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Abstract

This paper examines the conditional and unconditional mean returns and variance of returns of daily gold and silver contracts over the 1982-2002 period. Despite the importance of these metals as industrial and investment products, they have received scant attention in recent years. In particular, we focus on the issue of whether there exists detectable daily seasonality in these moments.

Using COMEX cash and futures data we find that under both parametric and non-parametric analysis the evidence is weak in the issue of daily seasonality for the mean but strong for the variance. There appears to be a negative Monday effect in both gold and silver, across cash and futures markets. When the mean and variance are analysed simultaneously in a GARCH framework we note that a leveraged GARCH model provides a best fit for the data and that in framework the Monday seasonal does not disappear, indicating that it is not a risk-related artefact, the Monday dummy in the variance equations being significant also. No evidence of an ARCH-in-Mean effect is found.

Introduction & Motivation

Gold and silver have historically been close substitutes for one another, both being precious metals that can be used to back currency and be used as currency. More recently the focus has switched to collectible coins and medals made from these metals: see for instance Kane (1984), Koford and Tschoegl (1998) & Roehner (2001). There is evidence that these metals can play a useful role in diversifying risk, as well as being an attractive investment in their own right. Thus, one might expect that the prices share similar dynamics.

However, there are also economic fundamentals that may act to drive the prices of gold and silver apart. While both are used extensively in industrial processes, there are significant differences between these uses. Silver is extremely reflective, a good conductor of electricity and has extensive use in optics and photography. Gold's industrial uses are fewer, with the majority of demand coming from the jewellery and dental markets as well as being driven by Central Bank reserve demand (official sector gold). Extensive documentation on the economics of the gold and silver markets can be found from the World Gold Council, www.gold.org, the Silver Institute, www.silverinstitute.org, and the International Precious Metal Institute, www.ipmi.org.

With the recent bear market showing no signs of abating, research has also begun to re-examine the relationship between these metals and equities. Thus for example Aggarwal and Sonen (1988), Johnson and Soenen (1997) and Egan and Peters (2001) show the defensive properties of gold in a portfolio, given its high negative correlation with equity indices. Brauer and Ravichandran (1986) perform a similar analysis for silver.

Given that over the 1980's and early 1990's much financial research in equity markets involved searching for anomalies, in particular daily seasonal effects in equity markets[1], it is interesting therefore to examine the extent and nature of any such seasonal in the precious metal markets. The prevailing theoretical asset pricing models such as the CAPM and derivatives thereof provide no place in the pricing kernel for daily seasonal variation to exist or, if it does, to persist. Moreover, in addition to the evidence noted above, there is significant evidence of persistent daily seasonality across a wide variety of assets other than equities.

For fixed income securities, Gibbons and Hess (1981), Flannery and Protopapadakis (1988) ,Jordan and Jordan (1991) , Singleton and Wingender (1994) ,Kohers and Patel (1996) and Adrangi and Ghazanfari (1996) have all detected various degrees of daily seasonality. Gold has been analysed by Ball, Torous and Tschoegl (1982) and Ma (1986) , while Chang and Kim (1988), Chamberlain, Cheun and Kwan (1990) and Johnston and Kracaw (1991) all investigate futures markets. Finally, Redman (1997) finds evidence of daily and monthly seasonality in real estate investment trusts. Surprisingly, a search of ABI-Inform, Econlit and of the Social Science Citation index failed to discover any studies of calendar seasonality, on the lines discussed above, for commodities or 'softs'[2].

Equally, there is evidence of daily variation in the higher moments of equity markets. Aggarwal and Schatzberg (1997) calculate aggregate skewness and kurtosis firm size

[1] See for example the research quoted in Keim and Ziemba (2000).

[2] There are of course a great deal of studies on the seasonal production pattern and demand of certain commodities, such as agricultural and other produces which are inherently seasonal. In addition there are numerous studies of the seasonal pattern of the futures of commodities and softs, but not of the underlying cash markets. What is striking is the lack of studies on such commodities as oil, rubber, cocoa, tin and aluminium, which although having a certain seasonal element embedded in their demand function are traded constantly in highly liquid markets and are of founding importance for the world economy.

classes and weekdays, and examine these directly using ANOVA and Kruskal-Wallis measures. Further evidence is to be found in Ho and Cheung (1994), Kramer (1996) and Tang (1997). Evidence in Choudhry (2000) on South-East Asian markets indicates a significant daily seasonal in the conditional variance of a number of equity indices. With the exception of Choudhry (2000) these have focused on the unconditional distribution of these moments.

The work on daily variation in the moments of gold and silver is extremely thin. We have been able to find no paper that has investigated seasonality in the silver market, and few indeed that have examined gold. Ball, Torous et al. (1982) investigate the morning and afternoon fixings of gold in the London metal exchange over the 1975-1979 period. They find little evidence of either a daily seasonal or a negative Monday. This is independent of whether Monday returns are measured as Friday AM – Monday AM or Friday PM – Monday PM .If anything, there appears to be a negative Tuesday return. Ma (1986) provides contradictory results. Ma analyses the afternoon fixings from January 1975. He finds that while both pre and post 1981 (when significant changes in settlement procedures and institutional arrangements were instituted) there existed daily seasonality, the nature of this seasonality changes. Pre 1981 there was a negative Tuesday (as found by Ball, Torous and Tschoegl) and a highly significant positive Wednesday. Post 1981 the negative Tuesday disappears and the average return on Monday switches from positive to significantly negative.

Since these works the examination of gold and related asset seasonality has appeared to lag. This paper thus attempts to fill that gap, using a variety of robust estimators that take account of the dynamics of the series. In particular, we investigate the daily seasonal in the conditional and unconditional first and second moments (mean and variance) of four assets: gold cash prices, silver cash prices, gold futures prices and silver future prices.

The importance of daily seasonality lies in the challenge that it may give to standard notions of market efficiency. While there are many definitions of an informational efficient market the basic element required is that there be no possibility of making persistent trading profits over and above a 'buy-and-hold' strategy from previous information. If there was a discernable pattern evident then prices would adjust to incorporate this and over time the pattern would disappear.

Gold and Silver Markets: An introduction

Gold and silver have acted as multifaceted metals down through the centuries, possessing similar characteristics to money in that they act as a store of wealth, medium of exchange and a unit of value (Goodman (1956), Solt and Swanson (1981)). Gold and silver have played closely related roles as precious metals and are considered as substitutes in portfolio diversification (Ciner (2001)).

The inclusion of gold and silver holdings leads to a more balanced portfolio by reducing volatility (see for example Ciner (2001), World Gold Council and London Bullion Market Association newsletters). According to Sherman (1983) gold markets behave efficiently - new information is quickly incorporated into the price. Under conditions of uncertainty many investors turn to gold because it is a "currency without borders" - a highly liquid and secure asset that can be accessed at any time. In times of economic distress most asset classes tend to move in the same direction. Gold and silver are negatively correlated to many assets, including equities and bonds, moving in the opposite direction. The economic forces that determine the price of gold are opposed to the forces that determine other financial assets. Therefore, gold and silver play important roles as diversifiers, acting as a stabilizing influence for investment portfolios. Thus a portfolio mix of equities with gold and silver would result in a portfolio of assets moving independently, with low correlation. According to Draper, R. Faff and Hillier (2002) portfolios that contain gold, silver or platinum perform significantly better than standard equity portfolios. Therefore the astute investor can minimise risk while maximising returns.

Gold and silver share a lot of similar properties as both are used as industrial components and investment assets. The quantity of gold and silver required is determined by the quantity demanded for industrial, investment and jewellery use. Therefore an increase in the quantity demanded by the industry will lead to an increase in the price of these metals (Radetski (1989) ; Draper, R. Faff et al. (2002)). Price changes can also be the result of a change in the Central Bank's holding of these precious metals. In addition changes in the rate of inflation, currency markets, political harmony, equity markets, producer and supplier hedging all affect the price equilibrium of these metals. However the CPM Group (www.cpmgroup.com), state that changes in the supply/demand relationship only explains 13.7% of the annual changes in price of gold.

The main factors of demand for gold are industrial use, Central Bank demand and jewellery demand. A sale of official gold reserves has a large influence on the price of gold. A large component of jewellery demand emanates from India and China. In addition private demand includes the physical hoarding of gold bars and investment in options and futures. Therefore a change in the attitudes of private investors can have significant altercations for the price of gold. According to the CPM Group, investment demand has the most important influence on the price of gold. Gold supply is composed of mine production with Indonesia having the largest producing mine; official sector sale, gold scrap with discarded jewellery the biggest component of scrap and net disinvestment (see Radetski (1989)).

The price of silver is determined by the interaction of the supply and demand components of the market, the global economy, consumer tastes and images, inflation, fluctuations in deficits, performance of the electronics industry etc. Silver is produced as a by-product of gold primarily and to a lesser extent lead, zinc and other metals. It is common practise for silver to follow the market movements of gold. The demand for silver as a private investment is not as strong as for gold as industry consumes silver while silver use in industry is much greater. According to the CPM group the factors which affect the price of precious metals will continue to be the availability of physical supplies to meet demand. Mexico, Peru and Australia are the three top silver producing countries.

Supply of silver is dominated by mine production, scrap recycling, disinvestment, government sales and producer hedging. Mine production is the largest component of silver supply accounting for approximately 70%. The supply of silver is subject to the economic performance of the economy. The main components of silver demand include industrial demand, jewellery and silverware, and photographic fabrication. Minor elements of demand are government purchases, producer hedging and investment.

Gold and silver prices float freely in accordance with supply and demand, responding quickly to political and economic events. A large range of companies from mining companies to fabricators of finished products, users of silver and gold content industrial materials and investors, draw on COMEX futures and options and the London Bullion Market primarily. LBM trades essentially physical gold and silver while Comex trades in the derivatives of these metals. Gold is quoted in dollars and cents per troy ounce, while silver is quoted in cents per troy ounce.

Gold and to a lesser extent silver are highly liquid. Gold can be readily bought or sold 24 hours a day, in large denominations and at narrow spreads. This cannot necessarily be said of most other investments. This is highlighted by Draper, R. Faff et al. (2002) who state that total annual production of gold (2300 tons) is cleared by the LBMA every 2.5 days. Silver is traded in London, Hong Kong, Chicago, Zurich and New York. In London, silver is traded on a physical basis for spot and futures prices. According to the Silver Institute London remains the true centre of the physical silver trade for most of the world, however significant paper contracts trading market for silver occurs in Comex.

Clearly, looking at the above, no more than in equity markets, we neither see systemic forces that act at the daily frequency to alter the dynamics of these markets nor would we expect to see such daily seasonality persist in these markets given the high degree of liquidity.

Methodology

We test both the conditional and unconditional means and variances of the series.

Testing the *unconditional* means is achieved by a series of regressions of the form $R_t = \sum_{i=1}^{5} \alpha_i + \varepsilon_t$, a simple dummy variable regression. The two sets of statistics that emerge are of course the regression *t*-statistics, which test the difference from zero of each coefficient, and the regression *F*-statistic which is a joint test of the equality of each coefficient to zero, simultaneously. To ensure robustness of the results from outliers we also apply a robust method, a trimmed least squares regression model. This uses the iterative resampling model of Rousseeuw and Leroy (2003)[3]. We also report results with Whites correction for disturbances in the error terms to control for hetroskedasticity and autocorrelation. This is discussed in more detail in Hansen (1982). In brief, given the regression model $\mathbf{Y} = \mathbf{X}\beta + \mathbf{u}$ the standard assumption regarding the distribution of the errors is $\mathbf{V} = E(\mathbf{uu'}) = \sigma^2\mathbf{I}$. This however is violated in the presence of hetroskedastic or autocorrelated disturbances. We can achieve consistent estimators of the coefficients, but the estimate $s^2\mathbf{X'X^{-1}}$ of the variance of these coefficients is not consistent. Accordingly, inference based on these estimates will be incorrect. Hansen (1982) shows that an estimate of the variance of the form $(\mathbf{X'X})^{-1} \sum_{k=-\ell}^{\ell} \sum_t u_t X_t' X_{t-k} u_{t-k} (\mathbf{X'X})^{-1}$, where ϑ is the number of serially correlated lags, is consistent.

Testing for seasonality in the unconditional variance is by means of Levene's test, an alternative to the well-known Bartlett test for equality of variance that is robust to non-normality.

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[3] Previous versions of this paper used a simple trim of the top and bottom 2.5% of data. The results are not significantly different

The Levene test tests H_0: $\sigma_i = \sigma_j \forall i, j$, Ha: $\sigma_i \neq \sigma_j$, at least one i, j pair ,

$$W = \frac{(N-k)\sum_{i=1}^{k} N_i \left(\overline{Z_i} - \overline{Z_{....}}\right)^2}{(k-1)\sum_{i=1}^{k}\sum_{j=i}^{N}\left(Z_{ij} - \overline{Z_i}\right)^2} \text{ where } Z_{ij} = \left|Y_{ij} - \tilde{Y}_i\right|, \tilde{Y} \text{ the median of subgroup i}$$

The Levene test rejects the hypothesis that the variances are homogeneous if $W > F_{(1-\alpha,k-1,N-1)}$ where $F_{(1-\alpha,k-1,N-1)}$ is the upper critical value of the F distribution with k - 1 and N - 1 degrees of freedom at a significance level of α.

GARCH models are by now well known as representations simultaneously of the *conditional* mean and variance of a series. Thus we do not propose here to give a detailed recapitulation. In general we can write the GARCH-M models with exogenous variables in both the mean and variance equations (here daily dummies) as

$$R_t = \alpha_0 + \eta_1\sqrt{h_t} \quad + \sum_{i=1}^{r}\beta_i R_{t-i} + \sum_{j=1}^{n}\delta_j X_j + \sum_{k=0}^{m}\phi_k \mu_{t-k} + \mu_t; \mu_t = \sqrt{h_t\varepsilon_t}; \varepsilon_t \approx (0,1)$$

which gives an ARMA(r, m) representation of the mean, $\eta_1 h_t^{0.5}$ the ARCH - in Mean

and $h_t = \gamma_0 + \sum_{d=i}^{n}\theta_i^* X_i + \sum_{j=1}^{p}\psi_j h_{t-j} + \sum_{i=1}^{q}\omega_i \mu_{t-i}^2$

which gives an ARMA(p, q) representation of the variance.

We can also account for potential asymmetric responses in the conditional variance by adding a leverage term to the variance itself, as proposed in Glosten, Jagannathan and Runkle (1993), giving the model as

$$R_t = \alpha_0 + \eta_1\sqrt{h_t} + \sum_{i=1}^{r}\beta_i R_{t-i} + \sum_{j=1}^{n}\delta_j X_j + \sum_{k=0}^{m}\phi_k \mu_{t-k} + \mu_t ; \mu_t = \sqrt{h_t \varepsilon_t} ; \varepsilon_t \approx (0,1)$$

$$h_t = \gamma_0 + \sum_{d=i}^{n}\theta_i^* X_i + \sum_{j=1}^{p}\psi_j h_{t-j} + \sum_{i=1}^{q}\omega_i \mu_{t-i}^2 + \upsilon \mathrm{I}_{t-1}\mu^2{}_{t-1} ; \begin{matrix} \mu_t < 0 \rightarrow \mathrm{I} = 1 \\ \mu_t < 0 \rightarrow \mathrm{I} = 0 \end{matrix}$$

and providing the Leveraged GARCH (LGARCH) model.

In a GARCH framework the ARCH-in-Mean element represents the payoff for taking on risk while the constant in the mean equation represents the element not related to risk, or the risk free return. The presence of dummy variables in the mean equation changes this somewhat. Then, the coefficients on the dummy variables are the conditional returns to holding the asset on that day, the intercept being the returns expected on days other than that and the AIM term remaining unchanged.

The inclusion of daily dummies allows us to not only model the conditional dependence between the mean and the variance but also potentially to examine the effect that daily seasonality has on these conditional estimates. Recall that the examinations earlier are of the unconditional mean and variance. By including dummy variables for days of the week we are in a position to examine the effect that these have both on the mean and the variance.

There is no agreement in the literature as to which dummy variables should be included. Clare, Ibrahaim and Thomas (1998) and Lucey (2000) include daily dummies in the mean and variance for those days that have been shown, from a standard OLS regression, to have significant coefficients in mean returns. Glosten, Jagannathan et al. (1993) include dummies for January and October, on similar justification. Beller and Nofsinger (1998) test all calendar variables. Another issue is the mode of propagation of calendar effects. As Beller and Nofsinger (1998) points out, there are of course three places where such dummies can go. The equations above make the implicit assumption that the effect on the conditional variance of calendar effects is through the intercept terms, in effect assuming that there is a different form of conditional variance for each day of the week etc. Alternatively, it could be the case that the relationship is propagated through the variance itself or through the unexpected returns (residuals).

As there have been very few if any studies published of the conditional variance of these metal contracts we confine ourselves here with the simplest interpretation. Where there is evidence that there are daily mean seasonals we include relevant dummies. We also are interested in the potential effect that each day may have on the variance. Thus we include 4 dummy variables in the conditional variance equations. We exclude Friday in each of the 4 contracts studied. The constant term in the variance equation can then be taken as either the mean variance and/or the effect on the variance of the excluded day. The daily dummies for the variance are then properly the differential effects on the variance of the relevant day.

We can interpret the dummy variables as follows: If any daily dummies included in the mean equation remain significant then we may conclude that seasonality is not due to daily variation in risk. If the dummies become insignificant in the mean equation but are significant in the variance equation, we can conclude that there is seasonality in market risk, whether this is priced or not. The extent, if any of the degree of a relationship from risk to return can also be seen from the magnitude and significance of the ARCH-in-Mean term. In all cases a GARCH(1,1) model is applied in Leveraged form.

Data

The data analysed here were sourced from Normans Historical Data Ltd, website (http://www.normanshistoricaldata.com/index.htm). Daily percentage changes are examined for COMEX gold and silver cash and futures returns. Futures are linked to form a continual series using the methodology proposed by Spurgin (1999). The method used is described in more detail therein, but in essence involves a continual roll strategy. Each day a percentage of the front contract is sold and rolled into the next-out contract. The roll strategy is linear, with the percentage P_t held in the near contract being $\frac{\text{\# days until first day of nearby contract expiry month}}{\text{\# days from last expiration to nearby expiration}}$. Each day $(P_{t-1} - P_t)$ is rolled. If NB is the nearby contract and NX the next-out then the spot index of any day is given by $S_t = NB*P_t + NX*(1-P_t)$. The data set extends over the period Jan 1982 – November 2002. In total we have 5256 data points available. Given the fact that the above roll mechanism will lose data at the end, the total adjusted future index gives us 5225 datapoints[4].

[4] We thank the editor for drawing our attention to this roll methodology.

Shown in Table 1 are the average daily volumes of trade on the four contracts over the period – in all cases the markets have shown growth, on this measure, over the period of analysis. Although gold has been freely traded since 1974, we have concentrated on the post 1982 period for a number of reasons including the attempted cornering of the silver market by the Hunt brothers, and the change in settlement procedures in London in late 1981. Shown in Figure 1 &

Figure 2 are the price levels over this period. All data are analysed in log-percentage return terms. Table 2 shows detail of the first four moments of gold and silver, by days of the week over the entire dataset.

As cited earlier there is significant evidence from the equity markets of the tendency of stock markets to decline on a Monday and peak on a Friday. Evidence from Fields (1931), Kelly (1930), French (1980), Lakonishhok & Levi (1982), Kohers & Kohers (1995) and Maberly (1995) all document a peak in returns on a Friday and a trough on Mondays. French (1980) analysed the S&P Index over the period 1953-1977. He identified an average Monday return of -0.17%. The riskiness of Monday returns, as proxied by the standard deviation, was the highest for all days.

Shown in Table 2 are some basic statistics. The above results correlate to the findings of this paper, that Monday returns are consistently negative and the lowest for all days of the week. As evidenced in the equity markets, Monday's standard deviation in both cash and futures gold and future silver is also the highest of all days of the week. Lakonishok & Levi (1982), Lakonishok & Smidt (1988) and Kohers & Kohers (1995) have reinforced the pattern of Monday having the lowest often negative return of the week despite having the highest, or at least the higher than average, risk as proxied by the standard deviation. Thus the pattern found stereotypically in equity markets follows here. This reflects evidence from previous studies on seasonality in equity markets and is in line with the results of Ma (1986).

In examination of higher moments in the equity markets, Scott & Horvath (1980) show that investors have a preference for kurtosis and are adverse to skewness. Aggarwal & Schatzberg (1997) find a negative Monday return. Skewness patterns follow those of the first two moments for the first time period they examine, but ‘flip’ in the second, with the Monday skewness going from lowest to highest. This result contrasts with the results here where Monday’s skewness statistics, with the exception of silver cash, are consistently the highest and negative. Kurtosis does not follow mean returns as reported in Aggarwal & Schatzberg (1997), Monday’s kurtosis are positive and the largest in gold cash and silver futures. These results on higher moments of the precious metals show greater similarity with evidence from Asian equity markets as reported in Ho & Cheung (1994) and Tang (1997), both of whom reported that higher moments do not follow a pattern similar to that of lower moments.

From the above results it appears that seasonality in the first moment may exist. Monday returns are low with no obvious explanation from risk. Similarly, the maximum returns, which occur not on Friday as in equity markets save for Cash gold, the remainder occurring on Thursday, have low standard deviations. However, risk premia in futures and cash markets differ in their derivation, with both however ultimately being a reward for the potential for loss arising from the tails of the distribution. What is interesting here is that the cash and futures markets are in broad agreement, indicating perhaps that the lack of payoff to potential risk is generalised.

Table 3 displays the results of the Kolmogorov Smirnov Z test and the Jarque-Bera statistics for the equality of distributions. The results for all variables reject the equality of the distribution at the 5% level, thus confirming that the data is non-normal. Also shown as Figure 5 are histograms of the data in log percentage change terms, with a normal curve superimposed. All data sets are very peaked due to the high kurtosis factor. The distributions do not display any obvious degree of skewness. Accordingly we do not carry out tests for seasonality in the higher moments.

Results

Unconditional Mean and Variance Results

Beginning the formal analysis, Table 4 shows the results of a regression analysis of the first moments. There does not appear to be an issue of daily seasonality in the first moment as none of the regressions show a significant F statistic, indicating that overall seasonality is not evident. However Monday has significant t-stats for Cash Gold and Cash Silver, while there are no significant coefficients for the futures series. The results for the robust regression, where the t-statistics are calculated according to whites procedure, are qualitatively the same as for the trimmed OLS, with the evidence being if anything weaker again. The trimmed least squares approach, TLS, shows no days as beign significantly different from zero.

We have evidence that the data are non-normally distributed, which would indicate that perhaps parametric methods are of limited use. Therefore, the Kruskal Wallis test, a non-parametric alternative to ANOVA, is used to supplement the results above. The results are shown in Table 5. While the evidence is such that we cannot reject the null that the cash series are drawn from a distribution where the daily returns are the same this is not the case for the futures data. This result is inconsistent with the regression results. Testing for a day of the week effect in equity markets, using both the regression F and Kruskal-Wallis test, Elyasiani, Perera and Puri (1996), Arsad and Coutts (1997) and Steeley (2001) all found agreement between the two sets of tests. Our finding here is thus perhaps evidence that the seasonality in the mean, if present, is weak and not statistically robust.

Table 6 shows the results for the presence of seasonality in the second moment. In all cases we can reject the null of homogeneity of variance across days of the week, indicating that there may well exist a daily seasonality in the variances of these assets.[5]. Thus, we can conclude for the unconditional means and variances that the evidence is stronger for seasonality, at the daily frequency, for the variance of the data than for the means.

Conditional Mean and Variance Results

Table 7 shows the results of GARCH models. Shown are the coefficients and beside them their *p*-values. The LGARCH specification provides a good fit to the data: the diagnostic statistics (available on request) indicate no significant residual serial correlation or

[5] The question remains open, given our dataset, as to whether this daily seasonal in variance is a weekend or Monday issue. The general consensus is that According to Cross (1973)) and French (1980) the Monday effect is Friday close to Monday close data. However Rogalski (1984) and Harris (1986) state that a weekend effect if evident is returns examined from Friday close to Monday opening. The consensus evidence for equities is for a weekend effect.

significant residual ARCH effects, the constant of variance is positive and significant for gold series, and the variance is non-explosive.

Forcash gold the constant in the mean, the payoff for non risk factors, is positive. However, it is negative for all other serie, but is in all cases insignificant. Thus, in no case can we assert that there is a significant payoff to gold or silver for factors related other than risk. Indeed, given that the ARCH-in-Mean terms are also statistically insignificant, indicating no payoff for risk, it appears that the precious metals are being priced by states outside the standard pricing model.

For cash gold and silver we note that the Monday dummy in the mean remains significant and negative. Overall therefore the Monday effect in the cash gold and silver prices is not driven by variations in risk on Monday. We should note that the dummies in the variance term properly refer to the differential impact that these days have on the variance versus Friday, which influence is subsumed in the constant of variance.

The daily dummies are significant in the variance equations for cash and futures gold, whereas for silver we note that only Monday appears to have a systemic effect. However, the magnitude of these effects is extremely small.

The leverage term is negative and significant in all cases, indicating that the effect of a negative innovation in the mean this period acts to reduce the variance next period. This is congruent with the implications of the sum of the variance terms being close to but less than 1, indicating slow but significant persistence of shocks to variance. The leverage terms are also, in absolute terms, quite large.

Conclusion and Discussion

Ma (1986) found significant negative Monday effects in the gold market. We confirm this finding for cash gold but not for the futures market, perhaps indicating a greater degree of efficiency in that series. The Monday effect in cash gold appears to be weak and statistically not robust. We also provide the first evidence of daily seasonality in silver prices. These are similar to the gold findings. The evidence from a GARCH model, using a leveraged GARCH specification, is that the seasonality in the mean may not result from seasonality in the variance. We also note that there is no evidence of a return-risk relationship as indicated by the ARCH-in-Mean being insignificant and negative.

This set of results indicates a number of unusual features. First, although the four assets are positively and significantly correlated with one another, there appears to be a different set of dynamics across the markets. The authors do not wish to imply that the cash and futures markets are not integrated. See for example Ciner (2001) where the author finds that the long run stable relationship between the futures prices of gold and silver has broken down during the 1990's. This is also supported by Escribano and Granger (1998) who found that since the 1990's the co-integration relationship between gold and silver has died. However, this is inconsistent with the results of Ma (1985), Ma and Sorensen (1988) and Wahab, Cohn and Lashgari (1994).

Second, in some ways gold in particular can be seen as the ultimate riskless asset, despite its having volatility. The finding that these markets appear to be driven almost entirely by their own lagged values, the autoregressive and moving average terms being significant, with neither risk (ARCH-in-Mean) nor non-risk (constant in the mean) variables having any significant impact indicates that returns to these assets are perhaps separate from other influences. Fuller investigation of the conditional mean responses of gold and silver to the equity market for example would require a multivariate GARCH modelling. Third, the finding that the leverage term is in many ways the most important element of the variance indicates that while the daily seasonal in the variance is important it is not as significant, again, as the markets response to its own dynamics.

Overall the results indicate that there are fruitful questions of investigation in these markets, and that an understanding of them requires at the least an understanding of the daily seasonal dynamics.

If we accept that there are daily seasonal influences, the question arises as to the source of these. As has been noted the equity markets are significant contributors to this literature. Drawing from this we find that there are three main theories regarding why markets would indicate a daily seasonal. The most relevant can be broadly summed up as the market settlement system (e.g. Bell and Levin (1998)), news to the market (e.g. Steeley (2001)) and news in the market (e.g. Pettengill and Buster (1994)) hypotheses. At first glance none of these would seem clear contenders for the causal mechanism. According to Steeley (2001) news announcements occur on Tuesday, Wednesday and Thursday in the UK. The author states that this allows investors to assimilate and consider information over the weekend, in the absence of additional news, and this perhaps favours Monday selling which could "depress prices and so produce a significantly negative return over the weekend" (2001:1942).

In the case of the settlement system we have in gold a rolling settlement, and the prices of both cash and future gold include the cost of carry (explicitly so in the case of the futures and via the gold lease rate in the case of cash gold) in the price. News generated internally in the market is difficult to extract from general news – the mechanism used by Pettengill and Buster (1994) involves data, rise/fall ratios, that have no analogy in the precious metal markets. Thus we are left with the potential that it is as a consequence of news arriving to the market, or an as yet unspecified mechanism, that induces daily seasonality, especially in the variance.

TABLE 1 : AVERAGE DAILY VOLUME / OPEN INTEREST, 2002 $M TERMS

	CASH SILVER	CASH GOLD	FUTURE SILVER	FUTURE GOLD
1982	$6.05	$25.83	$15.26	$70.50
1987	$12.90	$26.11	$57.49	$95.81
1992	$9.51	$18.95	$67.04	$84.18
1997	$17.69	$34.52	$85.01	$171.81
2002	$12.69	$35.93	$81.53	$158.32

TABLE 2: MOMENTS OF THE DISTRIBUTION BY DAY OF THE WEEK 1982-2002

		MEAN	STANDARD DEVIATION	KURTOSIS	SKEWNESS
Cash Gold	Monday	-0.0007	0.0121	17.1249	-1.0202
	Tuesday	0.0002	0.0097	7.6338	0.4657
	Wednesday	-0.0002	0.0095	6.7646	0.0263
	Thursday	0.0002	0.0085	6.0197	-0.2455
	Friday	0.0003	0.0102	16.3361	1.7727
Cash Silver	Monday	-0.0011	0.0173	4.1924	-0.3995
	Tuesday	0.0001	0.0180	32.3975	-2.5566
	Wednesday	-0.0002	0.0153	4.4904	0.0806
	Thursday	0.0004	0.0159	4.1718	-0.0643
	Friday	0.0001	0.0157	7.4818	0.3670
Futures Gold	Monday	-0.0002	0.0101	6.5391	- 0.2923
	Tuesday	-0.0001	0.0089	12.4844	0.8314
	Wednesday	0.0000	0.0079	4.3973	0.0618
	Thursday	0.0001	0.0087	11.2163	0.1556
	Friday	-0.0000	0.0098	8.6970	0.4981
Futures Silver	Monday	-0.0007	0.0171	11.0493	- 1.3391
	Tuesday	-0.0002	0.0152	9.6115	0.0542
	Wednesday	0.0001	0.0140	3.9647	- 0.0679
	Thursday	0.0006	0.0148	4.5205	0.2695
	Friday	-0.0006	0.0144	3.1528	- 0.1670

TABLE 3: NORMALITY TESTS OF DATA

	N	Z	P-VALUE.	JB	P-VALUE
Cash Gold	5256	6.379	0.00	70.99	0.00
Cash Silver	5256	6.164	0.00	8575.04	0.00
Futures Gold	5225	6.862	0.00	19450.95	0.00
Futures Silver	5225	5.713	0.00	10271.61	0.00

TABLE 4 : REGRESSION ANALYSIS OF DAILY SEASONALITY

			OLS	ROBUST	TLS	
	Variable	Coeff	Sig.	Sig.	Coeff	Sig.
Cash Gold	Monday	-0.0007	0.03	0.08	-0.0002	0.30
	Tuesday	0.0002	0.59	0.58	0.0000	0.96
	Wednesday	-0.0002	0.45	0.43	-0.0002	0.42
	Thursday	0.0002	0.60	0.55	0.0003	0.23
	Friday	0.0003	0.28	0.29	0.0002	0.48
	F(5256)	1.3628	0.23	0.30	F(4828)	0.72
Cash Silver	Monday	-0.0011	0.04	0.05	-0.0004	0.29
	Tuesday	0.0001	0.84	0.86	0.0003	0.37
	Wednesday	-0.0002	0.75	0.73	0.0000	0.93
	Thursday	0.0004	0.42	0.41	0.0005	0.17
	Friday	0.0001	0.86	0.85	0.0001	0.78
	F(5256)	1.024	0.40	0.43	F(4828)	0.79
Futures Gold	Monday	-0.0002	0.51	0.55	0.0000	0.82
	Tuesday	-0.0001	0.83	0.83	-0.0002	0.37
	Wednesday	0.0000	0.85	0/83	0.0000	0.82
	Thursday	0.0001	0.70	0.68	0.0001	0.63
	Friday	0.0000	0.87	0.88	-0.0001	0.72
	F(5256)	0.1678	0.95	0.98	F(4964)	0.94
Futures Silver	Monday	-0.0005	0.29	0.34	0.0001	0.78
	Tuesday	-0.0001	0.88	0.88	-0.0004	0.27
	Wednesday	0.0002	0.65	0.63	0.0003	0.47
	Thursday	0.0007	0.11	0.10	0.0002	0.63
	Friday	-0.0005	0.31	0.28	-0.0004	0.21
	F(5256)	1.2845	0.29	0.42	F(4965)	0.60

TABLE 5 : NON - PARAMETRIC ANALYSIS OF DAILY SEASONALITY

	KW STATISTIC	SIGNIFICANCE
Cash Gold	4.029	0.40
Cash Silver	5.908	0.20
Futures Gold	0.750	0.00
Futures Silver	2.824	0.00

TABLE 6: LEVENE'S TEST FOR HOMOGENEITY OF VARIANCE

	LEVENE STAT	SIG.
Cash Gold	7.879	0.00
Cash Silver	3.524	0.01
Futures Gold	4.865	0.00
Futures Silver	3.251	0.01

TABLE 7: GARCH RESULTS FOR CASH GOLD AND SILVER

	CASH GOLD		CASH SILVER		FUTURES GOLD		FUTURE SILVER	
		p		p				
Mean Equation								
α	0.00002	0.95	-0.00052	0.53	-2.38820	0.54	-0.00004	0.99
β	-0.36620	0.09	-0.56130	0.01	0.82730	0.00	-0.96960	0.00
ϕ	-0.63200	0.14	-0.53780	0.02	0.84430	0.00	-0.97600	0.00
η	-0.34854	0.94	0.02580	0.69	0.00250	0.66	-0.01880	0.80
$\delta_{i(monday)}$	-0.00005	0.02	-0.00078	0.03				
Variance Equation								
γ_0	0.00001	0.00	0.00000	0.83	0.00001	0.00	0.00000	0.54
ψ	0.08930	0.00	0.07930	0.00	0.05990	0.00	0.06510	0.00
ω	0.92960	0.00	0.93470	0.00	0.95810	0.00	0.95110	0.00
υ	-0.05010	0.00	-0.04220	0.00	-0.03590	0.00	-0.04140	0.00
$\theta_{1(monday)}$	-0.00001	0.00	0.01484	0.01	-0.00001	0.00	0.00001	0.05
$\theta_{2(tuesday)}$	-0.00002	0.00	0.00000	0.61	0.00001	0.00	0.00001	0.24
$\theta_{3(wednesday)}$	-0.00001	0.00	-0.00001	0.30	-0.00001	0.00	-0.00001	0.26
$\theta_{4(thursday)}$	-0.00001	0.00	0.00000	0.68	-0.00001	0.00	0.00001	0.20
Diagnostics								
Variance Sum	0.96881		0.97180		0.98211		0.97480	
Likelihood Ratio	17,684.00		14,909.19		18,026.06		15,090.19	
Residual Skewness	-0.14254		-0.22000		0.14		-0.03001	
Residual Kurtosis	9.24343		5.91000		8.86		6.73000	
Q(4)								
Q(8)								
F(4)								

F(8)									
$Q^2(4)$									
$Q^2(8)$									
Sign Bias Test									
- Sign Bias Test									
+ Sign Bias Test									
Joint Sign and Size Bias Test									

Table shows the results of a GARCH(1,1) model of the following type

$$R_t = \alpha_0 + \beta R_{t-1} + \phi\mu_{t-1} + \eta\sqrt{h_t} + \sum_{j=1}^{n}\delta_j X_j + \mu_t; \mu_t = \sqrt{h_t \varepsilon_t}; \varepsilon_t \approx (0,1)$$

$$h_t = \gamma_0 + \psi h_{t-1} + \omega_i \mu_{t-1}^2 + \sum_{d=i}^{n}\theta_i^* X_i + \upsilon \mathrm{I}_{t-1}\mu_{t-1}^2; \begin{matrix} \mu_t < 0 \rightarrow \mathrm{I} = 1 \\ \mu_t < 0 \rightarrow \mathrm{I} = 0 \end{matrix}$$

FIGURE 1: GOLD PRICES 1982-2002

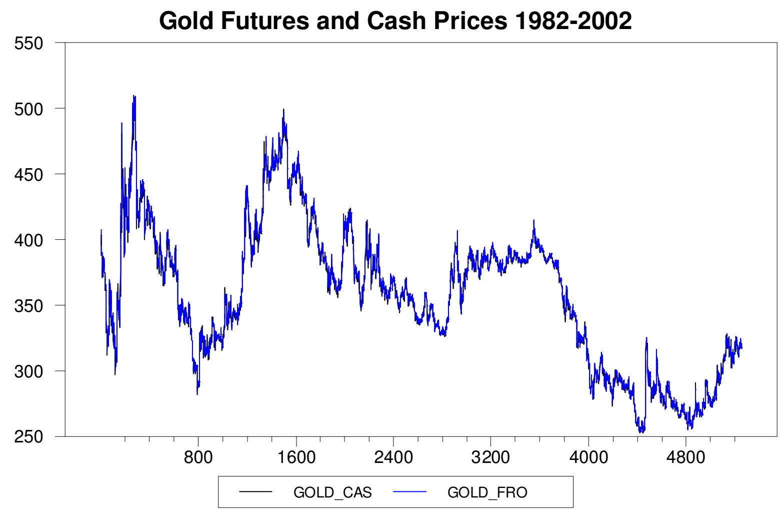


FIGURE 2 : SILVER PRICES 1982-2002

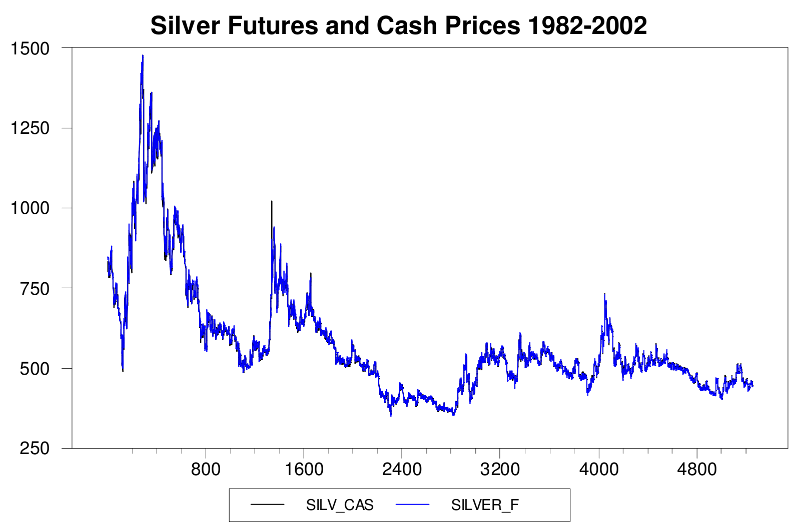


FIGURE 3 : DATA IN PERCENTAGE CHANGE

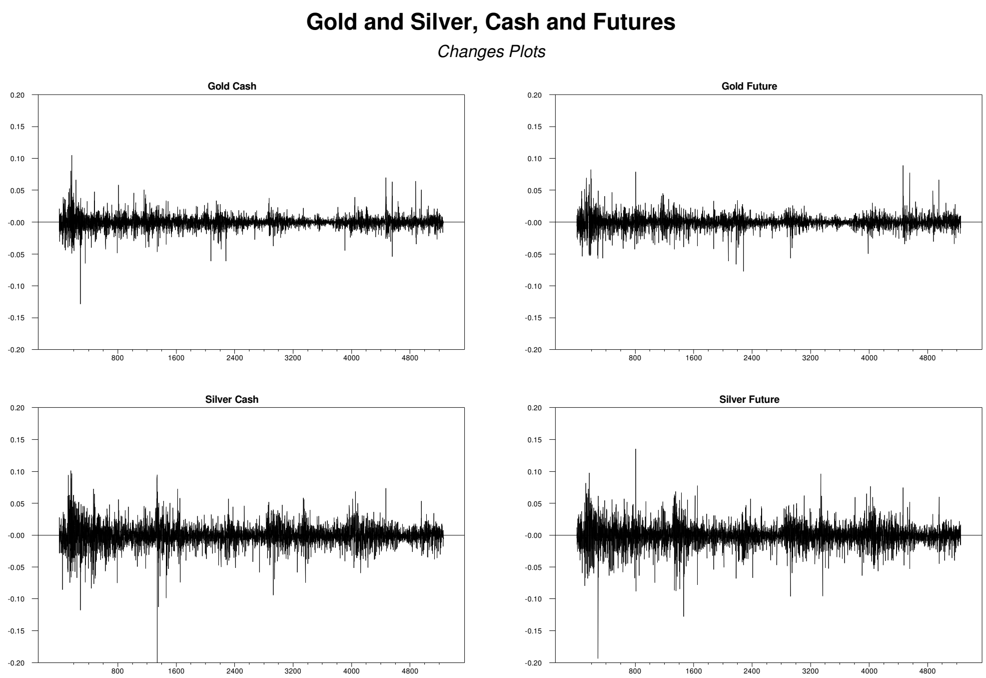


FIGURE 4: DATA RELATIVE CHANGES

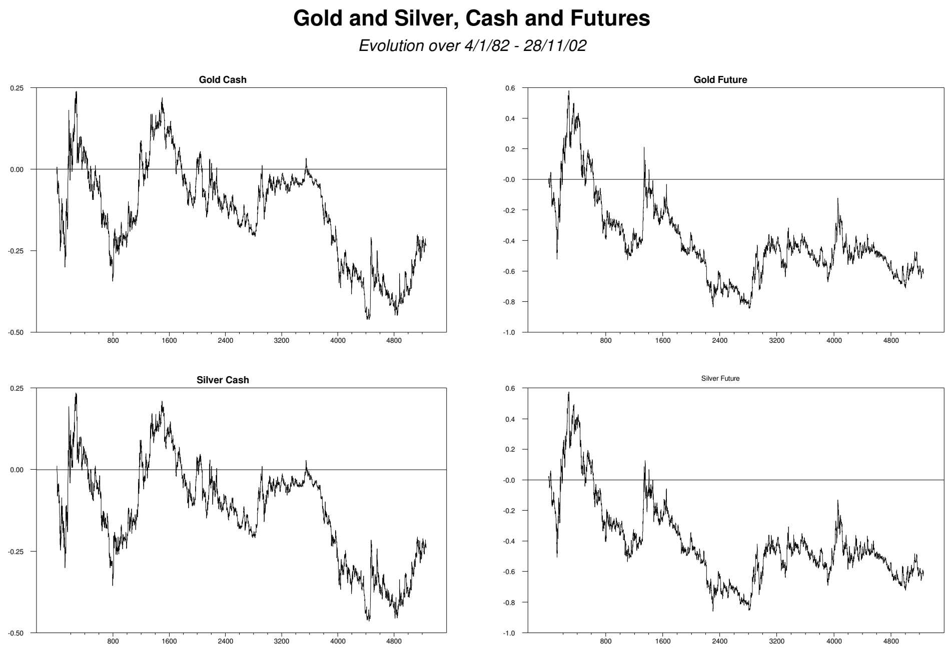
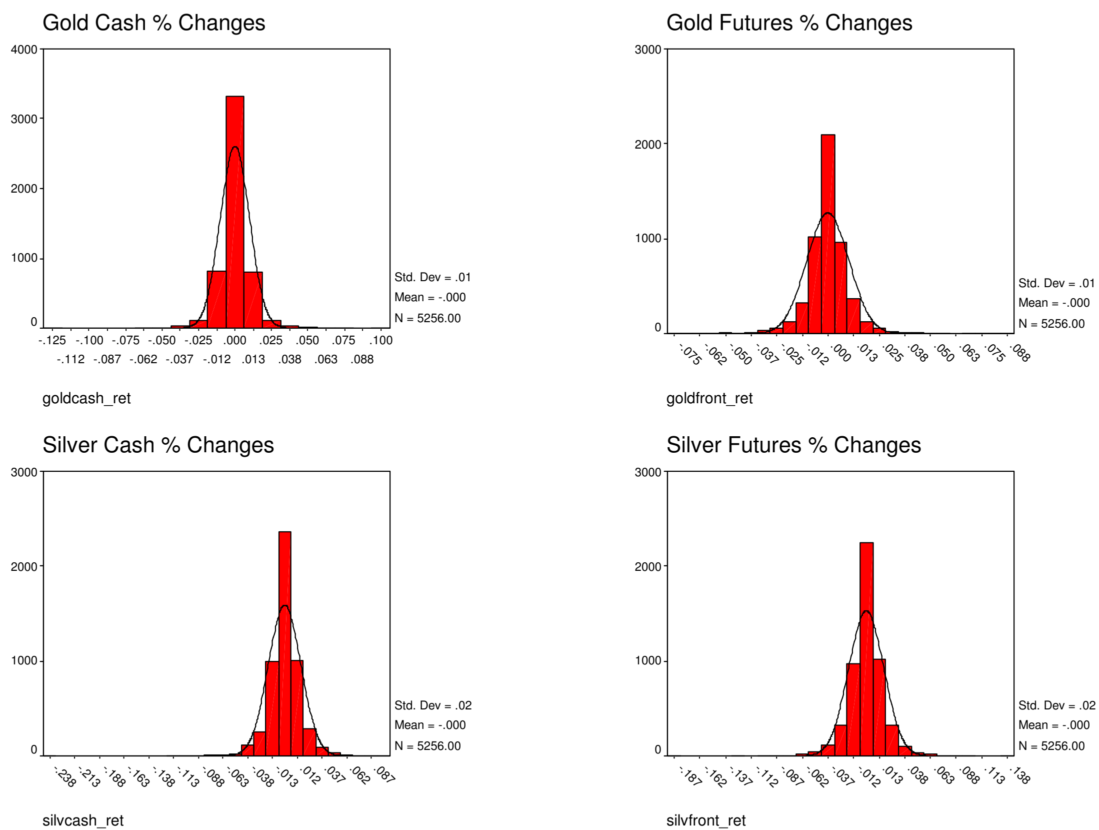


FIGURE 5 : HISTOGRAMS OF DATA PLUS NORMAL CURVE



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