WHAT MOVES THE GOLD MARKET?

JUN CAI*
YAN-LEUNG CHEUNG
MICHAEL C. S. WONG

In this article, we provide a detailed characterization of the intraday return volatility in gold futures contracts traded on the COMEX division of the New York Mercantile Exchange. The approach allows the study of intraday patterns, interday ARCH effects, and announcement effects in a coherent framework. We show that the intraday patterns exert a profound impact on the dynamics of return volatility. Among the 23 U.S. macroeconomic announcements, we identify employment reports, gross domestic product, consumer price index, and personal income as having the greatest impact. Finally, by appropriately filtering out the intraday patterns, we find that the high-frequency returns reveal long-memory volatility dependencies in the gold market, which have important implications on the pricing of

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*Correspondence author, Department of Economics and Finance, City University of Hong Kong, Kowloon, Hong Kong; e-mail: efjuncai@cityu.edu.hk)

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- *Jun Cai is an Associate Professor of Finance in the Department of Economics and Finance at City University of Hong Kong in Kowloon, Hong Kong.*
- *Yan-Leung Cheung is a Professor in the Department of Economics and Finance at City University of Hong Kong in Kowloon, Hong Kong.*
- *Michael C. S. Wong is an Assistant Professor in the Department of Economics and Finance at City University of Hong Kong in Kowloon, Hong Kong.*

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INTRODUCTION

The recent advent of high-frequency data has sparked a growing literature on a wide range of issues in the financial markets. Among the most puzzling issues is the behavior of volatility. One feature that characterizes high-frequency data is strong intraday patterns. Despite the different forms they take in different markets, intraday patterns have a similar impact on the dynamic properties of high-frequency returns.[1] The availability of high-frequency data also increases the power of researchers' efforts to estimate the volatility effect of public information or regularly scheduled macroeconomic announcements. Earlier studies often used dummy variables to control for announcements and intraday patterns of price volatility.[2]

The empirical literature on intraday activity patterns in market microstructure studies, event studies on reactions to macroeconomic announcements, and time-series evidence on interday volatility persistence (ARCH effects) have largely evolved independently. Although these factors have successfully captured a number of distinctive features in return volatility, little is known about their relative importance in various markets. Andersen and Bollerslev (1998) recently developed an integrated approach to examine various volatility components. The approach has been fruitfully applied to the foreign exchange, equity, and fixed-income markets. [3]

In this article, we offer a comprehensive study of the intraday volatility process for futures contracts on a universally recognized and widely traded physical asset: gold futures contracts on the COMEX division of the New York Mercantile Exchange (NYME). Existing studies on futures markets (and cash markets) often employ multivariate GARCH models to investigate the joint dynamics of the means, variances, and covariances

[1]Intraday patterns in absolute returns induced a distorted U shape in the sample correlogram of absolute returns that was incompatible with that implied by a standard ARCH or GARCH model. See Dacorogna, Muller, Nagler, Olsen, and Pictet (1993) and Andersen and Bollerslev (1997).

[2]The presence of long memory or volatility persistence in high-frequency data is another important feature. The fact that the long-memory feature also exists in high-frequency data suggests that it is inherent to the return-generating process itself rather than being caused by structural changes in the time series, as suggested in Lamoureux and Lastrapes (1990).

[3]See Andersen and Bollerslev (1998), Andersen, Bollerslev, and Cai (in press), and Bollerslev, Cai, and Song (in press).

(K. Chan, Chan, & Karolyi, 1991; Chatrath & Song, 1998; Wahab, 1995). Cecchetti, Cumby, and Figlewski (1988) and Baillie and Myers (1991) estimated optimal hedge ratios for financial and commodity futures within a bivariate GARCH framework. Although these models have successfully captured the temporal variation in returns and volatility at daily and intraday frequencies, they do not attempt to address other features of the data, that is, the intraday patterns, announcement effects, and interday volatility persistence in a coherent framework. Therefore, this article aims to fill a part of the gap by examining the gold futures market.

We focus on COMEX gold futures contracts during the NYME trading hours because of data limitations. Nevertheless, the New York gold market is the most active among the three main markets, Hong Kong, London–Zurich, and New York (Muller et al., 1990). Moreover, trading in the New York market is more important for price discovery and release of information (Dhillon, Lasser, & Watanabe, 1997).[4] Our sample of 5-min gold futures returns covers a 4-year period from 1994 to 1997, during which time the gold price dropped from US$390 to US$287 per ounce (Fig. 1). COMEX gold futures contracts remained actively traded, with a median daily trading volume and open interest of 24,360 and 84,530 contracts, respectively, during the sample period.[5,6]

Our main findings are as follows. First, there exists a distinctive U-shaped pattern in the intraday volatility corresponding to the opening and closing of the trading sessions. The strong intraday periodicity in turn gives rise to an equally strong and regular pattern in the autocorrelation of absolute returns. The periodic pattern is significantly reduced after the raw series is filtered. The filtered series displays a rapid initial decay in the autocorrelations, followed by an extremely slow rate of decay thereafter. This is a clear indication of the presence of a long-memory feature in the gold market.

Second, we examine the 25 largest 5-min absolute returns during the sample period. Most of these are linked to the following events: sales

[4]Dhillon et al. (1997) compared COMEX gold futures with gold futures traded on the Tokyo Commodity Exchange. They concluded that more information appears to be released in gold markets during U.S. trading hours relative to Japan.

[5]Earlier studies of the gold market include those on interday and intraday patterns (Ball, Torous, & Tschoegl, 1982; Dhillon et al., 1997; Lauterbach & Monroe, 1989; Ma, 1986; Muller et al., 1990), the effects of U.S. money supply and inflation announcements (Tandon & Urich, 1987), the efficiency and dynamics of gold and silver prices (Aggarwal & Soenen, 1988; Akgiray, Booth, Hatem, & Mustafa, 1991; M. Chan & Mountain, 1988; Solt & Swanson, 1981; Wahab, 1995), gold price and the inflation rate (Chua & Woodward, 1982; Feldstein, 1980), gold price and exchange rate movements (Beckers & Soenen, 1984; Sjaastad & Scacciavillani, 1996), and gold pricing models (Abken, 1980; Sherman, 1983).

[6]The daily trading volume was quite stable during the period 1983 to 1997, with a median of 25,550 contracts. The open interest increased from 40,000 to over 100,000 for the most active contracts, with a median of 56,160 contracts.

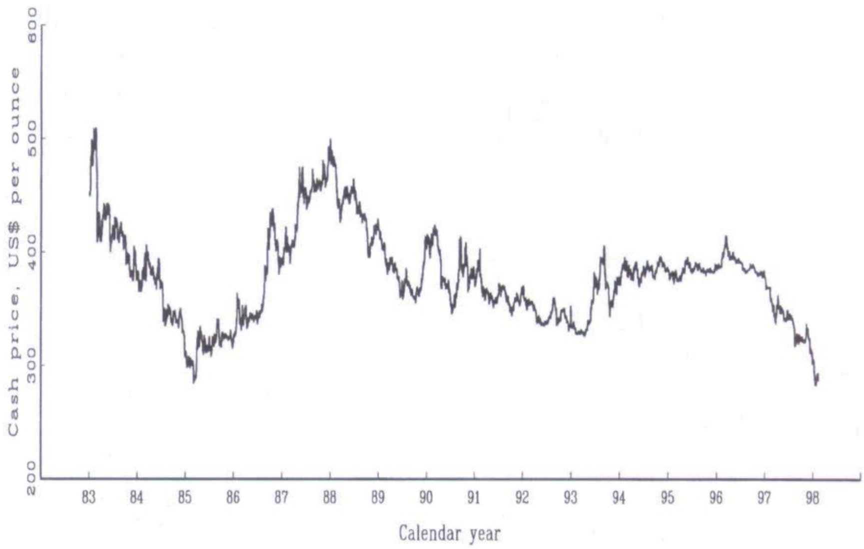


FIGURE 1
Cash price of COMEX gold for the 1983–1997 period.

of gold reserves by central banks, concerns about consumer demand for gold, interest rates, oil prices, inflation rates, U.S. unemployment rates, the Asian financial crisis, and political tension in South Africa. Notably, the largest absolute 5-min return of 2.638% occurred at 8:20 Eastern Standard Time (EST) on Monday, July 7, 1997, after the Reserve Bank of Australia said it had sold 167 tons of gold, or two thirds of its gold reserves. The COMEX gold futures price fell from US$326.5 to US$318, or by US$8.5, within the first 5 min of trading.

Finally, we examine the impact of 23 regularly scheduled U.S. macroeconomic announcements. We find that four have significant effects on the gold market's return volatility. In order of descending importance, these are employment reports, gross domestic product (GDP), consumer price index (CPI), and personal income. Despite the significant instantaneous jump in volatility following these individual announcements, their impact on the volatility over the course of the trading day is small. Among the three components (calendar, announcements, and ARCH effects), the announcement effects have the smallest marginal explanatory power on volatility at the intraday frequency. Compared to the reactions of the foreign exchange and Treasury bond markets, the gold market's reaction to the release of U.S. macroeconomic news is much smaller.

The remainder of this article is organized as follows. The Intraday Periodicity and Long Memory in Return Volatility section describes the data, summarizes the return and volatility patterns over the trading day, and estimates the intraday periodic and long-memory volatility components. The Largest Absolute 5-min Returns section looks at the largest absolute 5-min returns and associated economic and political events. The Macroeconomic Announcement Effects section examines the implications of major macroeconomic announcements on COMEX gold futures contracts. The Assessing the Importance of Volatility Components at Daily and Intraday Frequencies section assesses the importance of various volatility components at the daily and intradaily frequency. Finally, the last section concludes the article.

INTRADAY PERIODICITY AND LONG MEMORY IN RETURN VOLATILITY

Data

Intraday gold futures data covering the period January 1994 to December 1997 were provided by the Futures Industry Institute. The gold futures contracts were traded on the COMEX division of NYME. COMEX regulations stipulate delivery of 100 troy ounces of refined gold, assaying not less than 0.995 fineness, cast either in one bar or in three 1-kg bars. The delivery months are the current and next two calendar months and any February, April, August, and October within a 23-month period and any June and December within a 60-month period. During the 1994–1997 sample period, contracts maturing in February, April, June, August, and December were actively traded. The corresponding intraday returns are thus employed in the following analysis. The data specify the time, to the nearest second, and the exact price of the futures transaction. The intraday time series is partitioned into 5-min intervals. During each interval, the last recorded prices for the nearby futures contracts are employed to calculate the 5-min returns. The sample time is chosen to be between 08:20 and 14:35 EST, which corresponds to the trading hours for gold futures contracts on COMEX, resulting in a total of 75 5-min intervals during each trading day.[7] Finally, there are 970 trading days over the sample period, each consisting of 75 intraday 5-min returns, giving a total of 72,750 observations. The 5-min return, $R_{t,n}$, denotes the return in the nth interval on day t, where $n = 1, 2 \ldots 75$ and $t = 1, 2 \ldots 970$.[8,9]

[7]When transactions were missing for a particular 5-min interval, we used linear interpolation to determine the futures prices used to calculate the returns. This only happened occasionally.

[8]The sample mean of the 5-min raw returns, −0.000411%, is marginally significant, given the sample standard deviation of 0.061%. The sample skewness of −1.204 and the sample kurtosis of 64.3 suggest that the returns are not normally distributed.

[9]The first 5-min return was constructed with the opening price after 08:20 and the last price before 08:25 and, therefore, constitutes a special observation. The results were essentially the same if the first 5-min return was not used for all subsequent analyses.

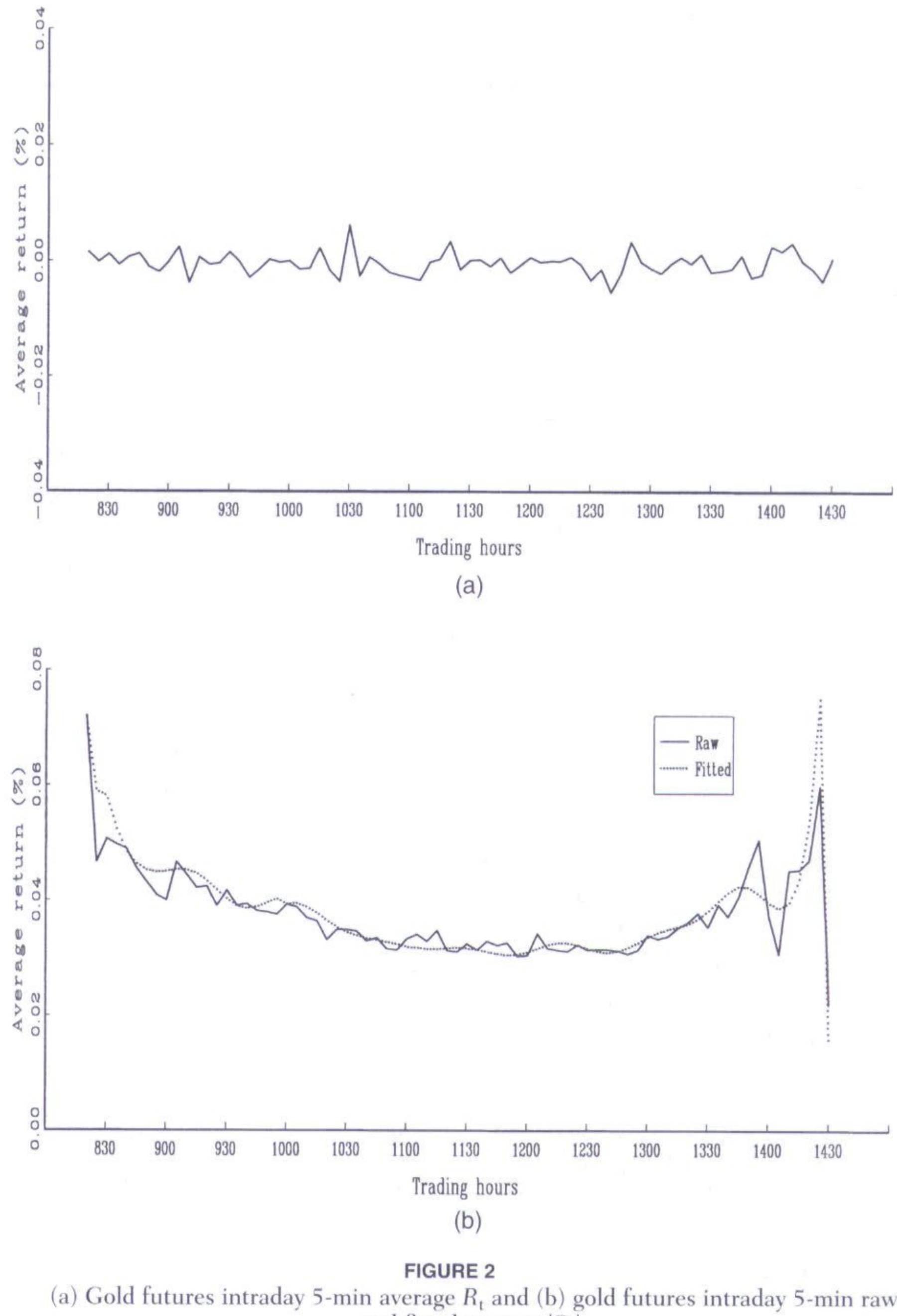


FIGURE 2
(a) Gold futures intraday 5-min average R_t and (b) gold futures intraday 5-min raw and fitted average $|R_t|$.

Intraday Periodicity and Its Estimation

Figure 2(a) shows that the average raw 5-min returns are centered around zero, with little evidence of a systematic pattern through a typical trading day. However, the average absolute returns show a familiar pattern of regularity in Figure 2(b). They start at nearly 0.076% early in the morning, drop to a lower level of 0.031% in the middle of the day, and rise to about 0.060% toward the end of day. There is an abrupt drop in volatility during the last 5 min of trading.[10] This pattern is consistent with the patterns found by Lauterbach and Monroe (1989) and Muller et al. (1990). In particular, Muller et al. plotted the 1-hr absolute return from the round-the-clock world gold market shown on the Reuters screen. The U-shaped pattern is evident in all three markets: East Asia, Europe, and North America.[11] The strong intraday U shape in turn gives rise to the repetitive pattern in the autocorrelations of absolute returns. Figure 3(a) displays a distorted U shape in the sample correlogram occupying exactly a 1-day interval. This is a clear indication of seasonality in the period of 1 trading day.[12]

To model the periodic volatility component in high-frequency returns, we apply the general framework developed in Andersen and Bollerslev (1997, 1998). The idea is to decompose the predictable part of volatility into a number of components, some associated with intraday patterns, some associated with the release of macroeconomic news, and some associated with a daily volatility factor. Specifically, our model for the 5-min returns takes the following form:

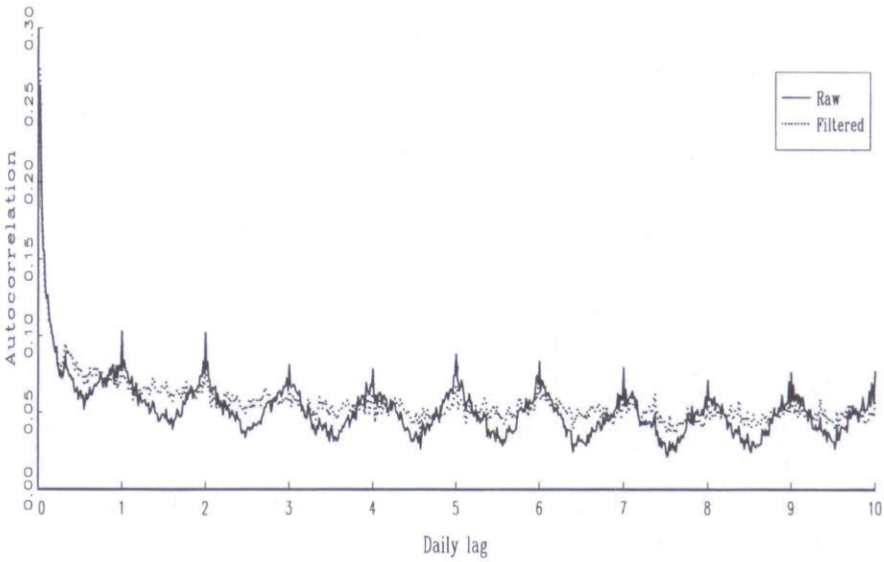
$$R_{t,n} - \bar{R} = s_{t,n} \cdot \sigma_{t,n} \cdot Z_{t,n} \tag{1}$$

where $\bar{R}$ denotes the sample mean of the 5-min returns (expected return), $\sigma_{t,n}$ denotes a daily volatility factor that is traditionally captured by ARCH models, $Z_{t,n}$ is an i.i.d. mean zero unit variance innovative term, and $s_{t,n}$ captures the intraday calendar features as well as the announcement effects. The components of Equation 1 are not identifiable without additional restrictions. Therefore, we take squares and logs, rearrange the terms, and obtain the following equation:

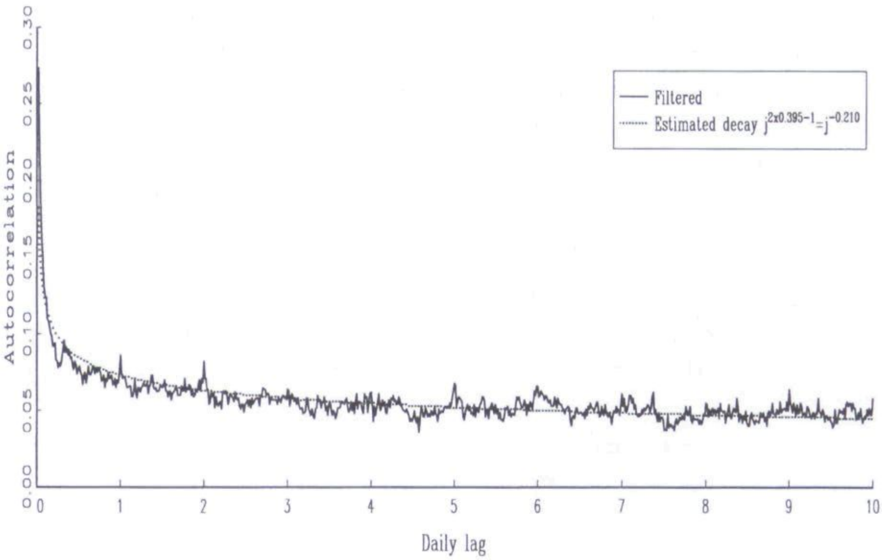
[10] This was due to the lack of trading activity in the last 5-min interval. The same pattern was observed for Standard & Poor's 500 futures 5-min returns (Andersen & Bollerslev, 1997).

[11] The volume and volatility patterns in Muller et al. (1990) also reflect the well-known fact that the East Asian market is less active in gold trading than the European and North American markets.

[12] The autocorrelations for the raw 5-min returns were all small and resembled the realizations of white noise.



(a)



(b)

FIGURE 3

(a) A 10-day correlogram for raw and filtered $|R_t|$ and (b) the actual correlogram for filtered $|R_t|$ and the estimated decay rate.

$$2\ln|R_{t,n} - \bar{R}| - \ln \sigma^2_{t,n} = \ln s^2_{t,n} + \ln Z^2_{t,n} \tag{2}$$

Now the two-step procedure for estimation becomes apparent. First, we estimate the daily volatility factor $\hat{\sigma}_t$ by applying a fractionally integrated GARCH (FIGARCH) model to a sample of 3,777 daily returns.[13] This model explicitly incorporates the long-memory feature in COMEX gold futures daily returns as in many other asset markets. The resulting 5-min volatility estimator is simply given by $\hat{\sigma}_{t,n} = \hat{\sigma}_t/N^{1/2}$. Second, we replace $\sigma_{t,n}$ by its estimate $\hat{\sigma}_{t,n}$ and run the following flexible Fourier form (FFF) regression:

$$\begin{aligned} 2\ln|R_{t,n} - \bar{R}| - \ln\hat{\sigma}^2_{t,n} &= c + \sum_{k=1}^{D} \lambda_k \cdot I_k(t,n) + \delta_{0,1} n/N_1 + \delta_{0,2} n^2/N_2 \\ &+ \sum_{p=1}^{P} [\delta_{c,p} \cdot \cos(2\pi pn/N) + \delta_{s,p} \cdot \sin(2\pi pn/N)] + \varepsilon_{t,n} \end{aligned} \tag{3}$$

where $N_1 = (N + 1)/2$ and $N_2 = (N + 1)(N + 2)/6$ are the normalizing constants. $I_k(t,n)$ is an indicator for event k during interval n on day t. It can easily capture the weekday effects or the announcement effects. We also include a dummy for the last ($n = 75$) 5-min interval to capture the abrupt drop in volatility.[14] The FFF regression provides a convenient way to capture the smooth intraday patterns with a limited number of parameters to estimate, especially when studying high-frequency data with a larger number of intraday intervals.

The actual estimation is based on all 4 years of 72,750 intraday 5-min returns. After some experimentation, we found that $J = 0$ and $P = 8$ will be sufficient to capture the basic shape of the periodicity. The individual point estimates for $\delta_{c,p}$ and $\delta_{s,p}$ are highly significant. Parameter estimates obtained by allowing for additional terms are not significant. The log–likelihood ratio tests also suggest that higher order terms are not necessary. Now let $f(t,n) + \hat{\varepsilon}_{t,n}$ denote the right-hand side of Equation 3, where $f(t,n)$ is the estimated intraday pattern and $\hat{\varepsilon}_{t,n}$ is the residual from the FFF regression; then, the absolute return can be derived as

$$|R_{t,n} - \bar{R}| = N^{-1/2} \cdot \hat{\sigma}_t \cdot \exp[f(t, n)/2] \cdot \exp(\hat{\varepsilon}_{t,n}/2) \tag{4}$$

[13]The sample period is January 3, 1983 to December 31, 1997. The MA(1)–FIGARCH(1,d,1) model for daily returns follows Baillie, Bollerslev, and Mikkelsen (1996). For all empirical analyses, we also used estimates from a longer daily return series from January 2, 1975 to December 31, 1997; the results were essentially the same. Details of the estimation are available on request.

[14]See Andersen and Bollerslev (1998) and Andersen, Bollerslev, and Das (1999) for a discussion of the consistency and small sample properties of the two-step estimators.

If we average $\hat{\sigma}_t$ and $\exp(\hat{\varepsilon}_{t,n}/2)$, respectively, over the trading days, we obtain the unconditional intraday volatility forecasts. The dotted line in Figure 2(b) plots the unconditional volatility forecasts with the announcement and day-of-the-week effects included. Clearly, the fitted value provides a close approximation to the overall volatility pattern in the COMEX gold futures market.

Long-Run Dynamic Dependencies in High-Frequency Data

One important finding that has recently emerged is the presence of a long-memory feature (slowly declining autocorrelogram) in daily squared or absolute returns of various financial asset prices, captured by the MA(1)–FIGARCH(1,d,1) model. In the FFF regression, because the first-stage volatility estimate, $\hat{\sigma}_t$, is derived from daily returns that cover a longer period, it is not clear whether it is appropriate in capturing the features in the volatility of 5-min returns, $\hat{\sigma}_{t,n}$. To answer this question, we need to examine whether the long-memory feature is also present in high-frequency data covering a shorter period. Figure 3(a) plots the autocorrelation of raw 5-min absolute returns, $|R_{\mathrm{t,n}}|$. The autocorrelogram is dominated by strong periodicity at the daily frequency and is not very informative on the long-run dependencies in autocorrelations. However, after the estimated intraday and announcements effects in 5-min returns are filtered, the filtered absolute returns, $|R_{\mathrm{t,n}}|/\hat{s}_{\mathrm{t,n}}$, display a strictly positive and slowly declining autocorrelogram, as shown in Figure 3(b).[15]

Figure 3(b) further suggests that the estimate for the degree of long-run dependence is easily obtained from the autocorrelogram of the filtered absolute 5-min returns. Because the autocorrelations of a long-memory process are eventually all positive, we can assume that for large j, the autocorrelations behave as $\rho_{\mathrm{j}} \approx c \cdot j^{2 \cdot \mathrm{d}-1}$. Equivalently, we have

$$\ln(\rho_{\mathrm{j}}) \approx \ln(\mathrm{c}) + (2 \cdot \mathrm{d} - 1) \cdot \ln(\mathrm{j}),$$

where ρ_{j} denotes the jth order autocorrelation and c is a factor of proportionality. With the autocorrelations replaced by the sample estimates $(\hat{\rho}_j)$, the resulting OLS estimate is given by $\hat{d}_{AC} = 0.395$. This time-domain-based estimate is fully consistent with the estimates from frequency-domain-based procedures.[16] The implied hyperbolic rate of decay,

[15] $\hat{s}_{\mathrm{t,n}}$ is the normalized estimate for the periodic component from FFF regressions incorporating the intraday patterns and announcement effects; see Andersen and Bollerslev (1997).

[16] Two alternative frequency-domain-based estimates are the log periodogram estimate (Geweke & Porter-Hudak, 1993) and the average periodogram estimate (Robinson, 1994). The 5-min returns yielded estimates of 0.302 and 0.371, respectively, for these alternative estimation procedures.

$j^{2\cdot 0.395-1} = j^{-0.210}$, closely follows the actual autocorrelogram [Fig. 3(b)]. This procedure only applies to the autocorrelations of filtered absolute returns but not to those of raw absolute returns, because the strong intraday periodicity significantly distorts the shape of the gradual decline and, hence, the estimate of d.

A related question is whether the long-memory component changes over time as a result of a major event or a sequence of major events. The gold futures market offers an interesting opportunity to examine this issue. During the 4-year sample period from 1994 to 1997, the Bre-X scandal took place. The scandal concerned a small Canadian gold-mining firm, Bre-X Minerals Limited, which claimed to have found a large gold reserve that subsequently turned out not to be true. Because the news about the Bre-X scandal lingered on for quite a long time, it is not clear whether the scandal had any impact on the persistence of volatility, or long-memory component, in the gold futures market. Therefore, we searched the *Wall Street Journal* and identified 107 stories related to Bre-X. The first one occurred on March 18, 1996 when the firm said it had discovered as many as 40 million ounces of gold on its property in the wilds of Indonesia. We used this day as the cutoff date and truncated the entire sample into two subsamples. With the same method applied, the estimates for the degree of fractional integration are close, 0.401 and 0.404 for the prescandal and scandal samples, respectively. There does not seem to be a break in the long-memory component of the volatility process after the scandal. Using alternative frequency-domain-based estimates yields the same conclusion.

LARGEST ABSOLUTE 5-MIN RETURNS

Figure 1 shows that from 1994 to 1997, the gold price declined from US$390 to US$287 per ounce. Much of the decline occurred in the last 2 years of the sample period. One major force behind this drop appears to have been the sales of gold reserves by a number of central banks. To see whether this is indeed the case, Table I displays the 25 largest absolute returns over the sample and indicates whether any economic or political event may account for the sharp price change. The evidence is striking, with 6 of the 25 largest absolute returns associated with the sales of gold reserves by central banks. Notably, the largest absolute 5-min return of 2.638% occurred at 08:20 EST on Monday, July 7, 1997, after the Reserve Bank of Australia announced that it had sold 167 tons of gold, or two thirds of its gold reserves. The COMEX gold futures price fell from US$326.5 to US$318, or by US$8.5, within the first 5 min of trading.

TABLE I

Largest Absolute 5-min Returns from COMEX Gold Futures Contracts during the 1994–1997 Period

Absolute Return (%)	*Date*	*Time*	*Weekday*	*Event*
2.638	97-07-07	8:20	Monday	Gold sales by the Reserve Bank of Australia
0.847	97-10-09	12:25	Thursday	Rise in interest rates in Europe
0.846	94-01-20	11:45	Thursday	Concern about weaker consumer demand for gold
0.805	97-07-17	11:20	Thursday	Concern about oil price
0.795	94-04-04	11:05	Monday	Political tension in South Africa
0.787	97-10-24	8:35	Friday	Concern about gold sales by the Central Bank of Switzerland
0.782	97-10-24	8:20	Friday	Concern about gold sales by the Central Bank of Switzerland
0.776	97-02-27	8:20	Thursday	Concern about gold sales by central banks in Europe
0.728	94-09-28	8:20	Wednesday	Concern about inflation in the United States
0.724	96-07-31	14:15	Wednesday	Political tension in South Africa
0.718	96-02-20	8:25	Tuesday	Concern about weaker consumer demand for gold
0.695	95-07-19	14:00	Wednesday	Concern about gold sales associated with stock market crash
0.686	94-01-05	13:35	Wednesday	Factory orders in the United States
0.670	97-09-25	9:40	Thursday	Demand from jewelry makers
0.669	97-07-18	14:20	Friday	Increased consumer demand for gold
0.660	94-10-07	8:45	Friday	Employment report in the United States
0.636	94-01-31	11:55	Monday	Concern about inflation in Japan
0.633	97-10-28	13:50	Tuesday	Concern about Asian financial crisis
0.614	97-10-24	13:55	Friday	Concern about gold sales by the Central Bank of Switzerland
0.600	97-02-20	11:35	Thursday	Weakening of the U.S. dollar
0.597	97-10-24	8:45	Friday	Concern about gold sales by the Central Bank of Switzerland
0.596	95-06-30	11:50	Friday	Middle East selling more crude oil
0.594	94-04-05	8:45	Tuesday	Political tension in South Africa
0.590	94-10-11	8:30	Tuesday	Concern about weaker consumer demand for gold
0.581	94-05-06	12:00	Friday	Concern about inflation in the United States

The absolute returns are based on the raw 5-min returns on COMEX gold futures. The sample period is from January 1994 to December 1997. The daily time interval is between 08:20 and 14:35 EST, which corresponds to the trading hours of COMEX gold futures contracts on the New York Stock Exchange, thus resulting in 75 5-min intervals during each trading day. Over the 4-year sample period, there were 970 trading days, making a total of 72,750 observations. For each 5-min interval, we subjectively indicate whether any economic or political event appears to have contributed to the absolute 5-min return.

On October 24, 1997, a committee set up by the Swiss Government released a report saying that Switzerland could do without as many as 1,400 of its total 2,590 tons of gold reserves. The Swiss government later affirmed a previous announced plan to sell 400 tons over a 10-year period. This resulted in 4 of the 25 largest price changes in a single day. Other large price changes were related to concerns about consumer demand for gold, interest rates, oil prices, inflation rates, U.S. unemployment rates, the Asian financial crisis, and political tension in South Africa.

MACROECONOMIC ANNOUNCEMENT EFFECTS

Important Announcements

We now examine the effects of macroeconomic announcements on the COMEX gold futures market. There already exists a sizeable literature on the effects of public information on the volatility of financial assets.[17] Studies on the gold market's reaction to the release of public information are scarce. Tandon and Urich (1987) reported significant impacts of unanticipated components of U.S. money supply and producer price index (PPI) announcements on daily gold prices. More studies look into the factors that affect the movement of gold prices using monthly data. Although these studies do not exactly investigate the effects of announcements, they provide us with an idea of what factors are most likely to move the gold market. For example, Fledstein (1980) showed that a rise in expected inflation will increase the relative price of gold. Chua and Woodward (1982) provided empirical evidence that, for U.S. investors, gold is an effective hedge medium against both expected and unexpected inflation. Abken (1980) examined the relationship between the gold price and 1-month U.S. Treasury bill yields. Sjaastad and Scacciavillani (1996) reported that floating exchange rates among the major currencies have been a major source of price instability in the world gold market. In particular, the appreciation or depreciation of European currencies has a strong effect on the price of gold in other countries. Sherman (1983) found that the log of the gold price is negatively related to the U.S. trade weighted exchange rate and the real Eurodollar interest rate lagged by 1 month and is positively related to the log of real world GDP, anticipated inflation, and unanticipated inflation.[18]

Interestingly, several major U.S. macroeconomic announcements have been shown to affect both foreign exchange and interest rates in a similar way. For example, U.S. macroeconomic announcements such as employment reports, durable goods orders, GDP, PPI, and retail sales have significant price effects on both the deutsche mark–U.S. dollar exchange rate and long-term and short-term U.S. interest rates. Bundes-

[17]Earlier studies include those on the short-term and long-term bond market (Balduzzi, Elton, & Green, 1997; Ederington & Lee, 1993; Fleming & Remolona, 1997, in press), on the foreign exchange market (DeGennaro & Shrieves, 1995; Goodhart, Hall, Henry, & Pesaran, 1993; Ito & Roley, 1987; Payne, 1996), and on the equity market (Berry & Howe, 1994; Cutler, Poterba, & Summers, 1989; Mitchell & Mulherin, 1994).

[18]Anticipated inflation is proxied by the ratio of quasimoney (savings accounts for the G7 countries) to GDP. Unanticipated inflation is the current inflation rate minus an 18-month moving average.

bank meetings, German M3 and GDP, and Japanese GDP also induce higher volatility in the deutsche mark–U.S. dollar exchange rate. We expect that a similar set of announcements will also affect the 24-hr world gold market.[19] However, mainly because of the tremendous difficulties in collecting news announcements from different countries, we can only focus on regularly scheduled macroeconomic news in the United States, which corresponds to the trading of COMEX gold futures in New York. Therefore, we collected the dates and release times of 23 different U.S. macroeconomic announcements from the "The Week Ahead" section of *Business Week* during the 1994–1997 period. Among the 23 regularly scheduled news releases, 12 are made at 08:30, covering employment reports, CPI, durable goods orders, housing starts, leading indicators, initial jobless claims, trade balances, PPI, retail sales, personal income, employment costs, and GDP; 8 are made at 10:00, covering business inventories, construction spending, consumer confidence, NAPM surveys, new single-family home sales, factory inventories, existing home sales, and productivity and costs; the remaining 3 announcements made at other times include industrial production (09:15), the Beige book (12:00), and the federal budget (14:00). Nonfarm payrolls and the unemployment rate are released together as part of the employment report. Industrial production and utilization are always released together.[20]

Estimate of the Announcement Effects

Because most macroeconomic news in the United States is released on a monthly basis, the occurrence of each type of news is limited. Therefore, it is impracticable to estimate separate news-specific coefficients. Instead, we follow Andersen and Bollerslev (1998) and assume that the volatility response pattern is of the form $\lambda(k,i) = \lambda_k \cdot \gamma(i)$, $i = 1, 2 \ldots 13$, where the prespecified $\gamma(i)$ coefficients are determined by a third-order polynomial with $\gamma(0) = 0.84346$ and $\gamma(13) = 0$.[21] For all announcements,

[19]Sjaastad and Scacciavillani (1996) found that a 10% appreciation of the deutsche mark against all other currencies increases the dollar price of gold by 6.5%. The same appreciation of the Japanese yen increases the dollar price of gold by only 1.7%. Because the world gold market is dominated by the Eurocurrency bloc, we expect that macroeconomic announcements from major European countries such as Germany will affect the gold price in a significant way.

[20]We also examined the impact of 12 major news items related to the Bre-X scandal during New York trading hours. The impact was not significant. One potential explanation is that the Bre-X news had been disseminated to the market continuously during the sample period. It is difficult to measure exactly when the major events hit the market. Many news items are also released outside New York trading hours.

[21]The third-order polynomial representation of the volatility pattern following the release of news is determined by $\gamma(i) = c_0 \cdot [1 - (i/13)^3] - c_1 \cdot [1 - (i/13)^2] \cdot i + c_2 \cdot [1 - i/13] \cdot i^2$, $i = 0, 1, 2 \ldots 13$, where the three parameters are given by $(c_0, c_1, c_2) = (0.84346, -0.12643, 0.00940)$. We estimated (c_0, c_1, c_2) for a set of four significant announcements (employment reports, GDP, CPI, and personal income). This uniquely identified the three parameters.

we choose the response horizon to be 1 hr and estimate the corresponding λ_k coefficients. With this specification in Equation 3, the immediate response of the absolute returns is given by $\exp[\lambda_k \cdot \gamma(0)/2] - 1$, whereas the response at the ith lag equals $\exp[\lambda_k \cdot \gamma(i)/2] - 1$. The cumulative impact over the entire 1-hr response horizon is given by $M(k) = \Sigma_{i=0}^{N} [\exp(\lambda_k \cdot \gamma(i)/2) - 1]$.

Table II summarizes the empirical results for the announcement effects. The estimation is based on the full system in Equation 3, using the first-step estimator of the daily volatility component that allows for heteroskedasticity. The announcements are ranked according to the loading coefficient λ_k. All together, 4 of the 23 announcements are significant, with employment reports, GDP, CPI, and personal income having the greatest impact in order of descending importance. Figure 4 displays the volatility response level, $\lambda(k,i) = \lambda_k \cdot \gamma(i)$, for each of the 4 significant announcements over the 1-hr horizon following the release. The response patterns are slightly different from those in the foreign exchange and Treasury bond markets, mainly because the dynamic pattern in the gold market is dominated by the first term in the polynomial representation.

The results from individual announcements are fully consistent with theoretical predictions and empirical evidence in earlier studies. Notably, the estimated loading coefficient of 1.26 for employment reports is highly significant. This translates into an instantaneous jump in volatility of 70% and a 5.5% average increase in the cumulative absolute return for trading days containing a scheduled employment report. Just as in the foreign exchange and Treasury bond markets, employment reports remain the most important announcement in the gold market. As argued by Sherman (1983), employment reports, GDP, and personal income mirror two forms of economic pressure on the gold market. First, they summarize economic activity and thus industrial and commercial demand for gold. Second, they summarize the growth rate of income of production factors (wages, profits, etc.) and thus reflect the demand for various assets including gold. The gold market remained sensitive to the inflation rate (CPI) when the gold price fell sharply during the last 2 years of the sample from 1996 to 1997. Existing studies on gold prices and inflation rates typically have focused on a period when both were rising, such as in the early 1980s.

Overall, several major macroeconomic announcements have a significant impact on the COMEX gold futures contracts. However, the impact is smaller than that on the foreign exchange and Treasury bond markets. For example, Andersen and Bollerslev (1998) reported that for the deutsche mark–U.S. dollar exchange rate, the "king of kings" employment report generates an instantaneous jump in volatility and an in-

TABLE II

Individual Macroeconomic News Announcement Effects

Announcements	*Coefficients*	*Robust t Statistics*	*Instantaneous Jump in Volatility (%)*	*Impact of Daily Cumulative Absolute Return (%)*
Employment reports	1.26	3.13**	70	5.5
GDP	1.12	2.57**	60	4.8
CPI	0.92	2.46**	47	3.8
Employment costs	0.78	1.42	39	3.2
Personal income	0.73	1.94*	36	3.0
Initial jobless claims	0.44	0.98	20	1.7
NAPM surveys	0.24	0.46	11	0.7
PPI	0.21	0.50	9	0.8
Retail sales	0.18	0.47	8	0.7
Business inventories	0.08	0.22	4	0.2
Factory inventories	0.07	0.16	3	0.2
Industrial production	0.01	0.03	0	0.0
Existing home sales	−0.01	−0.01	0	0.0
New single-family home sales	−0.04	−0.11	−2	−0.1
Merchandise trade balance	−0.06	−0.15	−2	−0.2
Federal budget	−0.09	−0.22	−4	−0.3
Beige book	−0.10	−0.14	−4	−0.2
Leading indicators	−0.12	−0.29	−5	−0.4
Durable goods orders	−0.14	−0.38	−6	−0.5
Housing starts	−0.19	−0.49	−8	−0.7
Consumer confidence	−0.56	−1.36	−21	−1.5
Construction spending	−0.63	−1.16	−23	−1.6
Productivity and costs	−0.96	−1.43	−33	−2.4

The dependent variables are based on raw 5-min returns on the COMEX gold futures. The sample period is from January 1994 to December 1997, with a total of 72,750 observations. The regressions take the form in Equation 1. The volatility response pattern following announcements is approximated by a third-order polynomial restricted to reach zero at the end of the response horizon of 1 h, or the 13th 5-min interval. Macroeconomic announcements made at 08:30 cover employment reports, CPI, durable goods orders, housing starts, leading indicators, initial jobless claims, merchandise trade balances, PPI, retail sales, personal income, employment costs, and GDP. Announcements made at 10:00 cover business inventories, construction spending, consumer confidence, NAPM surveys, new single-family home sales, factory inventories, existing home sales, and productivity costs. Announcements made at other times include industrial production (09:15), the Beige book (12:00), and the federal budget (14:00). The instantaneous jump in volatility measures the estimated increase in the 5-min absolute return for the interval when the announcement is made; the estimated total cumulative absolute return induced by the announcement over the assumed horizon is measured relative to the median cumulative absolute return over the sample period of 2.59% per day.

*Significance at the 10% level.

**Significance at the 5% level.

crease in daily cumulative absolute returns of 576 and 15%, respectively. In the Treasury bond market, Bollerslev, Cai, and Song (in press) showed that after the release of an employment report, the instantaneous and cumulative impacts are much larger in magnitude, being 1,523 and 77%, respectively. In the COMEX data, the gold market reaction to the release of employment reports is much smaller, as are the responses to other significant announcements.

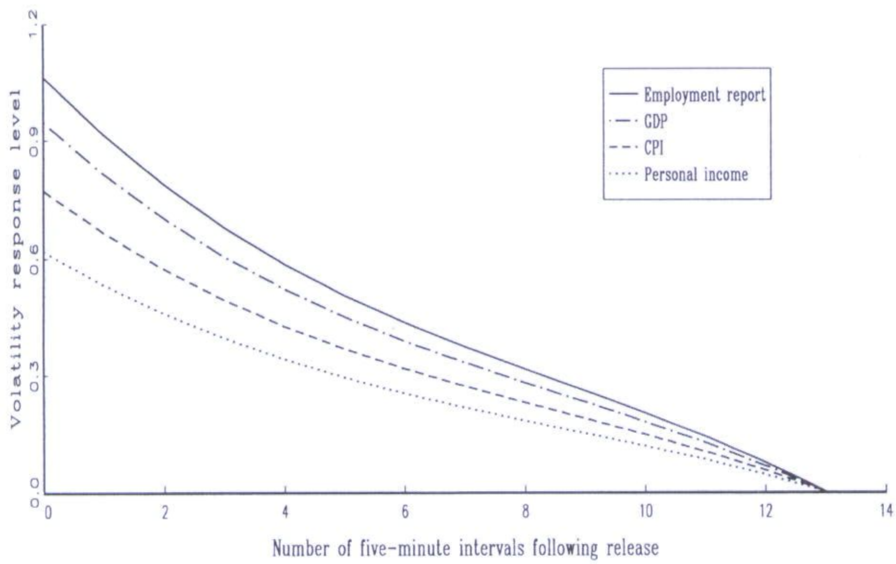


FIGURE 4
Estimated announcement responses patterns.

ASSESSING THE IMPORTANCE OF VOLATILITY COMPONENTS AT DAILY AND INTRADAY FREQUENCIES

Existing evidence suggests that the intraday calendar effects, macroeconomic announcements, and daily volatility factor are an integral part of the volatility process, but their relative importance varies for different markets. In this section, we assess the joint and marginal contribution of each of the three predictable volatility components in the COMEX gold futures market. The idea is to construct a volatility forecast from Equation 4 and then identify the proportion of explained variation accounted for by each of the three components. In particular, the 1-day-ahead (conditional on $\hat{\sigma}_t$) 5-min absolute return forecasts are obtained as

$$v_{t,n} = N^{-1/2}[\hat{\sigma}_t \cdot I_\sigma + \bar{\sigma} \cdot (1 - I_\sigma)] \cdot \exp\{[\hat{f}_c(t, n)I_c + \hat{f}_a(t, n)I_a + \hat{f}_w(t, n)I_w]/2\} \qquad (5)$$

where $f_c(t,n)$, $f_a(t,n)$, and $f_w(t,n)$ denote the estimated calendar, announcement, and day-of-the-week effects, respectively. The indicator variables I_c, I_a, and I_σ signify whether the corresponding feature is accounted for in the forecasts of absolute returns. The day-of-the-week effects are incorporated in all forecasts, that is, $I_w \equiv 1$. The forecasting performance of the 5-min volatility is measured by the coefficient of mul-

TABLE III

Explained Variation (R^2) from Regressions of the COMEX Gold Futures Daily Cumulative Absolute Returns or 5-min Absolute Returns on Alternative Absolute Return Forecasts

Model	*Daily Cumulative Absolute Return*	*5-min Absolute Return*
Complete model, $(\mathbf{I_c}, \mathbf{I_a}, \mathbf{I_\sigma}) = (1, 1, 1)$	0.402	0.069
No calendar effects, $(\mathbf{I_c}, \mathbf{I_a}, \mathbf{I_\sigma}) = (0, 1, 1)$	0.400	0.050
No announcements, $(\mathbf{I_c}, \mathbf{I_a}, \mathbf{I_\sigma}) = (1, 0, 1)$	0.400	0.068
No daily volatility, $(\mathbf{I_c}, \mathbf{I_a}, \mathbf{I_\sigma}) = (1, 1, 0)$	0.022	0.024
Calendar effects only, $(\mathbf{I_c}, \mathbf{I_a}, \mathbf{I_\sigma}) = (1, 0, 0)$	0.019	0.023
Announcements only, $(\mathbf{I_c}, \mathbf{I_a}, \mathbf{I_\sigma}) = (0, 1, 0)$	0.020	0.005
Daily volatility only, $(\mathbf{I_c}, \mathbf{I_a}, \mathbf{I_\sigma}) = (0, 0, 1)$	0.400	0.047
Day-of-the-week effects only, $(\mathbf{I_c}, \mathbf{I_a}, \mathbf{I_\sigma}) = (0, 0, 0)$	0.019	0.002

This table reports the explained variations (R^2) from regressing $\sum_{n=1}^{N} |R_{t,n} - \bar{R}|$ on $\sum_{n=1}^{N} v(I: t, n)$, $t = 1, 2, \ldots T$, for daily cumulative absolute returns and from regressing $|R_{t,n} - \bar{R}|$ on $v(I: t, n)$, $t = 1, 2, \ldots T$, $n = 1, 2, \ldots N$, for 5-min absolute returns. From Equation 2, $v(I: t, n)$ is the 5-min volatility forecast that, in turn, leaves out or includes only the contribution from each of the following components; the intraday calendar effects, the announcement effects, and the time-varying daily volatility factor. The indicator vector $(\mathbf{I_c}, \mathbf{I_a}, \mathbf{I_\sigma})$ signifies whether each of the three components is accounted for in the forecasts of absolute returns. For example, $(\mathbf{I_c}, \mathbf{I_a}, \mathbf{I_\sigma}) = (1, 1, 0)$ corresponds to the model where both the calendar and announcement effects are included and the daily volatility is constant. The day-of-the-week effects are always included in the regressions.

tiple correlation, or R^2, from the regressions of realized COMEX gold futures 5-min absolute returns on the corresponding volatility forecasts, $v_{t,n}$. The forecasting performance of daily volatility is measured by R^2 from the regressions of daily cumulative 5-min absolute returns on the corresponding daily cumulative 5-min forecasts, $\Sigma_{n=1}^{N} v_{t,n}$. R^2 allows for a simple model-free comparison without involving any particular loss functions.

Table III reports the forecasting performance for the eight different model configurations, as indicated by the triplet (I_c, I_a, I_σ). The results in the first data column refer to the degree of explained variation in daily cumulative absolute returns. The complete model explains an impressive 40.2% of the total variation. Removing either the calendar or announcement effects only slightly reduces the number of explained variations. In contrast, removing the daily volatility factor substantially lowers the number to 2.2% only. The evidence indicates that intraday patterns and announcement effects are significantly mitigated when aggregated to the daily level. The daily volatility factor is confirmed as the most important component for predicting volatility at the daily level.

Turning to the degree of explanatory power in high-frequency 5-min absolute returns, we observe that the overall explained variation drops to 6.9%. The daily volatility factor remains the most important component, explaining 4.7% alone. The calendar effects are secondary, explaining 2.3%. Major announcements only account for 0.5% of the total variation, despite their strong instantaneous impact in the 5-min intervals immediately after the release. The announcement effects are the least important among the three components in the gold market.

CONCLUSION

This article provides a detailed characterization of the COMEX gold futures return volatility using 5-min returns for a sample period of 4 years from 1994 to 1997. Consistent with previous findings, there exists a pronounced U-shaped pattern in the intraday volatility; that is, the volatilities at the market's open and close are higher than the volatility in the middle of the day. Strong intraday periodicity leads to equally strong patterns in the autocorrelation of absolute returns, which overshadows the slow hyperbolic decay or the long-memory feature. Nonetheless, high-frequency data from the gold market are as informative on long-run volatility dependencies as they are in other markets. Adjusting for the pronounced periodic pattern is critical in uncovering the complex link between the short-run and long-run volatility components.

We found that 6 of the 25 largest absolute returns are associated with the central banks' selling of gold reserves in our sample period, especially during 1997. The massive sales (planned sales) by central banks in countries such as Australia and Switzerland are the main force behind the sharp drop in the gold price. Other factors contributing to the large price changes include fluctuations in interest rates, oil prices, consumer demand, the Asian financial crisis, and tension in South Africa. In comparison with the foreign exchange and Treasury bond market, far fewer of the largest movements in the gold futures price are related to the release of U.S. macroeconomic announcements.

We finally examined the impact of 23 regularly released macroeconomic announcements in the United States and found that only 4 have significant effects on the volatility of the gold market. Employment reports turn out to be the most important announcement for the gold market, followed by GDP, CPI, and personal income. We also provided evidence on the incremental explanatory power of the announcement effects at both the daily and intraday frequencies. Overall, macroeconomic announcements have a smaller impact on the gold market than on the Treasury bond or foreign exchange markets.

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