SHS Web of Conferences **225**, 02010 (2025) https://doi.org/10.1051/shsconf/202522502010
ICFMDE 2025

Bitcoin's Impact on Gold Price Volatility: Evidence from ARMA-GARCH Models

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Abstract. With the continuous development of digital assets in the global financial system, whether Bitcoin affects the price volatility of traditional safe-haven asset gold has become a new topic worth exploring. Based on the daily data from 2018 to 2024, this paper constructs ARMA-GARCH and GARCH-X models to study the explanatory power of Bitcoin yield on gold volatility. Initially, we establish data stationarity using Augmented Dickey-Fuller tests, and introduces the Bitcoin yield on the basis of the ARMA-GARCH model, and establishes an extended model for empirical analysis. It is found that Bitcoin variables are statistically significant in the GARCH-X model, and can improve the fitting effect of the model to a certain extent. Further grouping regression shows that Bitcoin has a more stable explanatory power for gold volatility in normal market conditions, while its predictive power is weakened during periods of high uncertainty. In addition, the results of the Granger causality test also show that Bitcoin has a forward predictive effect on gold yield. This paper expands the theoretical framework of gold price modeling and provides an empirical reference for investors when allocating new and traditional asset portfolios.

1 Introduction

Over the past decade, the price volatility of gold has affected the hearts of countless investors, and it has always been the focus of attention in many fields such as finance. Gold, as the most representative safe-haven asset, is often regarded as a tool for value storage and risk hedging in times of inflation, geopolitical conflicts, changes in interest rates by central banks of major economies, or financial market turbulence [1-3]. Like the saying goes "Gold is not the answer, but it is the best insurance policy for uncertainty. " However, with the rapid rise of digital assets in recent years, especially the emergence of Bitcoin, the global asset allocation landscape is changing. Because of its decentralization and scarcity of total amount, Bitcoin is also called "digital gold" by some researchers [4]. At present, the modeling of gold price fluctuations mostly focuses on macro variables (such as interest rates, US dollar index, inflation rate, etc.), and there is still a lack of systematic testing on whether Bitcoin, as an emerging asset, has statistically "explanatory power" for gold price fluctuations [5]. This context makes Bitcoin's potential influence on gold price volatility a critical research focus. Methodologically, this study incorporates Bitcoin into gold volatility forecasting to extend existing theoretical frameworks for gold market determinants. The results of this study can

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provide investors with more comprehensive reference variables and optimize the stability of asset portfolios when market uncertainty intensifies.

2 Literature review

2.1 A study of the traditional drivers and volatility of gold prices

Prior studies establish gold's price sensitivity to macroeconomic factors, including inflationary pressures, dollar fluctuations, geopolitical risks, and investor sentiment. Illustratively, the COVID-19 crisis triggered pronounced safe-haven effects, enhancing gold's multifractal characteristics while diminishing market efficiency during upward trends [6]. In addition, an empirical analysis based on monthly data from 1987-2017 points to a significant correlation between gold prices and a number of macro variables: a strong positive correlation with copper prices ($r = 0.872$), crude oil prices ($r = 0.810$) and silver prices ($r = 0.956$), while with China ($r = -0.230$), Chinese inflation ($r = -0.202$) and US inflation ($r = -0.380$), there was a significant negative correlation (both significance levels were 0.01).

Traditionally, ARMA and GARCH have been widely used to characterize the volatility of gold prices [7]. For example, an empirical analysis based on the ARMA (1,1)-GARCH (2,2) model shows that the model can effectively capture the "peaks and thick tails" characteristics and volatility agglomeration of gold prices, dynamically characterize its data generation process [8], and provide investors with risk management tools by quantifying the historical volatility of gold prices.

2.2 Bitcoin's Correlation with Gold: An Overlooked Explanatory Variable

Today's research on Bitcoin is largely focused on its "safe-haven" effect as digital gold, which is rarely included as an explanatory variable in existing gold price models, but its specific relationship with gold is worth paying attention to [9]. The dynamic model reveals an inverse relationship between gold and Bitcoin prices during the sample period. (2013-2017) ($\beta = -0.051$), but this coefficient is not constant, and tends to be close to zero in some periods (such as 2016) [10].

2.3 Research hypotheses and theoretical frameworks

According to the above research and study of the literature, potential Bitcoin-gold interaction may theoretically have the following mechanisms:

1. Mutual hedging demand-driven mechanism: During periods of market turmoil, rising inflation expectations, or sudden geopolitical risks, investors may increase their holdings of gold and bitcoin at the same time, and the prices or volatility of the two may show a positive correlation, reflecting the "common risk hedging" behavior.

2. Asset Alternative Allocation Mechanism: When investors make a trade-off between gold and Bitcoin, funds may flow from traditional assets (gold) to crypto assets (Bitcoin) or vice versa. In this process, Bitcoin price fluctuations may affect the gold market through changes in capital flow and risk appetite, thus manifesting as periodic changes in gold volatility.

Hypothesis H1: Bitcoin yield has a significant impact on gold price volatility, i.e., the regression coefficient of Bitcoin as an exogenous variable is significantly non-zero when introduced into the GARCH model.

Hypothesis H2: The inclusion of Bitcoin returns can improve the fitting and prediction effect of the gold volatility model, which is manifested in improving the evaluation indicators of models such as AIC/BIC or reducing the prediction error.

Hypothesis H3: During periods of high market uncertainty, Bitcoin's explanatory power for gold volatility is more significant (which can be tested by sample grouping).

3 Methodology

This study uses a quantitative analysis method, and the data is derived from the R language package quantmod and Yahoo Finance.

3.1 Data preprocessing and basic testing

Firstly, the daily price data of gold and Bitcoin are converted into logarithmic yields to eliminate the interference of non-stationarity on modeling. Subsequently, the ADF unit root test was performed on the two types of return series to determine the stationarity of the series.

For the return series after stationarity confirmation, the ACF and PACF graphs are further drawn, and the lag order is identified by combining AIC, BIC and other information criteria, so as to provide a basis for the construction of the ARMA model. At the same time, the Ljung－Box Q test is performed on the residuals to verify whether they are white noise.

3.2 Mean and Volatility Modeling: ARMA-GARCH Model

After completing the data preprocessing, this paper constructs the following three types of models in turn to compare whether Bitcoin has a significant impact on gold volatility.

3.2.1 ARMA-GARCH benchmark model (no explanatory variables)

Firstly, the ARMA (p, q) + GARCH (1,1) model of gold yield is constructed to describe the fluctuation structure of gold itself. This model serves as a benchmark for subsequent model comparisons.

3.2.2 ARMA-GARCH-X Extension Model (Introducing Bitcoin Variables)

The GARCH model is constructed by introducing the Bitcoin yield as an exogenous explanatory variable in the GARCH model, i.e., constructing the GARCH-X model [11]. Verify whether it has statistically significant explanatory power for gold fluctuations by examining the significance of Bitcoin's coefficient (used to test hypothesis H1).

3.2.3 Comparison of model fitting effects

GARCH is compared with the GARCH-X model on metrics such as AIC, BIC, Sum of Squares of Residuals (RSS), or rolling prediction error (e.g., RMSE) to determine whether the introduction of Bitcoin improves model fitting and prediction (used to test hypothesis H2).

3.3 Extended test: heterogeneity analysis under market uncertainty

In order to further verify whether Bitcoin has enhanced its explanatory power to gold volatility during periods of extreme market volatility or significant increase in uncertainty [12]. This paper conducts the following extended analysis (Modeling of sample interval grouping):

Representative "high uncertainty periods" like the 2020 Covid-19 pandemic were selected, plus the samples were divided into "high uncertainty group" and "normal period group", and the GARCH-X model was constructed respectively. Compare the significance of the Bitcoin variable over time with the degree of improvement in model fitting (used to test hypothesis H3).

3.4 Ancillary analysis: granger causality test

In order to supplement the verification of the dynamic causal relationship between the yield of Bitcoin and the yield of gold, this paper conducts the Granger Causality Test on the two to assist in determining whether Bitcoin is a leading indicator of gold volatility, and serves as an external verification method for the results of the GARCH model [13].

4 Research findings

4.1 The result of data preprocessing and basic testing

4.1.1 Sequence stationarity test

The ADF unit root test was first conducted separately on the log return data for Bitcoin and gold. The p-value (<0.01) significantly exceeds the 0.05 threshold, leading to rejection of the null hypothesis and confirming stationarity in both return series, which can be used for the construction and analysis of subsequent ARMA and GARCH models.

4.1.2 Judgment and test of the lag order of the ARMA model

The auto.arima procedure was applied to the daily log returns of both gold and Bitcoin to determine optimal model specifications, and the results show that the gold yield series can be fitted by the ARIMA(0,0,0) model, that is, it shows an approximate white noise process without significant autocorrelation structure. The fitting result of the Bitcoin yield series is ARIMA(4,0,0), indicating that it has a fourth-order autoregressive structure, and the yield has a significant dependence on its own changes in the past four periods (see Figure 1 and 2).

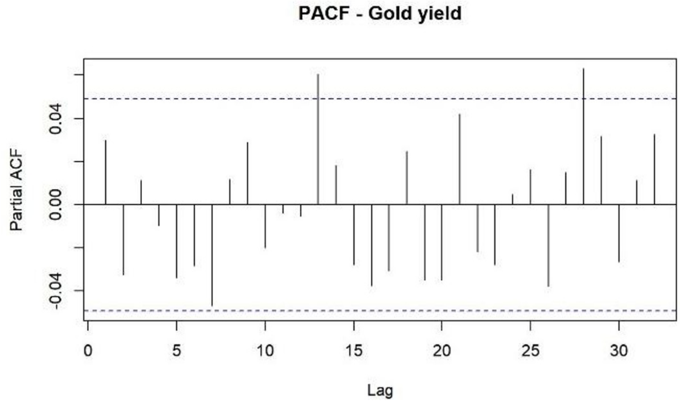

Fig.1. PACF plot of Gold yield

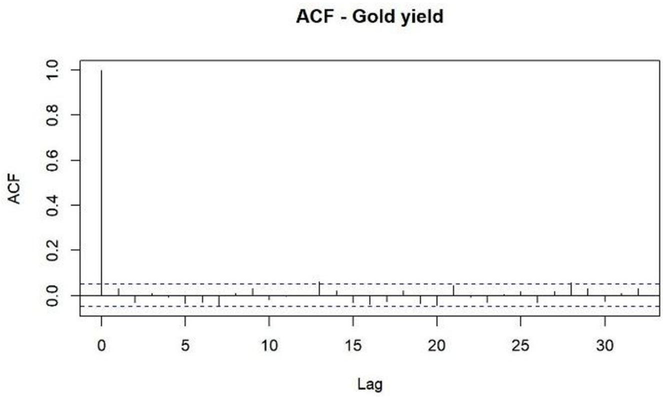

Fig.2. ACF plot of Gold yield

To further verify the plausibility of the selected ARMA model, the Ljung－Box Q test is performed on its residuals. The results show that the residual sequences of the ARMA(0,0) model of gold returns and the ARMA(4,0) model of Bitcoin returns do not show significant autocorrelation ($p > 0.05$) at the 20th order lag, indicating that the residuals are similar to white noise, and the model fits well, which can be used as the basis for the subsequent GARCH model.

4.2 The result of Mean and Volatility Modeling: ARMA-GARCH Model

4.2.1 ARMA-GARCH benchmark model

The goal is to build a volatility model that relies only on gold's own yield, which can be used as a "baseline model" for subsequent comparisons.

In this study, the GARCH(1,1) structure was used to characterize the conditional heteroskedasticity. The empirical results show that the ARCH and GARCH terms in the model are significant at the 1% significance level, $\alpha + \beta < 1$, confirming that the GARCH process is stable.

Simultaneously, residual diagnostics showed no significant autocorrelation or heteroskedasticity based on Ljung-Box and ARCH-LM tests, indicating that the model fit well and could be used as a control baseline model for the subsequent introduction of Bitcoin variable (GARCH-X). The AIC is -6.7004 and the BIC is -6.6869.

4.2.2 Construct ARMA + GARCH(1,1) model with exogenous variable Bitcoin yield (GARCH-X) and comparison

The goal is to test whether Bitcoin yields have statistically explanatory power (H1) for gold volatility; Compare the information criteria (AIC/BIC) to see if there is an improvement (H2).

To examine whether Bitcoin returns influence the volatility of gold prices, this paper incorporates Bitcoin returns as an exogenous regressor in the GARCH(1,1) variance specification, and constructs the GARCH-X model for extension. The specific model is set to:

$$r_t = \mu + \varepsilon_t, \varepsilon_t \mid F_{t-1} \sim N(0, h_t), h_t = \omega + \alpha\varepsilon_{t-1}^2 + \beta h_{t-1} + \delta \cdot BTC_t \quad (1)$$

The empirical results show that the coefficient estimate of the exogenous variable Bitcoin yield (vxreg1) is 0.000058 and the t-value is 2.845, which is statistically significant at the 1% significance level ($p = 0.0044$). The use of robust standard error is still significant ($t = 2.074$, $p = 0.0381$), indicating that Bitcoin has a positive explanatory power for gold condition fluctuations, supporting the hypothesis H1.

In terms of model information criteria, the AIC of the GARCH-X model is -6.7037, which is slightly lower than that of the benchmark model, and the BIC is basically the same, indicating that the introduction of Bitcoin brings about a marginal fit improvement and validates the hypothesis H2.

In terms of residual diagnosis, the Ljung - Box test showed no autocorrelation of residuals ($p > 0.3$), and the ARCH-LM test and Sign Bias test did not find significant heteroskedasticity or fluctuation asymmetry. Although the Nyblom joint statistic (3.6668) was slightly higher than the critical value, the individual tests of all parameters were within the acceptable range, and the overall structure of the model was stable.

The GARCH-X model incorporates Bitcoin yield as an external regression variable in the variance equation. Compared to the benchmark GARCH model, GARCH-X shows slightly smoother and more responsive volatility during periods of high uncertainty, suggesting that Bitcoin helps explain the conditional variance of gold yields, providing visual support for Hypothesis 1 and Hypothesis 2.

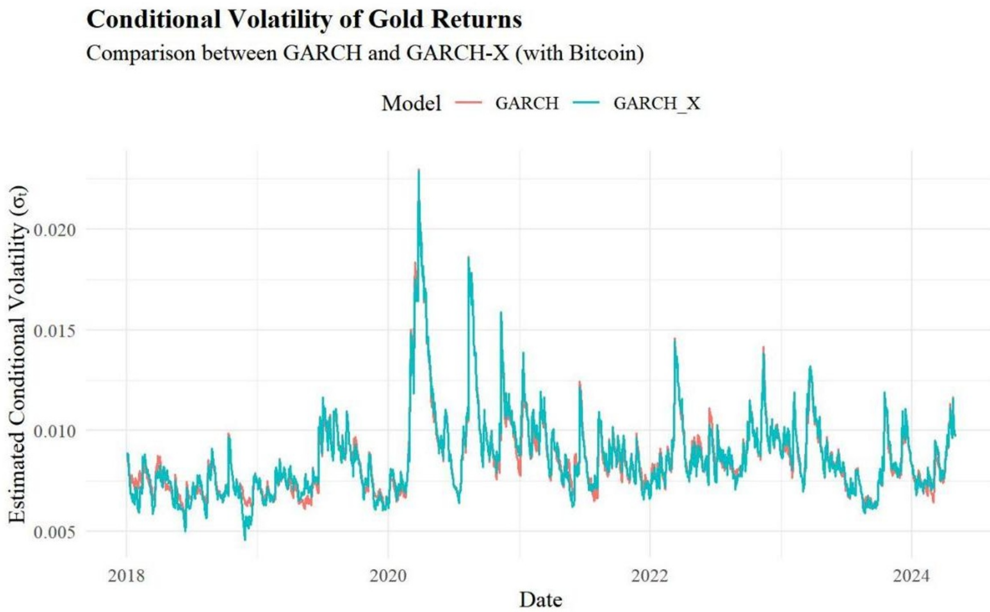

Fig. 3. Comparison between GARCH and GARCH-X

In summary, the GARCH-X model performs better than the benchmark model, and Bitcoin as an explanatory variable significantly affects the volatility of gold, supporting its behavioral association with traditional safe-haven assets (see Figure 3).

4.3 The result of extended test

4.3.1 Bitcoin's explanatory power to gold volatility during abnormal periods

In order to test whether Bitcoin's explanatory power on gold volatility is significantly improved during the period of increased market uncertainty, this paper divides the sample into a "period of high uncertainty" (the early stage of the epidemic from February 15, 2020 to June 30, 2020) and a "normal period", and constructs the GARCH-X model respectively.

In the model during the period of high uncertainty, the estimated value of the Bitcoin return term (vxreg1) is 0.000000, the p-value is 1.000, which does not reach statistical significance, and the overall log-likelihood of the model is 272.89 and the AIC is -5.6997, indicating that during the extreme period, although gold volatility has increased significantly (see Figure 4), Bitcoin has not shown a stable explanatory role.

In contrast, in the GARCH-X model under normal periods, the Bitcoin variable is estimated to be 0.000055, which is significant at the 1% significance level ($p = 0.000050$), and the t-value is still 3.38 ($p = 0.000735$) after using the robust standard error, indicating that it has stable positive explanatory power for gold condition fluctuations, supporting the hypothesis H1. The model has a log-likelihood of 5072.53 and an AIC value of -6.7748, and the goodness of fit is significantly better than that of the high-uncertainty sample.

Figure 4 shows the estimated trajectory of the volatility of gold yield conditions over two periods, showing that volatility spiked rapidly in the early days of the pandemic and then plateaued off. Despite the significant increase in volatility, Bitcoin has not shown any greater predictive power during this period, and the assumption that H3 is not supported suggests that its explanatory power is more stable in a regular market environment.

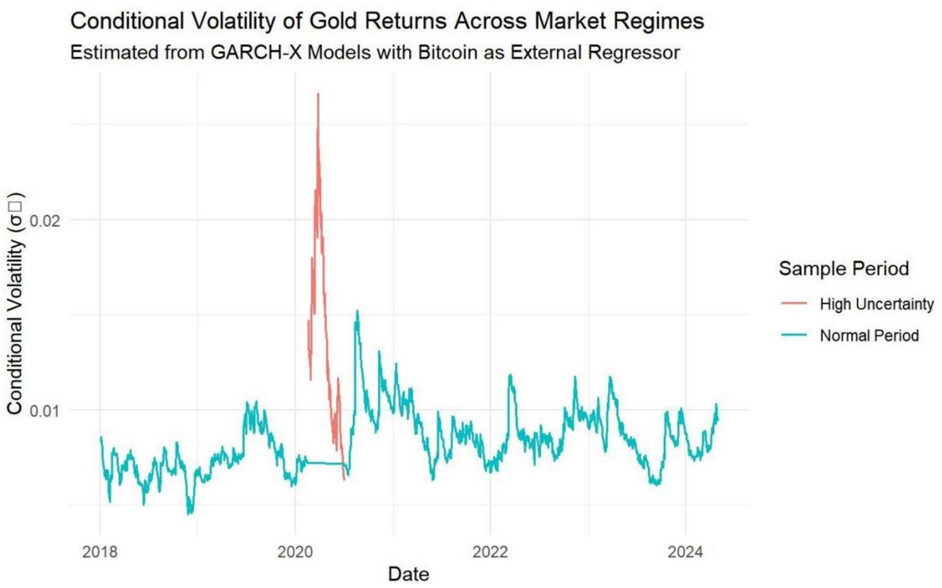

Fig. 4. Estimated from GARCH-X Models with Bitcoin as External Regressor

4.4 Granger causality test

Ancillary tests were performed with the Granger causality test.To provide additional evidence on whether Bitcoin exerts a directional influence on gold price fluctuations, this paper conducts a Granger causality test on the daily return series of the two. According to the AIC minimum criterion, the lag order was selected as 4, and the VAR model was constructed for causality test.

The results indicate that the rejection of the null hypothesis "Bitcoin does not granger causes gold" ($F = 2.4075$, $df = 4$, $p = 0.0474$) at the 5% significance level suggests that Bitcoin yields have a statistically significant predictive effect on gold yields. This conclusion supports the empirical findings in the GARCH-X model from the causal level, that is, Bitcoin has a certain explanatory power for the volatility of gold, which provides an external basis for the hypothesis H1.

5 Discussion

In this study, we systematically evaluate the impact of Bitcoin on the volatility of gold by constructing ARMA-GARCH and GARCH-X models. The empirical results show that Bitcoin is significantly effective as an exogenous variable in the GARCH model throughout the sample period, which supports the hypothesis that Bitcoin has explanatory power for gold fluctuations. However, during periods of high uncertainty (such as the early days of the pandemic in 2020), Bitcoin's variables were not significant, indicating that its explanatory power is environmentally sensitive. This may reflect a drastic shift in investors' attitudes towards bitcoin dominated by extreme market sentiment, thus weakening its synchronization with gold.

Different from previous studies that mainly focused on the safe-haven properties of Bitcoin or the modeling of gold fluctuations, this paper introduces Bitcoin into the modeling system of gold fluctuations for the first time, and empirically proves the marginal role that digital assets may play in the price behavior of traditional safe-haven assets. This finding is helpful to enrich the pricing logic of gold and promote the linkage research between crypto assets and traditional financial assets.

Of course, there are limitations to research. On the one hand, the data coverage time is limited and cannot reflect long-term structural changes. On the other hand, this paper only uses GARCH-like models, and does not introduce structural models such as MS-GARCH and SVAR to hedge potential heteroskedasticity variation.

Future research can be expanded to include more macro variable control terms, extend the time window to recent geopolitical events, or compare the behavioral characteristics of other crypto assets with gold, so as to further enrich the theory of cross-asset price modeling.

6 Conclusion

From a modeling perspective, this paper examines whether Bitcoin can explain the volatility of gold prices. By constructing ARMA-GARCH and GARCH-X models, and empirically analyzing the daily data from 2018 to 2024, it is found that Bitcoin, as an exogenous variable, has a significant positive explanatory power for gold fluctuations in the overall sample, and can improve the fitting effect of the model to a certain extent. The Granger causality test further demonstrates Bitcoin's predictive power against gold. However, under extreme market sentiment, Bitcoin's explanatory power weakened.

Overall, this paper verifies the dynamic relationship between Bitcoin and gold, expands the modeling framework of gold price fluctuations, and provides a new perspective for understanding the interrelationship between digital assets and traditional safe-haven assets. The research results have certain practical significance for asset allocation, risk management and macro financial market observation.

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