LONDON GOLD PRICES AND STOCK PRICE INDICES IN EUROPE AND JAPAN

by

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February 2002

Abstract

This paper provides empirical evidence on the relationship between the price of gold and stock price indices for Europe and Japan for the period beginning in January 1991 and ending in October 2001. Three London gold prices and stock price indices for 17 European markets and Japan are used. The short-run correlation between returns on gold and returns on the stock price indices is frequently small and negative, for some series and time periods it is insignificantly different from zero and occasionally it is small and positive. All of the gold prices and stock price indices are I(1). Over the period examined, gold prices and stock price indices are not cointegrated. That is, there is no long-run equilibrium.

Keywords: Gold price, correlation coefficients, stock price indices, cointegration.

I. INTRODUCTION

When the economic environment becomes more uncertain attention turns to investing in gold as a safe haven. As stock prices fall, the gold price rises. For example, in the ten days following the catastrophic events of September 11, 2001 the FTSE All Share Index decreased by 9.0% in US$ terms. On September 21st, the gold price set in the London afternoon fixing was US$ 292.5 per troy ounce compared with US$ 271.5 per troy ounce on September 10th, an increase of 7.45%. Also, following the collapse of US energy group Enron, the price of gold rose above $300 an ounce—a much larger increase than in September 2001. Clearly, increased uncertainty associated with political events and increased financial risk are both associated with falling stock prices and higher gold prices.

This paper focuses on London gold prices, the prices of stocks in Europe and Japan and possible linkages between them. In work of this type, it is important to distinguish the short- and long-runs. The former is often examined with correlation coefficients or short-term linear relationships, the latter with tests of cointegration.

The potential gains to an investor from diversifying investments internationally, rather than only investing in a single country, are well-known from the work of, for example, Grubel (1968) and Lessard (1973). Potential gains from international portfolio diversification are determined by the covariation between asset returns on domestic and foreign markets. The same type of analysis can be used to examine the benefits of diversification between equities and gold. Suppose *G* is the price of gold and *S* is a stock price index (both in US$) and consider a diversified portfolio with proportions of stocks and gold p_s and p_g respectively with

$0 < p_s, p_g < 1$ and $p_s + p_g = 1$. The variance of the return on the diversified portfolio is given by

$$\operatorname{var}(p_s R_s + p_g R_g) = p_s^2 \operatorname{var}(R_s) + p_g^2 \operatorname{var}(R_g) + 2 r p_s p_g \sigma_{R_s} \sigma_{R_g} \qquad (1)$$

where $R_s = \Delta s = \Delta \ln S$

$R_g = \Delta g = \Delta \ln G$

$\sigma_{R_s}, \sigma_{R_g}$ are the standard deviations of stock and gold returns respectively and

r is the correlation coefficient, $-1 \leq r \leq 1$.

The extent to which diversification reduces risk depends on the magnitude of the correlation coefficient. If returns on stocks and gold are perfectly correlated, $r = 1$ and international diversification will not reduce risk. If the correlation between returns on these assets is positive and less than one then diversification reduces risk—but not completely. If returns on gold and stocks are negatively correlated then theoretically diversification can eliminate risk.

Correlations between returns focus on short-term association. Over the long term, the potential gains from diversification which might accrue to investors with longer holding periods are less if stock and gold prices are cointegrated. With nonstationary series that are cointegrated, long-run equilibrium relationships exist between them. The stochastic trends of the cointegrated equity and gold prices would be linked and the markets not move independently. In these circumstances, the potential gains from diversifying between stocks and gold depend on how closely prices are linked to the common trend.

The rest of this paper is organised as follows. Section II discusses the empirical methodology employed. Section III describes the data and their characteristics. In section IV the results are presented. Section V provides a brief conclusion.

II. METHODOLOGY

This paper focuses on the empirical evidence on short-run and long-run linkages between gold prices and stock price indices. Correlation coefficients are often used for examining short-run co-movements between stock price indices (see, for example, Peiró *et al*, 1998). They can also be used to examine short-run association between returns on gold and returns on stocks. A correlation coefficient measures the degree of linear association between two random variables. In work on financial markets, correlation coefficients are usually calculated between returns see: Kasa (1992), Byers and Peel (1993) and Lin, Engle and Ito (1994). The sample correlation coefficient is given by

$$r = \frac{\mathrm{cov}(R_g, R_s)}{\sigma_{R_g}\sigma_{R_s}}. \tag{2}$$

Suppose the population correlation coefficient is ρ. The first hypothesis to be tested is that the population correlation coefficient is zero against the two-tailed alternative that it is not. If ρ is zero, in large samples the random variable $\frac{1}{2}\ln\left(\frac{1+r}{1-r}\right)$ is normally distributed with mean zero and variance $\frac{1}{T-3}$ where T is the sample size. Therefore, the test statistic

$$\frac{\frac{1}{2}\ln\left(\frac{1+r}{1-r}\right)}{\sqrt{\frac{1}{T-3}}} \tag{3}$$

has an asymptotic standard normal distribution if the null hypothesis is true.

It is also useful to test whether correlation coefficients for two different time periods are equal. Kendall and Stewart (1961) show that for two independently sampled populations, $H_0\colon \rho_1 = \rho_2$ can be tested against $H_1\colon \rho_1 \neq \rho_2$. In large samples, the variable

$$\frac{1}{2}\ln\frac{1 + r_1}{1 - r_1} - \frac{1}{2}\ln\frac{1 + r_2}{1 - r_2} \tag{4}$$

where r_1 and r_2 are the sample correlation coefficients for periods 1 and 2 respectively, is normally distributed with zero mean and variance $1/(T_1 - 3) + 1/(T_2 - 3)$ where T_1 and T_2 are the sample sizes for periods 1 and 2 respectively. Therefore, The test statistic

$$\frac{\frac{1}{2}\ln\left[\frac{(1 + r_1)}{(1 - r_1)}\frac{(1 - r_2)}{(1 + r_2)}\right]}{\sqrt{\frac{1}{T_1 - 3} + \frac{1}{T_2 - 3}}} \tag{5}$$

has an asymptotic standard normal distribution under the null hypothesis of equal correlation coefficients in periods 1 and 2.

Cointegration tests are used to identify possible long-run relationships. Consider two time series which are integrated of order one, I(1). Suppose there is a causal relationship between them. Although the two series are changing through time, they tend not to drift away from each other in the longer term. That is, there is equilibrium between the long-run components of these series and they share a common stochastic trend. That is, they are cointegrated. Before testing for cointegration, it is necessary to establish the order of integration of the series. Are the series I(1)? Phillips and Perron (1988) unit root tests are used to examine orders of integration on the logarithms of the series, *g* and *s*. These tests are implemented sequentially from the general model which includes both an intercept and time trend

$$y_t = \mu_1 + \beta_1\left(t - \frac{T}{2}\right) + \alpha_1 y_{t-1} + \epsilon_{1t} \tag{6}$$

to the more specific model which has an intercept but no time trend

$$y_t = \mu_2 + \alpha_2 y_{t-1} + \epsilon_{2t} \tag{7}$$

and the model with neither intercept nor trend

$$y_t = \alpha_3 y_{t-1} + \epsilon_{3t}. \tag{8}$$

By making non-parametric corrections to test statistics, Phillips-Perron tests allow for possible autocorrelation and heteroscedasticity in the residuals of the regression on which the test is based. Both of these characteristics are frequently found in financial time series.

With only two variables under consideration in any one test, the Engle-Granger approach is used to test for the existence of a long-run equilibrium relationship between I(1) gold prices and stock price indices. This is based on the equation

$$s_t = \alpha_0 + \beta_0 g_t + \epsilon_t \tag{9}$$

where s_t and g_t are the logarithms of a stock price index and gold price at time *t* and ϵ_t is the disequilibrium error, that is, the deviation from long-run equilibrium. Conventional, cointegrating regression augmented Dickey-Fuller tests are used to test the null hypothesis of no cointegration. The test regression is

$$\Delta e_t = \alpha e_{t-1} + \delta_1 \Delta e_{t-1} + \ldots + \delta_m \Delta e_{t-m} + u_t \tag{10}$$

where the $\{e_t\}$ are the residuals from the OLS regression (9) and the test statistic is the '*t*' statistic for the test of the hypothesis that $\alpha = 0$. The Schwarz Bayesian Criterion is used to select *m* and hence the test statistic.

If s_t and g_t are cointegrated then they are generated by error-correction models (ECMs) of the form

$$R_{g,t} = \alpha_1 + \sum_{j=1}^{n} \beta_{1j} R_{g,t-j} + \sum_{j=1}^{n} \gamma_{1j} R_{s,t-j} + \lambda_1 w_{g,t-1} + v_{g,t} \tag{11}$$

and

$$R_{s,t} = \alpha_2 + \sum_{j=1}^{n} \beta_{2j} R_{s,t-j} + \sum_{j=1}^{n} \gamma_{2j} R_{g,t-j} + \lambda_2 w_{s,t-1} + v_{s,t} \tag{12}$$

in which $R_{g,t} = g_t - g_{t-1}$, $R_{s,t} = s_t - s_{t-1}$, the $v_{i,t}$ are stationary disturbances and the $w_{i,t-1}$ error-correction terms. The ECMs capture both short- and long-run effects. The coefficients on lagged returns in equations (11) and (12), γ_{1j} and γ_{2j}, represent the short-run elasticities of $R_{g,t}$ and $R_{s,t}$ with respect to $R_{s,t}$ and $R_{g,t}$ respectively. The respective long-run elasticities are obtained from cointegrating regressions of the type given by equation (9). The coefficients on the disequilibrium errors, λ_1 and λ_2, measure the speed of adjustment of g_t and s_t respectively to the error in the previous period. With cointegration, at least one of the $\lambda_i \neq 0$. If the series are both I(1) and not cointegrated then there is no long-run equilibrium relationship between them. The regression in levels of g_t on s_t is spurious and $\lambda_1 = \lambda_2 = 0$.

III. THE DATA AND THEIR PROPERTIES

Three London gold prices and twenty-three stock price indices are used. The gold prices are those set at the 10.30 am and 3 pm fixings held at the offices of N. M. Rothschild & Sons in the City of London and the closing price. All of them are expressed in US$ per troy ounce.

A wide variety of stock price indices is used. They cover markets in Japan and Europe (both within and outside the euro zone). In general, widely quoted indices have been selected—two for each of the five largest markets by end-1998 capitalisation (Japan, UK, Germany, France and Switzerland) and one for each of thirteen smaller markets (Netherlands, Italy, Spain, Sweden, Belgium, Finland, Denmark, Greece, Portugal, Norway, Austria, Turkey and Ireland).[1] Of the seventeen European markets, eleven now use the euro.

The two indices covering Japan are the Nikkei 225 Stock Average and the Tokyo Stock Exchange Price Index (TOPIX). The former tracks the performance of 225 actively traded stocks listed on the Tokyo Stock Exchange's First Section. The First Section consists of larger companies which have generally operated for at least five years and satisfy size and liquidity criteria. Like the Dow Jones Industrial Average for the US, the Nikkei 225 is price-weighted and so a change in the price of a stock with a relatively high price changes the average more than the same change in the price of a relatively low-priced stock. The TOPIX is a broadly-based index which tracks the performance of all domestic common stocks listed on the First Section. It has capitalisation weights; for each stock, the price is multiplied by the number of shares outstanding. Hence, the larger the capitalisation of a company, the greater the weight the stock has in the index regardless of whether the share price alone is high or low.

For the four largest European markets by capitalisation, two stock indices are used. The Financial Times-Stock Exchange 100 (FTSE 100) tracks the prices of the 100 largest capitalisation stocks traded on the London Stock Exchange. The FTSE Actuaries All Share Index covers the prices of all stocks which are sufficiently liquid to be included, approximately 99% of the UK market. Stocks on the Frankfurt Stock Exchange in Germany are covered here by the Frankfurter Allgemeinen Zeitung

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[1] Stock markets are listed in order of decreasing market capitalisation at the end of 1998.

(FAZ) Aktienindex which tracks the *prices* of 100 large capitalisation, actively traded stocks and the DAX 100 tracks the *total return* of 100 liquid large capitalisation stocks. For France, the CAC 40 (Cotation Automatique Continue) and SBF-250 are used. The former covers the performance of 40 French stocks traded on the Paris Stock exchange, accounting for approximately 60% of market capitalisation. The 250 shares covered by the SBF-250 covers approximately 95% of the domestic stock market. The Swiss Market Index (SMI) covers the prices of the largest and most liquid Swiss stocks traded on the Basle, Geneva and Zurich stock exchanges. It includes approximately 24 stocks. The Swiss Performance Index (SPI) tracks the prices of all securities listed on the main and official parallel markets of these exchanges.

The Central Bureau of Statistics (CBS) All Share Index which covers the prices of all Dutch stocks, excluding investment and property funds, traded on the Amsterdam Stock Exchange is used for the Netherlands. For Italy, the Banca Commerciale Italiana (BCI) All Share index, which monitors the prices of all stocks traded on the Milan Stock Exchange is used. The Madrid General Index covers the prices of actively traded, large capitalisation stocks listed on the Madrid Stock Exchange. For Sweden, the Affarsvarlden All Share Index, which tracks the prices of all equities listed on the Stockholm Stock Exchange, is used. The Belgian (BEL) 20 Index follows the prices of 20 actively traded Belgian companies listed on the Brussels Stock exchange. For Finland, the HEX General Index is used. This tracks the prices of all stocks traded on the Helsinki Stock Exchange. The Copenhagen Stock Exchange (KFX) Index covers the prices of 20 actively traded domestic stocks listed on the Copenhagen Stock Exchange which account for approximately half of total market capitalisation. The Athens General tracks the prices of 65 large capitalisation stocks listed on the Athens Stock Exchange. The PSI 30 tracks 30 of the largest and most actively traded stocks on the Lisbon Stock Exchange. The Oslo Stock Exchange All Share *total return* index is used for Norway. The Austrian Traded Index (ATX) covers the prices of the largest, most actively traded domestic stocks listed on the Vienna Stock Exchange; they account for approximately 70% of turnover. The Istanbul Stock Exchange (ISE) 100 Index tracks the prices of 100 liquid, large capitalisation stocks accounting for approximately 85% of total market capitalisation. The Irish Stock Exchange Equity Price (ISEQ) Index covers the prices of all stocks, except investment funds and companies registered in the UK, that are traded on the Irish Stock Exchange.

All indices except the Nikkei 225 have capitalisation weights. The data begin in January 1991 and end in October 2001 and, where appropriate, daily, weekly and monthly frequencies are used.[2] The source is *EcoWin*.

All stock market indices are expressed in a common currency, the US$, for comparability with the London gold prices. This removes exchange rate risk from the empirical analysis. For each of the seven non-euro countries, the underlying currency of the stock price index is in local terms. It is adjusted using a local currency to US$ exchange rate. For countries which now use the euro, the adjustment is different. Consider the CAC40. For the period before €-day on 1 January 1999, the underlying currency for this stock price index is the French Franc and so the series is adjusted to US$ terms by using the FF to US$ exchange rate. On 1 January 1999, the euro was introduced as a legal currency and the exchange rates of the 11 participating

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[2] The ATX data begin in 1992.

currencies were irrevocably set. For the period from 1 January 1999, the underlying currency is the € and the stock price index is adjusted to US$ terms by using the US$ to € European Central Bank exchange rate. The level of the series from 1 January 1999 is larger by a factor equal to the FF to € fixed conversion rate of 6.55957 on 31 December 1998 and this is used to adjust the level of the observations from 1 January 1999. A similar procedure was used for the other nine countries for which local currency to euro exchange rates were fixed at the end of 1998. The stock price index for the Athens Stock Exchange was treated separately using the drachma to euro exchange rate fixed on 31 December 2000.

Table 1 reports summary statistics for daily returns. For the three gold prices, average returns are negative. For the stock price indices, they are positive for all markets except those in Japan, Austria and Turkey which have negative average returns. Under the hypothesis that returns are normally distributed, the coefficient of skewness is asymptotically distributed as $\mathrm{N}(0, 6/T)$ where T is the sample size. The distributions of returns on gold and the Tokyo and Athens stock markets are skewed to the right. For all of the other equity markets, the distributions of returns are negatively skewed. Under normality, the coefficient of excess kurtosis asymptotically follows a $\mathrm{N}(0, 24/T)$ distribution. For all of the series considered here, the distributions of daily returns are leptokurtic; that is, they have higher peaks about the mean and thicker tails than the normal distribution. The evidence clearly rejects the hypothesis that daily returns on gold and stock price indices in Japan and Europe are normally distributed.[3]

[3] Descriptive statistics for weekly and monthly returns, not reported here, show similar nonnormal characteristics.

IV. RESULTS

Table 2D reports 72 contemporaneous correlation coefficients for daily returns for the entire period. All of them are small in magnitude and only 22 are significantly different from zero at the 0.05 level; 17 of these are negative and 5 (involving stock markets in Japan and Portugal) positive.[4] The latter is the only significant coefficient involving returns on the price set in the morning fixing. A useful perspective is gained by comparing these figures with comparative correlation coefficients between equity returns. The sample correlation coefficient between returns on the Tokyo TOPIX and FTSE All Share Index is 0.2425, the DAX 100 and FTSE All Share Index coefficient is 0.6060 and DAX 100 and SBF 250 coefficient is 0.7591.

With 2826 observations even correlation coefficients which are very small can be significantly different from zero.[5] It is not particularly surprising therefore that fewer significant correlation coefficients are found with weekly and monthly returns. Table 2W reports contemporaneous correlation coefficients for weekly returns over the same sample period. Only 2 of the 72 estimates are significantly different from zero and these involve the Lisbon PSI 30 and Istanbul Stock Exchange 100 indices. Not even one of the 72 correlation coefficients for monthly returns, reported in Table 2M, is significantly different from zero.

In considering whether contemporaneous or lagged correlations should be examined, it is necessary to view price interactions from two perspectives (i) as a possible effect from stock returns to gold returns and (ii) from gold returns to stock

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4 Similar results are obtained with an ARCH model and those for the FTSE100 are reported in the Appendix.

5 The test statistic (3) can be written as $\sqrt{T - 3}\left[\frac{1}{2}\ln\left(\frac{1 + r}{1 - r}\right)\right]$.

returns. These are discussed first for the Tokyo and, secondly, for the European stock price indices.

The trading times of the London gold market and Tokyo stock market do not overlap. Consider times in GMT and the 24 hour period ending with the London gold closing price at 17.00. This period includes the closing values of the Nikkei 225 and Topix stock price indices at 06.00. There may be contemporaneous correlations between daily returns on these and returns calculated for the three London gold prices. Now consider a perspective from Japan. Tokyo's day *t* determining period spans the 24 hour period ending at 06.00 GMT. This includes the previous day's three London gold prices. Returns on yesterday's gold prices may be correlated with returns on today's Tokyo closing prices. However, with successive gold prices becoming available, the information conveyed in an earlier gold price is superceded. For the Tokyo market, the information contained in yesterday's London closing price is the most recent and it is with this that the strongest effect might be expected.

The trading times of the European markets overlap. Consider, first, the 24 hour period ending with the gold price determined at the 10.30 fixing—its day *t* determining period. This includes all of the previous day's closing values for the European stock price indices. Returns on yesterday's stock price indices may be correlated with returns on today's 10.30 gold price. The day *t* determining period for the gold price set in the afternoon fixing covers the day *t* closing values of the stock price indices in Belgium, Finland, Denmark, Greece, Portugal and Austria and the previous day's closing values in the stock markets of the following eleven countries: UK, Germany, France, Switzerland, The Netherlands, Italy, Spain, Sweden, Norway, Turkey and Ireland. Similarly, the day *t* determining period for the 17.00 London closing price for gold covers day *t* closing prices in all stock markets except those in Germany and Ireland for which the previous day's closing price falls within range.

Now consider day *t* determining periods from the perspective of the closing values of the stock price indices. For the stock markets in Germany and Ireland, this covers all three of today's gold prices. For the stock markets in the following nine countries, it includes both of the gold prices set in today's fixings and yesterday's closing price: UK, France, Switzerland, The Netherlands, Italy, Spain, Sweden, Norway and Turkey. The day *t* determining period for the following equity markets spans the gold price set in today's morning fixing and yesterday's prices set in the afternoon fixing and at closing: Belgium, Finland, Denmark, Greece, Portugal and Austria.

Table 3D reports correlation coefficients between London gold returns in day *t* and returns on stocks in day *t*-1. It is based on the notion that causality (in the Granger sense of precedence in time) runs from stock returns to gold returns. There is relatively little evidence of significant correlation between returns on the gold price set in the morning fixing and returns on yesterday's closing prices in the major European stock markets. The correlation coefficients involving returns on gold prices set later in the day are significant and positive. They are, however, very small—typically one-tenth of the size of the correlation coefficient between returns on two stock market indices.

Table 4D reports correlation coefficients stock returns in day *t* and returns on gold in day *t*-1. This is based on Granger-causality running from gold returns to stock returns. The correlation coefficients between returns on gold prices set at 15.00 and 17.00 GMT yesterday and returns on the closing prices of Tokyo stock market indices at 06.00 today are negative, small and significantly different from zero at the 0.05 level. All other reported correlation coefficients are insignificantly different from zero.

Table 5D reports contemporaneous correlation coefficients for daily returns with the sample split into two equal subperiods, periods 1 and 2. Period 1 begins on 2 January 1991 and ends on 29 December 1995 (1303 observations); period 2 starts on 1 January 1996 and ends on 31 October 2001 (1523 observations). For the major European markets, sample correlation coefficients are negative and significant in period 1 and zero in period 2, irrespective of the particular gold price used. For three stock markets, those in Tokyo, Athens and Oslo, sample correlation coefficients are zero or negative in period 1 and significant and positive in period 2 when returns on the afternoon fixing and closing gold prices are used. For these three markets, correlation coefficients are insignificantly different from zero in period 2. For the smaller European stock markets, correlation coefficients are often zero (for example, Denmark, Turkey and Ireland) but Portugal is an exception. The hypothesis of equal correlation coefficients for the two subperiods is rejected for Japan irrespective of the particular gold price and also for many European stock markets, particularly the larger capitalisation ones and returns involving the gold prices set in the morning and afternoon fixings.

In summary, the weight of the evidence for the last decade is that the short-run contemporaneous correlation between returns on gold and European stock price indices is generally small and negative and often insignificantly different from zero, but occasionally it is small and positive. When positive, it is typically one-tenth of the size of the sample correlation coefficient between returns on the FTSE All Share and

DAX 100 indices over the same period. For Japan, there is evidence of zero or small and positive contemporaneous correlation coefficients (Tables 2D, 2W, 2M and 5D) and small negative correlations involving lagged gold returns (Table 4D).

If the logarithms of gold prices and a stock price indices are generated by difference stationary processes then there is the possibility of a long-run equilibrium relationship among them—that is, they may be cointegrated. Phillips-Perron unit root tests are used to investigate the time series characteristics of the series and, in particular, examine orders of integration. Preliminary results, not reported here, test the hypothesis that the logarithm of each series is I(2) against the alternative that it is I(1). The null hypothesis is always rejected. Tests that each series is I(1) against the alternative of I(0) are reported for daily data in Table 6D. Tests are carried out sequentially beginning with the general model

$$g_t = \mu_1 + \beta_1\left(t - \frac{T}{2}\right) + \alpha_1 g_{t-1} + \epsilon_{1t} \tag{13}$$

for which $Z(\alpha_1)$, $Z(t\alpha_1)$ are the normalized coefficient and *t*-tests for $H_0\!: \alpha_1 = 1$, $Z(t\beta_1)$ is the *t*–statistic for the test $H_0\!: \beta_1 = 0$, $Z(t\mu_1)$ is the *t*-test for $H_0\!: \mu_1 = 0$ and $Z(\Phi_3)$, $Z(\Phi_2)$ are the regression *F*-tests for $H_0\!: \alpha_1 = 1, \beta_1 = 0$ and $H_0\!: \alpha_1 = 1, \beta_1 = 0, \mu_1 = 0$ respectively. When $\beta_1 = 0$, we have the regression equation

$$g_t = \mu_2 + \alpha_2 g_{t-1} + \epsilon_{2t} \tag{14}$$

Here, $Z(\alpha_2)$, $Z(t\alpha_2)$ test $H_0\!: \alpha_2 = 1$, $Z(t\mu_2)$ is the *t*-test for $H_0\!: \mu_2 = 0$ and $Z(\Phi_1)$ is the regression *F*-test of $H_0\!: \alpha_2 = 1, \mu_2 = 0$. Perron (1988) notes that the test statistics based on this model are not invariant with respect to the drift parameter and are appropriate only if $Z(\Phi_2)$ does not reject $H_0\!: \alpha_1 = 1, \beta_1 = 0, \mu_1 = 0$. If a series has zero mean then the following restricted regression may be more appropriate

$$g_t = \alpha_3 g_{t-1} + \epsilon_{3t} \tag{15}$$

for which $Z(\alpha_3)$, $Z(t\alpha_3)$ test $H_0\!: \alpha_3 = 1$. Not one of the test statistics in Table 6D is significant and so the evidence from these Phillips-Perron unit root tests can be summarised concisely: all of the series are generated by difference stationary processes and are I(1).

Test of cointegration are used to establish whether there is long-run equilibrium between a set of nonstationary time series which are generated by difference stationary processes. In the present context, is a linear combination of nonstationary gold and stock price series stationary? A number of tests are available. However, since pairwise tests of cointegration between a single gold price and a single stock price index are relevant, Engle-Granger tests are useful.

Table 7D reports results for tests which use the logarithm of the gold price set in the afternoon fixing. These statistics are obtained from sets of cointegrating-regression augmented Dickey-Fuller tests generated with the number of lagged dependent variables *m* sequentially taking values from zero to twelve lagged. The Schwarz Bayesian Criterion is used to select the reported test statistics. The first two results report tests of cointegration between the gold prices. There is clear evidence of pairwise cointegration between (i) the two gold prices set in the morning and afternoon fixings and (ii) the price set in the afternoon fixing and the closing price.[6] Since the gold prices are cointegrated it is only necessary to use one of them in tests of cointegration involving each of the stock price indices. For the five largest stock

[6] Further tests of multivariate cointegration using the Johansen maximum likelihood approach with VAR(1) find two cointegrating vectors among the three London gold prices. That is, the three gold prices share one common trend and are integrated in a long-run statistical sense.

markets, two stock price indices are used. Preliminary tests of cointegration between these pairs of stock price indices for each of these five markets, not reported here, did not reject the null hypothesis of no cointegration. The coverage of, for example, the FTSE100 and FTSE All-Share indices is sufficiently different for there to be no long-run equilibrium between them over the period under consideration.

Not one of the tests between a stock market price index and the gold price set in the afternoon fixing rejects the non-cointegration null hypothesis and so there is no long-run equilibrium between gold prices and the stock price indices for the Tokyo and European stock markets considered here.[7] Given that two stock price indices for the same market are not cointegrated, it is not surprising that a stock price index and the gold price are not cointegrated.

V. CONCLUSIONS

For the period beginning in January 1991 and ending in October 2001 empirical evidence is examined on the relationship between the price of gold and stock price indices for markets in Europe and Japan. Three gold prices set in London and 23 stock price indices for 18 countries are used. The short-run correlation between returns on gold and returns on US stock price indices is small and negative and for some series and time periods insignificantly different from zero. Occasionally it is small and positive—but typically only one-tenth of the magnitude of the sample correlation coefficient between returns on the FTSE All Share and DAX 100 indices. All of the gold price and stock price indices are I(1). Over the period examined, there

[7] Further tests using data of different frequencies are not reported since it is data span, rather than frequency of observation, which is important in determining the power of cointegration tests (Otero and Smith, 2000).

is no cointegration involving a gold price and a stock price index. That is, there is no long-run equilibrium and the series do not share a common stochastic trend. Only weak short-run relationships are evident.

APPENDIX

Consider the model

$$R_{s,t} = \beta_0 + \beta_1 R_{g,t} + u_t \tag{A1}$$

where $u_t | \Psi_{t-1} \sim N(0, h_t)$. (A2)

The variance of the error term is positively related to the size of previous errors, that is, it depends on past volatilities,

$$h_t = \alpha_0 + \alpha_1 u_{t-1}^2 . \tag{A3}$$

The variance of u_t is in part constant and partly depends on last period's news about volatility (modelled as last period's squared residual, the ARCH term). When u_{t-1}^2 is large, the variance of the next innovation is large. Using returns on the FTSE 100 and gold price set in the afternoon fixing we have the following regressions.

	β_0	β_1	α_0	α_1	R^2
OLS	0.0002	–0.0645			0.0021
t	1.00	–2.46			
ARCH(1)	0.0004	–0.0514	0.0001	0.1924	0.0018
t	1.90	–1.90	34.68	8.07	

The first regression is estimated by OLS and this underlies the result reported in Table 2D. The correlation coefficient of –0.0462 reported in that table is the (negative) square root of R^2 reported here. ARCH estimation generates similar estimates for the βs and R^2.

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Table 1D Summary Statistics for Daily Returns

	Gold			Japan		UK		Germany	
	AM Fixing	PM Fixing	Closing	Nikkei 225	TOPIX	FTSE100	All Share	FAZ Aktien	DAX100
Mean	–0.0001	–0.0001	–0.0001	–0.0003	–0.0001	0.0002	0.0002	0.0002	0.0003
Standard Deviation	0.0078	0.0074	0.0071	0.0163	0.0143	0.0103	0.0094	0.0131	0.0128
Skewness	1.6190	0.7150	0.5535	0.2958	0.3210	–0.1363	–0.1983	–0.7105	–0.6277
Excess Kurtosis	21.9916	13.1918	16.3580	3.2691	3.7211	1.9856	2.4001	7.4942	7.1402
Jarque-Bera	58,161.6	20,724.8	31,641.1	1299.6	1679.0	473.0	696.8	6851.0	6188.8

	France		Switzerland		Netherlands	Italy	Spain	Sweden	Belgium
	CAC 40	SBF 250	SMI	SPI Gen	CBS All Sh	BCI	Madrid	Affars	BEL 20
Mean	0.0002	0.0002	0.0004	0.0004	0.0004	0.0001	0.0002	0.0003	0.0002
Standard Deviation	0.0128	0.0112	0.0112	0.0101	0.0108	0.0141	0.0127	0.0142	0.0105
Skewness	–0.2553	–0.3886	–0.2023	–0.2844	–0.3759	–0.3824	–0.3636	–0.1591	–0.5300
Excess Kurtosis	3.8739	4.5699	4.3882	4.5260	4.0543	3.2587	4.9361	4.2706	7.5821
Jarque-Bera	1797.8	2530.2	2286.8	2450.1	2002.0	1319.3	2931.2	2159.4	3462.2

	Finland	Denmark	Greece	Portugal	Norway	Austria	Turkey	Ireland
	HEX Gen	KFX	Athens Gen	PSI 30	Oslo All Sh	ATX	ISE 100	ISEQ
Mean	0.0005	0.0003	0.0002	0.0004	0.0002	–0.0001	–0.0002	0.0004
Standard Deviation	0.0195	0.0113	0.0185	0.0115	0.0123	0.0116	0.0353	0.0105
Skewness	–0.5300	–0.2910	0.1194	–0.2719	–0.5032	–0.2681	–0.1481	–0.1395
Excess Kurtosis	7.5821	3.3305	3.0882	3.6214	7.5916	2.5192	5.1408	3.0446
Jarque-Bera	6901.6	1346.0	1123.0	1286.3	6905.4	4734.8	3122.2	1100.6

Notes: The standard errors of the coefficients of skewness and excess kurtosis under the hypothesis of normality are 0.046 and 0.092 respectively. The .05 critical value for the Jarque-Bera test is 5.99.

Table 2D Correlation Coefficients for Daily Returns, January 1991 – October 2001

	Japan		UK		Germany		France	
	Nikkei 225	TOPIX	FTSE100	All Share	FAZ Aktien	DAX100	CAC 40	SBF 250
AM Fixing	–0.0050	0.0031	–0.0163	–0.0198	–0.0337	–0.0244	–0.0092	–0.0081
P M Fixing	0.0673*	0.0748*	–0.0462*	–0.0420*	–0.0105	–0.0506*	–0.0631*	–0.0523*
Closing	0.0882*	0.0979*	–0.0636*	–0.0554*	–0.0092	–0.0594*	–0.0853*	–0.0738*

	Switzerland		Netherlands	Italy	Spain	Sweden	Belgium	Finland
	SMI	SPI Gen	CBS All Sh	BCI	Madrid Gen	Affars	BEL 20	HEX
A M Fixing	–0.0023	0.0012	0.0106	–0.0319	–0.0046	–0.0204	0.0122	0.0136
P M Fixing	–0.0319	–0.0201	–0.0356	–0.0172	–0.0320	–0.0225	–0.0167	0.0226
Closing	–0.0355	–0.0224	–0.0387*	–0.0103	–0.0458*	–0.0337	–0.0371*	0.0195

	Denmark	Greece	Portugal	Norway	Austria	Turkey	Ireland
	KFX	Athens Gen	PSI 30	Oslo All Sh	ATX	ISE 100	ISEQ
A M Fixing	–0.0019	–0.0028	0.0524*	–0.0273	–0.0074	–0.0177	–0.0155
P M Fixing	–0.0054	0.0328	0.0387	–0.0005	–0.0118	–0.0486*	–0.0165
Closing	0.0082	0.0312	0.0211	0.0136	–0.0033	–0.0377*	–0.0186

Notes: The asymptotic standard errors are 0.0188.
*Significantly different from zero at the 0.05 level

Table 2W Correlation Coefficients for Weekly Returns, January 1991 – October 2001

	Japan		UK		Germany		France	
	Nikkei 225	TOPIX	FTSE100	All Share	FAZ Aktien	DAX100	CAC 40	SBF 250
AM Fixing	–0.0096	0.0061	–0.0433	–0.0400	0.0070	–0.0389	–0.0553	–0.0499
P M Fixing	–0.0103	0.0251	–0.0386	–0.0367	0.0134	–0.0076	–0.0458	–0.0391
Closing	–0.0077	0.0185	–0.0363	–0.0344	0.0444	–0.0195	–0.0232	–0.0172

	Switzerland		Netherlands	Italy	Spain	Sweden	Belgium	Finland
	SMI	SPI Gen	CBS All Sh	BCI	Madrid Gen	Affars	BEL 20	HEX
A M Fixing	–0.0014	0.0086	–0.0363	–0.0109	–0.0146	–0.0618	–0.0187	0.0181
P M Fixing	–0.0011	0.0098	–0.0141	–0.0102	–0.0081	–0.0630	0.0004	0.0120
Closing	–0.0166	0.0287	–0.0001	0.0022	0.0011	–0.0426	0.0014	0.0301

	Denmark	Greece	Portugal	Norway	Austria	Turkey	Ireland
	KFX	Athens Gen	PSI 30	Oslo All Sh	ATX	ISE 100	ISEQ
A M Fixing	0.0370	0.0337	0.0646	0.0112	0.0347	–0.0886*	0.0097
P M Fixing	0.0416	0.0390	0.0754	0.0173	0.0423	–0.0762	0.0113
Closing	0.0366	0.0497	0.0970*	0.0234	0.0601	–0.0609	0.0203

Notes: The asymptotic standard errors are 0.0421.
*Significantly different from zero at the 0.05 level

Table 2M Correlation Coefficients for Monthly Returns, January 1991 – October 2001

	Japan		UK		Germany		France	
	Nikkei 225	TOPIX	FTSE100	All Share	FAZ Aktien	DAX100	CAC 40	SBF 250
AM Fixing	0.1112	0.1564	–0.0149	–0.0222	–0.0218	–0.0394	–0.0824	–0.0614
P M Fixing	0.1066	0.1524	–0.0140	–0.0220	–0.0249	–0.0460	–0.0733	–0.0535
Closing	0.1212	0.1659	–0.0182	–0.0281	–0.0409	–0.0378	–0.0819	–0.0637

	Switzerland		Netherlands	Italy	Spain	Sweden	Belgium	Finland
	SMI	SPI Gen	CBS All Sh	BCI	Madrid Gen	Affars	BEL 20	HEX
A M Fixing	0.0012	0.0267	0.0021	–0.0573	–0.0643	0.0075	0.0667	0.0628
P M Fixing	0.0062	0.0298	–0.0021	–0.0741	–0.0796	0.0189	0.0699	0.0449
Closing	–0.0086	0.0148	–0.0139	–0.0757	–0.0918	0.0321	0.0694	0.0412

	Denmark	Greece	Portugal	Norway	Austria	Turkey	Ireland
	KFX	Athens Gen	PSI 30	Oslo All Sh	ATX	ISE 100	ISEQ
A M Fixing	–0.0365	0.0730	0.0381	–0.0034	0.0417	–0.0013	0.0154
P M Fixing	–0.0415	0.0506	0.0202	–0.0038	0.1102	–0.0103	0.0091
Closing	–0.0471	0.0459	0.0141	0.0003	0.08214	–0.0192	–0.0036

Notes: The asymptotic standard errors are 0.0887.
*Significantly different from zero at the 0.05 level

Table 3D Correlation Coefficients for Daily Returns Using Previous Day's Stock Price Indices, January 1991 – October 2001

	Japan		UK		Germany		France	
	Nikkei 225	TOPIX	FTSE100	All Share	FAZ Aktien	DAX100	CAC 40	SBF 250
AM Fixing			–0.0096	0.0001	0.0694*	0.0255	–0.0101	0.0016
P M Fixing			0.0472*	0.0515*	0.0777*	0.0655*	0.0598*	0.0622*
Closing					0.0746*	0.0937*		

	Switzerland		Netherlands	Italy	Spain	Sweden	Belgium	Finland
	SMI	SPI Gen	CBS All Sh	BCI	Madrid Gen	Affars	BEL 20	HEX
A M Fixing	0.0110	0.0211	0.0285	0.0571	0.0126	0.0223	0.0180	0.0366
P M Fixing	0.0416*	0.0445*	0.0787*	0.0688*	0.0667*	0.0392*		
Closing								

	Denmark	Greece	Portugal	Norway	Austria	Turkey	Ireland
	KFX	Athens Gen	PSI 30	Oslo All Sh	ATX	ISE 100	ISEQ
A M Fixing	0.0546	0.0498*	0.0434*	0.0559*	0.0221	0.0232	0.0456*
P M Fixing				0.0631*		0.0266	0.0541*
Closing							0.0600*

Notes: The asymptotic standard errors are 0.0188.
*Significantly different from zero at the 0.05 level.

Table 4D Correlation Coefficients for Daily Returns Using Previous Day's Gold Prices, January 1991 – October 2001

	Japan		UK		Germany		France	
	Nikkei 225	TOPIX	FTSE100	All Share	FAZ Aktien	DAX100	CAC 40	SBF 250
AM Fixing	–0.0238	–0.0167						
P M Fixing	–0.0581*	–0.0516*						
Closing	–0.0625*	–0.0583*	0.0122	0.0080			0.0262	0.0257

	Switzerland		Netherlands	Italy	Spain	Sweden	Belgium	Finland
	SMI	SPI Gen	CBS All Sh	BCI	Madrid Gen	Affars	BEL 20	HEX
A M Fixing								
P M Fixing							0.0112	–0.0071
Closing	0.0108	0.0109	0.0210	–0.0121	0.0218	–0.0118	0.0281	–0.0050

	Denmark	Greece	Portugal	Norway	Austria	Turkey	Ireland
	KFX	Athens Gen	PSI 30	Oslo All Sh	ATX	ISE 100	ISEQ
A M Fixing							
P M Fixing	–0.0068	–0.0061	0.0117		0.0234		
Closing	0.0043	–0.0018	0.0367	–0.0288	0.0187	0.0145	

Notes: The asymptotic standard errors are 0.0188.
*Significantly different from zero at the 0.05 level.

Table 5D Correlation Coefficients for Daily Returns, January 1991 – October 2001

		Japan		UK		Germany		France	
		Nikkei 225	TOPIX	FTSE100	All Share	FAZ Aktien	DAX100	CAC 40	SBF 250
AM Fixing	Period 1	−0.0692*§	−0.0466§	−0.0781*§	−0.0774*§	−0.0861*§	−0.1148*§	−0.1027*§	−0.1025*§
	Period 2	0.0294§	0.0296§	0.0158§	0.0118§	−0.0090§	0.0195§	0.0423§	0.0395§
P M Fixing	Period 1	−0.0405§	−0.0240§	−0.1159*§	−0.1065*§	−0.0641*	−0.0919*	−0.1592*§	−0.1414*§
	Period 2	0.1312*§	0.1329*§	−0.0063§	−0.0031§	−0.0171	−0.0286	−0.0058§	−0.0030§
Closing	Period 1	−0.0260§	−0.0086§	−0.1082*	−0.0952*	−0.0300	−0.0704*	−0.1519*§	−0.1289*§
	Period 2	0.1571*§	0.1617*§	−0.0376	−0.0311	−0.0298	−0.0536*	−0.0449§	−0.0428§

		Switzerland		Netherlands	Italy	Spain	Sweden	Belgium	Finland
		SMI	SPI Gen	CBS All Sh	BCI	Madrid Gen	Affars	BEL 20	HEX Gen
A M Fixing	Period 1	−0.0914*§	−0.0825*§	−0.0748*§	−0.0746*	−0.1176*§	−0.0907*§	−0.0620*§	0.0339
	Period 2	0.0452§	0.0469§	0.0435§	−0.0045	0.0554*§	0.0151§	0.0493§	−0.0060
P M Fixing	Period 1	−0.1079*§	−0.0868*§	−0.1089*§	−0.0646*	−0.1313*§	−0.0958*§	−0.0792*§	0.0708*
	Period 2	0.0125§	0.0196§	−0.0049§	−0.0171	0.0256§	0.0181§	0.0174§	0.0027
Closing	Period 1	−0.0805*	−0.0554*	−0.0723*	−0.0657*	−0.1221*§	−0.0712*	−0.0598*	0.0658*
	Period 2	−0.0091	−0.0027	−0.0248	−0.0308	−0.0007§	−0.0127	−0.0247	−0.0000

		Denmark	Greece	Portugal	Norway	Austria	Turkey	Ireland
		KFX	Athens Gen	PSI 30	Oslo All Sh	ATX	ISE 100	ISEQ
A M Fixing	Period 1	−0.0368	−0.0484	0.0346	−0.1006*§	−0.0872*§	0.0168	−0.0534
	Period 2	0.0181	0.0197	0.0568*	0.0164§	0.0247§	−0.0369	0.0054
P M Fixing	Period 1	−0.0212	−0.0341§	0.0837*	−0.0950*§	−0.0561*	−0.0224	−0.0509
	Period 2	0.0046	0.0689*§	0.0256	0.0622*§	0.0128	−0.0646*	0.0044
Closing	Period 1	−0.0014	−0.0462§	0.0957*§	−0.0628*§	−0.0489	−0.0187	−0.0237
	Period 2	0.0144	0.0737*§	−0.0005§	0.0653*§	−0.0253	−0.0495	−0.0155

Notes: The asymptotic standard errors for periods 1 and 2 are 0.0277 and 0.0256 respectively.
*Significantly different from zero at the .05 level.
§Correlation coefficients for periods 1 and 2 are significantly different at the .05 level.

Table 6D Phillips-Perron Unit Root Tests

	Series	$Z(\alpha_1)$	$Z(t\alpha_1)$	$Z(t\beta_1)$	$Z(t\mu_1)$	$Z(\Phi_3)$	$Z(\Phi_2)$	$Z(\alpha_2)$	$Z(t\alpha_2)$	$Z(t\mu_2)$	$Z(\Phi_1)$	$Z(\alpha_3)$	$Z(t\alpha_3)$
Gold	AM Fixing	−10.55	−2.37	−1.70	2.21	2.47	1.87	−4.11	−1.43	1.41	1.36	−0.06	−0.86
	PM Fixing	−9.54	−2.20	−1.69	2.17	2.37	1.83	−3.86	−1.37	1.35	1.32	−0.06	−0.90
	Closing	−8.73	−2.02	−1.68	2.15	2.34	1.81	−3.82	−1.37	1.34	1.31	−0.06	−0.91
Japan	Nikkei 225	−8.48	−1.90	−1.74	1.62	1.87	1.52	−3.36	−0.88	0.84	0.79	−0.17	−0.94
	TOPIX	−7.11	−1.75	−1.27	1.76	1.91	1.36	−5.82	−1.49	1.47	1.24	−0.09	−0.58
U K	FTSE100	−4.62	−1.14	0.56	1.07	0.99	1.04	−2.11	−1.30	1.37	1.42	0.10	0.99
	FTSE All Share	−4.24	−0.99	0.55	1.05	1.07	1.13	−2.19	−1.34	1.42	1.55	0.10	1.04
Germany	FAZ Aktien	−7.71	−1.49	0.69	1.19	1.20	0.99	−2.75	−1.42	1.47	1.30	0.09	0.66
	DAX 100	−5.92	−1.18	0.60	1.04	1.12	1.16	−2.22	−1.38	1.47	1.57	0.13	1.00
France	CAC 40	−9.89	−2.06	1.47	1.89	1.91	1.66	−2.46	−1.31	1.38	1.43	0.13	0.99
	SBF 250	−8.47	−1.75	1.35	1.74	1.72	1.58	−2.20	−1.27	1.34	1.47	0.12	1.06
Switzerland	SMI	−1.74	−0.47	−0.06	0.53	1.41	2.35	−1.94	−1.68	1.86	3.52	0.20	1.88
	SPI General	−0.96	−0.26	−0.15	0.35	1.27	2.64	−1.63	−1.58	1.80	3.94	0.21	2.15
Netherlands	CBS All Share	0.02	0.00	−0.64	−0.11	1.37	1.99	−1.73	−1.53	1.69	2.78	0.17	1.64
Italy	BCI	−6.78	−1.77	1.70	2.03	2.00	1.38	−2.36	−1.07	1.10	0.65	0.05	0.30
Spain	Madrid General	−4.77	−1.39	1.06	1.46	1.08	0.96	−1.77	−1.02	1.08	0.88	0.11	0.77
Sweden	Affarsvarlden	−2.64	−0.69	0.30	0.84	0.86	0.93	−2.02	−1.28	1.37	1.35	0.14	0.91
Belgium	BEL 20	−3.01	−0.80	0.25	0.99	1.22	1.17	−2.76	−1.55	1.62	1.74	0.11	0.93
Finland	HEX General	−7.18	−1.93	1.94	2.10	2.05	1.98	−0.77	−1.59	0.79	1.08	0.25	1.25
Denmark	KFX	−9.80	−2.13	2.04	2.25	2.46	2.14	−1.46	−0.88	0.97	1.15	0.14	1.17
Greece	Athens S E General	−4.70	−1.43	1.37	1.70	1.38	0.98	−1.93	−0.98	1.02	0.56	0.07	0.31
Portugal	PSI 30	0.14	0.05	0.75	0.33	2.36	2.26	−2.80	−1.98	2.07	2.97	0.12	1.29
Norway	Oslo All Share	−4.55	−1.14	0.87	1.39	1.11	0.89	−2.44	−1.23	1.27	0.98	0.08	0.58
Austria	ATX	−8.31	−1.82	−0.75	1.92	2.10	1.51	−8.72	−1.91	1.85	1.94	−0.09	−0.60
Turkey	Istanbul S E 100	−10.93	−2.03	0.94	2.29	2.71	1.83	−9.80	−2.15	2.11	2.35	−0.21	−0.48
Ireland	ISEQ	−5.17	−1.28	1.19	1.51	1.24	1.90	−1.35	−1.05	1.21	2.16	0.19	1.69
	0.05 critical value	–21.80	–3.41	±3.11	±3.38	6.25	4.68	–14.10	–2.86	±2.83	4.59	–8.10	–1.95

Table 7D Engle-Granger Cointegration Tests with Gold Price Set in PM Fixing

	Series	CRADF	*m*
Gold	AM Fixing	−35.5187	1
	Closing	−50.2559	0
Japan	Nikkei 225	−2.5174	0
	TOPIX	−2.3570	1
U K	FTSE100	−2.3293	0
	FTSE All Share	−2.2351	0
Germany	FAZ Aktien	−2.1554	0
	DAX 100	−2.0335	0
France	CAC 40	−2.9847	0
	SBF 250	−2.6266	0
Switzerland	SMI	−1.8960	0
	SPI General	−1.8475	0
Netherlands	CBS All Share	−1.8966	0
Italy	BCI	−3.0817	0
Spain	Madrid General	−2.6486	0
Sweden	Affarsvarlden	−1.7749	0
Belgium	BEL 20	−1.8568	0
Finland	HEX General	−1.8951	0
Denmark	KFX	−2.4737	0
Greece	Athens S E General	−2.6151	0
Portugal	PSI 30	−3.0081	0
Norway	Oslo All Share	−1.5037	0
Austria	ATX	−2.0413	3
Turkey	Istanbul S E 100	−2.4757	1
Ireland	ISEQ	−2.0379	0

Note: The 0.95 critical value is −3.3398