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A Study on the Asymmetric Volatility of Price Index of Gold and Crude Oil

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***Abstract*:**
This study used daily indices of gold and crude oil prices from January 2, 1987 to June 28, 2019 to find out whether the impacts on the volatility of gold and crude oil prices are different according to type of information that arrive in each market. An empirical analysis was conducted using GJR(1,1)-MA(1) model. The analysis result showed that GJR(1,1)-MA(1) model is an specification model for analyzing asymmetrical response for the information. Volatility in gold and crude oil prices was shown to respond asymmetrically according to type of information. As for gold market before the global financial crisis, unpredictable, positive yield rate increased the volatility of gold price much more than unpredictable, negative yield rate. After the global financial crisis, however, unpredictable, negative yield rate was shown to increase volatility in gold price more than unpredictable, positive yield rate. On the other hand, in the crude oil market, unpredictable, negative yield rate increased the volatility in crude oil price more than unpredictable, positive yield rate both before and after the global financial prices.

Keywords—Gold Price, Crude Oil Price, Information, Asymmetrical Volatility, GJR model

1. INTRODUCTION

Volatility in gold and crude oil prices respond either strongly or weakly according to the flow of information that affects each asset market. Since volatility refers to risk in each asset market, it is an important variable in understanding the relationship between the yield rate and the risk of an asset. Volatility in stock price is known to show difference according to whether the information that arrives in the stock market is good news or bad news. Black(1976) argued for asymmetrical response, meaning that volatility of stock price responds more greatly to bad news. Afterwards, French, Schwert and Stambaugh(1987), Nelson(1991), Engle and Ng(1993), Glosten, Jagannathan and Runkle(1993), Dolde and Tirtiroglue(2002), Kam, Shin and Park(2007), Hossain and Latif(2009), Kim(2009), Kim, Bao and Do(2011), and Albu, Lupu and Călin(2015) analyzed asymmetrical response on information utilizing GARCH(Generalized Autoregressive Conditional Heteroskedastic) model.

French, Schwert and Stambaugh(1987) analyzed that volatility increases when public and private information that can affect investment decision-making is likely to reach the market, and a large portion of the volatility comes from error in price information. Nelson(1991) used EGARCH model to analyze the relationship between change in volatility and risk premium in the US stock market from 1962 to 1987 using CRSP Value-Weighted Market Index data. The analysis result showed that a significant asymmetric relationship exists between unpredictable yield rate and conditional dispersion.Engle and Ng(1993) used daily stock price yield rate of Japan to analyze asymmetrical response of yield rate of sock price through modified ARCH model. The analysis result showed that, while EGARCH model has too large volatility of dispersion for various flow of information, GIR model captures asymmetrical response better than EGARCH model. Glosten, Jagannathan and Runkle(1993) argued that an inverse relationship exists between conditional expected yield rate and conditional dispersion using monthly data of weighted stock price index in CRSP (center for research in security prices) in the United States from 1951 to 1989. This means that negative yield rate (bad news) lowers expected yield rate that has no bee expected and increases conditional volatility. Therefore, the result showed that conditional yield rate shows asymmetrical response on negative yield rate (bad news). Dolde and Tirtiroglue(2002) used GARCH model to show that 36 volatility factors are important in volatility of local housing market. While the most of volatility factors are local factors, 3 of them are national factors. The study reported that volatility in local housing price spreads locally, but does not decrease. Notably, it found that mortgage investors and general investors need new insight in economic condition, volatility in stock price, and yield rate. Kam,Shin, and Park(2007) used stock price indices of South Korean industries for 16 years, from January 2, 1990 to December 31, 2005 using GJR model and EGARCH model to analyze the effect of volatility in stock price according to type of information. The analysis result showed that, throughout this period, an unpredictable negative yield rate increased volatility of stock market in construction, finance, and manufacturing industries much more than positive yield rate. The study analyzed that, during sub-phase analysis before and after the East Asian financial crisis, bad news increased volatility in stock price much more than the good news before the East Asian financial crisis. Hossain and Latif(2009) used housing price index in Canada to analyze the relationship between time variability of housing price volatility and macroeconomic variables using GARCH model and VAR model. The analysis showed that volatility in housing price changes by time, and that volatility is greatly affected by GDP growth rate, inflation rate, and growth rate of housing price. Kim(2009) analyzed spillover effects of risky assets, such as stock, bonds, and real estate, on price volatility using GJR(1,1)-M model. Kim analyzed that the Korean stock market affects volatility in bond market and real estate market, and is the most market with the most independent volatility. On the other hand, the study found out that volatility of the bond market and real estate market does not affect volatility in stock market. However, it was analyzed that, after the exchange rate crisis, volatility of the stock market and the bond market spread to one another, weakening the independence of the stock market. Kim, Bao and Do(2011) used GJR-GARCH model to analyze syntonization of stock market using S&P 500 index of USA, KOSPI of Korea, and SSEC of China from January 4, 1999 to March 31, 2008. Thy found that, while the Korean and the Chinese stock markets do not affect the American stock market, the American stock market brings about a positive impact on the Korean and the Chinese stock markets. Also, the study found that an asymmetric response exists in the Korean and the Chinese stock markets, where their volatility increases on bad information rather than good information. Albu, Lupu and Călin(2015) used GARCH model to conduct an empirical analysis on asymmetric response of the East European stock market. The study found a negative correlation between volatility of financial assets and yield rate.

These studies showed that an asymmetric response on information exists in the stock market or the housing market. However, studies on whether volatility of gold and crude oil prices on information shows asymmetric response are lacking. Therefore, this study was conducted to empirically clarify whether volatility of gold and crude oil prices would show symmetric or asymmetric response on information and obtain practical utility of searching for predictive models. Unlike most of preceding studies which empirically analyzed asymmetric response of stock price, this study is unique in that it empirically analyzes whether the volatility of gold and crude oil prices, which are real assets, show asymmetric response on information.

The study consists of the following parts. Chapter II discusses analysis methods, Chapter III presents analysis results, and Chapter IV organizes conclusion and implications.

2. ANALYSIS METHOD

2.1. GARCH(1,1)-MA(1) MODEL

To explain GARCH model that can show asymmetric response on information of gold and crude oil prices, GARCH model, presented by Bollerslev(1986), should first be explained. Bollerslev(1986) explained conditional volatility of stock price using GARCH model. Replacing stock price with gold and crude oil prices, the GARCH model changes as equation (1).

$$h_t = \alpha + \sum_{n=1}^{p} \beta_i e_{t-n}^2 + \sum_{k=1}^{q} \gamma_i \, h_{t-k} \qquad (1)$$

Conditional dispersionh_t in Equation (1) is a model where unpredictable change in gold and crude oil prices that are the information indices of period t-1, that is, the square of residual in period t-1, an conditional volatility of gold and crude oil prices in period t-1, which reflects all information before period t-1, express conditional volatility of gold and crude oil prices in period t. Assuming that information in period t-1 is known, setting expected yield rate as $\overline{R_t}$ and conditional dispersion as h_t results in $\overline{R_t} \equiv E(R_t|\Omega_{t-1}),\ h_t = Var(R_t|\Omega_{t-1})$. Unpredictable yield rate in period t is$e_t \equiv R_t - \overline{R_t}$, and e_t is the aggregate of information in period t. Here, large value of$|e_t|$, which is the absolute value of unpredictable yield rate of gold and crude oil prices that are expressed as residual, means that a large change occurred in gold and crude oil prices. Equation (2) is GARCH-MA model. In Equation (2),R_t is daily yield rate in gold and crude oil prices, and Ω_{t-1} refers to aggregate of all information up to period t-1.

$$R_t = \omega + Z_t \quad (2)$$
$$Z_t = e_t - \alpha e_{t-1}$$
$$e_t = |\Omega_{t-1}| \sim N(0, h_t)$$
$$h_t = \beta + \gamma e_{t-1}^2 + \delta h_{t-1}$$

While GARCH model well expresses change of time in volatility of gold and crude oil prices, it has limitations in analyzing asymmetric response of the prices on information. This is because GARCH model is designed so thate_{t-1}, the aggregate of information in period t-1, has conditional volatility in period t to respond uniformly. However, GARCH-MA model is used here in order to compare asymmetric response of volatility of gold and crude oil prices with GJR-MA model.

2.2. GJR(1,1)-MA(1) MODEL

There are various models that modify GARCH model to capture asymmetric response of information. This study uses GJR(1,1)-MA(1)(Moving Average(1)) model, as shown in Equation (3), where GJR model of Glosten et al.(1989) is modified by Ohk(1997). To obtain unpredictable yield rate in Equation (3) or to address the issue of autocorrelation of yield rate, MA(Moving Average) was added on GJR model. For degree of MA, GJR(1,1)-MA(1) model was adopted in accordance with the parsimony principle of the model based on AIC and SBC statistical norm.

$$R_t = \omega + Z_t \quad (3)$$
$$Z_t = e_t - \alpha e_{t-1}$$
$$e_t = |\Omega_{t-1}| \sim N(0, h_t)$$
$$h_t = \beta + \gamma e_{t-1}^2 + \theta_D S_{t-1}^- e_{t-1}^2 + \delta h_{t-1}$$

where, $S_{t-1}^- = \begin{cases} \text{x},\ e_{t-1} < 0 \\ \text{x},\ e_{t-1} \geq 0 \end{cases}$

$e_t, e_{t-1}$is new information aggregate in each period. When positivee_t, e_{t-1} refers to good information and negative values refer to bad information. Good information refers to rise in the yield rate of gold and crude oil prices, and bad information refers to drop in yield rate of gold and crude oil prices. h_t refers to conditional dispersion. s_{t-1}^- is dummy variable for showing asymmetry of information. This is 1 if e_{t-1} is negative and 0 if it is positive. Therefore, $S_{t-1}^- e_{t-1}^2$ shows asymmetry of volatility in gold and crude oil prices. A positive coefficient θ_D means that a negativee_{t-1} (bad news) in period t-1 increases the volatility of gold and crude oil prices in period t by a greater range than positive e_{t-1} (good news). δ is a coefficient that shows persistence of volatilityChoi(2019).

To obtain maximum likelihood estimate of parameter for GJR-MA model and GARCH-MA model, this study used nonlinear optimization technique, which maximizes log likelihood function, based on BHHH algorithm of Berndt, Hall, Hall, and Hausman(1974). Likelihood ratio (LR) statistic is often used to test the validity of maximum likelihood estimator and the model. Assuming that the null hypothesis of GARCH-MA model is L(H_0) (Note, $H_0 : \alpha, \gamma, \theta_D, \delta$) and alternative hypothesis of GJR-MA model L(H_a) (Note, $H_a: \alpha, \gamma, \theta_D, \delta$), LR $= 2[\text{L}(H_a - L(H_0)]$ shows asymptotic x_n^2(Note, n=1) distribution. If the value of LR test statistic estimated here is greater than x_n^2 statistic, the null hypothesis is dismissed.

3. ANALYSIS RESULT

3.1. BASIC STATISTICS AND STATIONARY TEST

For the rate of daily change in gold and crude oil prices used in this study, the daily indices of gold and North Sea oil prices announced by Federal Reserve Bank of St. Louis were used. Gold price index is the ending price in dollar per ounce as of 3 PM in Greenwich Mean Time, and the North Sea oil price index is the daily ending price in dollar per barrel. Daily data from June 1, 1987 to June 28, 2019 were used. Table 1 shows basic statistics of the data.

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Table I. Basic Statistics of Yield Rate of Gold and Crude Oil Price Index

	Gold	Crude oil
Mean($\times10^2$)	0.0154	0.0145
Standard deviation($\times10^2$)	0.9791	2.2638
Skewness	-0.2090	-0.5328
Kurtosis	9.8557	16.4300
Jarque-Bera statistics	15849.04 (0.0000)	61884.25 (0.0000)

Note: ( ) is the significance level.

For skewness, both gold and crude oil showed skewed distribution to negative direction. For kurtosis, the distribution as a sharper cusp than standard deviation. Also, Jarque-Bera statistic dismisses the null hypothesis that distribution of yield rate of gold and crude oil price indices form a standard deviation at a 1% significance level, implying that a GARCH model based on heteroscedasticity can be established. Meanwhile, time series analysis requires stationary test of data. To test stationary condition of variables, ADF(Augmented Dickey-Fuller) and PP unit root test were conducted. The test result is shown in Table 2. Tie series data with log differential of each index were all shown to be stationary at 1% significance level.

Table II. Unit root test

	Gold		Crude oil	
	Level variable	Differential variable	Level variable	Differential variable
ADF	-0.0757	-90.3904***	-1.5677	-87.7112***
PP	-0.0416	-90.4082***	-1.6457	-87.7876***

Note) 1. p<0.01***, p<0.05**, p<0.1* 2. Lag for test was set as 1, including a constant term.

3.2. ESTIMATION RESULT ON ASYMMETRIC RESPONSE OF VOLATILITY IN GOLD AND CRUDE OIL PRICES ON INFORMATION

GARCH(1,1)-MA(1) model and GJR(1,1)-MA(1) model were used to analyze whether the volatility of yield rate of gold and crude oil price indices on information shows asymmetric response. The result of estimation is shown in Table 3. Maximum likelihood estimates were used for the parameters of each model, and nonlinear optimization technique based on BHHH algorithm was used for such estimates. First, GARCH model was estimated to see whether the volatility of yield rate of gold and crude oil prices changes by time. In GARCH model, α, the coefficient that shows sequential correlation of yield rate of gold and crude oil price indices, was shown to have positive value in 1% significance level. This means that the yield rate of gold and crude oil price indices have negative sequential correlation, implying that there are predictable portions in yield rate of gold and crude oil price indices. To eliminate these predictable portions, MA term was included in GARCH and GJR models. γ, a coefficient showing sensitivity of volatility, and δ, a coefficient showing persistence of volatility were positive at 1% significance level, implying that GARCH(1,1)-MA(1) model is specification model for estimating time change in volatility of gold and crude oil prices. Also, $\gamma+\delta$ was smaller than 1, showing that degree of dispersion is stable.

To analyze the asymmetry where unpredictable yield rate –that is, the rise in gold price (decrease in crude oil price) due to good (bad) news- affects volatility of gold and crude oil prices in GARCH-MA(1) model, GJR-MA(1) with coefficient $\theta_D$was analyzed. θ_D, the coefficient of gold, was positive at 1% significance level, and θ_D, the coefficient of crude oil, was positive at 1% significance level. This means that, as for the gold market, unpredictable, positive yield rate (good news), increases volatility of gold price by a greater level than unpredictable, negative yield rate. As for crude oil market, this means that unpredictable, negative yield rate (bad news) increases volatility of crude oil price by a greater level than unpredictable, positive yield rate (good news). This result implies that volatility of gold and crude oil prices respond asymmetrically according to type of information. Therefore, when estimating the volatility of gold and crude oil prices, there is a need to classify the type of information that reaches each market.

Next, to study how shocks such as the global financial crisis affected asymmetric response of gold and crude oil markets, additional results were conducted by classifying data before (5404 observed data) and after (2659 observed data) the global financial crisis as of December 31, 2008. The result is shown in Table 4-5.

Table III. Asymmetric response in gold and crude oil market (all period)

Statistic	Gold		Crude oil	
	Coefficient	z statistic	Coefficient	z statistic
GARCH-MA				
$\omega(\times10^2)$	0.0040	0.7211	0.0005	3.7398***
α	0.5240	149.3724***	0.4916	117.3131***
$\beta(\times10^2)$	0.0002	15.4591***	0.0007	11.0680***
γ	0.2923	29.7272***	0.1857	23.3307***
δ	0.6913	84.0699***	0.7969	110.4186***
Log likelihood	30044.70		23161.78	
GJR-MA				
$\omega(\times10^2)$	0.0059	1.0147	0.0004	3.1639***
α	0.5235	149.3265***	0.4915	117.5198***
$\beta(\times10^2)$	0.0002	14.9666***	0.0008	11.4823***
γ	0.3082	22.3323***	0.1610	17.0892***
θ_D	-0.0531	-3.6597***	0.0486	4.2948***
δ	0.7035	84.8542***	0.7943	109.1344***
Log likelihood	30048.74		23168.67	
LR statistic	8.08***		13.78***	

Note: 1. p<0.01***, p<0.05** , p<0.1* , 2. x_1^2statistic is 7.879, 5.024, 3.841 at 1% , 5%, 10% significance level, respectively.

In Table 4, just like the entire period, the asymmetric volatility before the global financial crisis was shown to respond greater on good news for gold and on bad news for crude oil, regardless of the analysis model.

Table IV. Asymmetric Response of Gold and Crude Oil Markets (Before Global Financial Crisis)

Statistic	Gold		Crude oil	
	Coefficient	z statistic	Coefficient	z statistic
GARCH-MA				
$\omega(\times10^2)$	-0.0040	-0.6334	0.0005	3.7398***
α	0.5215	119.7237***	0.4916	117.3131***
$\beta(\times10^2)$	0.0002	13.6392***	0.0008	11.0680***
γ	0.3062	23.6055***	0.1857	23.3307***
δ	0.6878	72.2931***	0.7969	110.4186***
Log likelihood	20445.45		23161.78	
GJR-MA				
$\omega(\times10^2)$	0.0002	12.5506***	0.0005	3.1639***
α	0.5206	118.7497***	0.4915	117.5198***
$\beta(\times10^2)$	0.0002	12.5506***	0.0008	11.4823***
γ	0.3321	20.1060***	0.1610	17.0892***
θ_D	-0.1064	-6.1161***	0.0486	4.2948***
δ	0.7163	74.8204	0.7943	109.1344***

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Log likelihood	20456.69	23168.67
LR statistic	22.48***	13.78***

Note: 1. p<0.01***, p<0.05** , p<0.1* , 2. x_1^2statistic is 7.879, 5.024, 3.841 at 1% , 5%, 10% significance level, respectively.

However, in GJR(1,1)-MA(1) model ofTable 5, θ_D, the coefficient of gold, was shown to have positive value at 5% significance level. As for gold market after the global financial crisis, unpredictable, negative yield rate (bad news) was shown to increase the volatility of gold price by a greater level than unpredictable, positive yield rate (good news). This implies that the shock from the global financial crisis had a large effect in changing the asymmetric response of the gold market from positive yield rate (good news) to negative yield rate (bad news).

Table V. Asymmetric Response of Gold and Crude Oil Markets (After Global Financial Crisis)

Statistic	Gold		Crude oil	
	Coefficient	z statistic	Coefficient	z statistic
GARCH-MA				
$\omega(\times 10^2)$	0.0003	3.0482***	0.0077	0.2443
α	0.5385	89.7303***	-0.0102	-0.7740
$\beta(\times 10^2)$	0.0012	10.2660***	0.0002	3.2617***
γ	0.4033	15.8814***	0.0498	9.4047***
δ	0.3648	11.1262***	0.9463	178.4859***
Log likelihood	9620.16		6987.27	
GJR-MA				
$\omega(\times 10^2)$	0.0003	2.8488***	-0.0002	-0.7554
α	0.5388	87.7986***	-0.0140	-1.0497
$\beta(\times 10^2)$	0.0013	10.3241***	0.0001	2.9365***
γ	0.3566	8.4109***	0.0122	2.8254***
θ_D	0.0993	2.0771**	0.0530	8.1081***
δ	0.3545	10.2534***	0.9581	231.5756***
Log likelihood	9622.12		7008.43	
LR statistic	3.92*		21.16***	

Note: 1. p<0.01***, p<0.05** , p<0.1* , 2. x_1^2statistic is 7.879, 5.024, 3.841 at 1% , 5%, 10% significance level, respectively.

Also, to test the fitness of the model, log-likelihood of GARCH(1,1)-MA(1) model and GJR(1,1)-MA(1) model was compared after the analysis. The result showed that the LR statistic for yield rate of gold and crude oil prices indices for GJR(1,1)-MA(1) model was higher, dismissing the null hypothesis significantly at 1% significance level. Therefore, GJR(1,1)-MA(1) model was shown to be a more specification model in analyzing asymmetric response on information than GARCH(1,1)-MA(1) model.

3.3. RELATIONSHIP BETWEEN UNPREDICTABLE YIELD RATE AND CONDITIONAL VOLATILITY

Whether the effect of unpredictable yield rate of gold and crude oil prices on their volatility is symmetric or asymmetric can easily be found out by drawing a graph with e_{t-1}, the unpredictable yield rate in period t-1, on the x-axis and h_t, the conditional volatility of gold and crude oil prices, on the y-axis. In GARCH(1,1)-MA(1) model, unpredictable yield rate in period t-1 is shown as the size of coefficient γ, and in GJR(1,1)-MA(1) model, it is shown as the size of γ and θ_D. In analysis result of GARCH(1,1)-MA(1) in Table 3, α of gold is 0.5235, affecting h_t , the conditional volatility in period t, by 52.35% ofe_{t-1}^2. α of crude oil is 0.4915, affectingh_t , the conditional volatility in period t, by 49.15% of e_{t-1}^2 . In the analysis result of GJR(1,1)-MA(1), γ and θ_D of gold are 0.3082 and –0.0531. For unpredictable, negative yield rate (bad news) that reaches the gold market ($e_{t-1}^2 < 0$), 0.2551%(0.3082-0.0531) of e_{t-1}^2 affects

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conditional volatility in period t. For unpredictable, positive yield rate (good news) that reaches the gold market ($e_{t-1}^2 \geq 0$), 0.3082% of e_{t-1}^2 affects conditional volatility in period t. This means that, for the gold market, unpredictable, positive yield rate affects the conditional volatility in period t by a greater level than unpredictable, negative yield rate. For crude oil, γ and θ_D are 0.1610 and 0.0486. For unpredictable, negative yield rate (bad news) that reaches the crude oil market ($e_{t-1}^2 < 0$), 0.2096%(0.1610+0.0486) of e_{t-1}^2 affects conditional volatility in period t. For unpredictable, positive yield rate (good news) ($e_{t-1}^2 \geq 0$), 0.1610% of e_{t-1}^2 affects conditional volatility in period t. This means that, for the crude oil market, unpredictable, negative yield rate affects the conditional volatility in period t by a greater level than unpredictable, positive yield rate. Based on the analysis result of Table 3, the relationship with unpredictable yield rate (e_{t-1}) and volatility of stock price (h_t) is shown in Figure 1 and Figure 2. Figure 1 shows asymmetric response of volatility in gold price. As discussed previously, the graph shows that, for gold, unpredictable, positive yield rate had a greater effect on conditional volatility in period t than unpredictable, negative yield rate. Figure 2 shows asymmetric response of volatility in crude oil price. As discussed previously as well, the graph shows that, for crude oil, unpredictable, negative yield rate had a greater effect on conditional volatility in period t than unpredictable, positive yield rate.

This study showed that the asymmetric volatility of gold and crude oil prices on information was different before the global financial crisis, but, after the global financial crisis, asymmetric response of volatility of gold and crude oil prices is greater from unpredictable, negative yield rate (bad news) rather than unpredictable, positive yield rate (bad news). There is a need to enhance the establishment of the model for the sake of estimating the volatility of asset price and enhancing investment strategies.

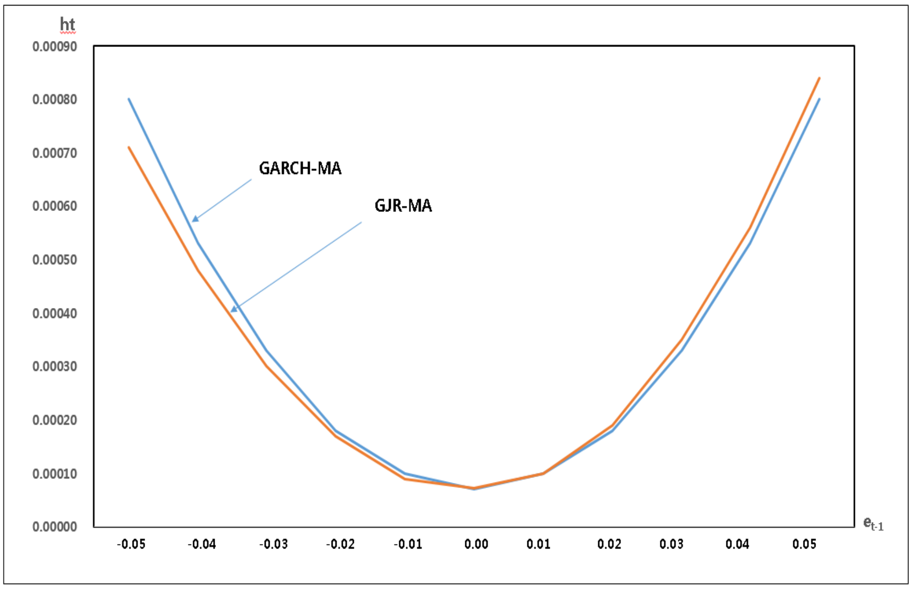

Fig. 1 Asymmetric Response on Volatility of Gold Price

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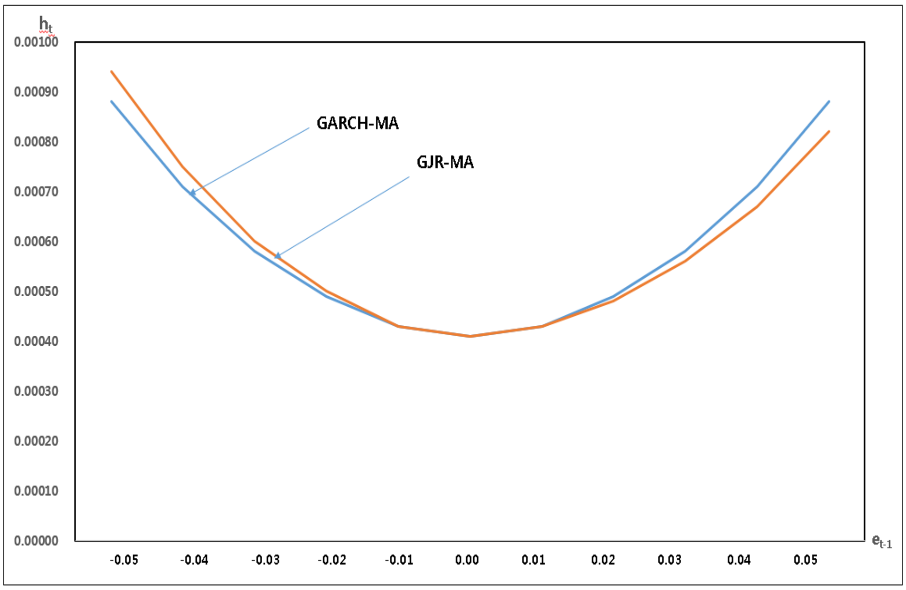

Fig. 2 Asymmetric Response on Volatility of Crude Oil Price

4. DISCUSSIONS AND CONCLUSION

This study used daily gold and crude oil price indices announced by Federal Reserve Bank of St. Louis to study whether the volatility of each index on information shows asymmetric response using GJR(1,1)-MA(1) model. The analysis result showed that GJR(1,1)-MA(1) is an specification model for analyzing asymmetric response on information. For gold, unpredictable, positive yield rate (good news) affects conditional volatility in period t by a greater level than unpredictable, negative yield rate (bad news). On the other hand, for crude oil, unpredictable, negative yield rate (bad news) affected conditional volatility in period t by a greater level than unpredictable, positive yield rate (good news). These relationships were shown in figures. However, after the global financial crisis, asymmetric response of volatility in gold and crude oil prices on such information showed greater response on unpredictable, negative yield rate than on unpredictable, positive yield rate. This means that bad news, rather than good news, affects volatility of gold and crude oil prices by a greater level in the gold and crude oil market.

This study has limitations in that past yield rate and volatility of the indices were used as variables for explaining the current yield rate and volatility. However, the study could derive the following implications. After the global financial crisis, both the gold and crude oil markets showed greater asymmetric volatility on bad news, rather than good news, calling for the need to ensure stable supply of gold and crude oil. This study is significant in that it presented asymmetric volatility response of information on gold and crude oil for the first time, and can be used as the basic data for following studies. Following studies should add macroeconomic data for enhanced robustness of the study.

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