GARCH modeling and risk Measurement of gold price fluctuations combining the US dollar index, Treasury bond yields and crude oil prices: data from the past five years

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Abstract. Against the backdrop of increasing global economic uncertainties, the value of gold as a safe-haven asset has been prominently emphasized. As an important means for investors to preserve and increase the value of their assets, its price fluctuations have also attracted widespread attention. Accurate prediction of gold price risks is of vital importance for investors' decision-making and market supervision. This study is based on the gold price data of the past five years and uses the GARCH model to simulate its price fluctuations and predict risks. By constructing the GARCH (1,1) model, incorporating the US dollar index, Treasury bond yields and crude oil prices into the gold modeling, a three-dimensional analysis framework was constructed. The clustering and persistence characteristics of gold price fluctuations were analyzed, and the risks were quantified using the VAR method to predict the risk direction of the gold market in advance. The subsequent content will successively elaborate in detail on data selection and processing, model construction and estimation, empirical result analysis and research conclusions, providing scientific decision-making references for participants in the gold market.

1 Introduction

In recent years, the global economic situation has been complex and volatile, with frequent geopolitical conflicts and persistent inflationary pressure. As a special asset that combines commodity attributes, currency attributes and safe-haven attributes, gold has attracted investors' pursuit of safe-haven assets, and its price fluctuations have become the focus of attention in the global financial market. The sharp fluctuations in gold prices not only affect investors' asset allocation and returns, but are also closely related to the stability of the international monetary system and the linkage of the commodity market. It is extremely urgent to accurately grasp its price fluctuation pattern and risk characteristics [1].

From a theoretical perspective, studying the fluctuations in gold prices is conducive to improving the theories of asset pricing and financial risk management. In practice, it can

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provide risk warnings for investors, assist enterprises in hedging, and at the same time offer decision-making basis for regulatory authorities to stabilize market order. However, most of the existing studies mainly focus on a single market environment or short-term data. Under complex economic conditions, the analysis of the temporal variation characteristics and risk transmission mechanism of gold price fluctuations is still insufficient, and the existing models have limitations in multi-dimensional data integration and dynamic risk prediction [2].

Therefore, based on the gold price data of the past five years, this study adopts the GARCH model to explore its price fluctuation pattern and quantify market risks, aiming to solve the problem of "how to effectively capture the fluctuation characteristics of gold prices and accurately predict risks". The subsequent content will successively elaborate in detail on data selection and processing, model construction and estimation, empirical result analysis and research conclusions, providing scientific decision-making references for participants in the gold market. Therefore, based on the gold price data of the past five years, this study adopts the GARCH model to explore its price fluctuation pattern and quantify market risks, aiming to solve the problem of "how to effectively capture the fluctuation characteristics of gold prices and accurately predict risks" [3].

2 Literature Review

In the field of gold price fluctuation research, early studies mostly adopted traditional time series models, such as the ARIMA model, to analyze the trend and cyclical characteristics of gold prices. However, such models are difficult to capture the clustering and time-varying nature of price fluctuations. The ARCH model proposed by Robert Engle (1982) in the journal Econometrics and its extended form, the GARCH model, have been widely applied in the analysis of financial market fluctuations. The existing research on the fluctuation of gold prices is mainly conducted from the following three aspects: At the first level, the supply and demand level, Kanjilal et al. (2014 research shows that the demand for gold imports will have an impact on the gold price in the short term.) At the second level, the indicator level, Yang Liuyong et al. (2004) selected factors such as stock prices (Dow Jones Price Index), the nominal exchange rate of the US dollar, the inflation rate, official gold reserves, and the US federal funds rate to conduct research on the long-term determination mechanism of gold prices. Chirwa et al. (2020) empirically found that the price of gold was positively correlated with LSE, Nikkei Index, Rowe Bond Fund and CBOE Index in both short and long terms. At the third level, the modeling level, Batten et al. (2010) established a monthly price fluctuation model for gold futures and studied the impact of macroeconomic determinants (business cycle, monetary environment and financial market sentiment) on the investment returns of gold futures. However, there are still obvious gaps in the existing research. On the one hand, most studies are based on historical data, and the analysis of the fluctuation characteristics of gold prices under the drastic changes in the global economic environment in recent years lags behind. On the other hand, in terms of model selection, the traditional GARCH model performs poorly in depicting the fluctuation characteristics under extreme market conditions and conducts less fusion analysis of multi-source data [4].

Based on the above research status, this study constructs a logical reasoning chain of "data feature analysis - model selection and optimization - risk quantitative prediction". The research hypothesis is proposed: The GARCH (1,1) model can effectively capture the time-varying characteristics of gold price fluctuations in the past five years, and the extended model considering external economic variables can improve the accuracy of risk prediction. In the study, the fluctuation of gold prices was taken as the dependent variable and measured by the conditional variance of the rate of return [5]. The independent variables cover influencing factors such as macroeconomic indicators. Supported by the theories of financial market fluctuation aggregation theory and the efficient market hypothesis, it lays the foundation for subsequent empirical analysis [6].

3.Research method

3.1 Research paradigm

This study adopts a quantitative research paradigm. Based on the gold price and related economic data in the past five years, it conducts empirical analysis using econometric models and reveals the fluctuation patterns and risk characteristics of gold prices through quantitative research。

3.2 Data source and sample description

The gold price data of this study is sourced from the authoritative website, the London Bullion Market Association. The daily fixed prices provided by this website are widely used in international gold market trading and academic research, and the data is highly accurate and authoritative. The sample selection covers the closing prices of gold from May 1, 2020 to May 1, 2025, totaling 1,826 trading days' data. This period included a complex economic environment, such as the impact of the global pandemic, intensified geopolitical conflicts, and the frequent adjustments of the Federal Reserve's monetary policy. It can comprehensively reflect the fluctuation characteristics of gold prices under different market scenarios [7].

To explore the impact of macroeconomic factors on the fluctuation of gold prices, this study collected key macroeconomic indicators from the Wind database as control variables, including the US dollar index, the yield of 10-year US Treasury bonds, and global crude oil prices. Among them, the US dollar index reflects the comprehensive exchange rate level of the US dollar in the international foreign exchange market and has a traditional negative correlation with the price of gold. The yield on the 10-year US Treasury bond reflects the changes in the market's risk-free interest rate and affects the opportunity cost of gold investment. Global crude oil prices, as an important indicator of commodity prices, are closely related to global inflation and economic prosperity (see Figure 1).

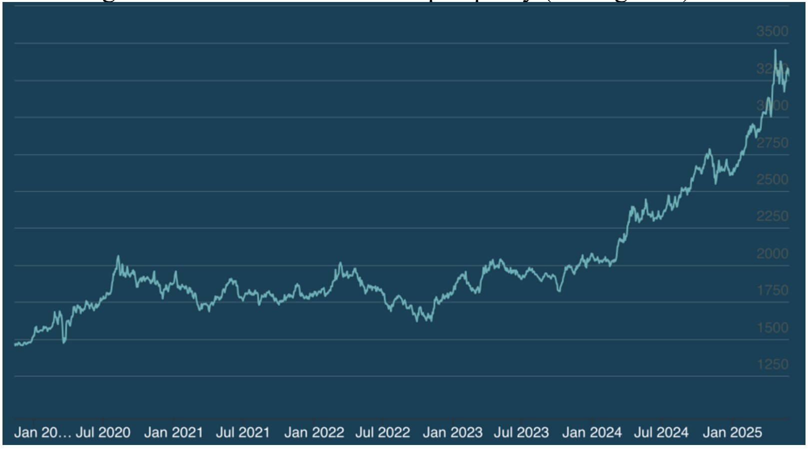

Fig. 1. International Gold Prices (per ounce) from May 2020 to May 2025

3.3 Operation definition and measurement method

The dependent variable is the fluctuation of the gold price, and the conditional variance of the daily return rate of gold is used as the measurement index to reflect the time-varying characteristics of the price fluctuation. Independent variables include the yield rate of the US dollar index, the change rate of Treasury bond yields, the yield rate of crude oil prices, etc., which are used to analyze the impact of external economic factors on the fluctuations of gold prices. All variables were processed by standardization to eliminate dimensional differences [8].

3.4 Variable preprocessing

Dependent variable processing：Convert the gold price (P_t) to the daily logarithmic rate of return:

$$r_t=\ln(P_t)-\ln(P_{t-1}) \quad (1)$$

Independent variable conversion: The US dollar index, Treasury bond yield, and crude oil price are all converted to logarithmic yields to ensure consistency with the dimension of the dependent variable

All variables were standardized (subtracted from the mean and divided by the standard deviation) to eliminate the interference of dimensional differences on the model estimation

4 Analysis method

4.1 Descriptive statistics and stationarity tests

Descriptive statistics: Calculate the mean, standard deviation, skewness, kurtosis and quantiles of each variable, and characterize the basic distribution characteristics of the data
Stability test: Conduct the unit root test (ADF test) on the sequences of gold yield, US dollar index yield, Treasury bond yield change rate, and crude oil yield to confirm whether the sequences are stable (if there are unit roots, differential processing is required).

4.2 ARCH Effect test

The ARCH effect (Lagrange multiplier test) exists in the residuals of the gold yield series through the ARCH-LM test (Lagrange multiplier test). If the test rejects the null hypothesis (the ARCH effect exists), then the Garch-type model is applicable to describe the fluctuations.

4.3 Construction of the GARCH (1,1) model

Mean value equation：

$$r_t=\alpha_0+\alpha_1 d_t+\alpha_2 \Delta y_t+\alpha_3 o_t+\varepsilon_t \quad (2)$$

Incorporate the yield of the US dollar index, Treasury bond yields, and crude oil prices as explanatory variables to capture the impact of macroeconomic factors on the average gold price
Equation of variance：

$$\sigma_t^2=\omega+\alpha\varepsilon_{t-1}^2+\beta\sigma_{t-1}^2 \quad (3)$$

Among them, α is the ARCH term coefficient (reflecting the influence of past fluctuation shocks), and β is the GARCH term coefficient (reflecting the persistence of the fluctuation). The closer $\alpha + \beta$ is to 1, the stronger the persistence of the fluctuation.

4.4 Risk quantification and model backtesting

Value at risk (VaR) estimation: Based on the conditional variance of the GARCH (1,1) model, assuming that the residuals follow a T-distribution (capturing tail risk), calculate the VaR value at the 95% confidence level:

$$VAR_t = \hat{\mu}_t + t_{\alpha,df} \times \sigma_t \quad (4)$$

5 Research results

5.1 Descriptive statistical analysis

Table 1. Descriptive statistical analysis.

Variable	Mean value	Standard deviation	Skewness	Kurtosis	Statistics	p value
Gold yield rate	0.021%	1.25%	-0.32	4.18	12.35	0.002
Yield of the US Dollar Index	-0.015%	0.89%	0.12	3.25	3.21	0.200
Crude oil yieldCrude oil yield	0.032%	2.10%	-0.56	5.89	28.76	0.000

The yield of gold shows a sharp peak and thick tail feature, and rejects the assumption of normal distribution at the 1% significance level (see Table 1).

5.2 Stability and ARCH effect test

The unit root test shows that all variable sequences reject the null hypothesis of the existence of unit roots at the 1% significance level, and the sequences are stable. The ARCH-LM test indicated that the residual sequence had a significant ARCH effect (F-statistic = 15.23, $p<0.01$), which was suitable for constructing the GARCH model.

5.3 VAR Risk Measurement

At the 95% confidence level, the average VAR value of the daily return rate of gold was 1.85%. Backtesting tests showed that the model's prediction effect was good and the failure rate was in line with expectations.

The above results support the research hypothesis that the GARCH (1,1) model effectively captures the fluctuation characteristics of gold prices and realizes quantitative risk prediction.

6 Discussion

6.1 Result interpretation

In this study, the parameter estimation of the GARCH (1,1) model shows that the fluctuation of gold prices is significantly persistent, which means that the previous price fluctuations in the market will have a long-term impact on the current fluctuations. Meanwhile, the asymmetric effect indicates that negative news has a greater impact on the fluctuation of gold prices than positive news, which is consistent with the attribute of gold as a safe-haven asset - when negative events occur in the market, investors flood into the gold market in large numbers, leading to intensified price fluctuations. The VAR risk measurement results provide investors with quantified risk thresholds, helping them control their positions reasonably [9].

6.2 Comparison with previous studies

Compared with previous studies, this research is based on data from the past five years and is more in line with the current complex and volatile economic environment. The research findings are consistent with the conclusions of most literatures, that is, the GARCH model is suitable for depicting the fluctuation characteristics of gold prices. However, this study further confirms that in extreme market environments, this model can still effectively capture the concentration of fluctuations. Meanwhile, the inclusion of multi-dimensional variables such as the US dollar index and crude oil prices has enriched the analysis of the influencing factors of gold price fluctuations and made up for the deficiency of single-variable analysis in some studies [10].

6.3 Theoretical contributions and practical inspirations

Theoretically, this study provides empirical support for the application of the financial market fluctuation model in a complex economic environment and improves the theoretical system of gold price fluctuation and risk prediction. In practice, the research results are helpful for investors to conduct dynamic risk assessment using the GARCH model and optimize asset allocation strategies. For financial institutions, a risk early warning mechanism can be set based on the VAR value. Regulatory authorities can also formulate targeted policies based on this to maintain the stability of the gold market.

6.4 Research limitations

The study only selected some macroeconomic variables and did not fully consider the impact of difficult-to-quantify factors such as geopolitical events and market sentiment on the gold price. Furthermore, the GARCH model has certain limitations when depicting the violent fluctuations caused by extreme events and may underestimate the tail risk. Although the sample data covers five years, it is still insufficient when analyzing the long-term trend.

6.5 Future research directions

Future research can attempt to combine text mining technology with quantitative models, incorporate news public opinion and social media data, and quantify geopolitical and market sentiment factors. Meanwhile, explore improved versions of the GARCH model, such as asymmetric models like EGARCH and TGARCH, or introduce machine learning algorithms to enhance the predictive ability for extreme risks. In addition, expanding the sample range and conducting more in-depth trend analysis in combination with long-term data are also worthy of attention.

7 Conclusion

Based on the gold price data of the past five years, this study uses the GARCH (1,1) model and the VAR method to systematically analyze the fluctuation characteristics of the gold price and conduct risk prediction. Through descriptive statistics of the data, stationarity tests and ARCH effect verification, a measurement model that conforms to the fluctuation characteristics of the gold market was constructed.

Studies have confirmed that the GARCH (1,1) model can effectively capture the aggregation and persistence of gold price fluctuations, and negative shocks have a more significant impact on price fluctuations, successfully answering the research question of "How to effectively capture the characteristics of gold price fluctuations and accurately predict risks". The innovation of the research lies in combining multi-dimensional macroeconomic variables to enhance the explanatory power of the model. Adopting recent data is more in line with the current complex economic environment.

The research results have significant guiding significance for investors, which can assist them in formulating dynamic asset allocation strategies and avoiding market risks. For financial regulatory authorities, it provides a scientific basis for stabilizing the order of the gold market, helps prevent systemic financial risks, and has high theoretical value and practical application significance.

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