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Price Dynamics of the World Gold Market: A Model Incorporating Inventories*

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Gold is regarded as a strategic mineral in many countries and its price is a key indicator of global business confidence. There is need for dynamic modelling of the world gold market, which would enhance understanding of the world market conditions, especially the long-term tendency of world gold prices, and hence facilitate long-term planning. This study incorporates inventories into the world market model and uses simultaneous equation approaches to estimate the model. From this estimation, the paper derives the time-path for the world annual price of gold. Results show that the price time-path converges without oscillations, from below, towards an intertemporal equilibrium. This equilibrium is estimated at about US$105,000.00 per kilogram based on a projected average world income. If the assumption of average income is relaxed, the intertemporal equilibrium price becomes variable dependent on the actual values of world income at a given time, which however, does not alter its dynamic characteristics. The results, therefore, show that gold price is dynamically stable. Short-term fluctuations, which are sometimes extreme, have no long-term effect on gold attractiveness.

Keywords: world gold prices, inventories, dynamic stability

Introduction

Gold is an important mineral to the world economy and its price is used as an indicator of business confidence. The gold sector contributes significantly to the economies of both developing and developed countries. While there are many studies on gold in business literature, there is a dearth of research on dynamic modelling of the world gold market. The few existing studies in this area are old (based on old data) and their validity outside the old business environment cannot be assumed (for example, Lipschitz & Otani, 1977). An understanding of world market conditions of gold, especially the long-term tendency of world gold prices over the last three decades, is lacking among the business community. Production schedules in many producing countries, especially in the developing world, have reacted to short-term fluctuations in prices, making them unstable.

This study estimates a world market model for gold, which incorporates inventories. Simultaneous equation approaches are used. From this model, the paper derives the time-path for the world market price of gold and its dynamic characteristics in terms of whether there is evidence of converge (dynamic stability) or divergence (dynamic instability). Understanding the dynamics of world price is important, especially for

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developing countries, because almost all the gold produced is exported. In addition, this understanding of price dynamics will help guide policy-planning as well as business decision-making, as it will indicate the likely path that prices will take in future. The implications of a dynamically stable price is that when the price of the good is shocked by external forces, it will gravitate towards its equilibrium level over some time of adjustment, which would mean that no long-term production capacity adjustments need be undertaken. However, if the price has the tendency to diverge then long-term business changes may need to be considered.

The rest of the paper is organized as follows. The second section looks at features characteristic of the mineral market, making pertinent references to the world gold market, especially demand and supply conditions. The third section presents a theoretical dynamic market model incorporating inventories, which is developed into an empirical model. It also discusses the econometric approaches used to estimate the empirical model. The fourth section presents and discusses the estimation results, which are then used to specify the time-path for world gold price. In the final section, the paper concludes on the question of dynamic stability of the world gold price, and briefly indicates limitations of the study and suggestions for further research.

Literature Review

As explained extensively in various sources (for example, World Gold Council, 2007; Lipschitz & Otani, 1977), gold is demanded for manufacture of jewellery, as an industrial good in electronics and dentistry, and as an investment good (an asset or store of value). Jewellery use is by far the greatest use accounting for about 70% of final demand, followed by industrial demand at about 12% (electronics—7%, gold plating, coating, gold threads and other industrial application other than electronics—2%-3%, dentistry slightly less than 2%) and then investment the remainder (World Gold Council, 2007). The main geographical sources of demand include India, USA, China, Middle East (including Dubai), Saudi Arabia, Gulf States, Egypt, Turkey, Italy, Japan, North America and Germany—with India, USA, and China roughly topping the list in that order in terms of gold jewellery demand (World Gold Council, 2007). This distribution reflects the importance of gold jewellery in Indian culture and in other special occasions common to many countries such as weddings, Christmas, birthdays, Valentine’s Day, and anniversaries.

The demand for minerals, in general, is significantly determined by the following factors (Gocht, Zantop, & Eggert, 1988, p. 174): (1) development of new areas of use through research, which leads to an increase in demand; (2) technological progress in mineral processing which leads to reduction in the consumption of minerals (miniaturization, greater efficiency, etc.), which reduces demand; (3) substitution of one mineral by another; and (4) changes in consumer habits. With respect to gold, in addition to the above, any other factor that affects any of the three components of gold demand identified above affect total demand for gold. Such factors include (Amey, 2011; Indyainfo, 2011): (1) the US$ exchange rate movements (the US$ is a substitute to gold in asset holding); (2) politics, social crises and war, which increase demand for gold as a safe haven; (3) interest rate movements, which induce substitution in demand between gold and purely monetary assets such as bonds and equities; (4) official demand, such as from Central Banks; (5) speculation; and (6) general inflation. It may be argued that inflation, by introducing unstable planning environment and affecting the value of the currency, may actually lead to a rise in demand and hence price of gold as safe investment or store of value.

Components of world gold supply include mine production (averaging 61% from 2002 to 2006), recycled gold (averaging 25% from 2002 to 2006) and Central Bank sales (averaging 14% from 2002 to 2006) (World Gold Council, 2007). Major sources of mine production supply of gold have included South Africa, Australia, United States of America, Latin America, China, Peru, Russia, Indonesia, and Canada. Recycling is mainly done on jewellery, and minor quantities are from electronic components and investment gold bars and coins.

Factors determining supply of minerals in general, can be grouped into short-term and long-term factors (Gocht, Zantop, & Eggert, 1988). Long-term factors include: reserves, ore grades, mineral associations, deposit type in terms of ore body geometry, depth and size, technology both for mining and processing, availability of exploration and mining development finance, economic and legal framework, and infrastructural conditions where the mineral deposits exist. In the short-term supply can fluctuate due to: (1) existence of commercial stockpiles held especially for speculative purposes or in commodity exchanges, whose levels are affected by the rate of interest, price expectations and the risks of procurement; (2) strategic stockpiles held by government to ensure that the mineral is available in times of emergencies; and (3) secondary production (that is, recycling).

Gold is traded on the world market in fine gold bars of 99.5% purity and as gold coins such as Krugerrands of South Africa and the Royal Leaf of the Royal Canadian Mint in Ottawa (Gocht, Zantop, & Eggert, 1988, p. 138). While forces of demand and supply play a major role in the markets for minerals, the way these forces manifest themselves in the market to influence price dynamics is complicated. The gold market, like any mineral market, is characterised by spot trading, commodity exchanges, forward contracts, futures contracts, options, hedging, and speculation.

Spot trading is a business transaction that involves immediate payment and immediate delivery of the commodity, except for reasons of technical constraints (Wikipedia, 2011). It normally involves actual inspection of the commodity or its sample and does not require standards. A forward contract is a transaction that involves both future payment, at a price agreed today (termed forward price), and future delivery of an agreed quantity (Wikipedia, 2011). A futures contract is, essentially, "a standardized forward contract in which the buyer and the seller accept the terms in regards to product, grade, quantity and location and are only free to negotiate the price" (Wikipedia, 2011). The future prices are indicators of consumers' expectations of prices; and we can have a situation where the future price is greater than the cash price, a situation called "contango", or a situation where the future price is less than the cash price, termed "backwardation" (Gocht, Zantop, & Eggert, 1988, p. 175). An option offers right without obligation (for which a premium has to be paid) to consummate a transaction by some future date at a predetermined price (termed strike price), hence avoids locking in prices (UNCTAD, 2010, p. 33). Hedging are activities normally undertaken by producers and processors of metals meant to safeguard themselves from unfavourable price movements, while speculation is done by investors betting on (future) price movements (UNCTAD, 2010, p. 34).

When mineral commodities are standardized with regard to quality and quantity, they can be negotiated on commodity exchanges where competitive forces of demand and supply determine prices (Gocht, Zantop, & Eggert, 1988, p. 174). UNCTAD (2010, p. 34) lists the following exchanges for futures contracts for metal commodities: Chicago Board of Trade (gold, silver), London Metal Exchange (aluminium, copper, lead, nickel, tin, zinc, steel, etc.), New York Mercantile Exchange (gold, silver, aluminium, copper, palladium, platinum), Shanghai Futures Exchange (China) (copper, aluminium) and the Tokyo Commodity Exchange (gold, aluminium, silver, palladium, platinum, copper).

Methodology and Data

The presentation of the following model is based on Chiang (1984) and makes extensions on the demand function and the inventory function. The following assumptions are made: (1) quantity demanded in period t

(Q_{dt}) is a linear function of current price and real world income (Y_t); (2) quantity supplied (Q_{st}) in period *t* is a linear function of the current price (P_t); and (3) sellers, in setting prices each year, take into account their inventories, so as to reduce them by lowering price if they accumulated, or to increase them by raising the price, if they depleted. Thus, we may present the model as:

$$Q_{dt} = \beta_0 - \beta_1 P_t + \beta_2 Y_t \tag{1}$$

$$Q_{st} = -\alpha_0 + \alpha_1 P_t \tag{2}$$

$$P_{t+1} = P_t - \theta(Q_{st} - Q_{dt}) \tag{3}$$

$$\beta_i, \alpha_i, \theta > 0 \tag{4}$$

By lagging (3) once we may rewrite it as:

$$P_t = P_{t-1} - \theta(Q_{st-1} - Q_{dt-1}) \tag{5}$$

$$P_t^d = \omega V_{t-1} \tag{6}$$

where $P_t^d = P_t - P_{t-1}$, $\omega = -\theta$, and $V_{t-1} = Q_{st-1} - Q_{dt-1}$.

Note that the term in parenthesis in the RHS of equation (3) denotes inventories accumulated in the current period. θ is the stock-induced price adjustment coefficient. Note also the conspicuous absence of the usual equilibrium condition—this is because there is no market clearing due to the existence of inventories, and therefore the price adjustment process is defined by the inventories rather than excess demand.

Our model is now made up of equations (1), (2), and (6). In this model, real world income, lagged inventories and lagged price (embodied in P_t^d) are predetermined variables, while quantity demanded, quantity supplied and price (embodied in P_t^d) are endogenous to the model. Note that in equation (5), the lagged price variable enters directly with a coefficient of 1 (like a constant) hence has limited variability characteristics as an explanatory variable. That makes it possible for us to transfer it to the LHS to form the composite variable P_t^d.

Substituting equations (1) and (2) into equation (3) and simplifying, we get:

$$P_{t+1} - [1 - \theta(\alpha_1 + \beta_1)]P_t = \theta(\alpha_0 + \beta_0) + \theta\beta_2 Y_t \tag{7}$$

We make the simplifying assumption that real income variable is in steady state, the steady state value ($\overline{Y}$) being estimated by the average of the variable over a long period, say a century, so that it is not changing over time. Thus, we may write:

$$P_{t+1} - [1 - \theta(\alpha_1 + \beta_1)]P_t = \theta(\alpha_0 + \beta_0) + \theta\beta_2 \overline{Y} \tag{8}$$

Equation (8) is a first-order non-homogeneous linear difference equation that solves to (Godana, 1997):

$$P_t = \left[P_0 - \frac{\alpha_0 + \beta_0 + \beta_2 \overline{Y}}{\alpha_1 + \beta_1}\right][1 - \theta(\alpha_1 + \beta_1)]^t + \frac{\alpha_0 + \beta_0 + \beta_2 \overline{Y}}{\alpha_1 + \beta_1} \tag{9}$$

Our intertemporal equilibrium price in this case is equal to the last term in the RHS of equation (9). Price dynamics are embodied in the term $[1 - \theta(\alpha_1 + \beta_1)]^t$. Let $1 - \theta(\alpha_1 + \beta_1) = b$. It is clear from the assumed definitions of the constants (4) that *b* cannot assume values greater than or equal to one. It can only assume the following ranges of values, which ranges imply characters of the price dynamics: $0 < b < 1$ (convergent without oscillation), $b = 0$ (constantly in equilibrium), $-1 < b < 0$ (convergent with oscillation), $b = -1$ (uniform oscillation), and $b < -1$ (divergent with oscillation).

The model is estimated by simultaneous equation approaches. The rank order condition of identifiability of simultaneous equations states that:

> In a model of M simultaneous equations, in order for an equation to be identified, the number of predetermined variables excluded from the equation must not be less than the number of endogenous variables included in that equation less 1. (Gujarati, 1988, p. 586)

That is: assuming that K and k denote exogenous variables in the model and those in the equation respectively, and M and m denote endogenous variables in the model and those in the equation respectively, for an equation to be identified this condition requires that:

$$K - k \geq m - 1 \quad (10)$$

According to the rank order condition, both demand and supply functions are over identified. The inventory function (equation (5)) is exclusively a function of predetermined variables (lagged endogenous variables). Thus, the demand and supply functions are estimated by the Two Stage Least Squares (2SLS) method while the inventory function (using equation (6)) is estimated directly by Ordinary Least Squares (OLS). Effectively we are estimating the following three functions by OLS:

$$Q_{dt} = \beta_0 - \beta_1 P_t^{es} + \beta_2 Y_t + u_{dt} \quad (11)$$

$$Q_{st} = -\alpha_0 + \alpha_1 P_t^{es} + u_{st} \quad (12)$$

$$P_t^d = \psi + \omega V_{t-1} + u_{vt} \quad (13)$$

The instrumental variable for current price is given by $P_t^{es} = \pi_0^{es} + \pi_1^{es} Y_t + \pi_2^{es} V_{t-1} + \pi_3^{es} P_{t-1}$ and superscript *es* denotes estimate; the last terms in the above equations are respective error terms; and ψ is a constant. The LimDep econometrics package is used to run the regressions.

World supply of gold is estimated by the total amount of world production of gold plus supply of scrap. The price for a particular year is the annual average for that year. Sources for these and other data items are detailed under the table in Appendix A.

Findings and Discussion

Application of the data in Appendix A (time-series, 1980-2009) on the equations immediately above yields the following results.

Demand Function

$$\begin{array}{llll} Q_{dt} = 224{,}857.2891 & - 26.4478 P_t & + 86.3938 Y_t & R^2 = 0.92 \\ \quad (158{,}275.82) & (8.6169) & (5.4154) & df = 26 \\ t = \quad (1.421) & (-3.069) & (15.953) & F_{2,26} = 150.94 \end{array} \quad (14)$$

The negative and positive coefficients of price and world income respectively are consistent with theoretical expectations. The coefficients are individually and jointly significant at 5% level of significance, with critical t-values of ± 1.706 and a critical F-value of 3.37. The demand function has a very high explanatory power of 92%.

Supply Function

$$\begin{array}{lll} Q_{st} = 2{,}013{,}525.593 & + 55.9505 P_t & R^2 = 0.16 \\ \quad (361{,}421.01) & (24.8015) & df = 27 \\ t = \quad (5.571) & (2.256) & F_{1,27} = 5.08 \end{array} \quad (15)$$

A very high and statistically significant positive constant of 2,013.5 tonnes is unexpected, according to theory which postulates a negative constant. However, expectations, which are rife in the minerals market, may explain positive production even when price is zero. The positive price coefficient is consistent with theoretical expectations which state that quantity supplied is positively related to price. While the price coefficient and the whole model are significant with critical *t*-value of 1.703 and a critical *F*-value of 4.21, the model's explanatory power is very weak.

Inventory Function

$$\begin{array}{llll} P_t^d = 347.8669 & -0.0015 V_{t-1} & & R^2 = 0.03 \\ \quad (432.6174) & (0.0017) & & df = 27 \\ t = \ (0.804) & (-0.919) & & F_{1,\,27} = 0.84 \end{array} \tag{16}$$

The results on the inventory function are as expected. If last period's inventory accumulations increased, then this period's price will be less than last period's, ceteris paribus. However, the results are insignificant.

Price Time Path and Price Dynamics

From the above estimations the structural parameters and the income in steady state, including the initial price (1980 price), take the following values:

$$\theta = -\omega = 0.0015, \quad \alpha_0 = -2,013,525.593, \quad \alpha_1 = 55.9505, \quad \beta_0 = 224,857.2891,$$
$$\beta_1 = 26.4478, \quad \beta_2 = 86.3938, \quad \overline{Y} = 120,552, \quad P_0 = P_{1980} = 19,694.23$$

The value given of average income of US$120,552 billion (to the nearest 1 billion) is the annual average real world GDP over a century (1980-2079), based on figures given in United Nations (2011), where 2010-2079 figures are projections based on an annual average rate of income growth of 2.96% computed from 1971-2009 figures. From the above values b = 0.8764. Applying these values to equation (9), the general time path equation, we get the following particular time-path for the price of gold:

$$P_t = -84,995.75(0.8764)^t + 104,689.98 \tag{17}$$

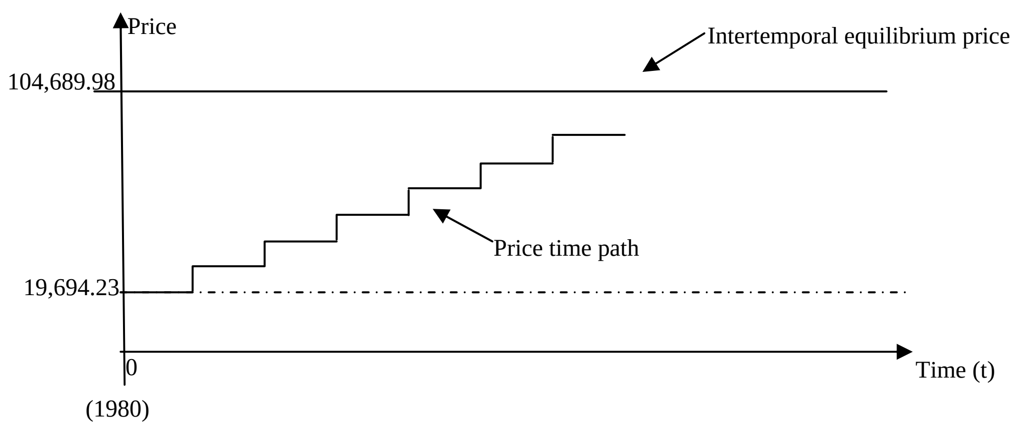

Figure 1. Gold price time path.

Equation (17) shows that the intertemporal equilibrium price of gold is US$104,689.98. The time-path begins below the intertemporal price by US$84,995.75. Since the value of b is a positive fraction the time-path converges without oscillation towards the intertemporal equilibrium price. Thus, the gold market is dynamically stable in the long-term. Diagrammatically, the time-path (equation (17)) can be depicted as in Figure 1.

Conclusion

The results show that gold price is dynamically stable. Any short-term fluctuations in price have no long-term effect on gold attractiveness, which means that they must not be allowed to affect long-term production plans, especially if they are reductions in prices. The long-term planning price for gold then is about US$105,000. The price of gold approaches the equilibrium from below, showing a gradual rising trend over time, towards intertemporal equilibrium.

The model estimated above apparently treats quantities demanded and supplied as functions of current prices only. However, from the discussion on gold markets, expectations on future prices are an important determinant of hedging and speculative behaviour, which in turn, affect quantities actually currently supplied and demanded. Therefore, the model may be enhanced by including price-expectations. Inclusion of price expectations in the model would also indicate that not all inventories are unintended, since expectations create intended inventories, especially in mineral commodity markets. The study has also assumed a constant world income. If this assumption is relaxed the intertemporal equilibrium price becomes variable dependent on the actual values of world income at a given time. That is, it becomes some sort of moving equilibrium. However, this does not alter its basic dynamic characteristics.

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Appendix A: Global Gold Statistics

Year	World annual price (US$/kg)	World mine production (kg of metal content)	World supply of scrap (kgs)	Total world supply (production + scrap) (kgs)	World demand (kgs)	Real world income (real GDP) (US$ billion)
1980	19,694.23	1,220,000	500,000	1,720,000	1,617,245	22,041.1
1981	14,777.75	1,260,000	240,000	1,500,000	1,670,270	22,467.8
1982	12,085.77	1,300,000	240,000	1,540,000	1,723,294	22,591.4
1983	13,631.90	1,400,000	300,000	1,700,000	1,855,855	23,220.8
1984	11,595.47	1,400,000	300,000	1,700,000	1,855,855	24,287.4
1985	10,212.99	1,500,000	340,000	1,840,000	1,988,417	25,176.4
1986	11,839.17	1,564,000	520,000	2,084,000	2,073,256	25,958.1
1987	15,366.43	1,620,000	460,000	2,080,000	2,147,490	26,851.8
1988	14,091.97	1,798,000	380,000	2,178,000	2,383,449	28,069.2
1989	12,300.21	1,942,000	380,000	2,322,000	2,574,337	29,123.6
1990	12,375.77	2,133,000	500,000	2,633,000	2,827,528	29,992.9
1991	11,680.03	2,132,000	460,000	2,592,000	2,826,203	29,036.2
1992	11,091.03	2,233,000	480,000	2,713,000	2,519,100	29,762.3
1993	11,603.51	2,253,000	580,000	2,833,000	2,475,700	30,325.5
1994	12,391.20	2,220,000	620,000	2,840,000	2,460,100	31,414.0
1995	12,394.09	2,160,000	620,000	2,780,000	2,726,000	32,354.2
1996	12,509.19	2,270,000	640,000	2,910,000	2,779,500	33,445.1
1997	10,686.25	2,420,000	620,000	3,040,000	3,053,600	34,693.5
1998	9,488.96	2,460,000	1,080,000	3,540,000	2,714,100	35,606.7
1999	9,002.20	2,520,000	620,000	3,140,000	3,284,200	36,810.5
2000	9,002.20	2,550,000	619,000	3,169,000	3,264,400	38,378.9
2001	8,744.99	2,540,000	749,000	3,289,000	3,729,000	39,048.1
2002	9,998.87	2,530,000	873,500	3,403,500	3,363,000	39,831.4
2003	11,252.75	2,530,000	991,000	3,521,000	3,207,000	40,870.4
2004	13,213.94	2,400,000	881,400	3,281,400	3,515,000	42,498.6
2005	14,339.21	2,510,000	902,400	3,412,400	3,753,000	43,975.4
2006	19,611.93	2,360,000	1,132,800	3,492,800	3,435,000	45,716.4
2007	22,473.34	2,340,000	981,800	3,321,800	3,571,000	47,494.4
2008	28,099.71	2,290,000	1,315,600	3,605,600	3,812,000	48,248.8
2009	31,346.93	2,460,000	1,694,700	4,154,700	3,493,000	47,369.7

Notes. All mine production figures are obtained from Lofty, Sharp, Hillier, Singh, Lehall, Jones, and Davies (1983), Lofty, Sharp, Hillier, and Joseph (1987), Lofty, Hillier, Cooke, Linley, and Singh (1992), Taylor, Lofty, Hillier, Fellows, Bate, Linley, Mills, and White (1995), Taylor, Hillier, Mills, and White (2004), Stockwell, Hillier, Mills, and White (2000), Hetherington, Brown, Benham, Bide, Lusty, Hards, Hannis, and Idoine (2008), and Brown, Bide, Walters, Idoine, Shaw, Hannis, Lusty, and Kendall (2011); 1980-1998 prices are from Amey (2011) and the rest (1999-2009) are from Amey (2001, 2004) and George (2007, 2010, 2011); All prices are converted from dollars per troy ounce (1980-1998) or per ounce (1999-2009) to dollars per kg by multiplying by 32.1507 as indicated in Amey (2011). Real World GDP statistics are from United Nations (2011); World demand figures for 1992-2009 are from World Gold Council (1997, 2002, 2011). Demand figures for 1980-1991 are estimated by multiplying the respective production figures by the average ratio of production to demand over the period 1992-2009, equal to 1:1.325611. The source for demand figures for 1996-2000 (World Gold Council, 2002) indicates that these are a total of demand in key markets in the world including India, Greater China, Japan, S.Korea, SE Asia, Saudi Arabia, Gulf States, Egypt, Turkey, America and Europe. World supply of scrap figures for 2001-2009 are from GFMS Limited (2011, p. 68), and these are supply from fabricated old scrap. World supply of scrap figure for 2000 is from Grendon International Research Pty Ltd. (2010, p. 1). World scrap supply figures for 1980-1999 are estimates measured out of the bar chart in Klapwijk (2010).