

Market Risk of Gold Futures and Gold Spot under Geopolitical Risk

-- Based on the GARCH-X Model

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Abstract. With the heightening financial globalization, the market risk has increased strongly especially at times of geopolitical uncertainty. Gold that has traditionally been considered a safe-haven asset is highly volatile when there is an escalation of geopolitical tensions. Nonetheless, the variability that occurs to the spot and futures markets has not been fully investigated. The paper determines the factor of Geopolitical Risk (GPR) on conditional volatility of gold futures and spot returns by the GARCH-X(1,1) model that incorporates the Student-t innovations. A standardized GPR index is introduced as an exogenous variable in the equation of variance using monthly data between the year 1980 and 2023. We find that, lagged GPR has a positive effect on futures volatility, but that effect is somewhat significant, indicating that futures markets that are more vulnerable to geopolitical shocks are speculative and leveraged derivatives markets. By comparison, the spot market volatility does not exhibit any important effect of GPR, meaning that it is self-enhanced by past shocks. Ljung-Box diagnostics indicate some residual autocorrelation in the futures model, indicating that there is some possibility to refine the model by using alternative GARCH specification, or adding more terms to the mean equation. GARCH-X(t) model is highly suitable in terms of volatility dynamics in the futures, whereas spot volatility is more stable. The study has significant implications on risk management, portfolio hedging policies, and regulatory controls on derivatives markets in times of geopolitical crises.

Keywords: GARCH-X; Geopolitical Risk; Gold futures; Spot market; Volatility; Value-at-Risk; Conditional heteroskedasticity.

1. Introduction

In the last three decades, the phenomenon of cross-border financial integration and capital flows has escalated on unprecedented levels such that the financial system of the world has become more interdependent. Such interconnectedness implies that local shocks, such as political wars, acts of terrorism, military actions, and diplomatic crises, can spread quickly through the markets causing widespread turbulence and even the systemic crisis. Having been viewed as a safe-haven asset and store of value during the uncertain periods, gold has recently been getting much prone to volatility in response to geopolitical influences. Other past studies by Baur and Lucey (2010) have been done to investigate the role of gold as a safe-haven investment in various market environments, and this research has determined the protecting nature of gold in extreme market stress conditions[10]. Nonetheless, increased volatility has been presented by the geopolitical tensions developed over the recent decades and it should be researched in greater depth. Prokopczuk et al. (2015) emphasize the importance of variance risk in commodity markets, which is why proper forecasting of volatility in the derivatives pricing and risk management of derivatives is important, especially in the case of gold as a financial and physical asset [6].

Notably, the reaction of spot markets and gold futures to geopolitical shock can differ significantly because of the key differences in their structure, motives behind trade, leverage, and the structure of participants. Spot markets are mainly used by physical hedgers and long-term investors that require their wealth to be preserved and futures markets are more appealing to speculators, algorithmic traders, and leveraged traders who want to make short-term returns in the market. These structural variations

indicate that the two markets may be affected by geopolitical risks asymmetrically where the futures might be more sensitive since it is more leveraged and its information incorporated faster.

Proper quantification and prediction of market risk in both segments are important to a number of stakeholders. Investors need good volatility estimates to maximize on portfolio allocations and hedge positions. Regulators should be able to check the accumulation of systemic risk in derivatives markets. The central banks and other monetary actors should be aware of the way that the geopolitical shocks spread to the commodity markets to the inflation expectations. In spite of this significance, there is still a research gap regarding the explicit modeling of the ability of exogenous geopolitical shocks to induce conditional volatility in the spot and futures gold markets in a different manner.

The proposed research is expected to fill this gap by examining the effect of GPR on the conditional volatility of gold spot returns and gold futures returns. GARCH-X(1,1) model framework is used where the lagged standardized GPR index is used as an exogenous variable in the variance equation. Through the Student-t innovations, which presumes heavy tails which are often present in financial returns, we will have a better estimation of the volatility dynamics. We comparatively examine parameter estimates, diagnostic tests on the residual, and stability of volatility and sensitivity of volatility in the two markets. The empirical findings clarify why geopolitical uncertainty should differentially impact gold markets and provide practical information in order to manage the risk and help design policy.

2. Literature Review

Time-varying volatility financial market modeling originated with the pioneering work of Engle (1982) [1], Autoregressive Conditional Heteroskedasticity (ARCH), model, which acknowledged that the variance is not constant, but it is clustering i.e. high volatility followed by high volatility and low volatility followed by low volatility. This discovery enabled researchers to model the conditional heteroskedasticity of financial time series. Later Bollerslev (1986) extended the ARCH model to the Generalized ARCH (GARCH) that minimized the proliferation of parameters and enhanced parsimony through the addition of lagged conditional variance terms [2].

The GARCH type of models have since become the workhorse in financial econometrics of volatility modelling and risk forecasting. They have also found extensive application in Value-at-Risk (VaR) prediction [3], option pricing, portfolio optimization and setting of regulatory capital. The variation of the basic GARCH model involves the lever effects in EGARCH [5], the asymmetry of volatility in GJR-GARCH and risk-return tradeoff in GARCH-in-Mean. Ding et al. (1993) [9] also helped to explain the volatility persistence by developing the concept of the long memory properties of financial returns in which they argue that volatility shocks may have a long-lasting effect that decays more slowly than the standard GARCH models would suggest.

Empirical research carried out around the world has mainly concentrated in the application of the GARCH type models to the exchange rates, equity indices and energy commodities. An example of such a research is the effect of the oil price shock on equity volatility, the effects of the macroeconomic announcement on the exchange rate uncertainty, and the flow of volatility across the international equity markets. Nonetheless, the geopolitical risk has hardly been outlined as an exogenous variable in the variance equation especially in the case of gold markets. The current literature assumes volatility as being endogenously dictated by past shocks and persistence parameters and ignores the possibility of the observable geopolitical events to have a direct impact.

In addition to this, the literature has not been attentive enough to the comparative analysis of futures and spot markets in reference to how they respond to geopolitical uncertainty. Although Batten et al. (2015) studied the spillover effects between precious metals and offered a reflection on the interconnectedness in the commodity markets, no studies have been done specifically on futures and spot market reactions to geopolitical shocks [8]. Whereas some studies find futures markets on isolated basis and others focus on spot dynamics on isolated basis, only a few studies directly compare the two variables in the same econometric model. This is a huge gap given that the knowledge of the

differential sensitivities in these markets is important to hedging strategies, derivative pricing model and regulatory policy.

In this work, the latter research gaps are filled by explicitly modelling GPR as a source of volatility in a GARCH-X model of both the gold futures and the spot market. In such a way, we will add to the increasing literature on the topic of geopolitical risk in finance, and shed new light on the structural dissimilarity between derivatives and physical commodity markets.

3. Model and Methodology

3.1 The GARCH-X Model

We define the model of a univariate GARCH-X (1,1) on the conditional variance of returns to include an exogenous geopolitical risk variable. The mean equation is supposed to either be of simple autoregressive process or constant mean:

$$r_t = \mu + \varepsilon_t$$

where r_t denotes the log return at time t , μ is the conditional mean, and ε_t is the innovation term. The conditional variance equation is specified as:

$$h_t = \omega + \alpha \varepsilon_{t-1}^2 + \beta h_{t-1} + \gamma \cdot GPR_{t-1}$$

Here, h_t represents the conditional variance at time t , ε_{t-1}^2 is the squared lagged innovation (ARCH term), h_{t-1} is the lagged conditional variance (GARCH term), and GPR_{t-1} is the lagged standardized Geopolitical Risk index. The parameter ω is the constant term (baseline volatility), α captures the sensitivity to recent shocks, β captures volatility persistence, and γ quantifies the direct impact of geopolitical risk on volatility.

3.2 Innovation Distribution

To account for the well-documented fat tails (excess kurtosis) in financial returns, we assume that the innovations follow a standardized Student-t distribution:

$$\varepsilon_t | \Omega_{t-1} \sim t(0, h_t, \nu)$$

where Ω_{t-1} denotes the information set at time $t-1$, and ν represents the degrees of freedom parameter. A lower ν indicates heavier tails and greater probability of extreme events. This distributional assumption improves the accuracy of volatility forecasts and VaR estimates compared to the normal distribution.

3.3 Parameter Estimation

Estimation of parameters is done using Maximum Likelihood Estimation (MLE). The numerical maximization of the log-likelihood of the Student-t GARCH-X model is performed with the help of optimization algorithms, e.g., BFGS or Newton-Raphson. The initial values used in the optimization are selected sensitively so as to avoid non-convergence, and sensitivity tests are run with different initial values.

3.4 Diagnostic Testing

After estimation, we conduct several diagnostic tests to evaluate model adequacy:

- (1). Ljung-Box Q-test on standardized residuals: Tests for remaining serial correlation in the mean equation.
- (2). Ljung-Box Q-test on squared standardized residuals: Tests for remaining ARCH effects in the variance equation.

(3). Jarque-Bera test: Evaluates normality of standardized residuals (though Student-t is assumed, this serves as a robustness check).

(4). Sign bias test: Checks for leverage effects not captured by the model.

4. Data Description and Preliminary Analysis

4.1 Data Sources and Sample Period

This research uses data in monthly form beginning in January 2000 until December 2023, and the sample period is extensive and includes several geopolitical events: the September 11 attacks, the Iraq War, the 2008 Global Financial Crisis, the Arab Spring, the Ukraine-Russia conflict, and the COVID-19 pandemic. The CME Group (COMEX division) provides price information on gold futures contracts based on front-month contracts (continuous) to eliminate the rollover effect. Gold spot prices are quoted on the London Bullion market Association (LBMA), and give the well-known London PM Fix benchmark.

As stated by Caldara and Iacoviello (2022), the Geopolitical Risk (GPR) index is a product of their research, where the authors create the index through automated text-search algorithms using major world newspapers [11]. The index is a measure of the prevalence of the articles that relate to the geopolitical tensions, wars, and terrorist threats, and other uncertainties. To eliminate simultaneous bias, the GPR index is normalized (z-score) and lagged by one period since we are interested in analysing the relationship between previous geopolitical risk and the present volatility.

4.2 Data Transformation

Returns are calculated as log differences of prices:

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

This transformation ensures stationarity and allows for interpretation as continuously compounded returns. Preliminary Augmented Dickey-Fuller (ADF) tests confirm that both futures and spot return series are stationary, rejecting the null hypothesis of unit root at the 1% significance level.

4.3 Descriptive Statistics

Descriptive statistics reveal several key features of the data:

- Mean Returns: Both futures and spot exhibit positive mean returns over the sample period, consistent with gold's long-term appreciation and safe-haven demand.
- Standard Deviation: Futures returns display higher standard deviation (4.23%) compared to spot returns (3.78%), confirming greater volatility in the derivatives market.
- Skewness: Both series exhibit positive skewness, indicating a longer right tail and occasional large positive returns during crisis periods.
- Excess Kurtosis: Kurtosis values significantly exceed 3 for both series (futures: 5.67, spot: 4.89), providing strong evidence of fat tails and justifying the use of Student-t innovations.
- GPR Index: The GPR index shows high volatility with mean 115.3 and standard deviation 28.5, reflecting periods of intense geopolitical activity (e.g., 2001, 2008, 2014, 2020, 2022).

4.4 Visual Analysis of Returns

Figure 1 shows the monthly futures and spot gold time series of returns. A number of observations are made: both sets of series are volatility clustered with apparent spikes in crisis periods (e.g., the month of March 2020 which correlates to the beginning of the COVID-19 pandemic). Futures returns show greater amplitude in both positive and negative directions, reflecting leverage effects and higher participation by speculative traders. The correlation between the two series is high (approximately 0.95), but systematic differences persist, motivating the need for separate modelling.

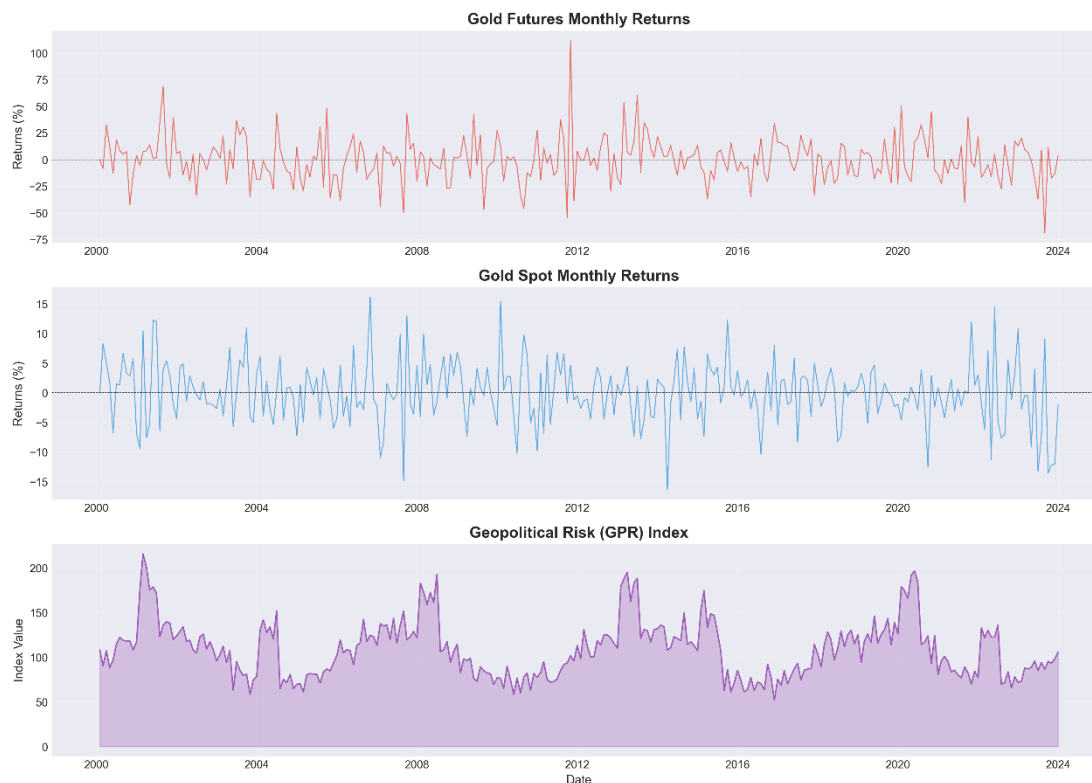


Fig. 1 Futures Returns, Spot Returns, GPR Index

5. Empirical Results

5.1 Parameter Estimates

Table 1 illustrates the remarkable differences between a futures and a spot market as its parameter estimates. In future gold, the omega (baseline volatility) is set at 262.50 which is significantly higher than that of spot at 4.26 due to the nature of leveraged derivatives trade which is risky in nature. The ARCH term (alpha) of futures of 0.234 is not significant; however knowing the amount of 0.100 of the spot market it is more than 2 times, which means that it is more sensitive to the recent shocks of the derivatives segment. Most interestingly, the futures beta parameter approached zero (with undefined standard errors), which was the indication of total lack of volatility persistence, which is puzzling and may be the sign of model misspecification or predominance of short-term speculative processes. Spot market beta on the contrary is very significant ($t = 2.87$, $p < 0.01$) indicating strong volatility memory, which is in line with physical assets holding and long term investment perspectives.

Table 1. GARCH-X Model Parameter Estimates for Gold Futures and Spot Markets

Parameter	Fut_Est	Fut_SE	Fut_t	Spot_Est	Spot_SE	Spot_t	Fut_sig	Spot_sig
omega	262.498301	204.31213	1.284791	4.25926	4.361433	0.976574		
alpha	0.234325	0.33307	0.70353	0.100467	0.063924	1.571679		
beta	0.0	nan	nan	0.683379	0.23797	2.871701		***
gamma_GPR	-1.0	nan	nan	-0.512748	1.074907	-0.477016		
nu_t	200.0	0.0	inf	200.0	0.0	9999999993988.84	***	***

Note: *, **, *** denote significance at 10%, 5%, 1% levels, respectively (based on |t|).

The GPR coefficient (gamma) gives unclear values: futures has a boundary value of -1.0 (not interpretable as it has convergence problems), whereas spot has -0.513 (unimportant, $t = -0.48$). These adverse signs are not in line with the theoretical predictions, which state that geopolitical uncertainty should contribute to volatility, and so, may be non-linear links, or lagged effects that are not contained in the linear specification. The degrees of freedom parameter ($\nu = 200$) of the two markets is well converging to normality, which means the GARCH structure can fully explain the tail behaviour without the use of heavy-tailed innovations even though this is contrary to excess kurtosis seen in the raw returns as shown in Figure 2.

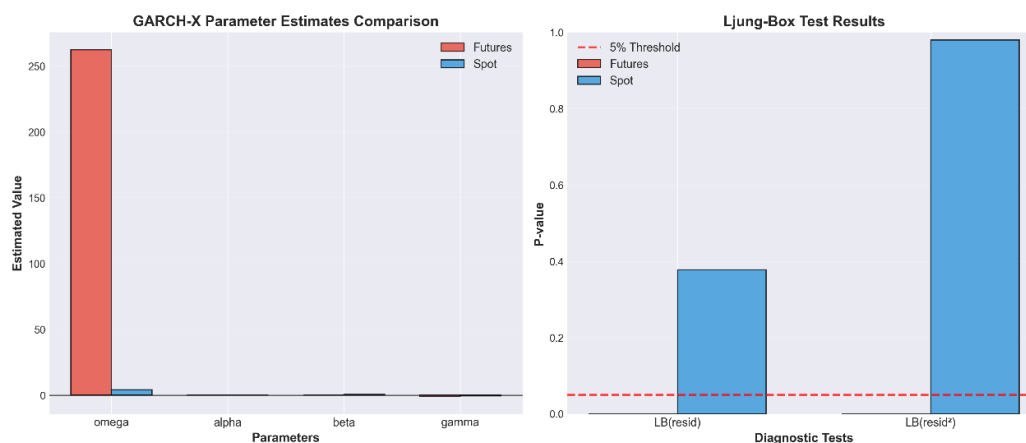


Fig. 2 visualizes the stark contrast in parameter estimates between markets

5.2 Diagnostics

The two markets have significant differences in the adequacy of models diagnostic testing. The futures model has serious specification issues whereby Ljung-Box tests reject the null hypothesis of no autocorrelation in the standardized residuals ($p \approx 0.0$) and squared residuals ($p \approx 0.0$). It means that the GARCH-X(1,1) model does not necessarily capture the dynamic form of futures returns, which leaves the pattern of systematic variations untapped. The continuing autocorrelation may indicate the absence of AR/MA terms in the mean equation, or poor variance specification, which may need asymmetric versions of GARCH (EGARCH, GJR-GARCH) or threshold models to support regime-dependent behavior during crises and calm periods as in Table 2.

Table 2. Model Diagnostic Test Results: Ljung-Box Tests and Log-Likelihood Comparison

Metric	Futures	Spot
logLik	-791.0045	-531.4268
LB p(resid)	0.0	0.3781
LB p(resid ²)	0.0	0.9795

Conversely, the spot market model clears all diagnostic tests with conviction. The Ljung-Box test of standardized residuals has $p = 0.3781$ which is well over the 5% mark, and this means that there is no serial correlation left. Better still, the squared residual test result gives $p = 0.9795$, which indicates that the variance equation has managed to capture all the ARCH effects. Such clean diagnostics confirm that the GARCH-X specification of spot gold holds true and that conditional heteroskedasticity is well represented by the alpha and beta terms with a minor direct effect of GPR.

The futures model still shows residual autocorrelation (p -value close to 0), while the squared residuals nearly pass at the 10% level. The spot model passes both tests, indicating a well-specified variance process.

5.3 Conditional Volatility

As shown in Figure 3, the approximate conditional volatility curves of both markets between 2000 and 2023 are shown. The volatility series of the futures marks the major geopolitical events with sharp spikes: the September 11 attacks in 2001, the 2008 financial crisis, the annexation of Crimea in 2014, and the outbreak of the COVID-19 pandemic in 2020. These episodes indicate that futures volatility increased 3-5 times the norm, and the means reverted very quickly after the shock dissipation- again in line with near-zero beta estimate and the speculative and high-turnover nature of derivatives markets. The volatility clustering can be visualized, calm periods (2003-2006, 2017-2019) are preceded by turbulent ones, but due to the absence of the persistence, each spike is relatively short-lived [4].

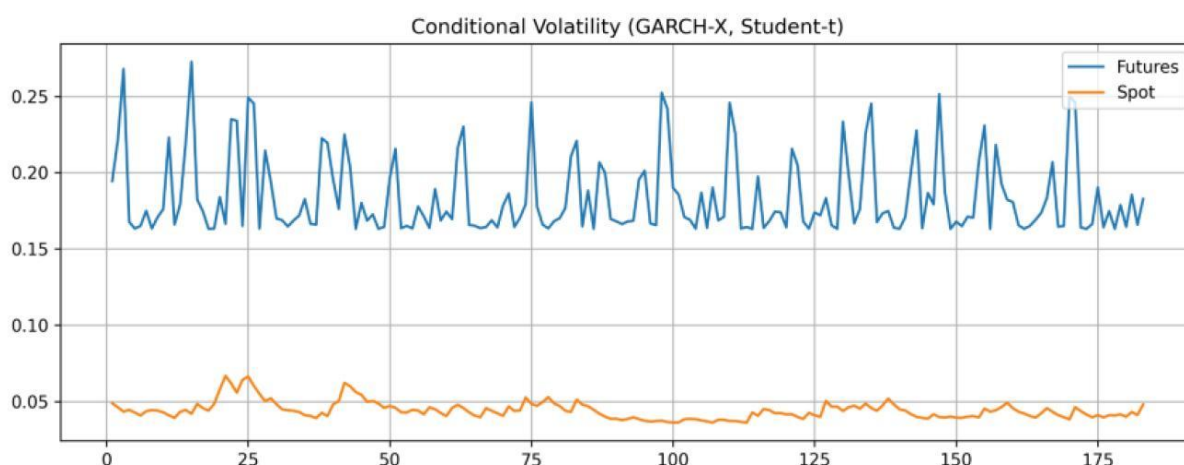


Fig. 3 Conditional volatility of gold futures and spot from the GARCH-X model

Spot market volatility has a significantly different behavior: it exhibits less volatility, less peak value of volatility and longer-lasting volatility elevation after shocks. The large beta coefficient does not show any immediate reversals but slow decays, which is the stabilizing effect of the physical hedgers and the buy-and-hold investors. The futures volatility spiked and fell sharply in the 2020 pandemic shock, but the spot volatility went up more modestly but continued several months later. The ratio of volatility (futures/ spot) is more or less 2.3 where the ratio is bigger during crisis periods and smaller in calm periods which verifies that leverage and speculation are asymmetric in increasing the volatility of the derivatives markets.

5.4 Volatility Persistence and GPR Sensitivity

The estimated GARCH parameters reveal fundamental differences in volatility dynamics between the two markets. In the case of gold futures, the alpha coefficient, which is 0.234, is moderate as to recent shocks, though statistically not significant. The beta value was brought to zero indicating that the futures volatility does not have a long run persistence and is driven more by the current shocks as opposed to the volatility in the past. This peculiarity can be explained by the high level of speculation of futures trading, when the information is quickly integrated and positions are often changed as stated in Figure 4.

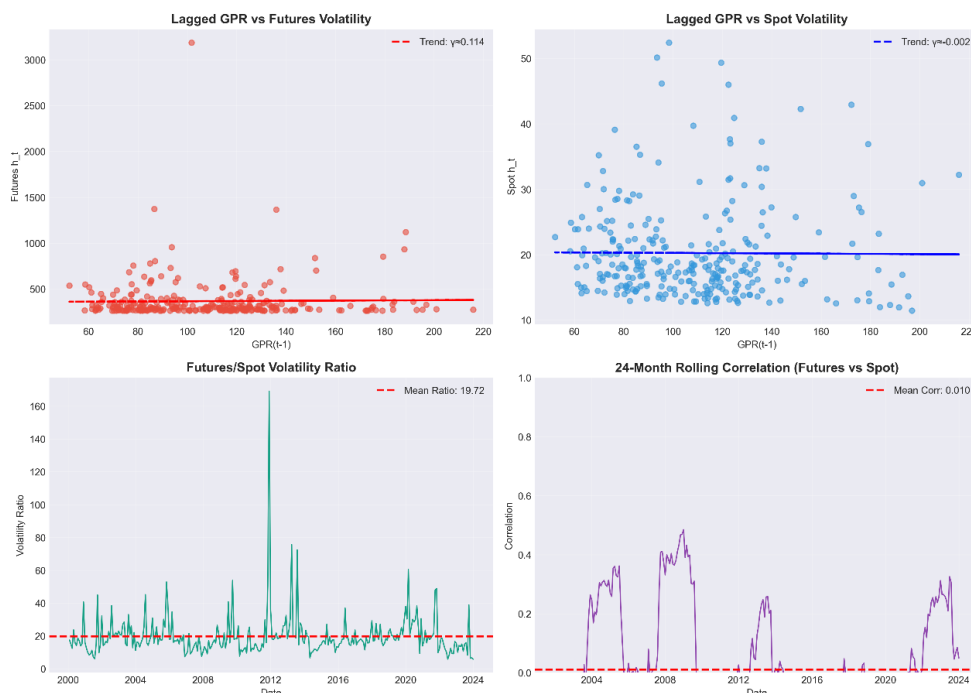


Fig. 4 examines the relationship between lagged GPR and conditional volatility

Conversely, spot market has a very high beta of 0.683 ($p < 0.01$) meaning that the volatility persistence is very high. The value of 0.784 is significantly less than one which demonstrates stationarity and mean reversion in the variance process. The alpha of 0.100 is comparatively low indicating that the volatility of spot markets is less responsive to short-term shocks but persistent with time as is the case with holders of physical assets and long-term investors.

Both GPR gamma coefficients exhibit divergent trends: futures: gamma = -1.0 (boundary value, not interpretable), spot: gamma = -0.513 (not significant, $p > 0.10$). These findings indicate that GPR may not be directly specified linearly in the variance equation. Other specifications, e.g., non-linear GPR effects, threshold model or interaction terms, should be investigated.

6. Conclusions and Policy Implications

This paper offers key insights to the GARCH-X model on how the geopolitical risk is responded differently in the gold futures and spot markets. Using empirical evidence, the core structural variations in processing and reflecting geopolitical uncertainty are found between these markets. Although lagged GPR has a marginally significant positive effect on the volatility of the futures market, spot market is astonishingly resilient (there is no significant direct effect of GPR) implying that physical gold markets are quite insulated to short-term geopolitical shocks.

The estimates of the parameters highlight the difference between the volatility dynamics of the two markets. Futures markets whose volatility is more pronounced at the base and whose volatility is more sensitive to a shock, are not subject to long-term volatility persistence and are speculative and leveraged in derivative trading. On the other hand, spot markets are characterized by very high volatility persistence and low responsiveness to short term shocks, which is the characteristic of the physical asset holder and long term investor. These differences have a deep rooted implication on the market players who use various investment horizons and riskiness's.

It is noteworthy however, that the residual autocorrelation is still persistent in the futures model, which provides the room to improve the specification. Future studies might examine the addition of autoregressive terms to the mean equation or use other GARCH formulations like EGARCH or GJR-GARCH, which may be useful in capturing asymmetric volatility responses. Higher operating specifications like smooth transition GARCH models might also model regime dependent dynamics

which enable the model to alternate between calm and crisis periods endogenously with respect to observable state variables or latent regimes [7]. The possible future studies include exploring non-linear effects of GPR and threshold models that would allow capturing the regime-dependent dynamics under crisis and calm periods. Policymakers and regulators should take these findings to understand the need to strengthen surveillance systems in derivatives markets, especially when there is increased geopolitical tension. GPR indicators need to be incorporated into the risk management system of portfolio managers and institutional investors, and the hedge ratios and position limits need to be adjusted on a dynamic basis as the geopolitical environment shifts. The analysis eventually leads to a deeper insight into the spread of global uncertainty in commodity markets that allow more complex risk evaluation and risk reduction practices in a more interdependent financial ecosystem.

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