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Abstract:

We investigate the volatility structure of gold, trading as a futures contract on the Chicago Board of Trade (CBOT) using intraday (high frequency) data from January 1999 to December 2005. Apart from investigating the now familiar GARCH properties we also utilize a rarely used measure of volatility—the Garman Klass estimator – to provide new insights in intraday and interday volatility. This non-parametric measure incorporates the open, close, high and low price within a particular time interval. Both sets of results suggest significant variation across the trading day and week consistent with microstructure theories, although volatility is only slightly positively correlated with volume when measured by tick-count.

Key words: Garman Klass estimator; volatility; gold; intraday patterns; futures

JEL: C22; C32; E31; F31

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I. INTRODUCTION

Despite the importance of gold as a key component of global monetary reserves, for trading and currency hedging (Capie, Mills and Wood, 2005), there is a paucity of studies that investigate the dynamics of the gold price in spot and futures markets. Studies investigating the dynamics of prices in futures markets, which have the advantage of greater transparency than over-the-counter spot markets, offer explanations concerning the empirical distribution of speculative prices and the importance of public and private information, as well as the relationship to other commodities and currencies (Adrangi, Chatrath and Christie, 2000).

The objective of this study is to report the volatility structure of gold, trading as a futures contract on the Chicago Board of Trade (CBOT). We utilise high-frequency intraday, as well as interday prices, from January 1999 to December 2005. Apart from investigating the GARCH properties of the return series we also estimate the Garman and Klass (1980) statistic, termed the GK estimator (GKe). The novelty of the GKe approach lies in the use of use of the open, close, high and low price *within* a particular time interval in its calculation. The GKe therefore provides an alternative, volatility measure to the standard deviation and GARCH approach, which utilises the price change *between* consecutive time intervals (Ding, 1999). The within period focus allows us to peer more deeply into the highfrequency dynamics than do other methods

The empirical literature on volatility in key financial asset markets, such as stocks, currencies and bonds, suggests regularities in the pattern of volatility across the trading day and week. Financial market microstructure theory (Lockwood and Linn, 1990; Park, 1993) argues that this pattern occurs as a consequence of the price discovery actions of traders. While information is assumed to affect financial prices in a random manner, asymmetries in the information between different traders ensures that markets are most volatile as traders seek out and discover relevant information from one another. This leads to volatility patterns, which tend to be “U-shaped”, being higher at the start and close of trading. Earlier researchers postulated specific

relationships with trading volume; of importance is the expected positive correlation between trading volume and volatility (Karpoff, 1987; Oliver and Verrecchia, 1991; Cyree and Winters, 2001) due to the information seeking actions of traders. A unique feature of our data is that we are able to monitor tick-flow (quotes from traders) over time, which enables a direct test to be undertaken of the correlation between information flows and gold price changes. To our knowledge this has not been done previously for gold.

In the next section we provide information on the data utilised, thereafter we present the results, with the final section allowing for some concluding remarks.

II. DATA

The New York Mercantile Exchange (NYMEX) offers futures trading in a 100 troy oz nominal COMEX contract that is deliverable (settled) against both cash and physical gold of the same standard (0.995 fineness, cast either in one bar or in three one-kilogram bars). This contract is available for the near month as well as any February, April, August, and October falling within a 23-month period; and any June and December falling within a 60-month period beginning with the current month (www.nymex.com). In this sense the futures contract is fully arbitrageable in an economic sense against gold trading in a variety of other worldwide cash and futures markets. Open-outcry trading commences at 08:20h and ends at 13:30h. Trading is also available simultaneously (termed side-by-side trading) on the GLOBEX electronic trading system available on the Chicago Mercantile Exchange (CME).

Our data comprises 56,814 observations of price quotes of the near month COMEX gold contract spanning the period 8:20 to 15:30, with the period from 13:30 to 15:30 being GLOBEX trading. We group these price quotes into 10-minute intervals. The number of price-quotes within an interval is termed the tick-count. The tick-count across the trading day (including both open-outcry and the overlap with GLOBEX trading) is plotted in Figure 1.

(Insert Figure 1)

This figure records a declining tick-count across the trading day commencing with a mean of 134.85 quotes in the 8:20-8:30 interval and ending with a mean of 81.03 in the 13:20-13:30 interval. Note that the tick-count across the trading day is statistically different with a one-way ANOVA of the tick-count versus time (as a 10-minute interval), recording a F -Statistic = 141.65 (P -value = 0.000).

III. RESULTS

(Insert Figure 2)

We first estimate the returns for gold $\Delta P_t = \log P_t - \log P_{t-1}$, where the interval $t-1$ to t , is 10-minutes. Figure 2 plots this distribution, which has a mean close to zero (0.000001) and a standard deviation of 0.0000071. The series is slightly skewed (1.48) and significantly leptokurtic (122.5). We allow for an ARMA(2,2) process to accommodate any autocorrelated innovations ε_t , the consequence of illiquidity effects. In addition, we apply a GARCH(1,1) conditional variance specification, necessary given the volatility clustering clearly evident in the return series. Therefore:

$$\Delta P_t = \alpha_0 + \beta_1 \Delta P_{t-1} + \beta_2 \Delta P_{t-2} + X_1 \lambda \varepsilon_{t-1} + X_2 \lambda \varepsilon_{t-2} + \varepsilon_t$$

$$\sigma_t^2 = \omega_0 + \omega_1 \varepsilon_{t-1}^2 + \omega_2 \sigma_{t-1}^2, \quad \omega_0 > 0, \omega_1, \omega_2 \geq 0 \quad (1)$$

(Insert Table 1)

The results of this estimation (Equation 1) are recorded in Table 1. The series all have significant ARMA(2,2) terms at the 95% level. Higher order ARMA terms were also estimated but these were not significant and so have neither been recorded nor estimated. This is consistent with price dependence (and potential arbitrage) being limited to at most 20 minutes (2 by 10-minute intervals). There are also significant GARCH effects, with the GARCH(1) term generally more significant than the ARCH(1) term. Both the coefficient of the mean and variance equation is not economically significant, with the mean equation coefficient being just statistically significant at the 90% level. The regression R-squared is also close to zero, suggesting that other factors drive changes in price other than the ARMA coefficients. This is consistent with trading in the gold futures market, at least across 20-minute intervals being efficient.

While it is commonplace to measure asset volatility based on the standard deviation of the log difference across a regular time interval, we also utilise a more complex measure, the GKe measure, which incorporates information about the open, close, high and low prices *within* a particular time interval. From Garman and Klass (1980), the GKe is:

$$GKe = \sigma^2 = 0.511(H-L)^2 - 0.019(C-O)(H+L-2C)(1-C) - 0.383(C-O)^2 \quad (2)$$

where H = log of interval high
L = log of interval low
O = log of interval open
C = log of interval close

(Insert Figures 3 and 4)

Over the entire sample period the Gke (10min) has an average of 0.000000335, skewness of 50.79 and kurtosis of 4684.99. The results of the GKe analysis for simplicity are presented in two figures, with the y-axis recording the Gke*100 and the x-axis recording time. Figure 3 plots the 10-minute gold Gke across the complete sample period from January 1999 to December 2005. There are a number of volatility spikes clearly evident at 9/28/1999; 2/7/2000; 5/24/2000; 9/11/2001; 6/28/2002. Importantly only one of these can be directly associated with a significant political or economic event (9/11/2001), with the others therefore likely to be the consequence of portfolio rebalancing at close of trading.

Figure 4 provides a plot of the 10-minute gold Gke across the trading day. We include the NYMEX trading as well as the next 2-hours of GLOBEX trading. A one-way ANOVA of Gke (10min) versus Time shows statistically significant variation across the trading day (F -Statistic = 11.28, P -value = 0.000). A “U-shaped” volatility

structure is clearly evident, although volatility tends to decline from the opening levels of 0.0000743 to 0.0000358 at the close of NYMEX trading. Notice that this also coincides with the declining tick volume shown in Figure 1. There is also a spike as GLOBEX opens, which is consistent with new information being provided by this market.

(Insert Figure 5)

Next we consolidate price and tick-count into hourly intervals with 36,260 observations of Gke matched with the specific number of quotes within the hour. Price quotes proxy for trading which also should be positively correlated with volatility. Figure 5 records the correlation between tick count and Gke volatility across the hourly trading day and week. Note that there is not an obvious pattern to the direction of the correlation over the trading day. For the entire sample there is a positive correlation of 0.28 between GKe and tick-count for positive changes in price and -0.30 for negative changes in price. Note that there is clear evidence of time varying hourly correlations (from 0.10 to 0.52) across the trading week. This may be interpreted within the recent microstructure models (such as Oliver and Verrecchia, 1991), where information content varies as well as information asymmetry

IV. CONCLUSIONS

The results suggest significant variation across the trading day and week in volatility, which is only slightly correlated with tick-count: a proxy for information. The stochastic nature of volatility in the gold market is therefore consistent with the complex interaction of price sensitive information from other asset markets rather than the price discovery actions of traders within the gold market itself. These findings are of considerable importance for gold investors and traders. Arbitrage between gold products for example, will be more difficult than otherwise expected based on historic short-term correlation and long term cointegration relationships. Thus, derivatives portfolios should be constantly rebalanced to accommodate the changing dynamics from these same short-lived price interactions with other asset markets.

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Table 1: Gold returns across a 10-minute interval using an ARMA-GARCH specification

	Coefficient	Standard Error	z-Statistic	Probability
Mean Equation				
α_0	0.00000	0.00001	1.64079	0.1008
AR(1) = $\beta_1 \Delta P_{t-1}$	1.23618	0.51536	2.39868	0.0165
AR(2) = $\beta_2 \Delta P_{t-2}$	-1.91887	0.95016	-2.01952	0.0434
MA(1) = $X_1 \lambda \varepsilon_{t-1}$	-1.28359	0.51899	-2.47324	0.0134
MA(2) = $X_2 \lambda \varepsilon_{t-2}$	1.97088	0.97966	2.01180	0.0442
Variance Equation				
ω_0	0.00000	0.00000	3.468757	0.0005
ARCH(1) $\omega_1 \varepsilon_{t-1}^2$	0.34590	0.05110	6.769711	0.0000
GARCH(1) $\omega_2 \sigma_{t-1}^2$	0.46017	0.05335	8.625466	0.0000
R-squared	-0.00541			
Adjusted R-squared	-0.00574			

Figure 1. Plot of 10-minute interval Gold volume (Tick-Count) across the trading day

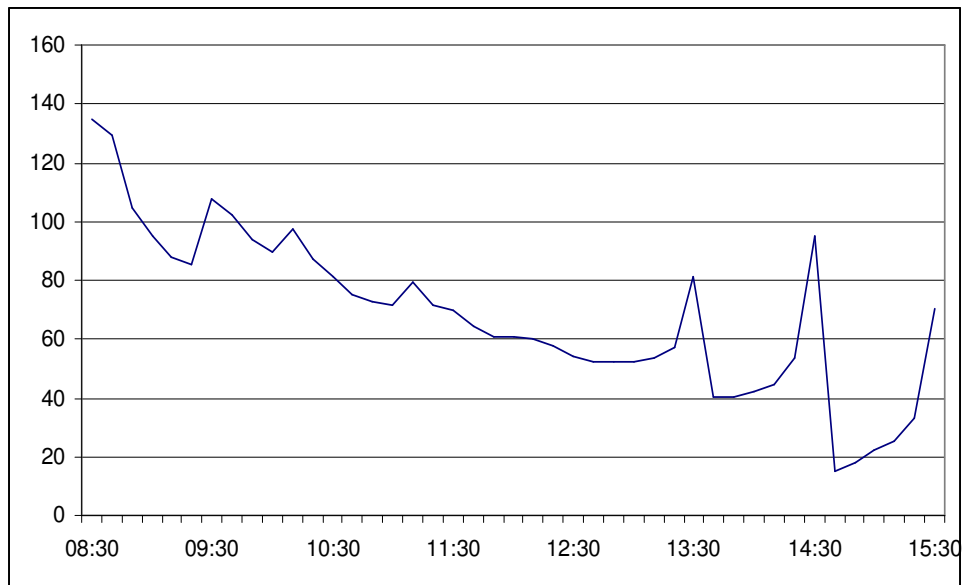


Figure 2. *Plot of the change in 10-minute gold price, January 1999 to December 2005*

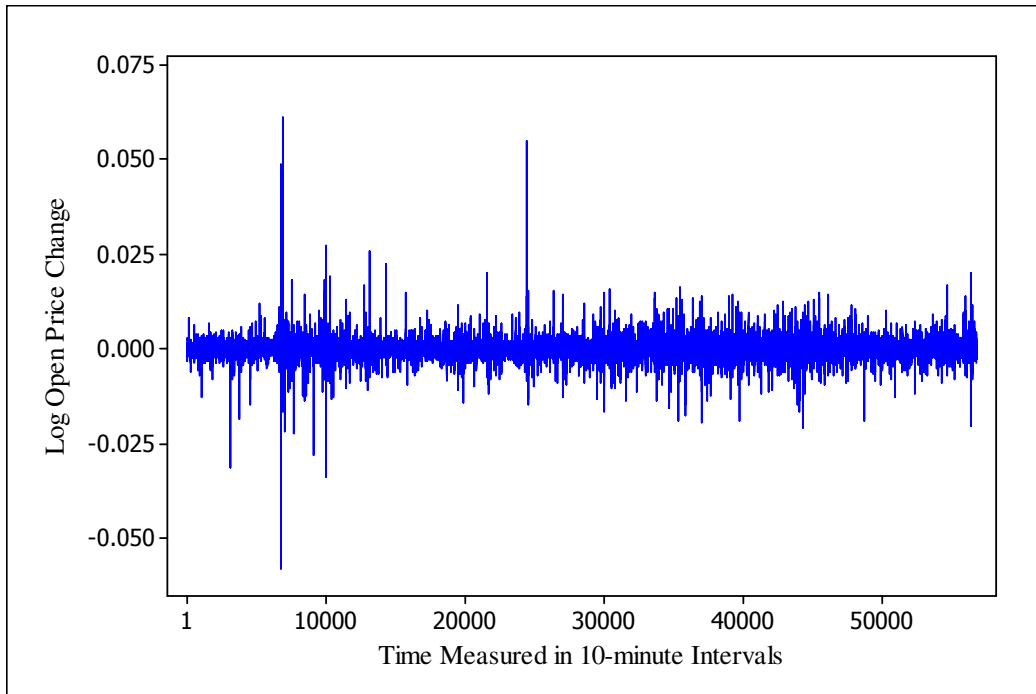


Figure 3. *Plot of 10-minute gold volatility (G_{ke}), January 1999 to December 2005*

Figure 4. Plot of 10-minute gold volatility (G_{ke}) across the trading day

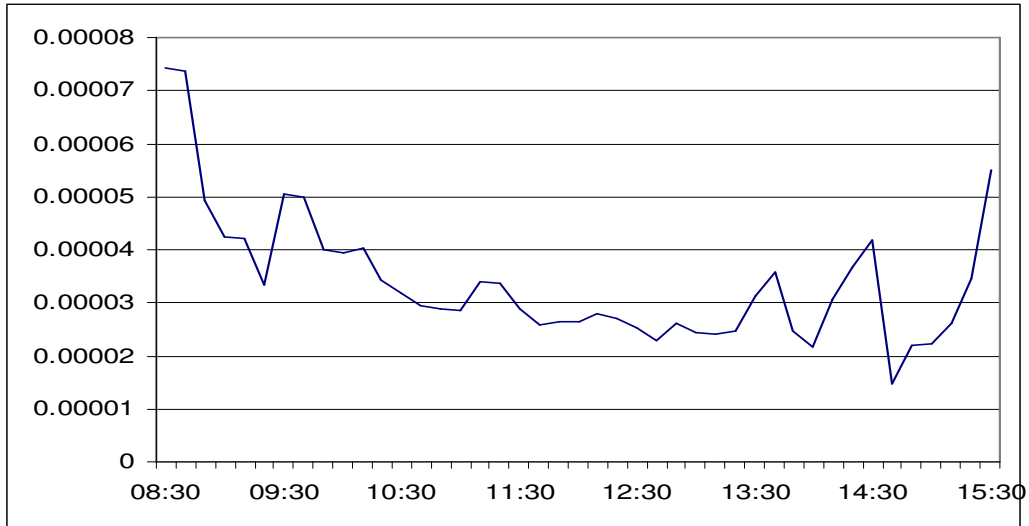
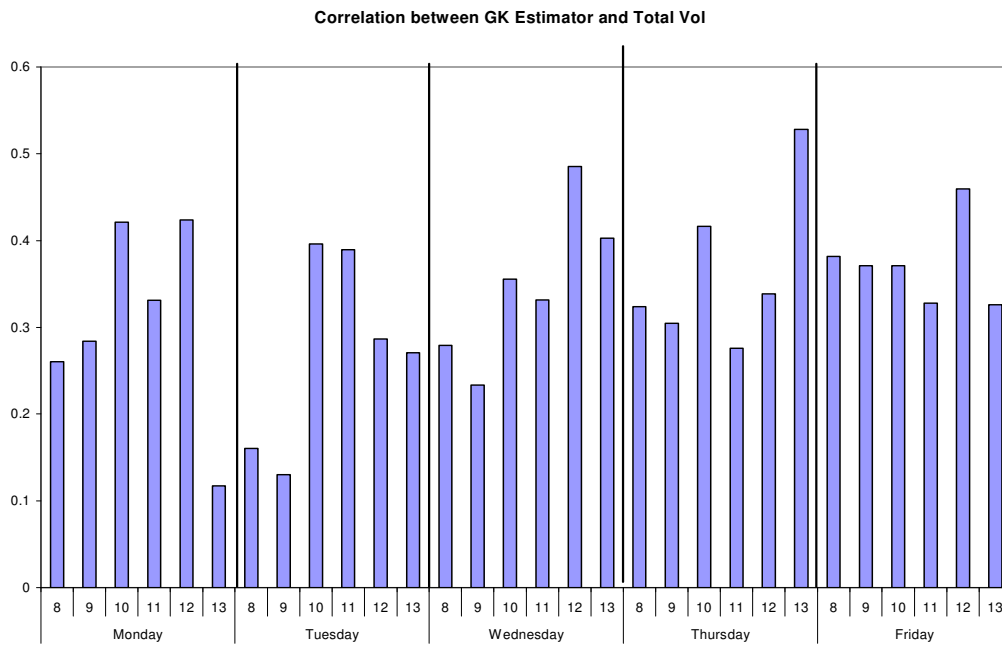


Figure 5. The correlation between 10-minute volatility (G_{ke}) and volume (tick-count) across the trading week





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