Dynamic Changes in Prices of Gold and Silver during Russia-Ukraine Conflict

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Abstract. The Russia-Ukraine conflict has upraised the crude oil price and its volatility, which leads to fluctuations in its corresponding industries and markets. Existing literatures have studied the impact of the oil shock in many respects, and the precious metal market has significant responses to the unusual events, same for the Russia-Ukraine conflict. This paper studies the spot gold and silver's price, return, and volatility with respect to the return and volatility of WTI, during the period of November 2021 to July 2022. The VAR model proved the lead-lag relation of the variables. Next, the impulse and response of gold and silver to crude oil show positive relations of the two metals to the increment in crude oil's price. Then the author estimated the ARMA-GARCH model to detect the relationship of volatilities of crude oil to the two metals. The results show that the increasing crude oil price leads to growth in the metal's return, and the silver's volatility is more impacted by the crude oil's fluctuation.

Keywords: Russia-Ukraine conflict; crude oil price; precious metal.

1. Introduction

Crude oil has been an important fuel resource worldwide and accounts for more than one-third of the world's energy consumption. In addition, it contributes a lot to the development of correlated industries like excavation and transportation. The crude oil itself and its derivatives are globally and actively traded in oil markets. Therefore, the import and export of this product have a profound influence on the economy of numerous countries. Russia plays a crucial part in the world market as the world's second-largest oil exporter. In 2021, Russian oil production accounted for 12.07% of the world's oil production as its oil exports reached 229.998 million tons and a value of $110.119 billion, with a growth of 51.8% compared to 2020 [1]. In 2022, affected by the outbreak of Russia-Ukraine conflict, the United States and some European countries imposed trade sanctions on Russia, which limit the circulation of Russia products in their markets. As a result, the global oil supply has been greatly reduced in the short term and leading to fluctuations in oil prices.

The volatility of crude oil price will be transmitted to other related industries through various price and risk transmission mechanisms, which will bring risks and challenges to the macro economy and various markets. Therefore, it is necessary to further study the influence of the price impact of crude oil and manage to control the risk. There have been numerous works about impact of the macroeconomic activities on the oil price changes, while the study of the influence of oil price on financial markets is still being continuously expanded. Among the most affected markets, such as the energy market, metal market, and commodity market, this literature chooses the precious metal market and mostly focuses on the gold and silver returns.

According to Solt and Swanson, gold and silver have been appointed as medium of exchange for a few countries at separate times [2]. Both of these two precious metals are widely traded in the world market, while they have quite different properties. Gold is mostly priced for its financial value, and is affected by the influence factors of the demand for jewelry as a precious metal [3]. Instead, the economic shocks only impact the gold price for a short duration. Therefore, gold is commonly regarded as "a safe haven against stocks o major emerging and developing countries", which shows posses a risk aversion property during financial crisis period [4]. Different from gold, silver has more industrial value than a monetary asset.

Instead of the whole metal market, more existing literature studied the relationship between crude oil and gold with respect to their price, returns, and volatility, some of them put together the exchange rate and inflation with the oil and gold' prices. Zhang and Wei were the first to prove the existence of cointegration relation between crude oil and gold price [5]. They examined the two markets by Granger causality which showed"fairly direct interactive mechanism", and tested the cointegration relationship which was proved to be significant [5]. In their opinion, there exists equilibrium relationship between crude oil and the gold market in the long term; and for short term, the impact of gold on the crude oil price is about 5 times greater than the reversed relation influence during the sampling period between 2000 and 2008 [5]. Their result on the short-term relationship between the two commodities was different from some of the following research. Yuan, Xu, and Liu suggested that the fluctuations of crude oil would be transmitted to the gold market, which is an unidirectional and asymmetric volatility spillover effect [6]. Moreover, they affirmed that the crude oil price could be applied to forecast the gold price, and the gold could be used to hedge the risk of fluctuation of crude oil price [6]. In 2012, Le and Chang further illustrated a nonlinear relationship between crude oil and gold returns. They also proved that the gold price's response to crude oil price shocks would die out quickly in a few months [4]. They also suggested that the relation of crude oil and gold was "insignificantly lead-and-lag", which was disapproved by some following scholars [4]. Wang and Chueh proved a following up trend of gold price to crude oil price, and they positively influenced each other in short term [7]. Against the former unidirectional relation, they argued that there existed a two-directional influence between the two variables, and they were also affected by their prices in the previous periods, which is the "lead-lag relationship" of threshold cointegration between the two variables, showed by M-TAR model [7]. In 2015, Meng and Zhang agreed with Zhang and Weithat the gold price is highly positively correlated to crude oil price and their fluctuation trend was quite consistent from 2002 to 2010 [8]. Different from the previous opinions, they suggested that the tradings in crude oil market could be adjusted by the gold prices since the Granger Causality showed that the gold price caused the Granger casulty of crude oil price [8]. Kanjilal and Ghosh put forward similar opinions to Wang and Chueh that there existed a lead-lag relationship in both commodities which is bidirectional, but only in unusual regime [9]. And for usual regime and long term, they argued that the gold price is the influencer of the oil price [9]. In 2019, Chen and Xu used GAS model to model and predict the volatility with regard to oil and gold prices and correlation between them. Their results presented that there existed sinificant volatility persistence. In accord with Le and Chang, they found nonlinear interaction effects between the price of WTI and spot gold [10].

Some other scholars conducted the study of the relationship between the crude oil and metal market more thoroughly, most of them considered the macroeconomic factors. In 2008, the GARCH family models were used by Hammoudeh and Yuan used to comprehensively research on the metal volatility with oil under interest rate shocks [2]. By CGARCH, in the long term, the permanent volatility component is also highly persistent for the models of gold, silver, and copper; by EGARCH, he found that during economic downturns, gold and silver perform well in investments [2]. Soytas, Sari, Hammoudeh, and Hacihasanoglu examined both long and short-term information transformation among oil price, spot gold and silver price, exchange rate, and interest rate in Turkey [11]. Their research showed that a high correlation existed between gold and silver, which were substitutable in Turkey, while the developed countries took silver more as industrial metal [11]. Moreover, from the impulse function, they observed negative initial impacts of oil shock on the three metals they considered. They concluded that gold and silver positively affect the crude oil price in Turkey in short term, and that influence would die off quickly [11]. Shurtens and Yurtsever applied VAR model to discuss the nonlinear relationship between oil price shocks and the value of European industries including industrial metals [12]. The industrial metals and mining industries were positively impacted by the oil price shocks. Although the oil shocks mostly brought negative effects to the economy, they did benefit some oil-intensive industries such as industrial metals [12]. Li and Zhang studied the dynamic relationship of the price of precious metals with respect to crude oil and CNY exchange rate [13]. Their impulse and response of gold and silver to crude oil were both positive at the initial point and altered across zero which might be resulted from inflation due to the rising oil price, then the effect died off quickly and came to zero on the third day [13]. In 2021, Umar, Jareño, and Escribano explored the dynamic return and volatility of metal markets to oil shocks [14]. Based on the theories of risk transmission, they argued that silver and gold were the volatility transmitter and return receivers of the shock [13].

Generally, the existing literatures have discussed the relation and correlation between crude oil and gold price, and some other precious metals such as silver and platinium, during selected usual periods or for specific events. The consensus includes: there exists nonlinear relationship between crude oil pice and that for precious metals, and the variables are highly correlated; the relationship is balanced for long term and would be different for special periods. The exact relationship between crud oil and other variables has not been consolidated and the influence factor and affected variable have not been agreed. This paper will focus on the data of the prices of crude oil, gold, and silver during the Russia-Ukraine conflict, and further explore the short term relationship between crude oil and the two metals respectively. By VAR and ARMA-GARCH models, this paper would figure out the relationship of the returns and volatilities among the three variables, which might contribute to hedging strategies against the fluctuation of crude oil price.

The rest components of this paper are organized as follows: Section 2 includes identification strategy, composed of data sources, unit root test, and model specification. Section 3 is empical results analysis with VAR model, impulse and reponse function, and ARMA-GARCH model. In section 4, the discussion the modelling results are presented, with regard to the practical importance and comparison with existing literatures. And section 5 provides a general conclusion for this paper.

2. Identification Strategy

2.1 Data Source

The WTI crude oil spot price is from NYMEX, quoted in U.S. dollars per barrel. The gold and silver price are the spot price of gold and silver on COM EX, quoted in ounces per dollar. All the prices are the daily close price from November 22, 2021, to July 8, 2022, in a total size of 157.

The price data are firstly transformed by taking log since they are financial prices, in order to make them stationary time series. The returns are calculated as the difference between the current closing price and the previous closing price, then divided by the current closing price and taken log.

2.2 Unit Root Test

Table 1. ADF test

Variables	t-statistic	p-value
Price		
Gold	-2.091	0.5510
Silver	-1.990	0.6068
Crude oil	-3.311	0.0644*
Yield		
Gold	-9.893	0.0000***
Silver	-9.575	0.0000***
Crude oil	-9.817	0.0000***

The unit root test checks the stationarity of the three logged price and return series. The package in Stata is the Augmented Dickey-Fuller test, which checks the null hypothesis that a unit root exists in an autoregressive time series model which presents non-stationarity by t-statistic. For the logged price series, the p-value of the crude oil, gold, and silver test are 0.0644, 0.5510, and 0.6068 in perspective, which are all non-stationary with the confidence level of 0.05, while the crude oil is relatively more stationary than the other two series. For the logged return series, the p-value of crude oil, gold, and silver's test are all less than 0.01, which proves significant stationarity of these three return series. The proved stationarity of the logged return series will further contribute to the ARMA-GARCH models in the following sections.

The ADF test results are summarized in the table above. By the p-values, the price series are not significantly stationary, while the yield series are all stationary.

2.3 VAR specification

The VAR (vector autoregressive) model is a common multivariate time series model. It has some advantages, like being relatively convenient for estimations by LS or ML method, both of which provide closed-form solutions. To illustrate the multivariate time series z_t by VAR(p) model, which is set as below, where φ_0 is a k-dimensional constant vector, φ_i are $k \times k$ matrices for $i > 0, \varphi_p \neq 0$, and a_t are i.i.d (independent identically distributed) random vectors with zero mean [15].

$$z_t = \varphi_0 + \sum_{i=1}^{p} \varphi_i z_{t-i} + a_t \tag{1}$$

The stationarity conditions of the VAR model are similar to AR model. The determinant equation of VAR(p) is referred by

$$\varphi(B) z_t = \varphi_0 + a_t \tag{2}$$

$$\varphi(B) = I_k - \sum_{i=1}^{p} \varphi_i B^i \tag{3}$$

Here B is the backshift operator, $\varphi(p) \neq 0$. By expanding the series, VAR(p) model can be rewritten in the form of VAR(1). Rewriting the model as below, where $b_t = (a_t{}', 0)'$

$$Z_t = \Phi Z_{t-1} + b_t \tag{4}$$

$$\Phi = \begin{bmatrix} \varphi_1 & \varphi_2 & \dots & \varphi_{p-1} & \varphi_p \\ I & 0 & \dots & 0 & 0 \\ 0 & I & \dots & 0 & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \dots & I & 0 \end{bmatrix} \tag{5}$$

The matrix Φ is the “companion matrix” of the matrix polynomial.

$$\varphi(B) = I_k - \varphi_1 B - \cdots - \varphi_p B_p = I_k - \sum_{i=1}^{p} \varphi_i B^i \tag{6}$$

The weak stationarity of the VAR(p) series requires a necessary and sufficient condition, which demands all solutions of |φ(B)|=0 (determinant equation) must be greater than 1 in modulus, or equally, outside the unit circle.

Here in Stata the companion matrix does not refer to the determinant equation, instead, it refers to the Φ matrix. So the stationarity condition is just reversed, which is required to be inside the unit circle.

To find the optimal lag order k for VAR model, this paper applies the LR (likelihood ratio) test, which is:

$$LR = -2(LogL_k - LogL_{k+1}), \text{ where } LR \sim \chi^2_{(N^2)} \tag{7}$$

When the LR statistic is smaller than the critical value, the lag order k is considered appropriate; if the LR statistic is larger than the critical value, it is argued that more lagged terms should be added as explaining variables to increase the lag order. Some other methods like AIC and BIC will also be considered in the next section.

2.4 ARMA-GARCH specification

The ARCH(p) model is

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

σ_t^2 is the variance of the current error term, expressed as a function of the actual sizes of the previous periods' error terms. The error terms ε_t's characteristics can be generally illustrated with ARCH (1). The conditional expectation $\mathrm{E}(\varepsilon_t|\varepsilon_{t-1})$ and unconditional expectation $\mathrm{E}(\varepsilon_t)$ of ε_t both equal to zero; the conditional variance of ε_t,

$$\mathrm{Var}(\varepsilon_t|\varepsilon_{t-1}) = \mathrm{E}({\varepsilon_t}^2|\varepsilon_{t-1}) = \alpha_0 + \alpha_1 \mathrm{E}({\varepsilon_{t-1}}^2|\varepsilon_{t-1}) = \alpha_0 + \alpha_1 {\varepsilon_{t-1}}^2 \tag{9}$$

Therefore, the larger α_1, the larger impulse of the previous error term is to the conditional variance σ_t^2. The unconditional variance is just $\mathrm{Var}(\varepsilon_t) = \alpha_0 + \alpha_1 \mathrm{E}({\varepsilon_{t-1}}^2)$, which is a constant and does not variate with time. The serial correlation of ε_t and ε_{t-i} is $\mathrm{E}(\varepsilon_t \varepsilon_{t-i}) = 0$, which shows that the error terms satisfy the assumptions of homoscedasticity and non-autocorrelation.

The GARCH model is based on the ARCH, with an additional part of autoregressive components of σ_t^2. The GARCH(p, q) is written as

$$\sigma_t^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \cdots + \alpha_p \varepsilon_{t-q}^2 + \gamma_1 \sigma_{t-1}^2 + \cdots + \gamma_p \sigma_{t-p}^2 \tag{10}$$

In some way, GARCH(1,1) is just the ARCH with infinite order, so the GARCH can reduce the parameters to be estimated by expressing σ_{t-1}^2 with ε_{t-2}^2, ..., ε_{t-p-1}^2.

The ARMA-GARCH model can forecast the return and volatility for time series at the same time by setting the mean functions of GARCH model as ARMA process. In detail, the ARMA (p, q) model is

$$Y_t = \phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \cdots + \phi_p Y_{t-p} + e_t - \theta_1 e_{t-1} - \theta_2 e_{t-2} - \cdots - \theta_q e_{t-q} \tag{11}$$

3. Empirical Results Analysis

3.1 VAR Identification

Table 2. VAR model identification

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	1036.69				1.2e-10	-14.3567	-14.3316	-14.2949*
1	1052.71	32.053	9	0.000	1.1e-10	-14.4543	-14.3538*	-14.2069
2	1055.58	5.7365	9	0.766	1.2e-10	-14.3692	-14.1932	-13.9361
3	1065	18.836	9	0.027	1.1e-10	-14.375	-14.1236	-13.7563
4	1077.18	24.367	9	0.004	1.1e-10	-14.4192	-14.0924	-13.6149
5	1089.62	24.874*	9	0.003	1.0e-10*	-14.4669*	-14.0647	-13.477
6	1095.71	12.185	9	0.203	1.1e-10	-14.4266	-13.9489	-13.251
7	1103.06	14.688	9	0.100	1.1e-10	-14.4036	-13.8505	-13.0424
8	1108.52	10.936	9	0.280	1.2e-10	-14.3545	-13.726	-12.8077
9	1112.24	7.4265	9	0.593	1.3e-10	-14.2811	-13.5771	-12.5487
10	1118.75	13.032	9	0.161	1.3e-10	-14.2466	-13.4672	-12.3286
11	1120.78	4.0602	9	0.907	1.5e-10	-14.1498	-13.295	-12.0461
12	1129	16.425	9	0.059	1.5e-10	-14.1388	-13.2086	-11.8496

In the last section, the LR has been illustrated to be following the chi-square distribution, so the LR with a smaller p-value is more preferred, which is more significantly appropriate. To decide the statistcal model, the information criteria's effectiveness are shown as follows. For AIC (Akaike information criterion), HQ (proposed by Hannan and Quinn), and BIC (Bayesian information criterion), the larger the better. The AIC penalizes each parameter by a factor of 2, while BIC and HQ adopt penalties depending on the sample size. In Table 2, LR, FPE, AIC show that lag 5 is preferred, while HQIC maximizes at lag 1. The difference in HQIC between lag 1 and lag 5 is not significant. Therefore, lag 5 is chosen for general consideration.

Figure 1 is the unit circle of companion matrix Φ. All the roots are inside the unit circle with modulus smaller than one, which proves the stationarity of the VAR model.

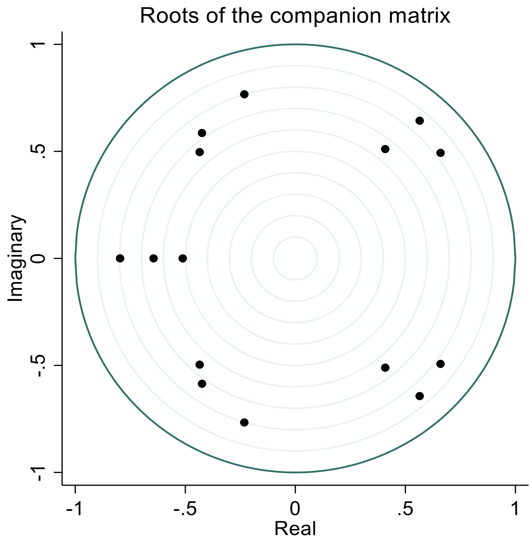

Fig. 1 VAR stationarity

3.2 Impulse and Response

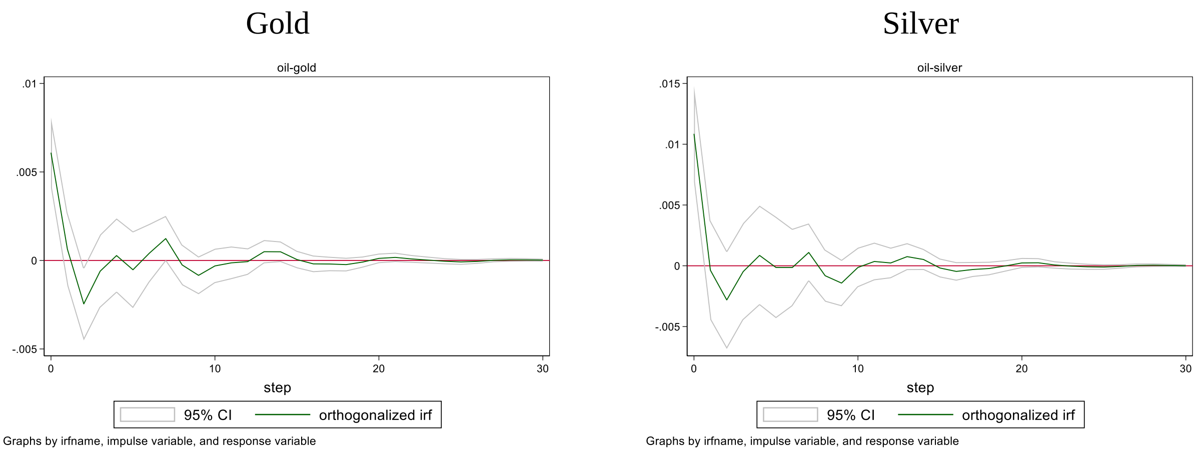

Fig. 2 Impulse and response

Figure 2 shows the impulse and response of gold and silver to crude oil respectively. From this result, the increase in crude oil prices resulting from Russia-Ukraine conflict will lead to growth of both prices of gold and silver. To be specific, when the spot crude oil price rise by 1%, with step T=1, the change in gold price is slightly larger than 0.5%, and the change in silver price is quite larger than 1%. As the step increases, the impulse and response function decays soon. At T=3, the effect turns negative, which is possibly resulted from market overreaction. After T=3, the effects swing from negative to positive and soon damp to zero. With respect to the modulus of positive and negative effects, the positive one is comparatively larger. Therefore, from a dynamic perspective, the net effect will be positive if the crude oil price keeps rising, which means that the Russia-Ukraine conflict will raise the price of gold and silver.

3.3 ARMA Identification

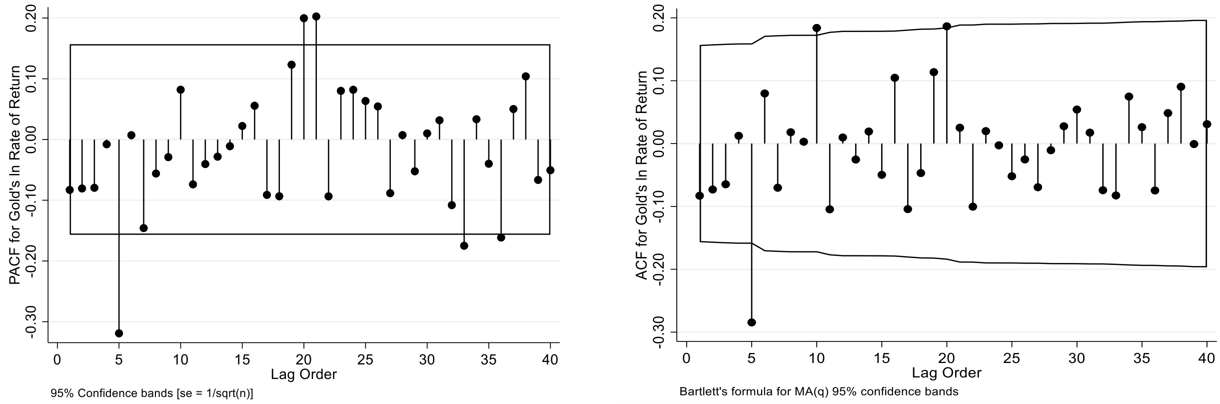

Fig. 3 PACF and ACF, gold

Before building the ARMA-GARCH model, it is a must to consider the ARMA (*p, q*) component first and determine its order. Based on the PACF and ACF plots of the logged return of gold price above in Figure 3, we can observe that the PACF is more like a cut-off pattern at lag 5 since the next two spikes at lag 20 and 21 are quite far, while the ACF also shows a cut off pattern at lag 5 and the lag 10 spike is not significant. Therefore, we could generate an ARMA (*p, q*) model with p=5, q=5.

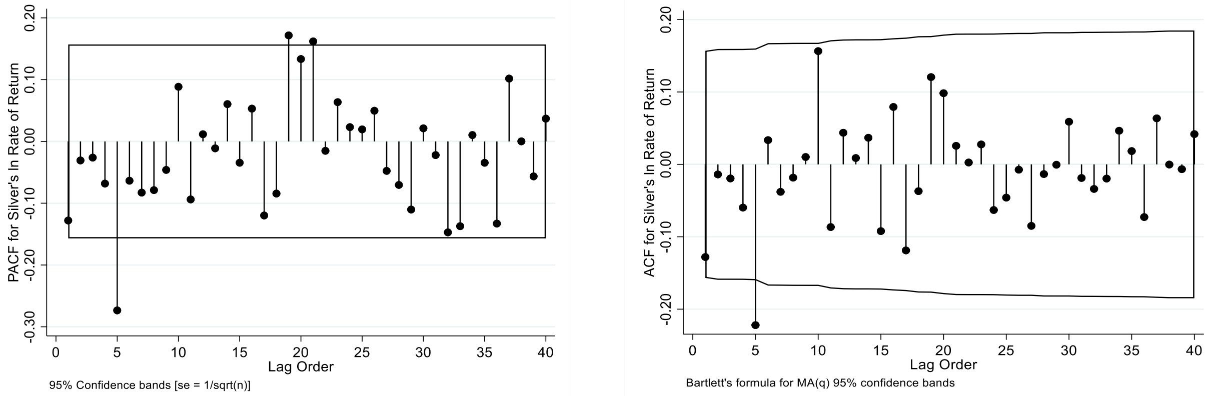

Fig. 4 PACF and ACF, silver

Based on the PACF and ACF plots of the logged return of silver price above in Figure 4, we can observe that the PACF is more like a cut-off pattern at lag 5, with two insignificant spikes at lag 20 and 21, while the ACF also shows a cut off pattern at lag 5 and has no other outer results. Therefore, we could generate an ARMA(*p, q*) model with p=5, and q=5 for the silver series.

3.4 ARMA-GARCH Estimation Results

The estimated parameters for ARMA-GARCH model are presented in Table 3 above. In the (1), (2), and (3) columns, the ARCH term is significant, while the GARCH term is significant in the (4), (5), and (6) columns. Among the 6 models, either one of ARCH's or GARCH's terms is significant. Therefore, the conditional heteroscedasticity exists for the returns of gold and silver, which allows them to be modeled by GARCH.

By analyzing the results of estimations, the variation of crude oil price has no significant effect on the volatility of gold return, instead, it improves the volatility of silver return. Considering the data from the (6) column, as the crude oil return increase by 1%, the variance of silver return will rise by 20.7497. The insignificant lag terms show no lag effect, and the financial market is efficient.

Table 3. ARMA-GARCH estimation results, variance equation

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	Gold			Silver		
Crude oil						
T=0	-1.7656	-1.5565	-1.8187	18.6451***	20.1920***	20.7497***
	(2.3014)	(2.4006)	(2.4440)	(5.0657)	(6.4056)	(7.1486)
T=-1		2.4018	2.4643		3.5970	6.0533
		(4.6034)	(4.6841)		(6.8916)	(5.7851)
T=-2			1.3853			8.5576
			(3.1935)			(7.8054)
GARCH						
ARCH (-1)	0.2103*	0.2189*	0.2312*	-0.0207	-0.0261	-0.0407
	(0.1137)	(0.1155)	(0.1217)	(0.0329)	(0.0331)	(0.0298)
GARCH (-1)	0.6844	0.0954	0.0549	0.7471***	0.7630***	0.7346***
	(0.4491)	(0.4258)	(0.4230)	(0.1408)	(0.1336)	(0.1164)
Constant	-8.8750***	-8.9338***	-8.8840***	-8.9339***	-8.8982***	-8.9087***
	(0.5943)	(0.6133)	(0.0586)	(0.7531)	(0.7888)	(0.6054)

4. Discussion

This paper illustrates the time series relationship of crude oil with respect to the return of gold and silver, under the background of Russia-Ukraine conflict. The statistical results show that the conflict will further cause the price of gold and silver to increase, and the volatility of silver return will be influenced by the change in crude oil price. Consistent with some of the existing literatures, the analysis of the impact of crude oil on gold price commonly agrees that the price between the two commodities has positive relation. The impulse and response of gold and silver to crude oil respectively proved that the impact of crude oil on both metals is significant, which is in accord with Soytas's result [11]. Moreover, the fluctuation of crude oil price has more effect on the silver volatility than on gold [14].

Since crude oil has noticable effect on the volatility of the silver price, and it is already a volatile commodity, the government should manage to hedge the fluctuations in silver prices by its related derivatives. Moreover, as the supply and demand for silver are well balanced in the industry, its financial feature will be more prominent, especially in countries with severe inflation. The gold price is expected to keep increasing as the conflict continues, so the government should argue gold supply to hedge the risk [16]. Also, this relation is only accurate for the short-term, in the long term, the gold price will remain relatively stable so the trade-offs must be without delays [5]. Moreover, many of the bachelors agreed that gold is regarded as a " haven" against crude oil price fluctuations during the financial crisis period, based on the experience of the 2008 financial crisis [3, 9, 10]. Therefore, the financial policy for gold must consider the progress of the conflict, in case the gold price variates.

5. Conclusion

In general, the VAR model of order 5 is suitable to estimate the relation between the returns of crude oil and gold/silver and shows the dynamic increase of the dependent variables with the growth of crude oil return. To investigate the volatile relationship of crude oil regarding gold and silver, this paper proposed ARMA-GARCH model, and it presents a significant effect of crude oil on silver's volatility. While the crude oil price is volatile and increases due to Russia-Ukraine conflict, the two precious metals—gold and silver price will therefore increase, and the silver's volatility will be significantly influenced by the variation of crude oil.

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