Gold as an Inflation Hedge?

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Abstract: This paper attempts to reconcile an apparent contradiction between short-run and long-run movements in the price of gold. A theoretical model is developed that suggests a set of the conditions that would have to be satisfied for the price of gold to rise over time at the general rate of inflation and hence be an effective long-run hedge against inflation. The model also demonstrates that short-run changes in such factors as the gold lease rate, the real interest rate, convenience yield, default risk, the covariance of gold returns with other assets and the dollar/world currencies exchange rate can seriously disturb this equilibrium relationship and generate significant short-run price volatility. Using monthly gold price data (1975-1999) and cointegration regression techniques, an empirical analysis confirms the central hypotheses of the theoretical model.

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" ... alterations in the quantity of money, either on one side or the other, are not immediately attended with proportionable alterations in the price of commodities. There is always an interval before matters be adjusted to their new situation; and this interval is as pernicious to industry, when gold and silver are diminishing, as it is advantageous when these metals are increasing."

David Hume, 1752

1. Introduction

The demand for gold can be divided into two main components. The first is the "use demand" for gold. For example, gold is used directly in the production of jewelry, medals, coins and electrical components and also in dentistry.[1] The second is the "asset demand" for gold. Governments, fund managers and individuals hold gold as an investment[2]. The asset demand for gold is traditionally associated with the view that gold is an effective "hedge". In other words, gold represents a store of value that investors believe will insulate them against inflation and other forms of uncertainty.[3] Although there is this belief that gold is an effective hedge, the reality is somewhat different. For example, Aggarwal (1992: 258) writes: "[T]he effectiveness of gold as a hedge against inflation and political uncertainty seems somewhat controversial for short- and medium-term horizons and it is contended that gold may be a hedge against inflation and political uncertainty only in the long run".

Figure 1 plots the nominal price and "inflation hedge" price of gold in the period 1895 to 1999 (annual averages).[4] The inflation hedge price is simply the price that gold would have to be in nominal dollars in order to maintain its 1895 purchasing power (as measured by the US consumer price index). For most of this period, the nominal price of gold was equal to or greater than the inflation hedge price, which is especially true for the late 1970s and early 1980s. In fact, in 1895 the price of gold was $20.70 per ounce, or about $379 in 1995 dollars, while in 1995 the price of gold was £387--virtually no change in the real value of gold over a one-hundred year period. Fitting a trend line indicates that the real price of gold increased on average by only 0.3 per cent per year in this hundred-year period. For the period 1895 to 1999, the elasticity of the price of gold with respect to the US Consumer Price Index (CPI) is 1.12. At least for American investors, long-run investment in gold may be an effective long-run inflation hedge.

<<<< *Figure 1 About Here* >>>>

Over the last few decades, however, gold has not proved to be a reliable hedge against inflation. Figure 2a to 2e plot the monthly nominal actual domestic price of gold and the price required for gold to be an inflation hedge (the inflation hedge price) in the "short-run" period 1982 to 1999 for five countries (USA, United Kingdom, Germany, France and Japan).[5] Since gold is priced in US dollars, both movements in the dollar price of gold and the exchange rate will affect the price of gold in any individual country. The nominal price of gold was $384 (per ounce) in January 1982 and $283 in December 1999. However, in order to be an inflation hedge for investors in the United States, by November 1995 the price of gold would need to have risen to a price of $691 (Figure 2a). In other words, by buying gold in January 1982 and holding it until December 1999, the real wealth of such an investor would have fallen to 41 per cent of the value of the initial investment--a loss of 59 per cent in the real value.

<<<< *Figures 2a to 2e About Here* >>>>

The situation is similar in other countries. In the United Kingdom the price of gold in January 1982 was £204 per ounce and this had fallen to £176 by December 1999 (Figure 2b). For an investor in the UK, the "buy and hold" strategy would have resulted in a loss of 59 per cent of the real value of the investment. In Germany an ounce of gold in January 1982 cost DM882; by December 1991 the price had fallen to DM548-- a real loss of 58 per cent (Figure

2c). In France, the price of gold in January 1982 was FF2,241 per ounce; by December 1999 the price had fallen to FF1,838--a real loss of 54 per cent (Figure 2d). In Japan, the price in January 1982 was Y86,412; by December 1999 it had fallen to Y29,065--a real lost of 74 per cent (Figure 2e). Based on the experience of these five countries over this period, gold was not an effective short-run inflation hedge for investors in these five countries in the 1982 to 1995 period.

Previous approaches aimed at empirically modelling the price of gold can be grouped into three categories. The first approach (e.g. Ariovich, 1983, Dooley, Isard and Taylor, 1995; Sherman, 1982, 1983, 1986; Sjaastad and Scacciallani, 1996) models variation in the price of gold in terms of variation in main macroeconomic variables such as exchange rates, interest rates, world income and political shocks. The second approach (e.g. Baker and Van Tassel, 1985; Diba and Grossman, 1984; Koutsoyiannis, 1983; Pindyck, 1993) focus on speculation or the rationality of gold price movements. The third approach (e.g. Chappell and Dowd, 1997; Kolluri, 1981; Laurent, 1994; Mahdavi and Zhou, 1997; Moore, 1990) examines gold as a hedge against inflation with a particular emphasis on short-run and long-run relationships between gold and the general price level. This paper attempts to reconcile what appears to be an inconsistency between the short-run and long-run movements in the price of gold. Gold may be an inflation hedge in the long-run but it is also characterised by significant short-run price volatility.

The remainder of the paper is organised as follows. Section 2 examines the short-run determinants of the price of gold and presents an explanation for gold price volatility. Section 3 presents the theoretical conditions under which gold would be regarded as an inflation hedge and shows that these conditions do not hold in the short-run. In Section 4 an empirical analysis is carried out using monthly gold price data, covering the period 1975 to 1999 and cointegration regression techniques. A brief conclusion follows in Section 5.

2. The Short-run Price of Gold

2.1 The Short Run Supply of Gold

The exhaustible resource depletion literature states that price, *P*, exceeds marginal cost, *MC,* in competitive markets. This difference, *P - MC,* or “royalty” increases over time at the rate of interest in order to equalise the present value of the marginal ounce extracted in each time period (see Hotelling, 1931). Gold, unlike most other natural resources, however, can be reused an infinite number of times. In this sense it is never “depleted” in the same manner as fossil fuels and other non-renewable resources. For example, Green (1981) suggests that 80 per cent of all gold that has been mined can be accounted for in the world stock of gold (see also, O'Callaghan, 1991). Because of this somewhat unique property of gold, Hotelling's influential model is not suitable for explaining the price path of gold over time.

It follows that over time the effect of gold mining activity is to increase the total available stock of gold above ground. A large proportion of this above ground stock is held by central banks. For example, Callaghan (1991) estimates that over one-third of the world's total gold stock is held by central banks (see also, Kaufmann and Winters, 1989). Since the early 1980's, central banks have been willing to lease gold. Gold producers (i.e. mines) have been able to supply their customers by leasing gold from central banks' gold stocks, as well as extracting it from their mines (see O'Callaghan, 1991). More specifically (as is described below), central banks lend out gold to gold producers via bullion banks who in turn sell it on to their customers. Therefore, there are two ways that gold producers can supply their customers, through mining and/or leasing.

The total supply of gold to the market in any period t, Q^S_t, is the sum of gold extracted by the industry, Q^S_{at} , plus the quantity of gold leased to the industry by central banks, Q^S_{bt} . That is:

$$Q^S_t = Q^S_{at} + Q^S_{bt} . \qquad (1)$$

Gold producers selling in the gold market are assumed to adopt profit maximising behaviour in a market of price takers. The law of diminishing marginal returns suggests that the quantity of gold supplied from extraction in any period t is directly related to price, P_t, and inversely related to the amount of gold that must be extracted in order to repay central banks for gold leased in the previous period, Q^S_{bt-1}. The amount of gold that must be repaid to central banks, Q_t^*, is the amount of gold leased in the previous period incremented by the physical rate of interest, Rg. That is:

$$Q_t^* = (1+Rg_{t-1})\, Q^S_{bt-1}, \qquad (2)$$

More generally, supply of extracted gold available to the market will be:

$$Q^S_{at} = Q^S_a(P_t, Q^S_{bt-1}, Rg_{t-1}) , \qquad (3)$$

where:

$\partial Q^S{}_a / \partial P \quad > 0$

$\partial Q^S{}_a / \partial Q^S{}_{bt-1} \quad < 0$

$\partial Q^S{}_a / \partial Rg_{t-1} \quad < 0$.

This supply function is simply an upwards sloping supply curve (in price) augmented by the costs associated with gold lease repayments .

The quantity of gold supplied by central banks for leasing, $Q^S{}_b$, (and hence the maximum physical amount available for gold producers to lease) is determined by central bank lenders adjusting their stocks of gold towards the level where the physical rate of interest, *Rg*, is equal to the convenience yield from holding gold, *Cy*, plus a default risk premium, ρ. When gold is leased, the central banks forgo the convenience yield for one period on the gold loaned out in return for the interest gained in the form of the physical interest rate for one period. The no-arbitrage condition requires that the central banks' convenience yield loss (adjusted for default risk), $Cy + \rho$, be equal to the interest gain, *Rg*. That is:

$$Rg_t = Cy_t + \rho_t \, . \qquad (4)$$

This point is illustrated in Figure 3. A fall in the real interest rate from Rg_0 to Rg_1, would increase the equilibrium stock of gold desired by central banks from Q_0 to Q_1. Likewise, a shift to the right in the convenience yield schedule, *Cy*, caused by for example political or financial turmoil, would lead to a rise in default risk from ρ to ρ'. This would also increase the equilibrium stock of gold desired by central banks from Q_0 to Q_1. In both cases there would be a decrease in the supply of gold leased to the market. Therefore, the quantity of gold leased to the industry by central banks in period *t*, $Q^S{}_{bt}$, is:

$$Q^S{}_{bt} = Q^S{}_b(Rg_t, Cy_t, \rho_t) \qquad (5)$$

where:

$$\partial Q^S{}_b / \partial Rg > 0$$

$$\partial Q^S{}_b / \partial Cy < 0$$

$$\partial Q^S{}_b / \partial \rho < 0 \ .$$

This supply function relates the supply of gold leased from central banks to the physical interest rate, the convenience yield and the default risk. It is important to note that the supply of gold leased is not related to the market price of gold, *P*.

<<<< *Figure 3 About Here* >>>>

It follows that the total supply of gold, Q^S, combines Eqs. (3) and (5):

$$Q^S{}_t = Q^S{}_a(P_t, Q^S{}_{bt-1}, Rg_{t-1}) + Q^S{}_b(Rg_t, Cy_t, \rho_t) \ . \qquad (6)$$

Or more generally:

$$Q^S_t = Q^S(P_t, Q^S_{bt-1}, Rg_t, Rg_{t-1}, Cy_t, \rho_t) . \qquad (7)$$

Lagging Eq. (5) one period gives:

$$Q^S_{bt-1} = Q^S_b(Rg_{t-1}, Cy_{t-1}, \rho_{t-1}) . \qquad (8)$$

After substituting Eq. (8) into Eq. (7), the total supply of gold (in period *t*) is:

$$Q^S_t = Q^S(P_t, Rg_t, Rg_{t-1}, Cy_t, Cy_{t-1}, \rho_t, \rho_{t-1}) . \qquad (9)$$

In other words, the total supply of gold is dependent on the current price of gold; the current and lagged values of the physical interest rate; current and lagged values of the convenience yield; and current and lagged values of the default risk premium.

2.2 The Short-run Demand for Gold

As mentioned above, the demand for gold, Q^D, consists of a use demand for gold, Q^D_U, and an asset demand for gold, Q^D_A. Therefore, the total demand for gold is simply:

$$Q^D_t = Q^D_{Ut} + Q^D_{At} . \qquad (10)$$

The use demand for gold is essentially the use of gold in the production of goods and services. Therefore, like any input into a production process, one would expect use demand to be primarily a function of price:

$$Q^{D}_{Ut} = Q^{D}_{U}(P_t) \qquad (11)$$

where:

$$dQ^{D}_{U}/dP < 0.$$

The asset demand for gold, Q^{D}_{A} , on the other hand can be considered as "gold as an investment" since it is believed that the negative beta of gold, βg, reduces portfolio risk (see Chua, Sick and Woodword, 1990). The effectiveness of gold in reducing portfolio risk is inversely related to the value of βg, because βg summarises the covariance between returns on gold and the returns on a well diversified portfolio of assets. Therefore if βg rises for a period of time, the demand for gold as an investment falls during that period, but rises at the end of the period as the value of βg reverts to its original value. Consequently, the period demand for gold as an investment is negatively related to the current value of βg and positively related to lagged values of βg.

The "price" or forgone alternative of the reduced portfolio risk obtained from holding gold is the interest that is not earned from other financial assets. The real interest rate, *R*, represents the opportunity cost of holding gold instead of an interest-bearing bond. Therefore, the real interest rate and the beta for gold primarily determine the asset demand for gold:

$$Q^{D}_{At} = Q^{D}_{A}(R_t, \beta g_t, \beta g_{t-1}) \qquad (12)$$

where:

$\partial Q^D{}_A / \partial R < 0$

$\partial Q^D{}_A / \partial \beta g < 0$

$\partial Q^D{}_A / \partial \beta g_{t-1} > 0$.

It follows that the total demand for gold, Q^D, is:

$$Q^D{}_t = Q^D{}_U (P_t) + Q^D{}_A (R_t, \beta g_t, \beta g_{t-1}) \qquad (13)$$

or:

$$Q^D{}_t = Q^D(P_t, R_t, \beta g_t, \beta g_{t-1}) ,$$

where: P is the price of gold; R is the real interest rate; and βg is the beta for gold.

2.3 Short-run Equilibrium

Equilibrium in the gold market occurs where supply equals demand:

$$Q^S{}_t = Q^D{}_t \qquad (14)$$

or from Eqs. [9] and [13]:

$$Q^S\,(P_t, Rg_t, Rg_{t-1}, Cy_t, Cy_{t-1}, \rho_t, \rho_{t-1}) \;=\; Q^D\,(P_t, R_t, \beta g_t, \beta g_{t-1}) \qquad (15)$$

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There is an arbitrage relationship that reduces the number of variables in this equilibrium relationship and also solves a potential problem in the empirical analysis with the measurement of the real interest rate. The real interest rate is central to the model described above but it is virtually impossible to obtain accurate empirical estimates of it. The gold leasing rate can be used as an empirical proxy for the real interest rate (see Levin, Abhyankar and Ghosh, 1994). Central banks lend out gold at a physical interest rate to bullion banks who sell the gold, use the proceeds to buy a bond which earns interest, and at the same time place a forward contract for gold to repay the gold loan at the end of the period.[6]

Arbitrage will drive this "trade" between central banks, the bullion banks and the gold producers to the point where:

$$P_t(1 + i_t) = P_t(1 + Rg_t)(1 + \pi g_t)\,, \qquad (16)$$

where: i is the one-period interest rate on the bond; π is the expected rise in the general price level; and πg is the expected rise in the price of gold. The Fisher equation can be used to decompose the one-period interest rate into an expected inflation rate component, π, and a real interest rate component, R:

$$(1 + i_t) = (1 + R_t)(1 + \pi_t)\ . \qquad (17)$$

Substituting Eq. [17] into [16] gives:

$$(1 + R_t)(1 + \pi_t) = (1 + Rg_t\ )\ (1 + \pi g_t)\ . \qquad (18)$$

Eq. [18] shows that *Rg* (which is observable) can be used as a proxy for *R* (which is not observable) if the price of gold is expected to rise at the general rate of inflation.

If the marginal cost of gold extraction, *MCg*, rises at the general rate of inflation, π, then

$$MCg_{t+1} = MCg_t(1+\pi_t)\ . \qquad (19)$$

If the price of gold is equal to the marginal cost of extraction (which would be the case in a competitive market) then:

$$P_{t+1} = MCg_t(1+\pi_t)\ , \qquad (20)$$

which implies that the price of gold is *expected* to rise at the general rate of inflation:

$$P_{t+1} = P_t\ (1+\pi_t)\ . \qquad (21)$$

In other words, $\pi g = \pi$ in Eq. [18][7]. Consequently, the real interest rate is equal to the physical interest rate, $R = Rg$. Therefore R and Rg are equivalent and can be measured by subtracting the observable gold forward rate, πg, from the observable interest rate, i. This measure also contains a default premium which cannot be separated out (see Levin, Abhyankar and Ghosh, 1994).

R and Rg are equal in equilibrium. This equivalence implies that the real interest rate need no longer appear directly in the equilibrium given in Eq. [15]. It is important however to recognise the significance of the real interest rate in the determination of the price of gold through its impact on inventory and the convenience yield. For example, although an exogenous rise in convenience yield would cause the price to rise, a rise in the convenience yield caused by a rise in the real interest rate would cause a reduction in the price of gold. More specifically, a rise in the real interest rate would cause central banks to reduce their inventories because the convenience yield of holding gold is now lower than the foregone alternative, the real interest rate. This sale of gold would lower the price of gold, and raise convenience yield to the level of the higher real interest rate at a new lower inventory.

Assuming linear functional forms for the supply and demand expressions [see Eq.(15)]:

$$Q^S_t = aP_t + bRg_t - cRg_{t-1} - dCy_t + eCy_{t-1} - f\rho_t + g\rho_{t-1} \qquad (22)$$

$$Q^D_t = - hP_t - iR_t - j\beta g_t + k\beta g_{t-1} \qquad (23)$$

and setting $R_t = Rg_t$ and solving for P_t gives:

$$P_t = -\frac{b+i}{a+h} Rg_t + \frac{c}{a+h} Rg_{t-1} + \frac{d}{a+h} Cy_t - \frac{e}{a+h} Cy_{t-1} + \frac{f}{a+h} \rho_t$$
$$- \frac{g}{a+h} \rho_{t-1} - \frac{j}{a+h} \beta g_t + \frac{k}{a+h} \beta g_{t-1} \quad (24)$$

where the derivatives with respect to price are:

$$\begin{array}{ll} \frac{\delta P_t}{\delta Rg_t} < 0 & \frac{\delta P_t}{\delta Rg_{t-1}} > 0 \\ \frac{\delta P_t}{\delta Cy_t} > 0 & \frac{\delta P_t}{\delta Cy_{t-1}} < 0 \\ \frac{\delta P_t}{\delta \rho_t} > 0 & \frac{\delta P_t}{\delta \rho_{t-1}} < 0 \\ \frac{\delta P_t}{\delta \beta g_t} < 0 & \frac{\delta P_t}{\delta \beta g_{t-1}} > 0 \end{array} \quad (25)$$

Increases in the current beta for gold and the current physical interest rate have an unambiguous *negative* effect on the price of gold, while increases in the current convenience yield and current default risk have an unambiguous *positive* impact on the price of gold. Lagged values of beta for gold and the physical interest rate have positive effects on the price of gold, while lagged values of the convenience yield and default risk have a negative effect on the price of gold.

3. The Long-run Price of Gold

Gold producers supply their customers both by extracting gold from mines and by leasing from central banks. If gold producers are profit maximisers, then they will substitute between the two alternative supply strategies to the point where:

$$MC_a = MC_b \ , \tag{26}$$

and the marginal cost of strategy "a" (e.g. mining) equals the marginal cost of strategy "b" (e.g. leasing). As discussed above, in a competitive market the price of gold equals the marginal cost of extraction which in turn equals the marginal cost of leasing. That is:

$$P_t = MC_{at} = MC_{bt} \ . \tag{27}$$

The marginal cost to the mine of supplying one ounce of gold in the current period by “borrowing” it for one period from a central bank, MC_{bt}, is equal to the present value of mining one ounce plus the physical rate of interest to be returned to the central bank in the next period. That is:

$$MC_{bt} = \frac{MC_{at}(1+Rg_t)(1+\pi_{Et})}{(1+R_t)(1+\pi_t)} \tag{28}$$

where π_E is the rate of increase in the costs associated with extracting gold and π is the general rate of inflation. As explained above, if the marginal cost of gold extraction rises at the general rate of inflation, then*:*

$$Mc_{at+1} = MC_{at}(1+\pi_{Et}). \tag{29}$$

Eqs. [27] and [28] imply that as long as extraction costs rise at the general rate of inflation, $\pi_E = \pi$, and $P = MC_a$, (or P is proportional to MC_a if gold mines have market power), and the price of gold will rise at the general rate of inflation.

4. Empirical Analysis

4.1 Statistical Model

The above theoretical analysis of the price of gold suggests a set of the conditions that would have to be satisfied for the price of gold to rise over time at the general rate of inflation. If these conditions hold then in the long-run gold would be an effective hedge against inflation. This analysis also helps explain the apparent contradiction between short-run and long-run movements in the price of gold. Gold may be an inflation hedge in the long-run but it can also be characterised by significant short-run price fluctuations.

In this section, we use cointegration regression techniques to model movements in the price of gold with monthly data covering the period January 1975 to December 1999. The model is of the basic structure:

$$Pg = f(Pusa, Pw, Rg, Y, \beta g, er, \theta) \qquad (30)$$

where: "*Pg*" is the nominal USA dollar price of gold; "*Pusa*" is the USA price index; "*Pw*" is the world price index; "*Rg*" is the gold lease rate; "*Y*" is world income; "β_g" is gold's "beta"; "*er*" is the dollar/world exchange rate; and "θ" are random shocks that impact on the price of gold. In it simplest interpretation, this model hypothesises that changes in the nominal price of gold will be driven by inflation, by changes in the gold lease rate, the returns on other forms of investment, income, the exchange rate and by financial and political shocks. Each of these variables are defined in detail below[8].

4.2 Measurement

The price of gold (*Pg*) is the monthly average spot price of gold per ounce denominated in US dollars. The variable is not adjusted for inflation or seasonality in any way, since we are interested in movements in the nominal price of gold. The variable was obtained from the *Kitco Minerals and Metals Inc*. web-site (www.kitco.com).

Two general price level variables are included. The first is the USA retail price index (*Pusa),* which is intended to be a measure of the overall price level in the United States. This variable was obtained from the *Bureau of Labor Statistics* web-site (www.stats.bls.gov). The second is the "non-adjusted IMF World Consumer Price Index" (*Pw*), which is intended to be a measure of the overall "world price level". This variable was obtained from *Datastream*. *Pw* is included in addition to *er* and *Pusa* to control for any additional impact on the dollar price of gold caused by a change in the price of gold relative to other goods outside of the USA after holding *er* and *Pusa* constant.

The theoretical model outlined above suggests that movements in the real interest rate, the convenience yield, the beta value for gold and default risk largely determine short-run movements in the price of gold. The convenience yield is not directly observable since it represents the "sum total" of all the reasons why central banks hold gold instead of interest earning assets. However, as argued above, the gold lease rate (R_g) is an effective proxy for the real interest rate plus a default premium that cannot be separated out. The gold lease rate is typically calculated by subtracting the three-month gold forward rate from three-month *LIBOR* dollar interest rate.

Gold leasing began in the early 1980s. We are indebted to Mr. Andrew Smith of *Mitsui Global Precious Metals* for providing the gold lease rate for the period January 1982 to September 1999. The gold lease rates for the remaining three months (October-December 1999) were obtained from the *London Bullion Markets Association* website (www.lbma.org.uk). It is important to note that gold was not leased every day during the early years. This means that end-of-month data for gold lease rates might actually refer to one or two weeks earlier. We avoid the problem of stale prices by using price and rates averaged over the month for the entire sample period.

Real income *(Y)* was constructed using real annual growth rates of "world" gross domestic product. These annual growth rates were first interpolated to generate monthly growth rates. The resulting series was then integrated to create a monthly index of real world income. The growth rate variable for the period 1975 to 1997 was obtained from *Datastream* and for 1998 to 1999 from the *OECD* website (http://www.oecd.org).

The beta for gold measures the covariance between the returns on holding gold and a well-diversified market portfolio. In this paper, gold's beta (βg) for each month t was estimated by fitting the following simple regression model:

$$(Pg_{t-n} - Pg_{t-n-1})/Pg_{t-n-1} = \alpha + \beta g_t\,[(d_{t-n} + SP_{t-n} - SP_{t-n-1})/SP_{t-n-1}] + \varepsilon_t \qquad (31)$$

where: *"Pg"* is the nominal price of gold; *"SP"* is *the Standard and Poor's 500 ("S&P500")* index; "*d*" is dividends; and "*n"* = 1 to 36 months. Therefore βg is estimated for each month by regressing the monthly gold return on the monthly *S&P500* (dividends reinvested) return, based on information from the previous 36 months. The *S&P500* total returns index was obtained from the *Economagic: Economic Time Series Page* website (www.economagic.com)

The price of gold is denominated in US dollars. Therefore, the price of gold in non-dollar areas would be affected by changes in dollar/world currencies exchange rate for reasons other than the maintenance of purchasing power parity. It is necessary to include the spot dollar/world currencies exchange rate (*er*) as a right-handside variable in the empirical model in order to control for gold dollar price movements attributable to gold market activity outside of the dollar area caused by exchange-rate-determined changes in the non-dollar gold price. The dollar/world currencies exchange rate was measured as the "nominal major currencies dollar index", which is a trade-weighted exchange rate of the dollar to the rest of the world. The variable was obtained from the *Federal Reserve Board* website (www.bog.frb.fed.us)

Default risk (ρ) is difficult to measure directly because it is associated with financial shocks, political turmoil and structural changes in the international economy. For example, a financial shock occurred following a warning from the governor of *The Bank of England* on 12 May 1988, and the subsequent collapse of *Drexel Burnham Lambert* in 1990 with large outstanding gold liabilities to central banks. Gold leasing was adversely affected in 1990 as central banks reassessed the default risk of this activity (see O'Callaghan 1991). Examples of political turmoil include the Malvinas and Gulf wars and the fall of the Berlin Wall. An international structural change that likely had an impact on the price of gold is exemplified by the transformation of India from a government-controlled economy to a market economy that significantly increased the user demand for gold.

It is difficult to directly model these "events". Ariovich (1983) and Sherman (1983) have documented a statistically significant relationship between the gold price and political tension measured by the Hudson political tension index. However, this index is no longer available. Nevertheless, it is important to take into consideration these events because of their potential effects on the default risk associated with the gold leasing rate and their effects on the stability of the other determinants of the price of gold. In the empirical analysis we attempt to capture the impact of these shocks and events by the inclusion of a series of time-specific dummy variables (θ). As is described below, the selection of what dummies to include is based on statistical criteria.

Finally, in the analysis all the variables except *Rg* and βg are expressed in natural logarithms (i.e. lnX). Some descriptive statistics for these variables are given in Tables 1 and 2. Means and standard deviations (both in levels and first differences) are shown in Table 1 while zero-order correlations are shown in Table 2. As mentioned above all data are available from 1976 with the exception of the gold lease rate which is only available from 1982. Since our aim is to model the nominal price of gold over the entire period that gold has freely floated, we estimate our model from the beginning of 1976 until the end of 1999, treating the gold lease rate as a missing variable until 1982, by constraining its effect to be zero.

<<<< Tables 1 and 2 About Here >>>>

4.3 Unit Root Tests

A variable is said to be integrated of order *I(d)* if it is required to be differenced "*d*-times" in order for the variable to become a stationary, invertible, non-deterministic. ARMA process (see Hendry, 1986). More importantly, if two or more variables are related in the long-run (e.g. the price of gold and the price level), then all variables must by definition be the same order of integration, *I(d).* To a certain extent this is a precondition for cointegration (see below). Therefore, establishing the order of integration of the variables is an important first step in any cointegration analysis.

In order to test for the presence of unit roots and establish the order of integration of the variables a number of statistical tests may be employed. The most popular tests in the applied literature are those developed by Dickey and Fuller (1979, 1981). We calculated the "augmented Dickey –Fuller" (*ADF*) test:

$$\Delta x_t = \alpha + \beta x_{t-1} + \sum \gamma_i \, \Delta x_{t-i+1} + \upsilon_t \qquad (32)$$

where x_t is the variable under consideration, $i = 2,\ldots,p$ and p is chosen so as to ensure that υ_t is white noise. Table 3 presents the results of our unit root tests, where p was chosen using the Schwarz Bayesian Criterion (see Schwarz 1978). Taken at face value, the results of the ADF test suggest that, at the 5 per cent level, *lnPg, lnPw, lnY, βg* and *lner* are *I(1)* variables while *lnPusa* and *Rg* are *I(0)* variables. That is, based on this test, all the variables included in the model are not the same order of integration. However, it is important to stress that the reported results, to some extent, are dependent upon the number of lags included in the ADF regression. Other lag selection criteria suggest a variety of different lag lengths may be appropriate for the unit root tests.[9] In some cases the lag length suggested by the alternative criteria significantly alter our conclusions. The non-rejection of the null-hypotheses that *lnPw*, *lnY*, *βg* and *lner* are I(1) variables appears robust to the different lag lengths suggested by the alternative criteria. However, our conclusions regarding the other variables are dependent upon the number of lags included in the unit root regression.[10]

<<<< Table 3 About Here >>>>

In what follows below, we proceed under the assumption that all variables are I(1) and are stationary on first differencing. We have decided to adopt such a strategy for four reasons. The first is that it is common to do so in the applied literature. Unit root tests have relatively low power and practitioners often rely on theoretical arguments to construct models based on cointegration methods when the results of unit root tests are inconclusive (see Engle and Granger, 1987; Muscatelli and Hurn, 1992; Hall, 1986). The second is that such an assumption allows us to pursue the possibility of long-run relationships through the use of cointegration methods, which is a key feature of our theoretical model. The third is that models that "mix" variables in levels with variables in differences often badly fail residual tests, with serial correlation proving to be a serious problem. The fourth is that such models are typically difficult to interpret in terms of the hypothesis suggested by the underlying theory.

4.4 Long-run Relationships

The theoretical model outlined above suggests that if there is a long-run relationship between the nominal price of gold and inflation, i.e. if gold is an effective long-run inflation hedge, the (nominal) price of gold and the general price level should "move together". That is, the variables should be cointegrated. However, which price level should gold be a hedge against? This is not an easy question to answer *a priori* so formal cointegration tests were carried out exploring the relationships between *lnP* and *lnPusa* and *lnPw*. The specific methods used are those developed by Johansen (1988, 1991).

Engle and Granger (1987) have proved that if two or more variables are cointegrated it implies the existence of a well-defined error correction mechanism (*ECM*). The *ECM* describes the short-run adjustment process of the cointegrated variables after a movement away from the long-run relationship. Since a key hypothesis of this paper is that there should be a long-run relationship between the general price level and the (nominal) price of gold then a meaningful *ECM* is of the form:

$$ecm_{t-1} = \gamma(\alpha lnPg_{t-1} - \beta lnPusa_{t-1} - \rho lnPw_{t-1}) \qquad (33)$$

where $lnPg_t$, $lnPusa_t$ and $lnPw_t$ are cointegrated variables and γ, the speed of adjustment parameter, lies between 0 and -1. Equation (33) implies the existence of a cointegrating vector of the following form:

$$\alpha lnPg_t = m + \beta lnPusa_t + \rho lnPw_t + \omega_t \qquad (34)$$

where ω_t is a white noise process and *m* represents possible non-stochastic elements of the vector (such as a constant or time-trend).

If the appropriate measure of the general price level is a linear combination of $lnPusa_t$ and $lnPw_t$ we would expect to find the restrictions $\alpha = -1$ and $\beta + \rho = 1$ in Eq. (34) hold. The Johansen procedure produces two test statistics: a likelihood ratio test statistic based on the maximum eigenvalue of the stochastic matrix of the cointegrating vector autoregression and a likelihood ratio test statistic based on the trace of the same matrix.[11] Tables 4 and 5 present the results of tests of cointegration. Both tests suggest the existence of a single cointegrating vector, both tests fail to reject the null of one or fewer cointegrating vectors against the alternative and reject the null of no cointegrating vectors. Having established the existence of a cointegrating vector the next step is to estimate α, β and ρ. This is achieved by normalising one of the coefficients (in this case we set $\alpha = 1$). The results presented in Table 6 suggest both β and ρ are non-zero. However, a likelihood ratio test of the restrictions suggested by Eq. (34) is rejected.[12]

<<<< Tables 4 to 6 About Here >>>>

One possible explanation for this rejection is the high correlation that exists between *lnPusa* and *lnPw* (see Table 2) The strong relationship between these two variables suggests it may be legitimate to remove one or other of the price level terms from our cointegrating vector and *ECM*. Tables Tables 7 and 8 present the results of cointegration tests when *lnPw* is excluded from the analysis. The results in this case are mixed, at the 95% level of significance, the trace test (Table 8) suggests the existence of one cointegrating vector. However, the maximum eigenvalue test results (Table 7) fail to give results that are easily interpreted, at the 95% significance level we would conclude the are no cointegrating vectors, and at the 90% significance level we would conclude there are two.

<<<< Tables 7 and 8 About Here >>>>

Such a finding is not uncommon (see for example Pesaran and Pesaran,1997) and in order to further investigate the relationship between the nominal price of gold and the price level we will assume the two variables are cointegrated. Note that if the two variables are not cointegrated we will not be able to establish a sensible *ECM*. Coefficient estimates of α (which is normalised) and β are presented in Table 7. A test of the restriction, $\alpha = 1$ and $\beta = -1$ cannot be rejected at the 90% significance level (although it can at the 95% level of significance).[13] We will therefore also proceed under the assumption that these restrictions hold (i.e. we have a unitary cointegrating vector). Finally, Tables 9 and 10 present the results of cointegration tests when *lnPusa* is dropped from Eq. (34). In this case both tests suggest there is no cointegration between *lnPg* and *lnPw*.

<<<< Tables 9 and 10 About Here >>>>

The cointegration tests provide some evidence for concluding that the retail price index in the United States and the nominal price or gold are involved in a long-run relationship. The tests also suggests that the implied elasticity of this relationship is one i.e. ($dlnPg/dlnPusa = 1$).This finding is consistent with view that gold is long-run hedge against inflation.

4.5 Short-run Relationships

In order to explore the short-run dynamics of the model, a model of the following general form was estimated over the period 1976(1) to 1999(12):

$$\begin{aligned} \Delta lnPg_t &= \alpha + aA(L)\Delta lnPg_{t-1} + bB(L)\Delta lnPusa_t + cC(L)\Delta lnPw_t + dD(L)\Delta Rg_t \\ &+ eE(L)\Delta lnY_t + fF(L)\Delta\beta g_t + gG(L)\Delta lnER_t \qquad (35) \\ &+ \theta_k t_k + \gamma ecm_{t-1} + u_t \end{aligned}$$

where: "α" is a constant; *A(L), B(L), …, G(L)* are finite order lag polynomials; "a", "b", …, "g" are vectors of the parameters associated with these lag polynomials; θ_k is an empirically determined set of period specific (t_k) dummy variables; "u" is a random error term; "ecm_{t-1}" is the error correction mechanism constructed from the results of the cointegration tests, that is we assume a cointegrating relationship between *lnPg* and *lnPusa* and a unitary cointegrating vector:

$$ecm_{t-1} = lnPg_{t-1} - lnPusa_{t-1} \qquad (36)$$

The parameters of this model were estimated following Hendry's "general to specific" strategy (see for example Davidson *et. al.* 1978). We started with the general model outlined in Eq. [33] that contains all those variables that we believe (from our theoretical discussion) will influence the price of gold in the short-run. To begin with, we use six lags to fully investigate the rich dynamics of the theoretical model. It is important to note that lagged values of ecm_{t-1} and the contemporaneous value of $\Delta lnPusa$ are not included since this would result in simultaneity bias.

The next step was to estimate the parameters of this model without including any period specific dummies. We carried out a number of tests in order to evaluate the suitability of this specification. These tests included: 1) a Lagrange multiplier test of residual correlation (see Godfrey 1978a, 1978b); 2) the Ramsey (1969) RESET test of functional form misspecification, using the square of the fitted values; 3) the Bera and Jarque's (1981) normality test of the residuals; and 4) a Langrange Multiplier test of heteroskedasticity based on the regression of squared residuals on squared fitted values (see Pesaran and Pesaran 1997). This empirical model did not perform well on these tests with the null hypotheses of normality, homoskedasticity and no functional form misspecification being solidly rejected.

A careful examination of a plot of the residuals from this model suggested a number of clear outliers that were likely responsible for the failure of these tests. We then included a number of time-specific dummy variables in the model in order to "dummy out" the effect of these outliers. The inclusion of these dummies resulted in a well-specified model that passes the above tests (test statistics given below). In order to make the model more parsimonious, we reduced the number of right-hand side variables by eliminating variables with statistically insignificant parameters. This was accomplished by testing for zero restrictions using a Wald (1949) test. This process was continued until the following "final" model was arrived at:

$$\begin{aligned}
\Delta lnPg_t = & -0.0129 + 0.228\Delta lnPg_{t-1} - 0.164\Delta lnPg_{t-2} + 0.114\Delta lnPg_{t-5} \\
& \quad [3.4] \qquad\quad [5.0] \qquad\qquad [4.0] \qquad\qquad [2.9] \\
& + 1.87\Delta lnPusa_{t-3} + 1.53\Delta lnPusa_{t-6} \\
& \quad [2.6] \qquad\qquad [2.0] \\
& -0.0148\Delta Rg_t - 0.0134\Delta Rg_{t-5} + 0.262\Delta Rg_{t-6} \\
& \quad [2.0] \qquad\quad [1.7] \qquad\quad [3.2] \\
& -0.108\Delta\beta g_t - 0.0520\Delta\beta g_{t-2} + 0.0454\Delta\beta g_{t-5} \qquad\qquad (37) \\
& \quad [3.7] \qquad\quad [1.8] \qquad\qquad [1.6] \\
& -0.671\Delta lner_t \\
& \quad [5.6] \\
& -0.0228ecm_{t-1} \\
& \quad [3.1] \\
& + 0.105t_{76(11)} - 0.108t_{78(11)} + 0.159t_{79(9)} + 0.147t_{79(12)} \\
& \quad [3.2] \qquad\quad [3.3] \qquad\quad [4.9] \qquad\quad [4.4] \\
& + 0.379t_{80(1)} - 0.0962t_{80(2)} - 0.0826t_{81(7)} - 0.103t_{82(3)} \\
& \quad [11.0] \qquad\quad [2.5] \quad [2.4] \qquad\quad [3.1] \\
& + 0.0957t_{82(4)} - 0.174t_{82(9)} - 0.0917t_{91(2)} + 0.115t_{99(10)} \\
& \quad [2.9] \qquad\quad [5.2] \quad [2.7] \qquad\quad [3.5] \\
& -0.119t_{99(11)} + u_t
\end{aligned}$$

[3.2]

The absolute value of each parameter's associated t-statistic is shown in parentheses.

The R^2 value of this model is 0.65 suggesting a good fit remembering that the variable being modelled is a first difference. The Lagrange multiplier test for serial correlation suggests no significant serial correlation is present: $\chi^2(12) = 7.6$ with a *p-value* $= 0.82$. The Ramsay RESET test for functional form suggests that the model is not misspecified: $\chi^2(1) = 1.1$ with a *p-value* $= 0.30$. The Bera-Jarque test for normality indicates that the residuals are normally distributed: $\chi^2(2) = 1.4$ with a *p-value* $= 0.49$. The test based on the regression of squared residuals on squared fitted values indicates that no significant heteroskedasticity is present: $\chi^2(1) = 0.5$ with a *p-value* $= 0.48$. The correlogram is shown in Figure 4, which plots the correlation coefficient between u_t and u_{t-k} for $k = 1,\dots ,K$. The correlation falls off quickly towards zero, suggesting that the residuals are indicative of a white noise process. Finally, a visual examination of the residuals suggest a random pattern with no obvious outliers (see Figure 5) Based on these tests (and unlike in case of the model that did not include period-specific dummies) serial correlation, non-normality, heteroskedasiticity and functional form misspecification are not problems.

<<<< *Figures 4 and 5 About Here* >>>>

Overall, the parameters estimates are consistent with the main hypotheses suggested by the theoretical model regarding the determinants of short-run movements in the price of gold. Lagged values of $\Delta lnPg$ are statistically significant at 1, 2 and 5 months. This finding that past values in the changes in the price of gold are predictive is not unusual in studies of asset pricing (e.g. exchange rates and stock prices). If markets were efficient then past information would <u>not</u>

assist in explaining current (and future) changes. This apparent predictability may be capturing the speculative behaviour of chartists, noise traders and other investors or more generally points to the possibility that the gold market is not an "efficient market".

Lagged values of $\Delta lnPusa$ are statistically significant at 3 and 6 months. These positive effects of "recent" USA inflation ($\Delta lnPusa_{t-3}$ and $\Delta lnPusa_{t-6}$) on the price of gold can be explained by short-run increases in the demand for gold that occur caused by inflation hedging. In other words, investors tend to hold less gold during periods of low inflation. This means that, quite apart from the long run price of gold rising with the overall price level, there are short-run changes in demand that impact on price.

The current value and two lagged values of ΔRg are statistically significant. The theory suggests that high current gold leasing rates depress the price of gold by increasing the supply of gold offered to the market by central banks. The theory also suggests that high gold leasing rates depress the price of gold by decreasing the demand for gold. Gold leasing rates are closely associated with real interest rates and a high real interest rate represents a high opportunity cost of holding gold relative to other interest-bearing investments. Therefore the gold lease rate (which should be equal to the real interest rate, apart from the default premium) both increases central banks' supply and reduces investors' demand for gold, thereby depressing the price. The negative signs on the parameters of ΔRg_t and ΔRg_{t-5} may be picking up these effects. However, the theory also suggests that current gold lease repayments to central banks should be positively related to earlier period high gold leasing rates. These repayments reduce the current supply of gold to the market and this supply effect should increase the price of gold. The positive sign on the parameter of ΔRg_{t-6} may be capturing this effect.

The current value and two lagged values of $\Delta\beta g$ are statistically significant. The highly desirable diversification property of gold is associated with its negative beta. Therefore gold is less attractive to hold in portfolios during periods when its beta is relatively high, and the gold price should fall in response to the lower investment demand for gold. This effect may be picked up by the negative signs on the parameters of $\Delta\beta g_t$ and $\Delta\beta g_{t-5}$. The positive parameter on $\Delta\beta g_{t-6}$ may indicate the effect of an increased short-run demand for gold as holdings of gold in portfolios revert to "normal" following a period when holdings of gold in portfolios were reduced because gold's beta was high.

The current value of $\Delta lner$ is statistically significant. The negative sign on the parameter of the dollar/world exchange rate is consistent with the theory. The demand for gold by non-USA investors falls in response to a rise in *er* because this change in the exchange rate would raise the price of gold expressed in non-dollar currencies to non-USA investors. When the dollar "strengthens", the price of gold rises for investors outside the dollar area even though the dollar price remains constant. Therefore a rise in *er* causes a reduction in demand for gold that depresses the dollar price of gold. If the gold market was entirely dominated by investors inside of the dollar area, the magnitude of the parameter estimate would be zero because movements in this exchange rate would be irrelevant. On the other hand, if the gold market was entirely dominated by investors outside of the dollar area, the magnitude of the parameter estimate would be minus unity. The finding that the magnitude of this parameter is -0.671 suggests (not surprisingly) that substantial components of the gold market lie both inside and outside the dollar area.

It is important to note that both ΔlnY and $\Delta lnPw$ do not enter the final specification as significant variables. This suggests that world income and world inflation are not important determinants of the price of gold. The finding that short-run changes in world income are not important is surprising but may be caused by the fact that we had to interpolate this variable from annual growth rates. However the finding that world inflation is not important is easier to justify. *Pw* was included in order to control for the possibility of an additional impact on the dollar price of gold caused by a change in the price of gold relative to other goods outside of the USA after holding *er* and *Pusa* constant. The absence of this variable in the final model indicates that the exchange rate tends to adjust in response to differences between the world inflation rate and the USA inflation rate.

In the final model there are thirteen statistically significant period-specific dummies. As discussed above it is difficult to precisely pinpoint the events that cause these sharp jumps and falls in the nominal price of gold. However, it is interesting to note that nine of these dummies cluster in the later 1970s and early 1980s. The late 1970s was a period of rapidly rising inflation (and inflation expectations) in the USA. More specifically in January 1977 the inflation rate was 4.5 per cent and by May 1980 it peaked at 13.3 per cent. After 1980 inflation fell rapidly reaching 3.5 per cent by January 1983. This inflation "spike" centred around 1980 likely caused increased volatility in inflation expectations which would impact on the price of gold in a manner not directly taken into consideration in our empirical model. We do not model the demand for assets that are believed to be hedges against inflation as a function of inflation because nominal interest rates should eliminate such a relationship via the Fisher relationship between nominal interest rates and expected inflation. Nevertheless, inflation volatility may well increase the demand for assets that provide hedges against inflation. However, this explanation is speculative.

The parameter of ecm_{t-1} is –0.0228. Therefore the error correction mechanism that we constructed is well behaved since it lies between 0 and –1. The finding confirms that *lnPg* and *lnPusa* are indeed cointegrated and lends further support to the hypothesis that these two variables move together in the long-run. However, the magnitude of this coefficient is "small" (i.e. closer to 0 than to –1). In addition, relative to some of the parameters in the short-run model it is also "small" in magnitude. This suggests that typically movements in the nominal price of gold are dominated by short-run influences and that the long-run relationship has less impact at any given point in time.

As a final check on the validity of this model, Figures 6 and 7 show plots of the actual and predicted implied by the model. Figure 6 is the actual and predicted changes in the logged nominal price of gold (i.e. $\Delta lnPg$). A visual examination suggests that the model does a good job of predicting what are essentially the slopes (proportionate monthly ups and downs) of the gold price series. No obvious major divergences between the actual and predicted values appear to stand out.

<<<<< *Figure 6 About Here* >>>>>

Figure 7 is a much more stringent test of how well the model "predicts". This figure plots predicted and actual movements in the level of the nominal price of gold (*Pg*). This was achieved by using the model to first predict changes in the logged nominal price of gold (i.e. the predicted values shown in Figure 6). These predictions were next exponentiated to transform them into nominal US dollar amounts. Finally, these dollar amounts were cumulated (integrated) using January 1976 as the "base" (*Pg* = US$142.20 per ounce), so both the actual and predicted series have the same starting point. This is an extremely demanding test (some would say too demanding) for three main reasons. The first is that model is couched in terms of changes and not in levels. Therefore by construction it was not designed to predict the level of gold prices. The second is that exponentiating these logarithmic differences introduces a non-linearity that increases the magnitudes of the divergences between actual and predicted values. The third is cumulating these predictions also cumulates any errors between actual and predicted values, which compounds the effect of “getting it wrong”. By employing the model in this way, we are putting it through a test that it was not explicitly designed to pass. It is precisely for this reason that we believe it is a good test of the validity of the underlying theoretical model which is ultimately trying to understand movements in the nominal price of gold. Despite such a difficult task, it is our view that the model performs quite well. As Figure 7 shows, the predicted series tracks the actual series quite well until about 1985, but does not capture completely the rise in gold prices that occurred in 1986-1987. After this period, the predicted series again seems to track the actual series quite well until about 1993 but does not capture fully the gradual rise in the price of gold that occurred in 1994-1996.

<<<<< Figure 7 About Here >>>>>

5. Conclusion

In this paper a theoretical model was developed that suggests a set of the conditions that would have to be satisfied for the price of gold to rise over time at the general rate of inflation. If these conditions are met then gold would be an effective long-run hedge against inflation. The model also demonstrated that this equilibrium relationship is consistent with sizeable short-run movements in the price of gold. It was argued that changes in such factors as the real interest rate, the covariance of returns to gold with a diversified portfolio of other assets, default risk, the convenience yield and particularly the gold lease rate can seriously disturb this equilibrium and generate considerable short-run volatility. This model helps reconcile an apparent contradiction between short-run and long-run movements in the price of gold.

Using monthly gold price data (1976-1999) and cointegration regression techniques, an empirical analysis confirms suggested a long-run relationship between the nominal price of gold and the USA retail price index, with an implied elasticity of one. We interpret this finding as gold being a long-run inflation hedge. This long-run relationship was then used to construct an error correction model that suggested that short-run movements in the price of gold are driven primarily by changes in the gold lease rate, gold's beta and the USA/World exchange rate. A key finding is that movements in the nominal price of gold appear to be dominated by these short-run influences and consequently the long-run relationship (although significant) is of much less importance.

Future research to extend this analysis would require examination of the assumptions made in this analysis. For example, the marginal cost of extracting gold may not rise at the rate of inflation. The convenience yield of gold may systematically alter over time if it is believed that the international financial system does not require central banks to hold any gold. The leasing rate may provide a biased measure of real interest rates if default risk is not a random variable. The supply of gold may not be a positive function of the price if high gold prices divert effort from extracting ore to extracting more gold from a smaller quantity of ore.

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Figure 1
The US Dollar Price of Gold Required for Gold to be an Inflation Hedge in the United States, 1895-1999

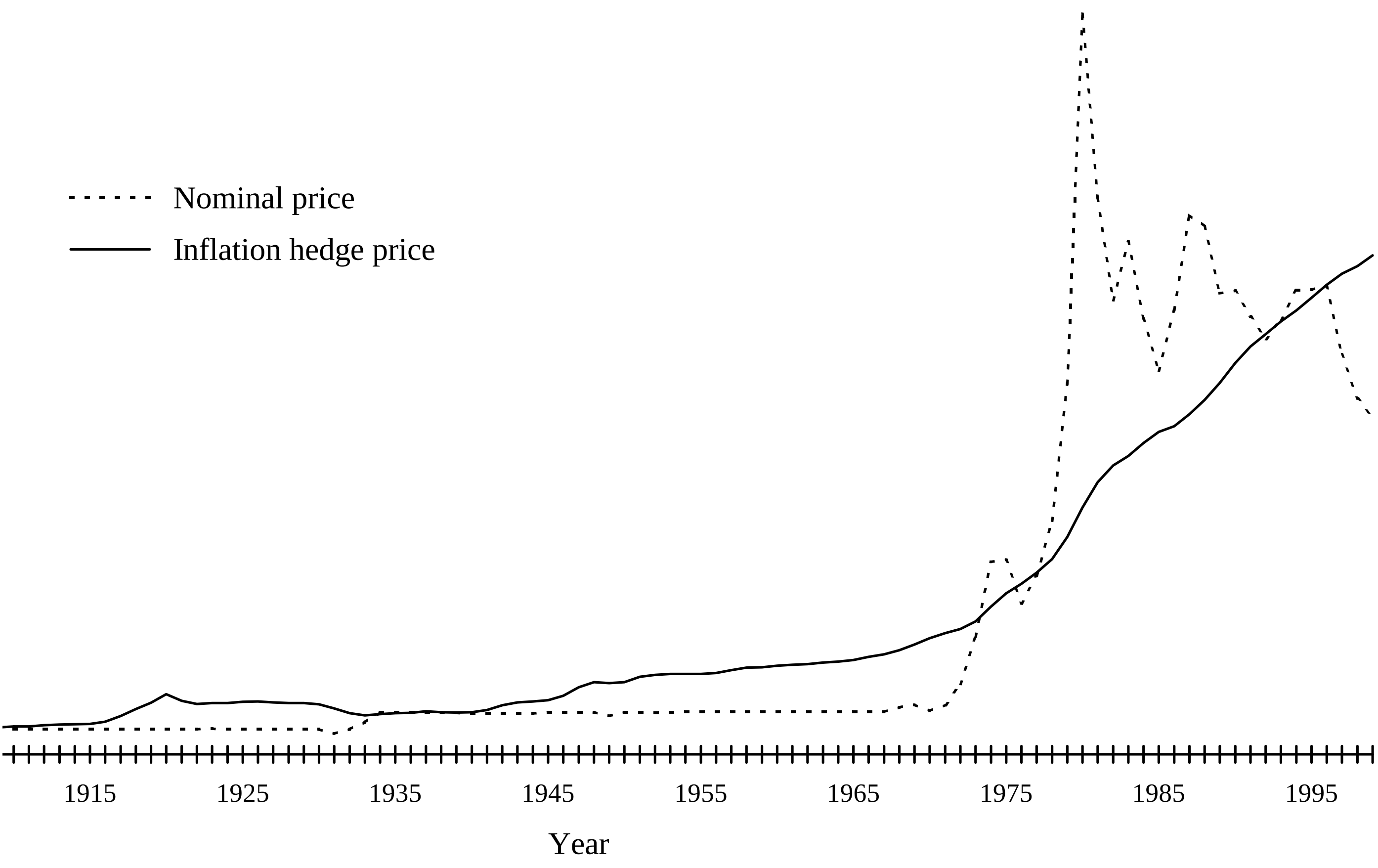

Figure 2a
The US Dollar Price of Gold Required for Gold to be an Inflation Hedge in the United States, 1982-1999

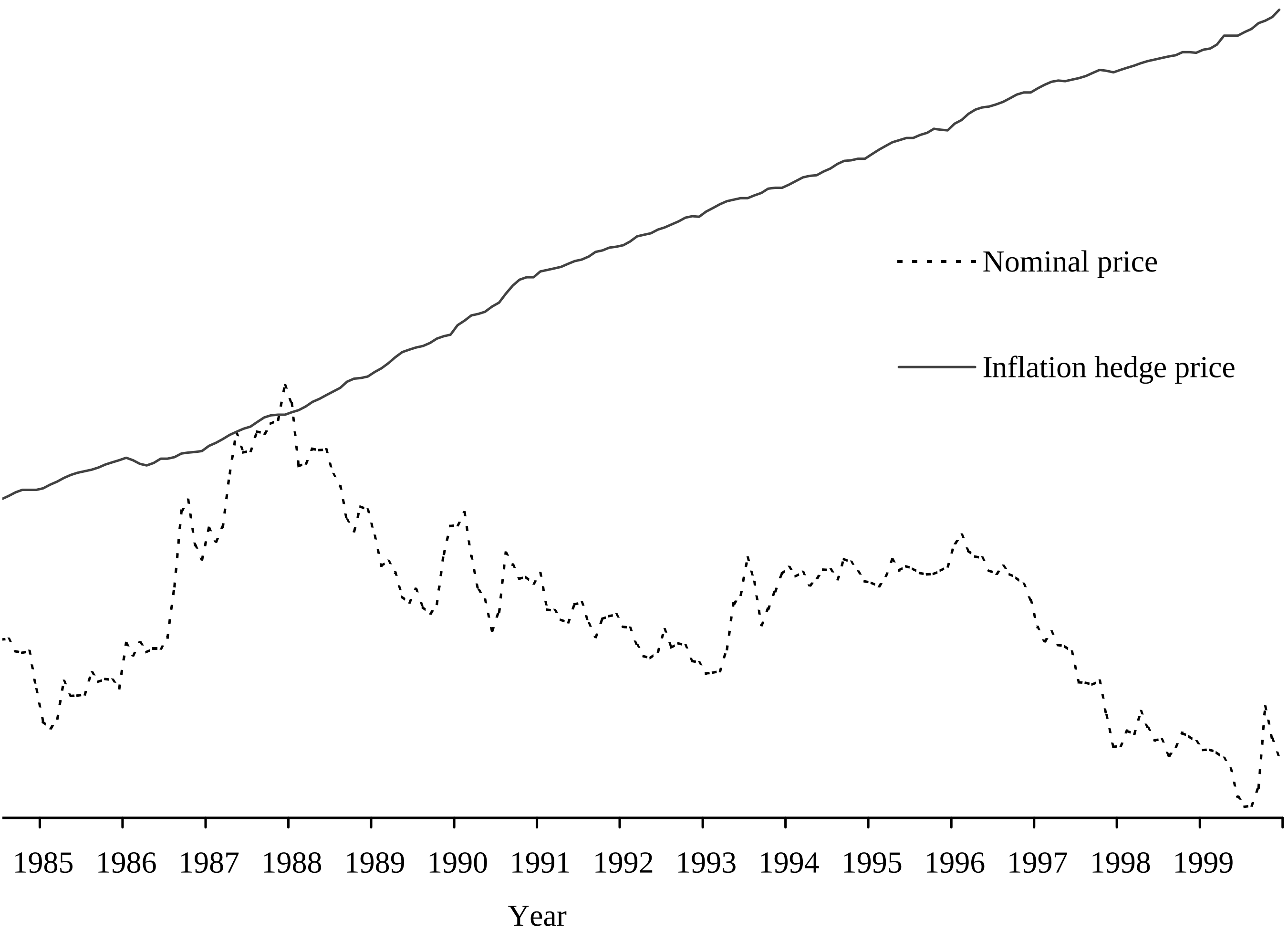

Figure 2b
The Pounds Sterling Price of Gold Required for Gold to be an Inflation Hedge in the United Kingdom, 1982-1999

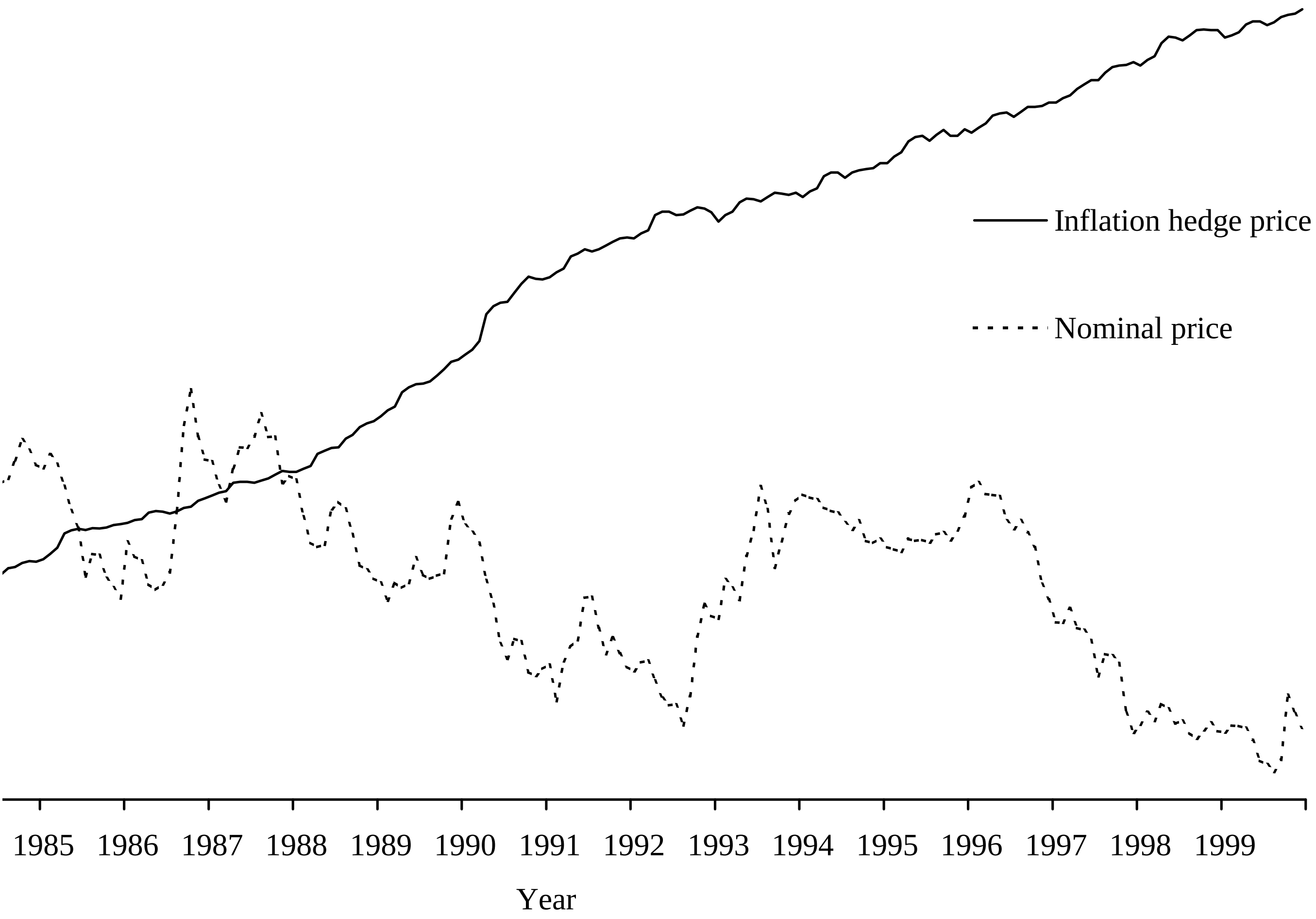

Figure 2c
The German Mark Price of Gold Required for Gold to be an Inflation Hedge in Germany, 1982-1999

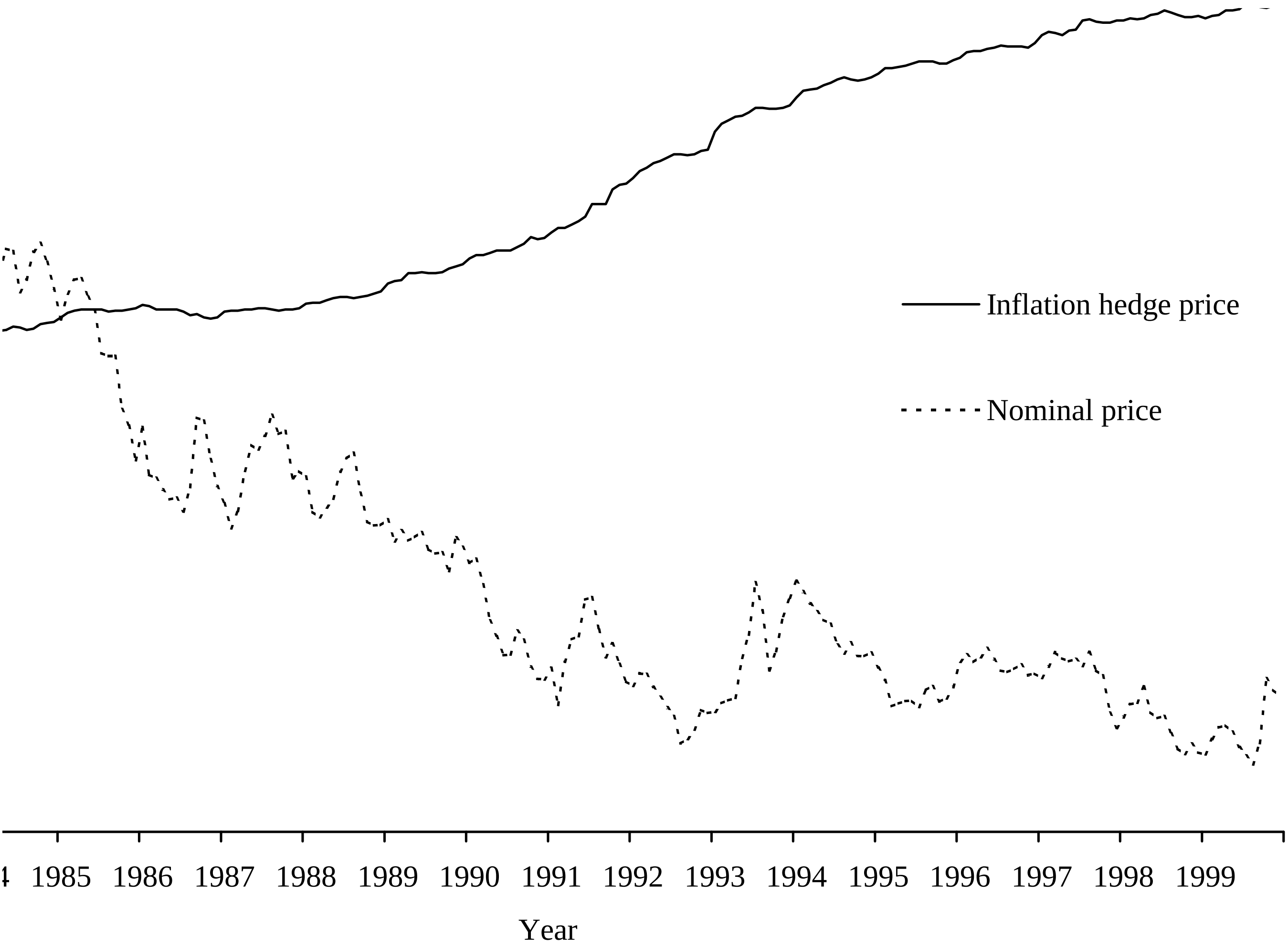

Figure 2d
The French Franc Price of Gold Required for Gold to be an Inflation Hedge in France, 1982-1999

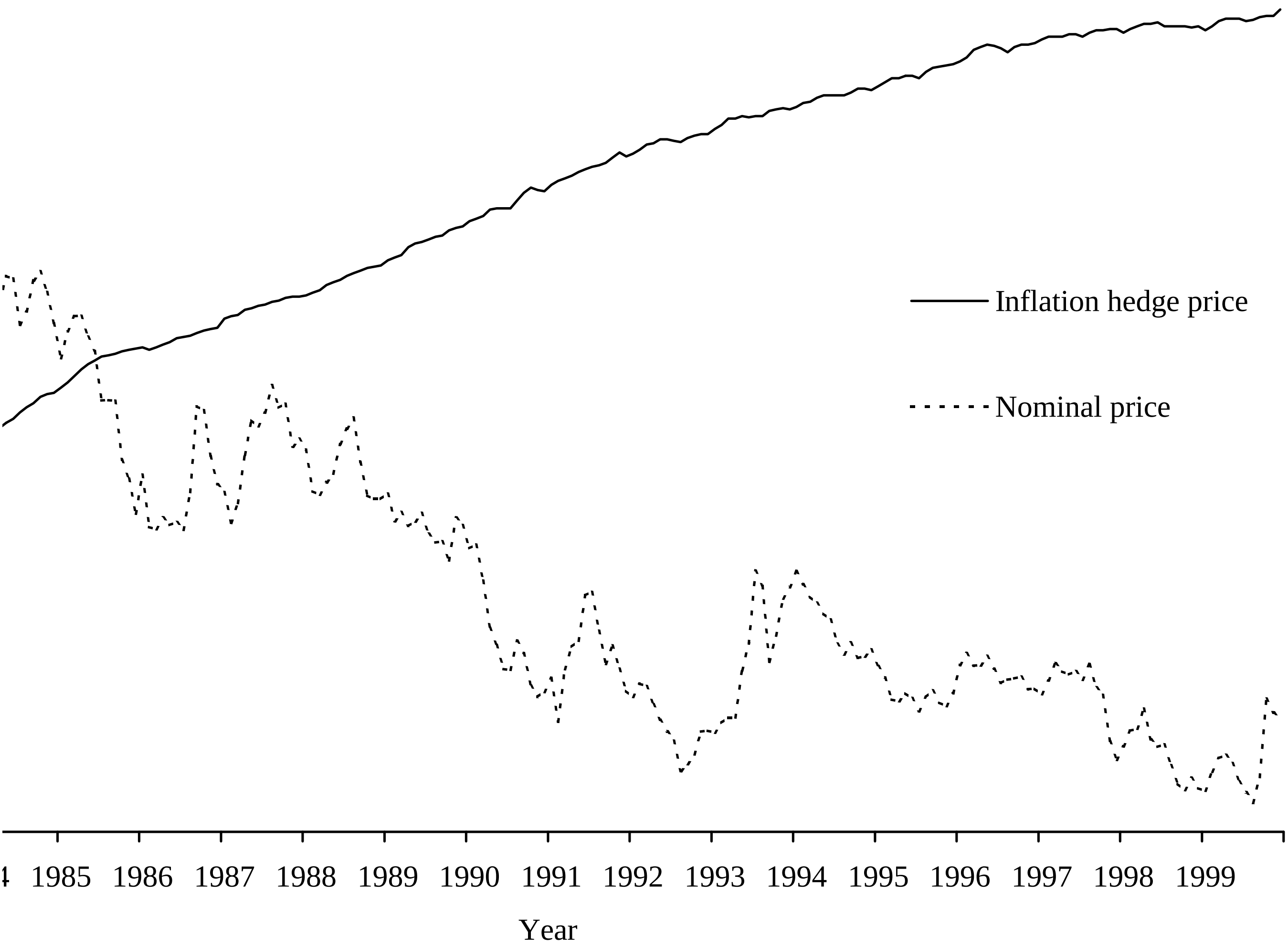

Figure 2e
The Japanese Yen Price of Gold Required for Gold to be an Inflation Hedge in Japan, 1982-1999

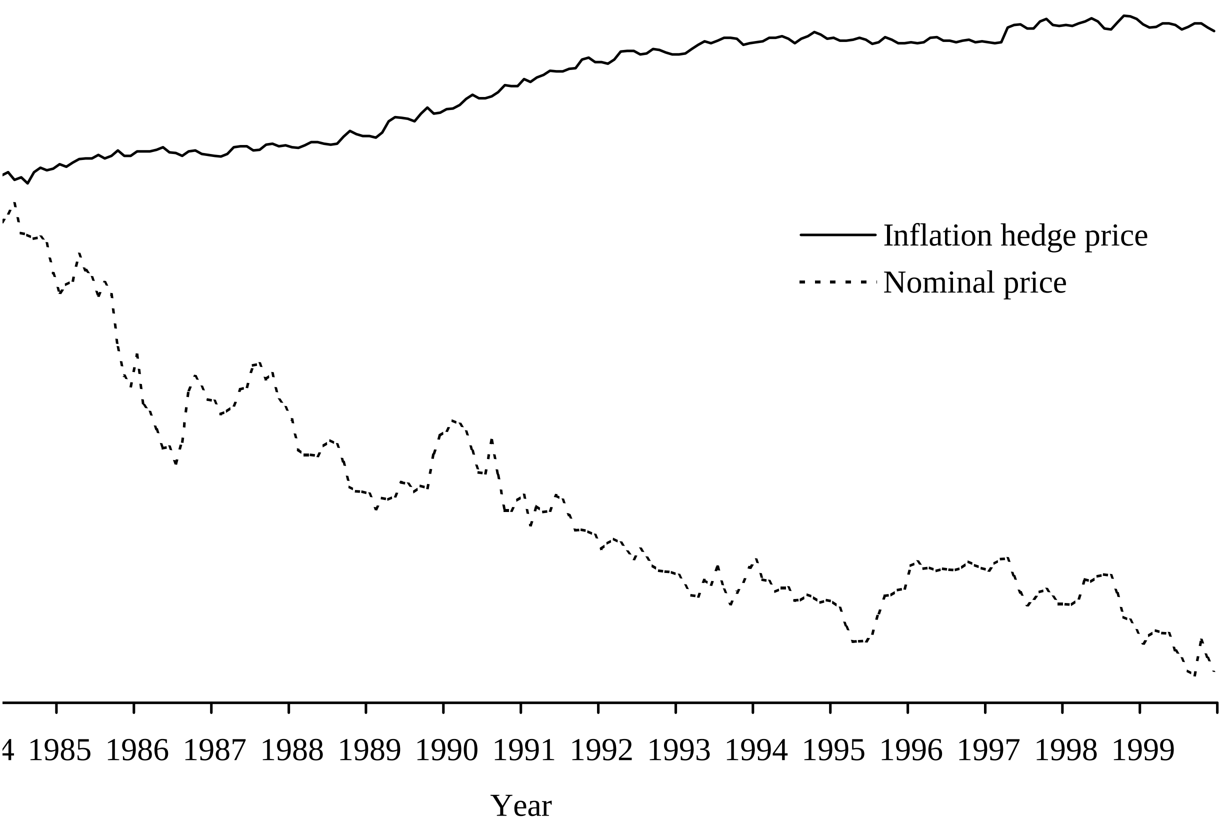

Figure 3
Equilibrium Asset Stock of Gold
And the Real Interest Rate

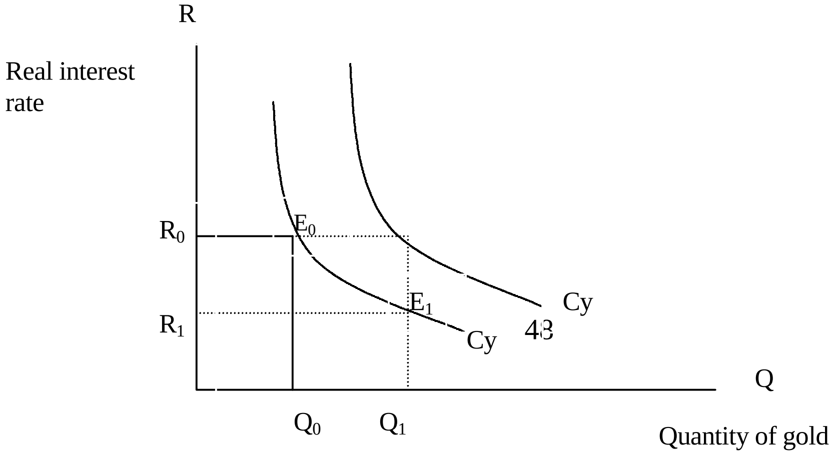

Figure 4
Correlogram

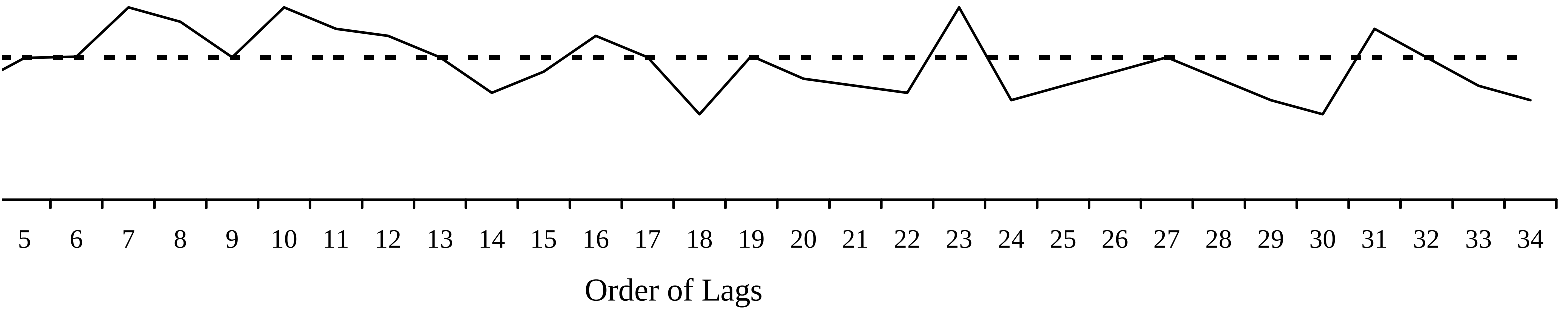

Figure 5
Residuals

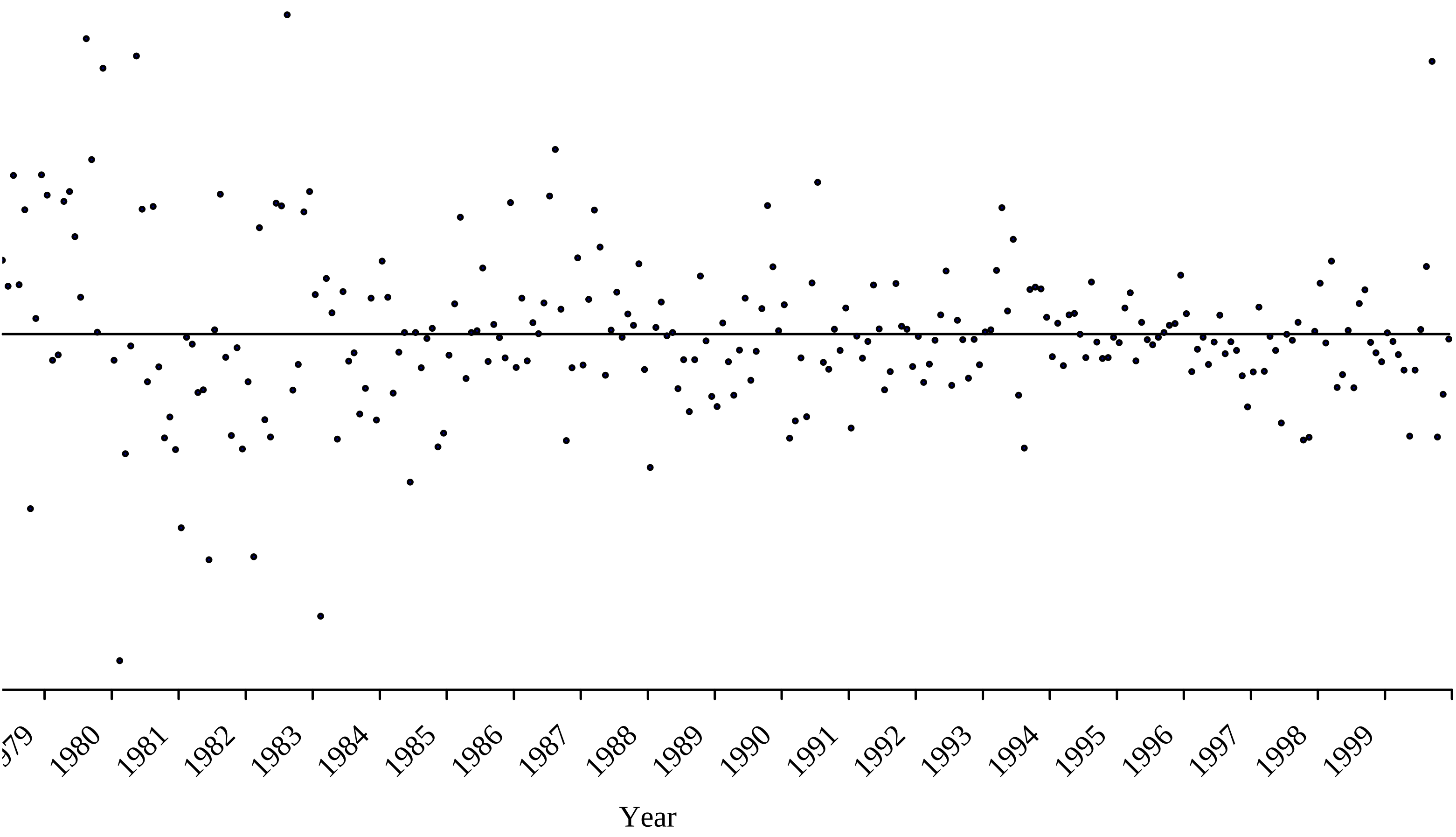

Figure 6
Actual and Predicted Changes in the Nominal Log Price of Gold
1976-1999

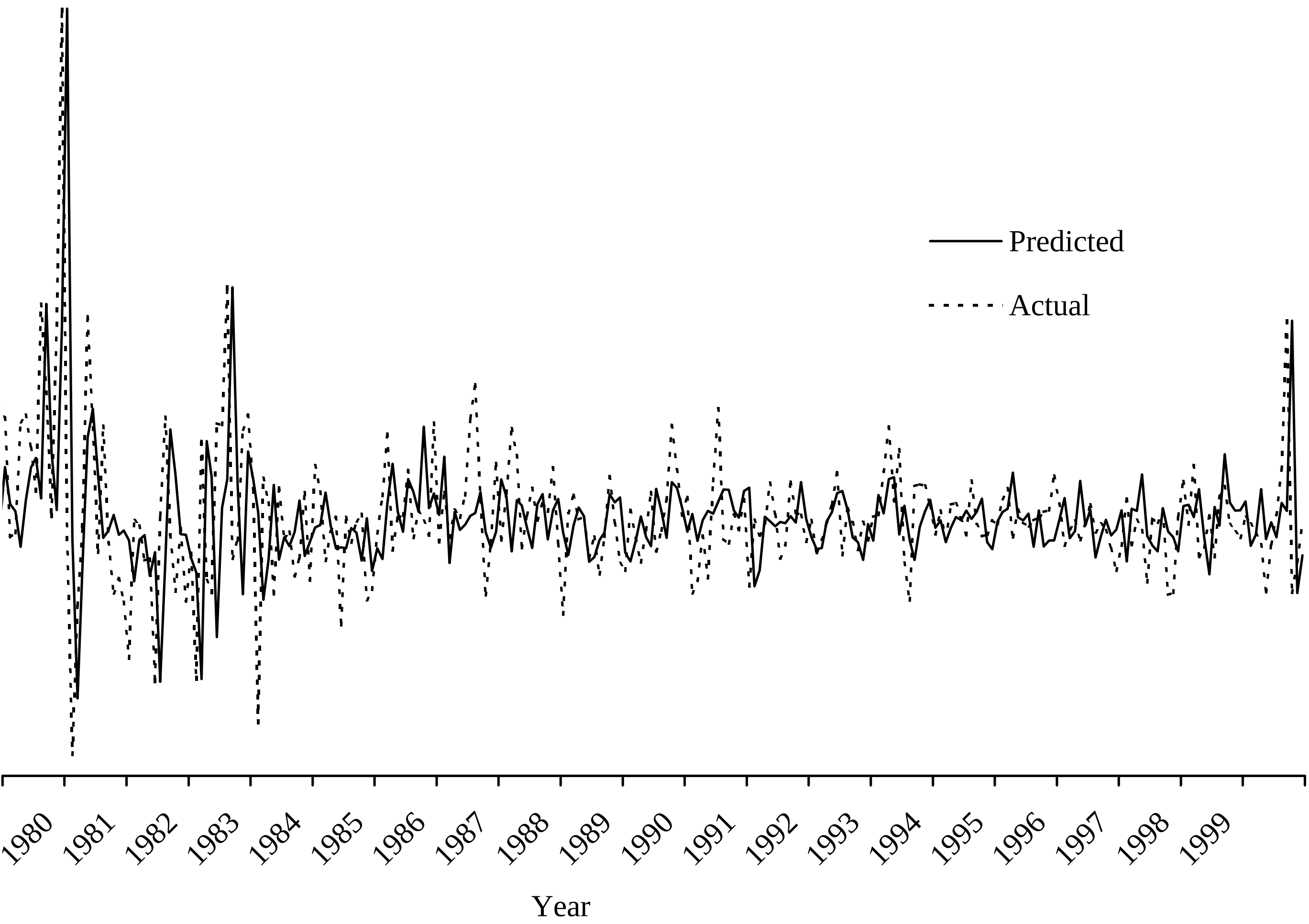

Figure 7
Actual and Predicted Nominal Price of Gold
1976-1999

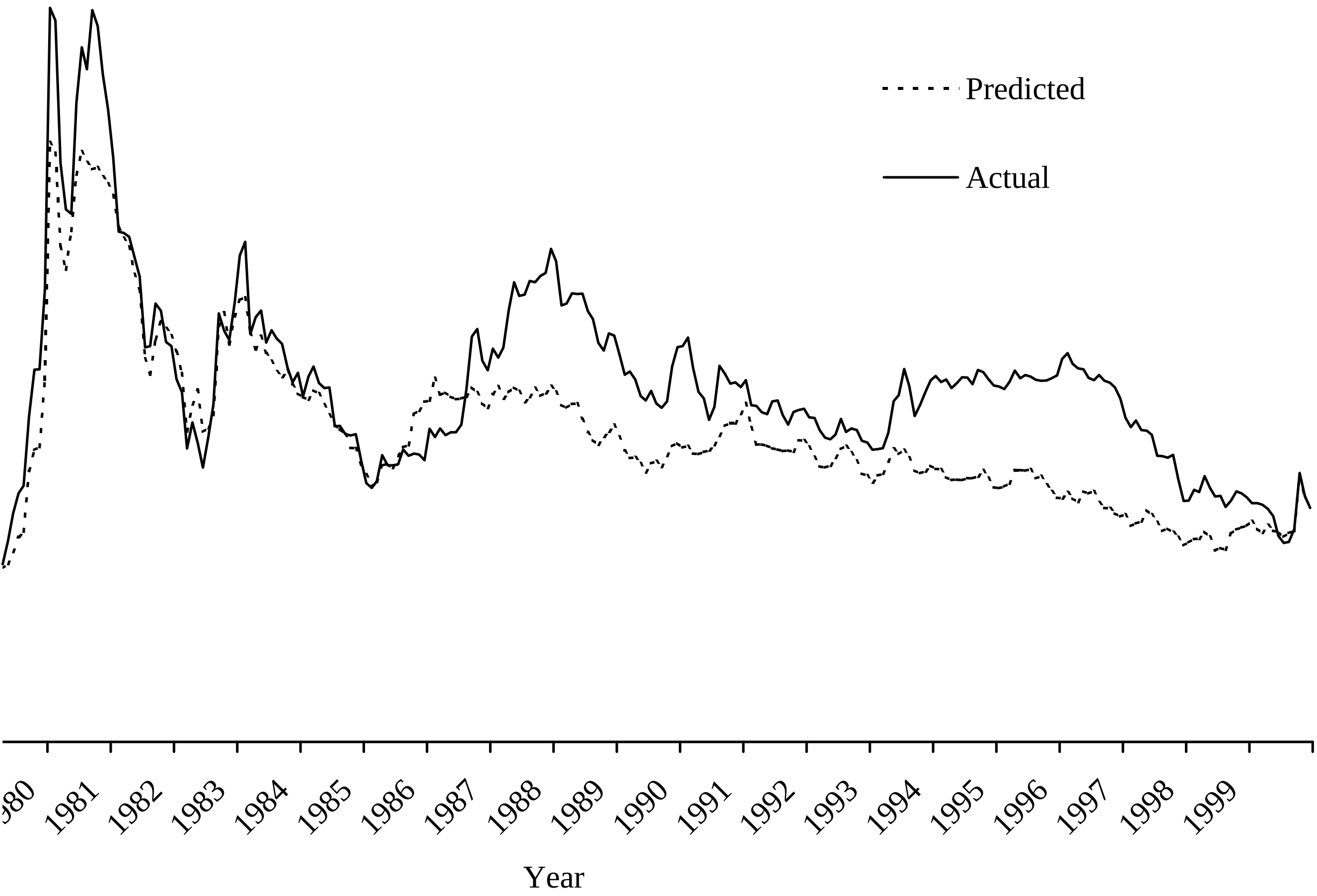

Table 1
Means [and Standard Deviations] of Variables

Variable (X)	Levels (X)	Logged Levels (lnX)	First Differences (ΔlnX)
Pg	*352.7* [103.5]	*5.81* [0.35]	*0.0025* [0.05]
Pusa	*342.3* [97.8]	*5.79* [0.32]	*0.0038* [0.003]
Pw	*1558.6* [1382.1]	*6.90* [1.00]	*0.011* [0.006]
	1.15 [0.7]	--	*0.0075* [0.34]
βg	*0.0047* [0.4]	--	*-0.0003* [0.07]
Y	*217.4* [53.2]	*5.35* [0.24]	*0.0029* [0.001]
er	*97.9* [13.5]	*4.58* [0.13]	*-0.0004* [0.02]

Notes: Period is 1976 (1) to 1999(11)

Table 2
Zero-order Correlations of Regression Variables

Logged Levels

lnPg	*1*						
lnPusa	*-0.432* [6.7]	*1*					

lnPw	*-0.416* *[6.5]*	*0.997* *[207]*	*1*				
Rg	*-0.330* *[4.8]*	*0.483* *[9.3]*	*0.472* *[9.1]*	*1*			
βg	*-0.033* *[0.6]*	*-0.542* *[8.1]*	*-0.507* *[7.7]*	*-0.177* *[2.9]*	*1*		
lnY	*-0.460* *[7.1]*	*0.992* *[132]*	*0.992* *[129]*	*0.512* *[10.0]*	*-0.489* *[7.4]*	*1*	
lner	*-0.139* *[2.3]*	*-0.734* *[18.2]*	*-0.724* *[9.9]*	*-0.343* *[5.5]*	*0.741* *[18.7]*	*-0.696* *[9.0]*	*1*
	lnPg	*lnPusa*	*lnPw*	*Rg*	*βg*	*lnY*	*lner*
First Differences							
ΔlnPg	*1*						
ΔlnPusa	*0.150* *[2.5]*	*1*					
ΔlnPw	*-0.038* *[0.6]*	*0.175* *[3.0]*	*1*				
ΔRg	*-0.042* *[0.7]*	*0.013* *[0.23]*	*-0.049* *[0.8]*	*1*			
Δβg	*-0.084* *[1.4]*	*0.088* *[1.5]*	*0.0007* *[0.0]*	*-0.046* *[0.8]*	*1*		
ΔlnY	*0.018* *[0.304]*	*-0.068* *[1.2]*	*-0.021* *[0.35]*	*-0.015* *[0.2]*	*-0.069* *[1.2]*	*1*	
Δlner	*-0.340* *[6.1]*	*0.062* *[1.0]*	*0.009* *[0.1]*	*-0.044* *[0.7]*	*0.171* *[2.9]*	*-0.093* *[1.6]*	*1*
	ΔlnPg	*ΔlnPusa*	*ΔlnPw*	*ΔRg*	*Δβg*	*ΔlnY*	*Δlner*

Notes:
(a)Absolute values of t-statistics in parentheses

Table 3
ADF Unit Root Tests

	Test Statistic for:	
Variable *(X)*	**Levels** *(X)*	**First Differences** *(ΔX)*
lnPg	*2.685*	*12.456**
lnPusa	*4.830**	*7.208**

lnPw	*1.062*	*5.283**
	*4.404**	*10.143**
βg	*1.382*	*8.371**
lnY	*0.198*	*3.235**
lner	*1.574*	*12.074**

Notes:

(1) Unit root tests follow Dickey and Fuller (1979) and include a constant term.
(2) "*" represents significance at the 5% level.
(3) The critical value for these tests comes from MacKinnon (1991) and is (-)2.872. Minus signs have been removed from all of the test statistics.
(4) The Schwarz Bayesian Criterion (Schwarz 1978) is used to select the appropriate lag-length of the unit root regressions.

Table 4

Maximum Eigenvalue Cointegration Test of *lnPg, lnPusa* **and** *lnPw*

Null Hypothesis	**Alternative Hypothesis**	**Max. Eigenvalue Test Statistic**	**95% Critical Value**	**90% Critical Value**

R=0	*R=1*	*23.25*	*21.12*	*19.02*
R<=1	*R=2*	*9.13*	*14.88*	*12.98*
R<=2	*R=3*	*4.64*	*8.07*	*6.50*

Note: R is the number of cointegrating vectors. Critical values are calculated by the *Microfit* program (Pesaran and Pesaran 1997).

Table 5

Trace Cointegration Test of *lnPg*, *lnPusa* **and** *lnPw*

Null Hypothesis	Alternative Hypothesis	Trace Test Statistic	95% Critical Value	90% Critical Value
R=0	*R>=1*	*37.02*	*31.54*	*28.78*
R<=1	*R>=2*	*13.77*	*17.86*	*15.75*

R<=2	*R>=3*	*4.64*	*8.07*	*6.50*

Table 6

Estimates of Restricted Coefficients in the ***ECM***

ECM coefficient	**Value (Standard error)**
α	*1.00* *(NA)*
β	*-3.70* *(0.57)*
ρ	*0.83* *(0.17)*

Note: α is normalised to unity

Table 7

Maximum Eigenvalue Cointegration Test of *lnPg* and *lnPusa*

Null Hypothesis	Alternative Hypothesis	Max. Eigenvalue Test Statistic	95% Critical Value	90% Critical Value
R=0	*R=1*	*12.54*	*14.88*	*12.98*
R<=1	*R=2*	*7.99*	*8.07*	*6.50*

Table 8

Trace Cointegration Test of *lnPg* and *lnPusa*

Null Hypothesis	Alternative Hypothesis	Trace Test Statistic	95% Critical Value	90% Critical Value
R=0	*R=>1*	*20.53*	*17.86*	*15.75*
R<=1	*R=2*	*7.99*	*8.07*	*6.50*

Table 9

Maximum Eigenvalue Cointegration Tests of *lnPg* and *lnPw*

Null Hypothesis	Alternative Hypothesis	Max. Eigenvalue Test Statistic	95% Critical Value	90% Critical Value
R=0	*R=1*	*9.84*	*14.88*	*12.98*

R<=1	*R=2*	*2.13*	*8.07*	*6.50*

Table 10

Trace Cointegration Tests of *lnPg* **and** *lnPw*

Null Hypothesis	***Alternative Hypothesis***	***Trace Test Statistic***	***95% Critical Value***	***90% Critical Value***
R=0	*R>=1*	*10.98*	*17.86*	*15.75*
R<=1	*R=2*	*2.13*	*8.07*	*6.50*

Endnotes

[1] In 1990, jewellery accounted for about 80 per cent of use demand (Aggarwal, 1992).

[2] About 40 per cent of all gold stocks are owned by governments (Aggarwal ,1992).

[3] The World Gold Council (1992:4-5) states: "Throughout recorded history, gold has held its value against inflation"; "Time and time again, gold has proved a successful hedge against the devaluation of an investor's national currency"; and "Gold is man's classic hedge against almost any monetary crises, moving independently of paper investments".

[4] For the period up until 1933 the price of gold was fixed at $20.70 per ounce. In 1935, this was raised to $35.00 per ounce. In 1968, a two-tier market for gold was introduced, with central banks not dealing in the new free market but trading amongst themselves at the $35 rate. With the demise of the *Bretton Woods Agreement* in 1976, the price of gold was allowed to fluctuate freely.

[5] These dollar values were calculated for each month between January 1984 and November 1999. For each country, the base period dollar price of gold (January 1982) was converted into the domestic currency of the purchaser. Then this value was raised by the domestic inflation rate in order to maintain its purchasing power, and finally converted back into US dollars in year "t' at the prevailing exchange rate.

[6] The enormous literature on a risk premium (Kolb, 1992) which might suggest a divergence between the expected future spot price and the current price plus the future premium is not relevant in the case of gold loans because by definition loans are not sales, and therefore do not carry any speculative or insurance risk (apart from the possibility of default).

[7] If the price of gold is proportional to the marginal cost of extraction, which would be the case in a non-competitive market, then Eq. [20] would be: $P_{t+1} = \alpha MCg_t(1+\pi_t)$, where α is a parameter (greater than one) that summarises the degree of non-competition. This implies that the price of gold is proportional to marginal cost. If α does not vary over time, both marginal cost and price, would rise at the rate of inflation and Eq. [21] would hold.

[8] An ASCII file of all the data used in this section will be sent to any interested reader upon receipt of an electronic message sent to the corresponding author.

[9] The alternative lag selection criteria we used were: a) the Aikeke Information Criterion (Aikeke 1974), b) initially running the test with zero lags, and sequentially adding lags until the null of no serial correlation could not be rejected and c) sequentially removing lags (starting at 13) until the null hypothesis of no serial correlation could not be rejected.

[10] More completely, we cannot (can) reject the null that *lnPg*, *lnPusa* and *R* are *I(1)* at 0-6 (7-13), 7-13 (0-6) and 6-13 (0-5) lags respectively.

[11] In carrying out the Johansen procedure we assume a VAR of order 6. We also include an unrestricted constant in the cointegrating VAR.

[12] The test statistic has a χ^2 distribution and one degree of freedom. The value of the test statistic is 11.05 which has a marginal significance level of 0.001.

[13] The value of the test statistic is 3.12, which has a marginal significance level of 0.077.