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INTEGRATION OF GARCH MODELS AND EXTERNAL FACTORS IN GOLD PRICE VOLATILITY PREDICTION: ANALYSIS AND COMPARISON OF GARCH-M APPROACH

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ABSTRACT

This study investigates the volatility of gold prices by applying the Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model and extending it with the GARCH-M model, incorporating the Federal Reserve's interest rate as an external variable. The GARCH(1,1) model revealed a positive average daily return for gold, with high sensitivity to recent price changes, indicated by the significant estimation of mu and a high alpha1 value. The persistence of past volatility on current volatility is reflected by a beta1 value close to one. In the GARCH-M model development, a significant negative relationship was found between the Federal Reserve's interest rates and gold returns, suggesting that an increase in the Federal Reserve's interest rates could potentially decrease gold returns. An increase in the Log Likelihood value and improvements in information criteria such as the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) indicate that the GARCH-M model provides a better fit than the GARCH(1,1) model that uses only gold price data. The study concludes that macroeconomic factors like the Federal Reserve's interest rates play a crucial role in influencing gold price volatility, and these findings can aid investors and portfolio managers in devising more effective risk management strategies. Additionally, the findings contribute to financial theory by highlighting the importance of multivariate models in the analysis of asset price volatility.

KEYWORDS *Gold Price Volatility, Predictive Model, GARCH, GARCH-M, Federal Reserve Interest Rate, Risk Management, Gold Market*

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INTRODUCTION

Gold, known by the chemical symbol Au (from the Latin word "aurum") and with an atomic number of 79, occupies a significant position in the periodic table as one of the naturally occurring elements with a high atomic number. It is a noble metal valued for its natural luster, resistance to most chemical reactions (anti-corrosion and oxidation), high thermal and electrical conductivity, and its malleability, allowing it to be processed into thin sheets. Since prehistoric times, gold has been used for jewelry, currency, and in various industrial applications, affirming its high economic and symbolic value in different civilizations and global economies.

Over the past three decades, the price of gold has experienced significant fluctuations, influenced by various economic, political, and market factors. In the early 1990s, the price of gold was stable but tended to be low, reflecting global economic stability and low investment interest in safe-haven assets. However, entering the 21st century, especially after the 2008 financial crisis, the price of gold skyrocketed dramatically, reaching its peak in September 2011 at $1,920.30 per troy ounce, in response to global economic uncertainty, inflation, and currency devaluation.

Since then, despite experiencing some ups and downs, the price of gold has remained relatively high, reflecting its role as a hedge against inflation and economic uncertainty. The fluctuation in the price of gold reflects the influence of various factors, including the monetary policies of the United States Federal Reserve, investment demand, macroeconomic conditions, and geopolitical tensions, highlighting the complexity of the gold market and its role as a barometer of the global economy.

The volatility of the price of gold is a key indicator in financial and investment markets. Although there have been many studies attempting to predict this volatility, several issues have been identified in the literature. Firstly, existing models often fail to account for the complex market dynamics and external factors that affect the price of gold. Secondly, the dynamics of the gold market often change, yet existing prediction models tend to be inflexible in adapting to these changes. Thirdly, investors require more accurate prediction models to manage their risks and investment decisions. Lastly, although the GARCH approach has proven effective, its application in the context of the gold price still requires further investigation.

Therefore, this research aims to develop a prediction model for the volatility of the price of gold using a GARCH approach that considers external factors, with the expectation of providing more accurate predictions for investors and market participants. The research limitations include the time period from 2003 to 2023, the use of daily gold price data in US dollars, a focus on the GARCH(1,1) and GARCH-M models, and consideration of external factors such as the monetary policies of the Federal Reserve. The research objectives are to analyze the patterns of gold price volatility, develop accurate prediction models, and compare the effectiveness of the GARCH model with the GARCH-M model. Thus, this research is expected to contribute to the financial literature and provide practical insights for investors and financial analysts.

RESEARCH METHOD

This research framework is designed to provide a methodological structure that encompasses data collection, data analysis, model development, and model evaluation. The steps of data collection include determining data sources, collecting data from selected sources, verifying and validating data, organizing data, and documenting the process. Furthermore, the research design includes the type of research (quantitative, applied, descriptive, analytical, and modeling), research methods (experimental parameters, evaluation methods, and GARCH model formulas), and model implementation and evaluation.

The data collection steps begin with identifying data sources from the World Gold Council for gold prices and US government websites for Federal Reserve interest rate data. The data are then extracted, metadata recorded, verified, and validated to ensure quality and accuracy. Subsequently, the data are stored and organized properly to facilitate further analysis.

The research design encompasses the type of research (quantitative, applied, descriptive, analytical, and modeling) as well as evaluation methods such as the Breusch-Pagan test, descriptive statistical analysis, model stability tests, parameter significance tests, and result analysis. Additionally, the GARCH model formulas and experimental parameters for model implementation and evaluation are also explained.

The research schedule is detailed in weekly activities, ranging from proposal preparation to the preparation of the final report. Stages include literature review, data collection, data validation, research execution, and report preparation. With this framework, it is expected that this research can be conducted systematically and effectively to produce quality results.

RESULT AND DISCUSSION

Model GARCH (1,1)

Conditional Variance Dynamics

GARCH Model	:	sGARCH(1,1)
Mean Model	:	ARFIMA(0,0,0)
Distribution	:	norm

Optimal Parameters

Parameters	Estimate	Std. Error	t value	Pr(>|t|)
Mu	0.000290	0.000139	2.0800	0.037524
Omega	0.000001	0.000000	1.6009	0.109406
Alpha1	0.039456	0.002826	13.9625	0.000000
Beta1	0.955353	0.002662	358.8633	0.000000

Robust Standard Errors

Parameters	Estimate	Std. Error	t value	Pr(>|t|)
Mu	0.000290	0.000146	1.98012	0.047690
Omega	0.000001	0.000003	0.21862	0.826949
Alpha1	0.039456	0.013422	2.93966	0.003286
Beta1	0.955353	0.013873	68.86312	0.000000

LogLikelihood : 13759.49 Information Criteria

Akaike	-6.3698
Bayes	-6.3639
Shibata	-6.3698
Hannan-Quinn	-6.3677

Weighted Ljung-Box Test on Standardized Residuals

Parameters	statistic	p-value
Lag[1]	0.4047	0.5247
Lag[2*(p+q)+(p+q)-1][2]	1.0429	0.4845
Lag[4*(p+q)+(p+q)-1][5]	2.1533	0.5827

d.o.f=0

H0 : No serial correlation

Weighted Ljung-Box Test on Standardized Squared Residuals

Parameters	statistic	p-value
Lag[1]	13.27	0.0002692
Lag[2*(p+q)+(p+q)-1][5]	13.60	0.0010501
Lag[4*(p+q)+(p+q)-1][9]	14.15	0.0057171

d.o.f=2

Weighted ARCH LM Tests

Parameters	Statistic	Shape	Scale	P-Value
ARCH Lag[3]	0.3960	0.500	2.000	0.5292
ARCH Lag[5]	0.4859	1.440	1.667	0.8878
ARCH Lag[7]	0.9842	2.315	1.543	0.9161

Nyblom stability test

Joint Statistic	**501.8692**
Individual Statistics:	
mu	0.3290
omega	70.7009
alpha1	0.2250

beta1	0.2038

Asymptotic Critical Values	10%	5%	1%
Joint Statistic	1.07	1.24	1.6
Individual Statistic	0.35	0.47	0.75

Sign Bias Test

Parameters	T-Value	Prob	Sig
Sign Bias	0.1212	0.9035254	
Negative Sign Bias	1.5970	0.1103430	
Positive Sign Bias	2.2982	0.0215992	**
Joint Effect	16.6151	0.0008479	***

Adjusted Pearson Goodness-of-Fit Test

	Group	Statistic	P-Value(g-1)
1	20	126.4	6.881e-18
2	30	164.1	8.455e-21
3	40	184.0	1.069e-20
4	50	193.8	4.123e-19

From the modeling results above, the following analysis can be provided:

GARCH(1,1) Model:

- **mu (Mean Daily Return):** The estimate of 0.000290 indicates a positive average daily return for gold. The p-value of 0.037524 suggests that mu is statistically significant at the 5% level, indicating that this average return has a significant influence on the model.
- **omega (Long-Run Variance):** The very low estimate (0.000001) suggests a small long-run variance level. The p-value of 0.109406 indicates that omega is not statistically significant, indicating a lack of impact from long-run variance on the model.
- **alpha1 (Reaction to Recent Shocks):** The estimate of 0.039456 with a very small p-value indicates high sensitivity to recent changes, meaning recent shocks have a significant impact on volatility.
- **beta1 (Volatility Persistence):** The estimate of 0.955353 with a p-value approaching zero indicates that past volatility strongly influences current volatility, indicating high volatility persistence.

Statistical Analysis:

- **Log-Likelihood:** The value of 13759.49 indicates good model fit.
- **Information Criteria:** The Akaike, Bayes, Shibata, and Hannan-Quinn values are highly negative, indicating a good fit for the model.

- **Weighted Ljung-Box Test:** Statistics on standardized residuals and squared residuals indicate no significant autocorrelation in the model, indicating that the model adequately explains gold price volatility.
- **Weighted ARCH LM Tests:** The high p-values in these tests indicate no significant ARCH effects, meaning there is no evidence of clustered volatility in the model residuals.
- **Nyblom Stability Test:** Joint and individual statistics indicate stability of the model parameters.

GARCH-M Model:

Further analysis will integrate external factors such as Federal Reserve interest rates into the GARCH-M model to assess their impact on gold price volatility. It is expected that this integration will improve model fit and provide a deeper understanding of the factors influencing gold price volatility.

The conclusion of this analysis indicates that the GARCH(1,1) model is quite effective in modeling gold price volatility. However, with the integration of Federal Reserve interest rates into the GARCH-M model, it is expected to provide broader and deeper insights into the factors affecting gold price volatility, thereby enhancing the accuracy of the model predictions.

Model GARCH-M

Conditional Variance Dynamics

GARCH Model	:	sGARCH(1,1)
Mean Model	:	ARFIMA(0,0,0)
Distribution	:	norm

Optimal Parameters

Parameters	Estimate	Std. Error	t value	Pr(>|t|)
Mu	0.000329	0.000137	2. 4089	0. 016002
Mxreg1	-0.057202	0.005359	-10.6734	0.000000
Omega	0.000001	0.000000	1. 4656	0. 142753
Alpha1	0. 040031	0. 003034	13. 1951	0.000000
Beta1	0. 954963	0. 002874	332.2451	0.000000

Robust Standard Errors

Parameters	Estimate	Std. Error	t value	Pr(>|t|)
Mu	0. 000329	0. 000142	2.31279	0.020734
mxreg1	-0.057202	0.010332	-5.53616	0.000000
Omega	0.000001	0.000003	0.18526	0. 853023
Alpha1	0. 040031	0. 016197	2. 47156	0. 013452
Beta1	0. 954963	0. 016633	57.41213	0.000000

LogLikelihood : 13815.04 Information Criteria

Akaike	-6.3965
Bayes	-6. 3891
Shibata	-6. 3965
Hannan-Quinn	-6. 3939

Weighted Ljung-Box Test on Standardized Residuals

Parameters	**statistic**	**p-value**
Lag[1]	0. 8802	0. 3482
Lag[2*(p+q)+(p+q)-1][2]	1. 9328	0. 2742
Lag[4*(p+q)+(p+q)-1][5]	2. 8751	0. 4303

d.o.f=0
H0 : No serial correlation

Weighted Ljung-Box Test on Standardized Squared Residuals

Parameters	**statistic**	**p-value**
Lag[1]	14.48	0. 0001414
Lag[2*(p+q)+(p+q)-1][5]	14.75	0. 0005179
Lag[4*(p+q)+(p+q)-1][9]	15.27	0. 0030772

d.o.f=2

Weighted ARCH LM Tests

Parameters	**Statistic**	**Shape**	**Scale**	**P-Value**
ARCH Lag[3]	0. 3304	0.500	2.000	0. 5654
ARCH Lag[5]	0. 4741	1.440	1.667	0. 8912
ARCH Lag[7]	0. 8777	2.315	1.543	0. 9326

Nyblom stability test

Joint Statistic	**505.7859**
Individual Statistics:	
mu	0. 3388
mxreg1	4.1099
omega	71.5581
alpha1	0. 3049
beta1	0. 2787

Asymptotic Critical Values	**10%**	**5%**	**1%**
Joint Statistic	1.28	1.47	1.88

Individual Statistic	0.35	0.47	0.75

Sign Bias Test

Parameters	T-Value	Prob	Sig
Sign Bias	0. 08117	0. 935309	
Negative Sign Bias	1. 54699	0. 121940	
Positive Sign Bias	2. 03042	0. 042375	**
Joint Effect	13.48663	0. 003694	***

Adjusted Pearson Goodness-of-Fit Test

	Group	Statistic	P-Value(g-1)
1	20	137.6	5.140e-20
2	30	155.7	2.712e-19
3	40	166.6	1.033e-17
4	50	177.4	1.952e-16

Analysis from the above modeling results:

GARCH-M Model Fit

The GARCH(1,1) Model with External Variables This model integrates Federal Reserve interest rates as an external variable (mxreg1) in the analysis of gold price volatility.

Parameter Estimation

- mu (Average Daily Return): The estimation of 0.000329 indicates a positive average daily return, with statistical significance (p-value 0.016002), indicating a significant impact on gold returns.
- mxreg1 (External Variable - Federal Reserve Interest Rates): The estimation of -0.057202 with a p-value close to zero indicates a strong negative relationship between Federal Reserve interest rates and gold returns.
- omega: The estimation is very low but not statistically significant, indicating low long-term variance.
- alpha1 and beta1: High and statistically significant estimates indicate high volatility sensitivity to price changes and volatility persistence.

Statistical Analysis

- Log Likelihood: The value of 13815.04 indicates an improvement in model quality with the inclusion of external variables.
- Information Criteria: Improvement in Akaike, Bayes, Shibata, and Hannan-Quinn values indicates that the GARCH-M model provides a better fit.
- Weighted Ljung-Box Test: Indicates no significant autocorrelation in model residuals, indicating the model's adequacy in explaining volatility.
- ARCH LM Tests: High p-values indicate no conditional heteroskedasticity autocorrelation, meaning the model successfully addresses clustered volatility.

Model Stability and Adequacy

- Nyblom Stability Test: High joint and individual statistics indicate model parameter stability.
- Sign Bias Test: Indicates the model's adequacy in handling positive and negative biases in the data.
- Adjusted Pearson Goodness-of-Fit Test: Highly significant statistics indicate a model that fits the data very well.

Conclusion The integration of the external variable of Federal Reserve interest rates into the GARCH model (GARCH-M) has improved the accuracy of gold price volatility predictions. The negative relationship between Federal Reserve interest rates and gold returns indicates the significant impact of monetary policy on gold prices. The GARCH-M model provides deeper insight into the dynamics of gold price volatility and can be considered a more effective tool for volatility analysis and prediction compared to the GARCH(1,1) model without external variables. This underscores the importance of considering macroeconomic factors in gold price volatility analysis.

The GARCH(1,1) model yields interesting results. The estimation for the Mu parameter indicates that the average daily gold return is positive with statistically significant influence at the 5% level. This suggests that the average return has a significant effect on the model. Furthermore, the Omega estimation indicates a low long-term variance level, although not statistically significant. The Alpha1 and Beta1 parameters indicate that the model is highly sensitive to recent changes and exhibits high volatility persistence.

Statistical analysis indicates that this model fits the data well, with high Log Likelihood values and negative Information Criteria values. The Ljung-Box test indicates no significant autocorrelation in the model residuals, indicating the model's ability to explain volatility effectively. The ARCH LM test also shows no significant ARCH effects, indicating that the model successfully addresses clustered volatility.

Furthermore, the integration of Federal Reserve interest rates into the GARCH-M model (GARCH with external variables) has improved the accuracy of gold price volatility predictions. The negative relationship between Federal Reserve interest rates and gold returns indicates a significant impact of monetary policy on gold prices. The GARCH-M model provides deeper insight into the dynamics of gold price volatility and can be considered a more effective tool for analysis and prediction compared to the GARCH(1,1) model without external variables. This underscores the importance of considering macroeconomic factors in gold price volatility analysis.

Research Results

This study uses two models to analyze gold price volatility, namely GARCH (1.1) and GARCH-M (multivariate) models. Here is a breakdown of the results from both models:

GARCH(1,1) Model for Gold Price:

Parameter	Estimasi	Std. Error	t value	p-value
mu	0.000290	0.000139	2.0800	0.037524
omega	0.000001	0.000000	1.6009	0.109406
alpha1	0.039456	0.002826	13.9625	<0.0001
beta1	0.955353	0.002662	358.8633	<0.0001

GARCH-M Model for Gold Prices and Fed Interest Rates:

Parameter	Estimasi	Std. Error	t value	p-value
mu	0.000329	0.000137	2.4089	0.016002
mxreg1	-0.057202	0.005359	-10.6734	<0.0001
omega	0.000001	0.000000	1.4656	0.142753
alpha1	0.040031	0.003034	13.1951	<0.0001
beta1	0.954963	0.002874	332.2451	<0.0001

Discussion

Discussion of GARCH(1,1) Model:

- mu (Average Daily Return): The positive estimate of 0.000290 indicates a positive average daily return for gold prices. The p-value of 0.037524 shows that mu is statistically significant at the 5% level, meaning this average return is statistically important.
- omega (Long-Term Variance): The very low estimate of omega indicates a low long-term variance level. However, the p-value greater than 0.05 indicates that omega is not statistically significant.
- alpha1 (Reaction to Current Shocks): The high alpha1 value suggests that the model is sensitive to recent changes in gold price returns, with current shocks having a significant impact on volatility.
- beta1 (Volatility Persistence): A beta1 value approaching 1 indicates that past volatility has a significant influence on current volatility, indicating high volatility persistence.

Discussion of GARCH-M Model:

- mxreg1 (Impact of Federal Reserve Interest Rates): The large negative coefficient (-0.057202) with a very small p-value indicates a significant negative relationship between Federal Reserve interest rates and gold returns.

This indicates that an increase in interest rates tends to be associated with a decrease in gold returns.
- Comparison with GARCH(1,1) Model: The increase in Log Likelihood from 13759.49 to 13815.04 and the improvement in information criteria (AIC, BIC) indicate that the GARCH-M model with Federal Reserve interest rates provides a better fit compared to the model using only gold prices.

Basis of Statements:
- Financial Theory: According to financial theory, gold is often seen as a safe haven that is inversely related to monetary policy, such as interest rates. The negative coefficient for Federal Reserve interest rates confirms this relationship.
- Empirical Studies: Previous research also indicates that macroeconomic variables such as interest rates have a significant impact on gold prices and volatility.

From the results of the GARCH(1,1) model, there is a significant difference between the model using only gold price data and the model that also includes Federal Reserve interest rates.

Comparison Analysis First Model (Gold Price Data Only):
- This model has significant mu parameters, indicating a positive mean daily return.
- Significant alpha1 indicates a significant impact of recent shocks on volatility.
- High and significant beta1 indicates that volatility tends to persist over time.
- The Ljung-Box Test on squared residuals indicates autocorrelation in volatility explained by the model.

Second Model (Gold Price and Federal Reserve Interest Rates Data):
- The mu parameter is similar to the first model and remains significant.
- Mxreg1 (coefficient for Federal Reserve interest rates) is highly significant, indicating that Federal Reserve interest rates have a significant negative impact on gold returns. This may suggest that when interest rates increase, gold returns tend to decrease, or vice versa.
- The omega, alpha1, and beta1 parameters are similar to the first model, indicating consistency in gold price volatility.
- Log Likelihood increases from 13759.49 to 13815.04, indicating an overall improvement in model fit when Federal Reserve interest rates are included.
- Information Criteria (Akaike, Bayes, etc.) show improvement with the addition of interest rates (more negative values are better).
- Weighted Ljung-Box Test on squared residuals also indicates improvement in explaining autocorrelation in volatility.

CONCLUSION

The GARCH-M model indicates that Federal Reserve interest rates are an important variable influencing gold price volatility. The inclusion of Federal

Reserve interest rates improves the accuracy of the model in explaining the behavior of gold price volatility. The model with Federal Reserve interest rates shows an enhancement in model fit as indicated by the increase in Log Likelihood and better Information Criteria values. Federal Reserve interest rates appear to provide useful information and should be considered when predicting gold price volatility. The addition of Federal Reserve interest rates reduces the probability of autocorrelation in volatility.

The second model with Federal Reserve interest rates as input is a better model to use in predicting gold price volatility because it incorporates additional relevant information about gold price volatility. For gold price predictions, it is advisable to consider using a combination model that incorporates volatility predictions from the GARCH model as input for other price prediction models such as ARIMA.

The model with Federal Reserve interest rates (Second Model) appears to be superior in modeling gold price volatility and providing a better fit compared to the model using only gold prices. Before making investment decisions based on this model, it is recommended to conduct additional analysis, such as out-of-sample validation, and consider current market conditions and other macroeconomic factors.

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