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The price of gold and the exchange rates: Once again

Larry A. Sjaastad[a,b,*]

[a]Department of Economics, University of Chicago, USA
[b]UWA Business School, The University of Western Australia, Australia

Abstract

This paper examines the theoretical and empirical relationships between the major exchange rates and the price of gold using forecast error data. Among other things, it is found that, since the dissolution of the Bretton Woods international monetary system, floating exchange rates among the major currencies have been a major source of price instability in the world gold market and, as the world gold market now seems to be dominated by the US dollar bloc, appreciations or depreciations of that dollar would have strong effects on the price of gold in other currencies. The results of this study are rather different from those obtained in an earlier study of the same subject.

JEL classification: D40; F33

Introduction

The main objective of this paper, as in a previous one, is to identify the effect of major currency exchange rates on the prices of internationally traded commodities.[1] For commodities that are traded continuously in organized markets such as the Chicago Board of Trade, a change in any exchange rate will result in an immediate adjustment in the prices of those commodities *in at least one currency*, and perhaps in both currencies if both countries are ‘‘large’’. For example, when the dollar depreciates against the euro, dollar prices of commodities tend to rise (and euro prices fall) even though the fundamentals of the markets—all relevant factors other than exchange rates and price levels—remain unchanged. The power of this effect is suggested by the events surrounding the intense appreciation of the dollar from early 1980 until early 1985, during which the US price level *rose* by 30 percent but the IMF dollar-based commodity price index *fell* by 30 percent, and dollar-based unit-value indices for both imports and exports of commodity-exporting countries as a group *declined* by 14 percent. The explanation for this anomaly lies in exchange rates: with respect to the DM, for example, the dollar appreciated in the same period by more than 90 percent in nominal terms, and by 45 percent in *real* terms.

The potential importance of this phenomenon is not limited to the major currency countries. With several minor currencies of the world being directly or indirectly tied to one of the three major currencies (the dollar, the euro, and the yen) or a currency basket, shocks to major currency exchange rates are felt not only by producers and consumers of internationally traded commodities in major currency countries, but also by many of the smaller, commodity-exporting countries, in the form of inflationary (or deflationary) shocks transmitted by fluctuations in the international prices of commodities. The idea of the Australian dollar as a ‘‘commodity currency’’ is an example.

*Corresponding author at: UWA Business School, The University of Western Australia, Australia.
E-mail address: sjaasta@worldnet.att.net

[1]To avoid unnecessary rewriting, and since the methodology in this paper is very similar to a previous one, substantial portions of what follows concerning methodology have been reproduced from my ‘‘The price of gold and the exchange rates,’’ (with Fabio Scacciavillani), Journal of International Money and Finance, December 1996; reprinted in Meher Manzur (Ed.), 2002. Exchange Rates, Interest Rates and Commodity Prices, Edward Elgar, and in MoonJoong Tcha (Ed.), 2003. Gold and the Modern World Economy, Routledge. The layout of the paper is very similar to that of the earlier one.

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In the first of the sections to follow, an international pricing model is developed, which predicts that changes in major currency exchange rates will impact on the prices of commodities in *all* currencies—major and minor alike. Section 2 is concerned with preliminary tests of the data and Section 3—the core of the paper—reports the findings of a study of the international market for gold. A short summary section concludes the paper.

Gold is a prime candidate for a study of the effects on commodity prices of fluctuations in major currency exchange rates. A highly homogeneous commodity, gold is traded almost continuously in well-organized spot and future markets. Moreover, as annual production (and consumption) of gold is minuscule compared with the global stock, the gold-producing countries, not all of whose currencies are traded in organized markets, are unlikely to dominate the world gold market.

Exchange rates and commodity prices: the model

The model developed in this section focuses on the effect of movements in exchange rates on the international price of a homogeneous commodity that is traded in an organized market; it is not the usual asset-pricing model, as it is not concerned with the rate of return on holding commodity in question.[2] The model has two basic elements: the law of one price and global market clearing in a world of M countries or currency blocs. Ignoring all barriers to trade *and with all variables expressed in natural logarithms,* the law of one price for an internationally traded commodity is simply:

$$P_1 = P_j + E_{1j},\ j = 1, \ldots, M. \tag{1}$$

P_j being the commodity price in currency j and E_{1j} the price of currency j in terms of the reference currency 1. Feedback from the commodity market to exchange rates is assumed to be negligible.

The *excess* demand (i.e., net imports), Q_j, for that commodity in currency bloc j is a function of its *real* price, $P_j^R \equiv P_j - P_j^*$, where P_j^* is the price *level* in that bloc, and a 1 by N vector $X_j = (X_{j1}, X_{j2}, \ldots, X_{jN})$ of (yet to be specified) market "fundamentals" specific to the commodity in question and currency bloc j:

$$Q_j = Q_j(P_j^R, X_j),\ \ \partial Q_j/\partial P_j^R \leq 0,\ \ j = 1, \ldots, M.$$

Global market clearing requires:

$$\sum_{j=1}^{M} Q_j(P_j^R, X_j) = 0,$$

and hence a local log-linear approximation can be written as:

$$\sum_{j=1}^{M}(\partial Q_j/\partial P_j^R)(P_j^R - \bar{P}_j^R) + \sum_{j=1}^{M}\left(\sum_{i=1}^{N}(\partial Q_j/\partial X_{ji})(X_{ji} - \bar{X}_{ji})\right) = 0, \tag{2}$$

where $\bar{P}_j^R$ and $\bar{X}_{ji}$ are means of the distributions of P_j^R and X_{ji}.

From Eq. (1), $P_j^R = P_1 - E_{1j} - P_j^*$. So Eq. (2) can be rearranged into a fairly simple expression for P_1:

$$P_1 = \text{constant} + \sum_{j=1}^{M} \theta_j(E_{1j} + P_j^*) + K(X), \tag{3}$$

where $\theta_j = (\partial Q_j/\partial P_j^R)/\sum_{j=1}^{M}(\partial Q_j/\partial P_j^R)$; while Q_j may be positive or negative, $\partial Q_j/\partial P_j^R$ is nonpositive. So the θ_j are nonnegative fractions that sum to unity. The *global* fundamentals are captured by

$$K(X) = -\sum_{j=1}^{M}\sum_{i=1}^{N}[(\partial Q_j/\partial X_{ji})X_{ji}] \Big/ \sum_{j=1}^{M}(\partial Q_j/\partial P_j^R);$$

i.e., X is a vector containing all elements of the country-specific X_j vectors.[3] As $P_k = P_1 - E_{1k}$ and $E_{kj} = E_{1j} - E_{1k}$, Eq. (3) can be specified in any currency k: $P_k = \text{constant} + \sum_{j=1}^{M}\theta_j(E_{kj} + P_j^*) + K(X)$. Changes in the global fundamentals have identical effects on the price of the commodity in question, regardless of currency of denomination.

By subtracting P_1^* from both sides of Eq. (3) we obtain:

$$P_1^R = \sum_{j=1}^{M} \theta_j E_{1j}^R + K(X), \tag{3R}$$

where $E_{1j}^R \equiv E_{1j} + P_j^* - P_1^*$ is the purchasing-power-parity (PPP) *real* exchange rate between currency blocs 1 and j. For the commodity in question, then, θ_j is simultaneously the elasticity of its *nominal* price in currency bloc 1 with respect to the *nominal* exchange rate (or price level) of bloc j, and the elasticity of its real price in currency bloc 1 with respect to the PPP *real* exchange rate between blocs 1 and j, holding all other variables constant in both cases. While the θ_j can be estimated with either nominal or real variables, the actual estimation will use forecast errors.

An interpretation of the "thetas"

The "thetas" in Eq. (3) are key to the analysis as they measure the *relative market power* possessed by each participant in the world market for the commodity in question. Consider a small depreciation of currency 1

[2] To the best of the author's knowledge, Ridler and Yandle (1972) were the first to use this approach to analyze the effect of exchange rate adjustments on commodity prices. The model presented here first appeared in Sjaastad (1985); following this, a similar approach was developed by Dornbusch (1987).

[3] *Global* fundamentals are defined as all factors *other than exchange rates and price levels* that influence the *global* demand for and supply of the commodity in question, including expectations.

against all other currencies (holding all P_j^* constant); the effect of that depreciation on P_1 is $\sum_{j=2}^{M}\theta_j = 1-\theta_1$. If currency bloc 1 is a price *taker* in, say, the world gold market, that depreciation will have no effect on the price of gold in other currencies, so the entire impact falls on the price of gold in currency 1 and hence $\theta_1 = 0$. In other words, currency bloc 1 is the classic "small" economy in the world gold market. On the other hand, if bloc 1 is an absolute price *maker*, that depreciation will have no effect on the price of gold in currency 1 as that bloc totally dominates the world gold market, so $\theta_1 = 1$, and all of the effect of the depreciation will appear in the price of gold in all other currencies.

To dominate the world market for any commodity, a country must have an extremely elastic excess demand for that commodity. When stocks are small compared with annual production and consumption (as in the case of wheat or copper), a country must be a major producer and/or consumer in order to dominate the price of a commodity. Precious metals are unusual in that *stocks* are very large compared with annual production and/or consumption and hence a country with a high propensity to hoard gold might dominate the world gold market without being a major, or even minor, producer.

Given the high variability of major currency exchange rates since 1973, the term $\sum_{j=1}^{M}\theta_j(E_{1j}+P_j^*)$ of Eq. (3) is a potentially important source of shocks to the price of a commodity such as gold, and hence estimates of the θ_j can be useful.[4] That information can help identify the sources (exchange rates versus the fundamentals) of the price shocks experienced by consumers and producers of gold; to the extent that exchange rates can be predicted, one can forecast the effects of movements in those rates on the price of gold. Finally, information about the θ_j can be exploited for portfolio management; by denominating their assets and liabilities in foreign currency in accordance with the θ_j, firms involved in gold production can reduce the financial impact of exchange rate shocks.

The forecast error approach

With appropriate time series data, the θ_j coefficients in Eq. (3) can be estimated, but that procedure confronts long-standing issues such as the stationarity of exchange rates. However, when the currencies and commodities are traded in both *spot* and *forward* markets, those issues can be finessed by using forecast errors, which involves writing Eq. (3) in terms of those errors extracted from spot and forward price and exchange rate data rather than with actual prices and exchange rates. As forecast error data typically are stationary and, if the relevant markets are "efficient" and serially uncorrelated as well, the econometric analysis can be considerably simplified.

To develop this approach, we begin with spot and forward versions of Eq. (3), given as Eqs. (3S) and (3F) as below:

$$P_{1,t}^{\mathrm{S}} = \text{constant} + \sum_{j=1}^{M}\theta_j(E_{1j,t}^{\mathrm{S}} + P_{j,t}^{*}) + K^{\mathrm{S}}(X_t), \tag{3S}$$

$$P_{1,t,n}^{\mathrm{F}} = \text{constant} + \sum_{j=1}^{M}\theta_j(E_{1j,t,n}^{\mathrm{F}} + P_{j,t,n}^{*\mathrm{F}}) + K^{\mathrm{F}}(X_t), \tag{3F}$$

where the S and F superscripts denote spot and forward, respectively, $P_j^{*\mathrm{F}}$ and $K^{\mathrm{F}}(X)$ are unobserved market forecasts of P_j^* and $K^{\mathrm{S}}(X)$, respectively, and n is the length of the forward contract. The θ_j are set equal in Eqs. (3S) and (3F) as there is no reason to expect them to differ for short-term (e.g., 90-day) contracts.

The forecast error for the price of the commodity in question, $Z_{1,t,n}$, is the difference between realized and forward prices:

$$Z_{1,t,n} \equiv P_{1,t}^{\mathrm{S}} - P_{1,t-n,n}^{\mathrm{F}},$$

and for exchange rates, the forecast error is:

$$Z_{E_{1j,t,n}} \equiv E_{1j,t}^{\mathrm{S}} - E_{1j,t-n,n}^{\mathrm{F}}.$$

Neglecting the constant term, the forecast error version of Eq. (3) is just the difference between Eqs. (3F) and (3S), with a n-period lag:

$$\begin{aligned} Z_{1,t,n} &= \sum_{j=1}^{M}\theta_j(Z_{E_{1j,t,n}} + [P_{j,t}^{*} - P_{j,t-n,n}^{*\mathrm{F}}]) + [K^{\mathrm{S}}(X_t) - K^{\mathrm{F}}(X_{t-n})] \\ &= \sum_{j=1}^{M}\theta_j Z_{E_{1j,t,n}} + [P_{W,t}^{*} - P_{W,t-n}^{*\mathrm{F}}] + [K^{\mathrm{S}}(X_t) - K^{\mathrm{F}}(X_{t-n})], \end{aligned}$$

where $P_{W,t}^{*} = \sum_{j=1}^{M}\theta_j P_{j,t}^{*}$ is the "world" price level and, as $P_{W,t-n}^{*\mathrm{F}}$ forecasts $P_{W,t}^{*}$, the terms $P_{W,t}^{*} - P_{W,t-n}^{*\mathrm{F}} \equiv Z_{p,t,n}$ and $K^{\mathrm{S}}(X_t) - K^{\mathrm{F}}(X_{t-n}) \equiv Z_{K,t,n}$ also are forecast errors. As neither $Z_{P,t,n}$ nor $Z_{K,t,n}$ are observable, the forecast error version of Eq. (3) is written as:

$$Z_{1,t,n} = \text{constant} + \sum_{j=1}^{M}\theta_j Z_{E_{1j}} + v_{1t}, \tag{4}$$

where $v_{1t} \equiv Z_{P,t,n} + Z_{K,t,n}$ also is a forecast error.

If markets are weakly efficient, $K^{\mathrm{F}}(X_{t-n}) = E[K^{\mathrm{S}}(X_t) | I_{t-n}]$ and $P_{W,t-n}^{*\mathrm{F}} = E(P_{W,t}^{*} | I_{t-n})$, where $E(\cdot)$ is the conditional expectation operator and I_{t-n} is the information set at time t–n, and hence $Z_{p,t,n}$, $Z_{K,t,n}$ and v_{1t} are serially uncorrelated. Weak market efficiency implies, then, that all variables in Eq. (4) are serially uncorrelated.[5] Given the potentially superior characteristics of forecast error

[4]See Frenkel (1981) concerning the large fluctuations in PPP, and hence in PPP real exchange rates, experienced by the major currencies during the 1970s and Edwards (1989) for a massive compilation of real exchange rate data for smaller countries.

[5]Lack of serial correlation in forecast errors also requires the absence of time-dependent risk premia. In what follows, that property is assumed to hold.

data, Eq. (4) will be the centerpiece for the empirical implementation of the pricing model.

Preliminary tests on the data

The spot gold price data consist of daily observations from January 1991 to June 2004 and the forward price data refer to 164 90-day contracts let at the beginning of each month during the same period, both in US dollars. The daily spot and forward gold price data were kindly provided by Bill Cowan of Anglo Gold Ashanti Australia Limited. Spot and 90-day forward exchange rates between the US dollar, the UK pound sterling, and the Japanese yen were obtained from the International Monetary Fund Data Bank (IMF) and cover the same period. Data for the DM exchange rates were obtained from the Bundesbank for the period 1991:01–1998:12, and data for the remaining exchange rates (and for the euro) were obtained from the IMF.

The spot and forward rates are generally very highly correlated, as is illustrated in the tabulations below.[6]

> Cross-correlations of gold spot and forward prices: monthly data from 1991:01 to 2004:05: 0.9989
>
> Cross-correlations of DM (euro) spot and forward exchange rates: monthly data from 1991:01 to 2004:05: 0.9689
>
> Cross-correlations of US dollar spot and forward exchange rates: monthly data from 1991:01 to 2004:05: 0.9976
>
> Cross-correlations of yen spot and forward exchange rates: monthly data from 1991:01 to 2004:05: 0.9996

Note that the cross-correlations for the DM (euro) are somewhat lower than that for any of the other series. But when using only the Bundesbank data for the subperiod 1991:01–1998:12, the results are:

> Cross-correlations of DM spot and forward exchange rates: monthly data from 1991:01 to 1998:12: 0.9977

There apparently are errors in the IMF DM (euro) data, but the author has not been able to correct them other than to use the Bundesbank data for the DM spot and forward exchange rates for the 1991:01–1998:12 portion of the period under investigation.[7]

Because the forecast errors require a three-month lag on the forward series, the useful data set is reduced to 161 overlapping (and hence serially correlated) observations. As the earlier study indicated that the UK "theta" is approximately zero, the pound sterling was designated as currency 1 and the price of gold and all exchange rates were denominated in pounds.

[6]All estimates reported in this paper were made by WINRATS 6.2.

[7]One wonders how much serious work at the IMF and elsewhere has been misled by these errors in basic data.

As the empirical analysis focuses on the relation between exchange rates and the price of gold, and as the fundamentals are difficult to specify in advance (apart from "world" inflation, which may influence the appeal of gold as a store of value), we made no attempt to do so; accordingly, in estimating Eq. (4), we assume that the exchange-rate forecast errors, $Z_{E_{1j,t,n}}$ and those concerning gold-market fundamentals, v_{1t}, are orthogonal.

Market efficiency tests

As was argued earlier, if the gold and foreign exchange markets are efficient, estimation of Eq. (4) is simplified as both the forecast errors and the residuals of Eq. (4) will be uncorrelated. Tests of both weak and semistrong market efficiency were conducted.

Weak market efficiency

The classic test for weak market efficiency is based on estimating the equation $P^S_{i,t} = \alpha + \beta P^F_{i,t-3,3}$ and testing the joint restriction $\alpha = 0$ and $\beta = 1$. But as market efficiency also requires serially uncorrelated forecast errors, the test for market efficiency was based on Eq. (5):

$$Z_{\cdot,t,3} = \gamma + \delta Z_{\cdot,t-3,3}, \tag{5}$$

in which estimates of δ should not differ significantly from zero. Four χ^2 statistics on the restriction $\delta = 0$ based on OLS estimates of Eq. (5) for the 156 overlapping observations using White's (1980) robust standard error routine appear in Table 1 below. That restriction is not rejected except in the case of the χ^2 statistic for the DM (euro), which is based on an OLS estimate of Eq. (5).[8] This rejection may be due to the errors in the DM (euro) data that were mentioned earlier. The standard errors were reestimated by the Hansen–Hodrick (1980) (H–H) method and the significance of *F* statistics on the $\delta = 0$ restriction, also reported in Table 1, are similar to the χ^2 statistics, except in the case of the DM (euro), where the restriction is now not rejected. In short, weak market efficiency is not rejected.

Semistrong market efficiency

In the context of the model developed in Section 1, semistrong market efficiency requires past gold price *and* exchange-rate forecast errors to be orthogonal with both the current gold price *and* exchange-rate forecast errors. The test for the gold market involves estimating the following equation:

$$Z_{1,t+3,3} = \mu + \vartheta_1 Z_{1,t,3} + \sum_{i=2}^{4} \vartheta_1 Z_{E_{1i},t,3}, \tag{6}$$

[8]Were Eq. (5) to be estimated with a single lag on the independent variable, the expected value of the estimate of δ would be roughly 0.67, since two-thirds of the innovations in any observation on forecast errors tend to be common to adjoining observations. To avoid that bias, the independent variable was lagged three periods (i.e., one prediction period).

Table 1
Market efficiency tests on forecast error data: 1991:1–2004:5

Statistic	Weak (Eq. (5)) forecast error for:					Semistrong (Eq. (6)) forecast error for:			
	Gold	DM	Dollar	Yen		Gold	DM	Dollar	Yen
$\chi^2(1)$[a]	0.19	7.86	0.18	0.27	$\chi^2(4)$	1.24	11.47	0.37	1.62
p-value	0.59	0.02	0.67	0.61		0.87	0.02	0.98	0.81
$F(1,156)$[b]	0.23	2.19	0.75	0.08	$F(1,153)$	0.32	2.60	0.39	0.78
p-value	0.63	0.14	0.39	0.77		0.87	0.04	0.82	0.54

[a]All χ^2 statistics are based on OLS estimates using White's (1980) Robust Error routine with two lags.
[b]All *F* statistics are based on standard errors estimated by the Hansen–Hodrick (1980) method.

and, for the *j*th exchange rate, Z_1 is replaced with $Z_{E_{1j}}$. Semistrong market efficiency is tested by the joint restriction that estimates of all four ϑ_i are zero. Table 1 presents the four χ^2 statistics on that joint restriction based on OLS robust-error estimates of Eq. (6) using the 153 overlapping observations; again, the joint restriction is rejected only in the case of the DM (euro). However, the four *F* statistics are based on H–H estimates of standard errors; semistrong market efficiency is not rejected for gold or for any of the exchange rates, except marginally so for the DM (euro). In summary, neither weak market nor semistrong market efficiency is rejected for any series, except possibly for the DM (euro).

Table 2
OLS estimate of Eq. (4): gold, 1991:01–2004:05 (Hansen–Hodrick standard errors)

A. Unrestricted			
Sum of θ_j coefficients:			0.9641
Standard error of sum:			0.0923
t-statistic (against unity):			–0.3886
p-value:			0.6981
Parameter	Estimate	*t*-statistic	*p*-value
B. Restricted			
θ_{DM}	0.1999	2.8909	0.0044
$\theta_{US\$}$	0.5779	7.8432	0.0000
θ_{Yen}	0.2222	4.0114	0.0000

$\bar{R}^2 = 0.3789$; SEE = 0.0497; D–W = 0.9892.

Estimates of the "thetas" for the world gold market

As the pound sterling was designated currency 1 (the reference currency) and the gold prices and all exchange rates were denominated in that currency, there are but three parameters to estimate: θ_{DM}, $\theta_{US\$}$, and θ_{Yen}. Eq. (4) was estimated using all 161 overlapping observations with the standard errors estimated by the H–H method. As a *t*-test on the estimates of the θ_j parameters, reported in panel A of Table 2, indicates that the unit-sum restriction cannot be rejected, that restriction was imposed and the results (again with standard errors estimated by the H–H method) are summarized in panel B of Table 2. The restricted and unrestricted regressions were nearly identical—apart from an increase in the *t*- statistics when using the H–H method to estimate standard errors. Apparently, the major gold producers, which include Australia, South Africa, and Russia, seem to have little power in the world gold market. Rather, that market is dominated by the US dollar, DM (euro), and yen blocs, with the dollar having by far the largest weight. Note further that the estimates of θ_{DM}, $\theta_{US\$}$, and θ_{Yen}. are all significant at the 0.00 percent level. The low value of the Durbin–Watson statistic is due to the overlapping nature of the date. *Q*-statistics are not presented for the same reason.

These results are quite different from those obtained in the earlier study, which covered the period 1983: 01–1990:12. In that study, the estimates of θ_{DM}, $\theta_{US\$}$, and θ_{Yen}, obtained in the same way as those in Table 2, were 0.5339, 0.2759, and 0.1902, respectively. Apparently, the power of the dollar bloc in the international gold market has grown over time, largely at the expense of the euro bloc. One possible explanation (but not a testable one) for that lies in the fact that, from the 1930s until the 1970s, US citizens were prohibited from owning gold (except in the form of jewelry, ornaments, etc.). As a result, gold bullion could not be part of US individual portfolios for a long period of time.

There also is some evidence from the earlier study that the power of the dollar bloc of the international gold market was growing over time. To test whether the θ estimates vary over time, Eq. (4) was reestimated in that study using two subsamples of equal length, which resulted in the following estimates: 0.5455 and 0.4995 for θ_{DM}, 0.2472 and 0.3045 for $\theta_{US\$}$, and 0.2073 and 0.1960 for θ_{Yen}, respectively, for the subsamples 1983:01–1986:12 and 1987:01–1990:12. While the importance of the dollar bloc may have increased over the period analyzed in the earlier study (and that of Europe declined), in no case did the difference between the two estimates exceed the smaller of the two standard errors.

"World" inflation and the price of gold

The estimate of Eq. (4) reported in Table 2 does not include any variables for the fundamentals, which are captured in Eqs. (3S) and (3F) by $K^S(X_t)$ and $K^F(X_{t-3})$. In the earlier study, a candidate for the fundamentals, albeit an anemic one, was found to be "world" inflation, changes in which may affect the price of gold (but not necessarily exchange rates). The same test for the effect of "world" inflation was carried out in this study. As the US dollar, the DM (euro), and yen blocs appear to dominate the world gold market totally, the "world" price level, P^*_W, was defined, as in the earlier study, as the natural logarithm of a weighted average of the European, US, and Japanese CPI price levels; the weights being the theta estimates reported in Table 2. The European price level was computed as a weighted average of German, UK, Italian, and French implicit GDP deflators. The weights, 0.3289, 0.2825, 0.1595, and 0.2291, respectively, were based on relative real GDPs during the second quarter of 2004. The quarterly "world" inflation rate was defined as $\Pi_{t,3} \equiv P^*_{W,t} - P^*_{W,t-3}$, and was converted to an annual rate, Π_t. As inflation may have lagged effects, the inflation components of $K^S(X_t)$ and $K^F(X_{t-3})$ were defined as $\gamma(L)\Pi_t$ and $\gamma(L)\Pi_{t-3}$. The inflation component of v_{1t} is $\gamma(L)(\Pi_t - \Pi_{t-3})$, and was parameterized as:

$$\gamma_0(\Pi_{t,3} - \Pi_{t-3,3}) + \gamma_1(\Pi_{t-1,3} - \Pi_{t-4,3}) + \gamma_2(\Pi_{t-2,3} - \Pi_{t-5,3}).$$

Moreover, using the property of any polynomial $A(L) = \Sigma_{i=0}^{N} a_i L^i$ and any time series Y_t, that $A(L)Y_t$ can be reparameterized in error correction form as;

$$A(L)Y_t = \sum_{i=0}^{N-1}\left(\sum_{j-0}^{i} a_j\right)\Delta Y_{t-i} + A(1)Y_{t-N},$$

the inflation term $\gamma(L)(\Pi_t - \Pi_{t-3})$ is expressed, in the case of two lags, as $\gamma_0\,\Delta(\Pi_t - \Pi_{t-3}) + \gamma_1\,\Delta(\Pi_{t-1} - \Pi_{t-4}) + \gamma(1)(\Pi_{t-2} - \Pi_{t-5})$, which permits a direct estimate of $\gamma(1)$, the long-run impact on the spot price of gold of a permanent change in the rate of "world" inflation.

The results of an OLS estimate of Eq. (4) augmented by the inflation variable with two lags are summarized in Table 3; the estimates of θ_j are similar to those reported in Table 2, although some standard errors are slightly smaller. In an earlier study (Sjaastad and Scacciavillani, 1996) the results show that "world" inflation, as a fundamental, was quite an anemic one: a (permanent) rise in the (annual) rate of "world" inflation by one percentage point lead to a mere 0.78 percent rise in the price of gold. The current study indicates that "world" inflation has a *negative* but statistically significant effect, albeit a very small one, on the price of gold. The results in the earlier study may have been influenced by the spike in "world" inflation in the very early 1980s.

In view of this curious result for the inflation variable, Eq. (4) was reestimated using a consumer-price-index-based inflation variable for the OECD countries (identified in the RATS-OECD data base as E15CPI). The results are presented in Table 4 . The estimates and significance of θ_{DM}, $\theta_{US\$}$, and θ_{Yen} are very similar to those reported in Table 3, but the effect of inflation on the price of gold is still negative and even more significant. There seems to be no explanation for this negative effect.

A more general formulation

The *overlapping* nature of the forecast error data results in strong serial correlation in the data and in the residuals of OLS estimates based on those data; indeed, the partial autocorrelations for the forecast error data are high for up to seven or eight lags. This serial correlation suggests that lags may be useful even though weak market efficiency has not been rejected. A more general specification of Eq. (4), which incorporates lags, is the following:

$$\alpha(L)Z_{1,t,n} = \text{constant} + \sum_{j=2}^{M}\Theta_j(L)Z_{E_{1j,t,n}} + \gamma(L)(\Pi_t - \Pi_{t-3}) + v_{1t}. \tag{4'}$$

Experimentation indicated that lags on the independent variables became redundant (i.e., $\Theta_j(\mathrm{L}) \equiv \Theta_j$) once lags on

Table 3
OLS estimate of Eq. (4) with inflation variable: gold, 1991:01–2004:05 (Hansen–Hodrick standard errors)

A. Unrestricted				
Sum of θ_j coefficients:				0.9237
Standard error of sum:				0.0908
t-statistic (against unity):				–0.8411
p-value:				0.4017
Parameter	Lag	Estimate	*t*-statistic	*p*-value
B. Restricted				
θ_{DM}	–	0.2371	3.6144	0.0004
$\theta_{US\$}$	–	0.5238	6.9461	0.0000
θ_{Yen}	–	0.2390	4.4852	0.0000
$\gamma(1)$	2	–0.2581	–2.3209	0.0217

$\bar{R}^2 = 0.3513$; SEE = 0.0499; D–W = 1.0517.

Table 4
OLS estimate of Eq. (4) with the OECD inflation variable: gold, 1991:01–2004:05 (Hansen–Hodrick standard errors)

A. Unrestricted				
Sum of θ_j coefficients:				0.9128
Standard error of sum:				0.0919
t-statistic (against unity):				–0.9489
p-value:				0.3442
Parameter	Lag	Estimate	*t*-statistic	*p*-value
B. Restricted				
θ_{DM}	–	0.2164	3.2605	0.0014
$\theta_{US\$}$	–	0.5436	7.3323	0.0000
θ_{Yen}	–	0.2400	4.3071	0.0000
$\gamma(1)$	2	–0.4281	–2.7418	0.0069

$\bar{R}^2 = 0.3516$; SEE = 0.0499; D–W = 1.0003.

Table 5
OLS estimate of Eq. (4′) with inflation variables and four lags on dependent variable: gold, 1991:01–2004:5 (Hansen–Hodrick standard errors)

A. Unrestricted				
Sum of θ_j coefficients:				1.0912
Standard error of sum:				0.1164
t-Statistic (against unity):				0.7836
p-value:				0.4346
Parameter	Lag	Estimate	t-statistic	p-value
B. Restricted				
Θ_{DM}	0	0.1250	3.2719	0.0011
$\Theta_{US\$}$	0	0.3436	7.1327	0.0000
Θ_{Yen}	0	0.1850	5.6360	0.0000
$\alpha(1)$	5	−0.6535	−9.2224	0.0000
θ_{DM}	0	0.1912	3.1719	0.0019
$\theta_{US\$}$	0	0.5257	6.4886	0.0000
θ_{Yen}	0	0.2831	5.6045	0.0000
Γ	2	−0.2556	−2.1941	0.0299

$\bar{R}^2 = 0.4424$; SEE $= 0.0428$; D–W $= 1.8535$.

the dependent variable were introduced; accordingly, the final effect on the spot price of gold of a permanent shock to the jth exchange rate is $\theta_j \equiv \Theta_j/\alpha(1)$, where $\alpha(1) = \sum_{i=0}^{I} \alpha_i$ and $\alpha_0 = 1$, and the long-run reaction of the real spot price of gold to a permanent shock to "world" inflation is captured by the parameter $\Gamma \equiv \gamma(1)/\alpha(1)$. With this modification, Eq. (4′) was estimated by OLS with lags being added until the estimate of $\alpha(1)$ stabilized (which occurred after the fourth lag) and the standard errors were estimated by the H–H technique; with the inflation variable being the same as the one used in the regression reported in Table 3. The results are reported in panel A of Table 5.[9] As the unit-sum restriction on the θ_j was not rejected at the 25 percent level of significance, Eq. (4) was reestimated with that restriction imposed; the results for both the Θ_j and θ_j are reported in panel B of Table 5.

Despite first differencing of the dependent variable, the new estimates of Eq. (4′) dominate those reported in Tables 2–4 . The $\bar{R}^2$ has increased by one quarter to 0.44 and the standard error of estimate has declined to 0.043 from about 0.050. The estimates of all thetas—both short and long run—are significant at the 0.00 level, and the point estimates of θ_{DM} , $\theta_{US\$}$, and θ_{Yen} are similar to the earlier estimates. The estimate of Γ, the effect of a permanent change in the rate of "world" inflation is still negative and quite significant.

It is clear from Table 5 that the US dollar, the yen, and the euro blocs dominate the international market. While a 10 percent appreciation of the DM (euro) against all other currencies increases the dollar price of gold by 1.9 percent (and vice versa), the same appreciation of the yen increases the dollar price of gold by only 2.8 percent. A 10 percent appreciation of the dollar against both currencies depresses the dollar price of gold by about five percent, and vice versa. In the new estimates, "world" inflation still has a negative effect on the price of gold, and that effect remains significant.

[9]An iterative procedure was used to set the weights in the world price level equal to the estimates of the thetas. Eq. (4′) was not parameterized to provide direct estimates of $\theta_j \equiv \Theta_j/\alpha(1)$ and $\Gamma \equiv \gamma(1)/\alpha(1)$, since the resulting nonlinear equation would preclude using the Hansen–Hodrick (1980) method to estimate standard errors; instead, estimation was by OLS and the standard errors of θ_j and Γ were obtained by Taylor expansions.

Summary of the main results

While we cannot claim that the empirical results for the case of gold can be generalized to other commodities, the main findings, based on an analysis of the gold and foreign exchange markets for the 1991–2004 period, are as follows.

- The tests support the hypothesis of market efficiency for the world gold market during the 1991–2004 period.
- The use of serially uncorrelated forecast error data greatly simplified the estimation process.
- While during the 1980s, the world gold market was dominated by the European currency bloc, which possessed over one half of the "market power" enjoyed by all participants in that market, in the 1990s and the early years of the current century, the dollar area appears to have become dominant (along with Japan). Accordingly, real appreciations or depreciations of the euro and the yen against the US dollar have profound effects on the price of gold in all other currencies.
- The major gold producers of the world (Australia, South Africa, and Russia) appear to have no significant influence over the world price of gold.
- Gold no longer seems to be a store of value against "world" inflation, as was found in the earlier study; indeed, just the opposite was found in this study.

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