\varepsilon_t = \sigma_t Z_t, \{Z_t\} \sim iid\ N(0,1), \tag{7}$$

where σ_t is the time-dependent standard deviation and z_t is a white noise random variable. The σ_t^2 series is modeled as follows

$$\sigma_t^2 = \alpha_0 + \alpha_1\varepsilon_{t-1}^2 + \alpha_2\varepsilon_{t-2}^2 + \cdots + \alpha_p\varepsilon_{t-p}^2, \tag{8}$$

where $\alpha_0 > 0$, $\alpha_i \geq 0$, $i = 1,2,\ldots,p$, and Z_t where $\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_t$ are independent for each t. The GARCH model is a generalization of the ARCH model developed by Bolerslev in 1986, where if ARCH is used when the residual model is in the form of AR, GARCH is used when the residual model is in the form of ARMA. The GARCH(p,q) model has a form like the ARMA model as follows

$$\varepsilon_t = \sigma_t\varepsilon_t, \varepsilon_t \sim N(0,1),$$

where

$$\sigma_t^2 = \alpha_0 + \alpha_1 r_{t-1}^2 + \cdots + \alpha_p\varepsilon_{t-p}^2 + \beta_1\sigma_{t-1}^2 + \cdots + \beta_q\sigma_{t-q}^2, \tag{9}$$

where $\alpha_0 > 0$, $\alpha_i \geq 0$, $i = 1,2,\ldots,p$, $\beta_j \geq 0$, $j = 1,2,\ldots,q$.

If $\{r_t\}$ is the return of mean, ε_t is Gaussian white noise with mean 0 and unit variance, $\{W_t\} = \{r_1, r_2, \ldots, r_{t-1}\}$, then $\{r_t\}$ is GARCH(1,1) if (Uwilingiyimana et al., 2015)

$$\varepsilon_t = \sigma_t\varepsilon_t, \varepsilon_t \sim N(0,1),$$
$$\sigma_t^2 = \alpha_0 + \alpha_1 r_{t-1}^2 + \beta_1\sigma_{t-1}^2.$$

To estimate this model from the previous ARIMA model, it must first be seen whether the residual model is heteroscedastic (containing ARCH elements), and if there is the next step, it is more or less the same as the estimation of the model means. If the diagnostic test has been carried out and the model is obtained, it must be re-checked for the heteroscedasticity of the estimated model. If the model estimate contains ARCH elements, then the model can already be used. The variance and average of these models will then be used in the next stage, namely the estimation of Value-at-Risk.

2.5. Value-at-Risk

Value-at-Risk (VaR) is a measurement of investment risk that shows the maximum possible loss. Therefore, Value-at-Risk is the amount of loss that may be obtained from a certain amount with a confidence level of α in the T period. VaR value is calculated under certain market conditions with a certain level of risk within a certain period. VaR estimation usually uses the standard method which assumes that the return data has one variable and is normally distributed with a mean of μ and a standard deviation of σ.

VaR estimation is done by determining the percentile to $(1-\alpha)\%$ of the standard normal distribution $z_{1-\alpha}$ (Artzner et al., 1999)

$$1-\alpha = \int_{-\infty}^{q} f(r)dr = \int_{-\infty}^{z_{1-\alpha}} \phi(z)dz = N(z_{1-\alpha}), \tag{10}$$

with quartiles $q = z_{1-\alpha}\sigma + \mu$, where $\phi(z)$ is the probability density function of the standard distribution, $N(z)$ is the cumulative normal distribution function, r is the value of the random variable stock return denoted by R, and $f(r)$ is the density function of the log return normal distribution with μ mean and σ variance.

Then the equation used to determine VaR is as follows (Artzner et al., 1999)

$$\begin{aligned} r_t &= \mu_t + \sigma_t z_t, \\ \widehat{VaR}_\alpha^t(r_t) &= -\inf(r_t | F(r_t) \geq \alpha) \\ &= -\hat{\mu}_t - \hat{\sigma}_t F^{-1}(\alpha). \end{aligned}$$

There are cases where the data distribution is not normal due to excess skewness and kurtosis resulting in deviations. So, to estimate VaR and ES, Cornish-Fisher expansion will be used to obtain the following formula (Situngkir, 2006)

$$VaR_\alpha^t(x) = -\widehat{\mu_t} + -\widehat{\sigma_t} F_{CF}^{-1}(\alpha), \tag{11}$$

$$\begin{aligned} F_{CF}^{-1}(\alpha) = \phi^{-1}(\alpha) + \frac{\varsigma}{6}([|\phi^{-1}(\alpha)|]^2 - 1) + \frac{k-3}{24}\left([|\phi^{-1}(\alpha)|]^3 - 3\phi^{-1}(\alpha)\right) \\ - \frac{\varsigma^2}{36}\left(2[|\phi^{-1}(\alpha)|]^3 - 5\phi^{-1}(\alpha)\right), \end{aligned} \tag{12}$$

where $\hat{\mu}_t$ is the estimated mean of the data at time t, $\hat{\sigma}_t$ is the variance of the data at time t, and $F_{CF}^{-1}(\alpha)$ is the α-quantile of the z_t distribution.

3. Results and Discussion

This section discusses the data used for analysis and the results of the analysis in the form of mean models, volatility models, and estimates of Value-at-Risk and Expected Shortfall for each selected stock.

3.1. Data

The data used for this research is historical data of daily closing prices of Gudang Garam Tbk. shares (GGRM) from September 1, 2017 to August 31, 2019. Data obtained at www.financeyahoo.id.

3.2. Data Properties

The data used have descriptive statistics which are presented in Table 1.

Table 1: Descriptive Statistics of each Preferred Stock

Stock	Samples (N)	Average	Median	Minimum	Maximum	Standard Deviation	Skewness	Kurtosis
GGRM	747	66984.64	67325	40500	85275	9635.243	-0.74631	3.536839

Based on the table, it can be seen that the stock data has a skewness and kurtosis that deviates from the skewness, and the data kurtosis is normally distributed (0 and 3) so that the stock closing data is not normally distributed.

Then using the help of Eviews 7, it was found that the original data was not stationary. Therefore, the data must be transformed using equation (2) until the data is stationary. After one transformation, the data from the transformation of each share is stationary. So, it can be concluded that the order of d for the ARIMA(p,d,q) model of GGRM stocks is 1.

3.3. Estimated Model Mean

Once it is known that the data is stationary, the shape of the model can be estimated. For the form of the mean model, the model used is the ARIMA model. After carrying out the estimation stage as described in section 2.3, it is found that the estimation of the mean stock model is in the form of ARIMA(2,1,2). The form of this model does not have a normally distributed residual. The estimation of the stock model is as follows.

The mean model for GGRM stock return data is

$$\hat{Z}_t = 2.349489Z_{t-1} - 1.98055Z_{t-2} - 0.638566Z_{t-3} + 1.394100\varepsilon_{t-1} - 0.630449\varepsilon_{t-2}.$$

3.4. Volatility Model Estimation

Before estimating the volatility model, it is first determined whether the mean model from the previous subsection has an ARCH element. After doing the ARCH-LM Test on each model using the help of Eviews 7, it was found that each model has an ARCH element. Because the model has an ARCH element, it is possible to estimate the volatility model. After the estimation stage, the GGRM stock volatility model is obtained in the form of GARCH(1,1). This model is significant after the validation test and the residual is white noise and is not normally distributed after the diagnostic test. Then after being checked, the models have ARCH elements so that they can be used for modeling. Here are the models.

The model for GGRM stock is

$$\hat{\sigma}_t^2 = 0.0000367 + 0.075830a_{t-1}^2 + 0.827581\sigma_{t-1}^2.$$

The variance and mean obtained from the estimation of this model are then used to estimate the Value-at-Risk in the next calculation.

3.5. Estimated Value-at-Risk

The models of each stock option do not have a normal distribution because the residuals in the model are also not normally distributed. Therefore, to estimate the value-at-risk of stocks, equations (11) and (12). GGRM stock estimation results are shown in Table 2.

Table 2: Value-at-Risk Value of GGRM Shares

Stock	Average	Variance	Standard Deviation	Skewness z	Kurtosis z	$\phi^{-1}(5\%)$	$F_{CF}^{-1}(5\%)$	$VaR_{5\%}$
GGRM	0.00273	0.0021	0.045826	0.168729	3.893378	-1.64485	-1.57832	0.069598

Based on Table 2, it can be seen that Gudang Garam's stock has a VaR of 0.069598. In other words, if an investment is made for GGRM shares of IDR 1,000,000.00 for 37 days (5% of 747 days) the investment period with a 95% confidence level, the maximum loss that may be borne by the investor is IDR 69,598.00.

4. Conclusions and suggestions

The first conclusion is that the original GGRM stock closing data has skewness and kurtosis that deviate from the skewness and kurtosis of the data are normally distributed (0 and 3) so that the stock closing data is not normally distributed. Then, the mean model of GGRM's stock is ARIMA(2,1,2) model, while the volatility model obtained from GGRM's stock is GARCH(1,1).

Finally, the risk level of GGRM shares has a VaR of 0.069598. In other words, if an investment is made for GGRM shares of IDR 1,000,000.00 for 37 days (5% of 747 days) the investment period with a 95% confidence level, the maximum loss that may be borne by the investor is IDR 69,598.00.

For further research, other models can be used, such as the Seasonal ARIMA (SARIMA) or ARFIMA for the mean model and the Exponential GARCH (EGARCH) or Fractionally Integrated GARCH (FIGARCH) for the volatility model.

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