Do Bubbles occur in Gold Prices? Evidence from Gold Lease Rates and Markov Switching Models.

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Abstract

We assess whether two classes of bubbles occur in the spot price of gold, rational speculative and periodically bursting bubbles, using gold's' lease rates for the first time in the literature as a measures of its fundamental value. This question is of particular significance as these are the only observable market measures of a yield that can be earned by owning gold. We use tradition unit root and cointegration tests for rational speculative bubbles and Markov Switching Augmented Dickey-Fuller tests for periodically bursting bubbles. Bubbles are found to possibly exist for in ADF and cointegration bubble tests, but under the markov switching model no bubble found to be present.

Keywords: Gold, Markov Switching, Bubbles, Lease Rates

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1. Introduction

In recent years gold has enjoyed a renewed prominence as a financial asset and is now being purchased once again in increasing quantities by a wide variety of sectors. Most major central banks up to 2010 had a long term policy of selling gold, but in 2010 and 2011 they purchased 77 tonnes and 455 tonnes respectively. New investment vehicles have emerged to allow small investors to buy gold with Exchange Traded Funds (ETFs) buying 368 and162 tonnes of gold in 2010 and 2011 respectively (GFMS Gold Survey, 2012). Under Basel 3 it is as ranked tier 1 capital for banks, with a zero per cent risk weighting. This has happened to a backdrop of huge increases in the price of gold in recent years, rising from just under $300 per fine troy ounce in 2000 to just over $1900 in mid-2011. Figure 1 below shows the rapidly increasing volume of open interest in gold futures contracts over the same period.

[Insert Figure 1 about here]

With both investors and the official sector now increasingly investing in this asset class again and new nominal highs in the gold price being reached recently it seems appropriate that an attempt is made to assess if gold's price is justified by its fundamental determinant, the income that can be earned by owning it.

We use gold lease rates, interest that can be earned by lending physical gold at various maturities, and supplement this with gold leasing cashflows, money that can be earned by leasing gold, as measures of gold's fundamental value. Despite these existing observable market measures of a cashflow that can be earned by owning gold these have never been used in research asking whether bubbles occur in gold.

We test for rational speculative bubbles and periodically bursting bubbles by testing for the existence of stationarity and cointergating relationships between the spot price of gold with its lease rates and leasing cashflows. We also test for periodically bursting bubbles using Markov-Switching Augmented Dickey-Fuller tests. These tests look at gold's value from two perspectives, the portfolio demand for gold and the Present Value (PV) of the cashflows that can be earned from gold through leasing respectively.

The rest of the paper is organised as follows. Section 2 discusses the literature on the fundamental and macroeconomic drivers of the price of gold. Section 3 gives an over view on the literature around bubbles, models of bubbles in the price of gold and evidence on bubbles in the price of gold. Section 4 discusses the methods used to answer the question, Section 5 describes the data used and Section 6 presents results while the conclusions are in Section 7.

2. What drives the price of gold?

2.1 Fundamental drivers

Like any asset we can consider a fundamental driver to be the earnable return on gold. In the case of gold, a physical asset, this causes clear difficulty. Prominent investors, such as Warren Buffet assert that gold has no such earned return and as such is, in the limit, valueless

(Denning, 2012). This is not quite the case. There are at least two measures of such a return; the convenience yield and the gold lease rate

Previously gold's Convenience Yield has been used to measure its fundamental value in studies such as Pindyck (1993), Went, Jirasakuldech and Emekter (2009) and Bialkowski et al. (2011). A commodities Convenience Yield is the benefit the holder of the physical commodity receives relative to the owner of a futures contract for the asset. It is measured as in equation 2.1 below:

$$F_t = P_t . e^{(r_f - CY_t)t} \quad \textbf{(2.1)}$$

Where F_t is the futures price at time t, P_t is the spot price at time t, r_f is the risk free rate of interest and CY_t is the Convenience Yield at time t. Convenience Yield is then the rate that allows for no arbitrage, as the futures price is equal to the spot price adjusted for the opportunity cost of investing in physical gold. This yield can then be used in a similar way to the yield on a financial asset such as a bond or a share to compute its present value.

A further, and we would argue better, measure of the return to gold is the gold lease rate. In so far as we can ascertain Gold Lease Rates have not previously been used to assess golds fundamental value. Gold lease rates are the annualised interest rates that can be earned by lending gold over 1, 2, 3, 6 or 12 months. It is technically referred to as the Derived Lease Rate, which is calculated by the London Bullion Market Association daily as the London Interbank Offer Rate (LIBOR) at a given maturity minus the Gold Offer Forward Rate (GOFO) at that maturity.

It can be thought of as gold's market value as a collateral instrument to lower the interest rate on US dollar loans as in theory it involves taking the following steps. Party A lends US Dollars to party B at the interest rate LIBOR and party B lends gold to party A at GOFO. At the end of the period both parties return what they borrowed plus the interest agreed (LBMA, 2008). The difference is the lease rate. As GOFO is generally lower than LIBOR dollars can generally be borrowed more cheaply in this way. In reality offsetting loans are not necessary; gold is simply lent and borrowed at the lease rate. The evolution of the 12 month GOFO and LIBOR rates are shown below with the 12 month lease rate derived from them.

[Insert Figure 2 about here]

Historically the main borrowers of gold were mining companies who would borrow a portion of their expected mine production in the lease market, and sell it to finance the mine production. This provided a cheap source of finance as lease rates on gold are generally less than dollar LIBOR interest rates. This also provided a hedge against falling gold prices as the leased gold would be returned from their mine production, making price changes irrelevant. This practise lessened in the early 21st century as gold prices rose steadily but 2011 once again sees net producer hedging (GFMS Gold Survey, 2012). Leasing agreements are also common for jewellery manufacturers as a method of hedging their exposure to gold prices movements in the time it takes to manufacture pieces.

The payment made at the end of the lease is calculated as the lease rate for the period times the ounces of gold times the PM Fixings price on the day of the agreement times the days over 360 (LBMA, 2008). This means that the leasing cashflows vary not only with the lease rate as a percentage, but also with the PM fixings price.

This paper posits that gold lease rates are superior to the convenience yield as a measure of gold's fundamental value for a number of reasons.

- They are a directly observable cashflow that can be earned from owning gold, whereas convenience yield must be inferred from the difference between the spot and futures prices of a commodity.
- This raises the problem that as a measure of gold's fundamental value convenience yield is derived from two gold prices, the variables that it seeks to explain, see equation 2.1 above.
- The concept of convenience yield is intended for to consumption commodities as it measures the benefits of having easy access to a commodity to allow smooth production and being able to avoid hold up problems. While gold is consumed in electronics and dentistry it is primarily held for investment with annual jewellery and investment demand accounting for over 80% of annual demand between 2000 and 2011 (GFMS Gold Survey, 2012).

Gold lease rates are rarely discussed in the literature. Levin, Abhyankar and Ghosh (1994) provide an arbitrage model arguing that the lease rate is a proxy for real interest rates through an arbitrage model. Levin and Wright (2006) use this finding to argue that the lease rate, as a proxy for the real interest rate, is the opportunity cost of hold gold as this is the amount that could have been earned in a risk free investment in their model of the gold price.

Barone-Adesi, Geman and Theal (2011) find that the lease rate is a good measure of the convenience yield of owning gold. This fits with the theory put forward by Levin and Wright (2006) where the lease rate is composed of the convenience yield of gold as well as default risk, as the gold lease rate is an over the counter transaction and subject to the risk that one party may default.

2.2 Macroeconomic Drivers

As for any other asset there are also macroeconomic influences on gold prices. What makes the case of gold intriguing from the perspective of bubble investigations is that there is little evidence of any fundamental determinant. Rather, we find that gold relates to other macroeconomic variables in predictable and economically sensible ways. Thus Levin and Wright (2006) find that US inflation is the sole correlate of the gold price over the long term. They argue that the relationship between gold and US CPI is an artefact of the cost of gold production.

Christie-David, Chaudhry and Koch (2000) use intraday data to assess whether macroeconomics *news* affects the price of gold futures. Consumer Price Index (CPI) releases were found to have a strong effect on returns, which fits with other research that finds that gold can be a hedge against inflation such as Ghosh, Levin and Wright (2004). This is posited to be because gold is a currency whose value cannot be diminished by increasing supply through printing, as is the case of fiat currencies such as the dollar or the euro, and provides an alternative reason to Levin and Wright (2006). Kutan and Aksoy (2004) test for the effect of news on the Turkish Gold Market and find that Turkish CPI does not affect the US Dollar gold price, further backing up Levin and Wright's assertion that US CPI and not world prices are what matters.

Gold is traded primarily in dollars and the strength of the dollar (as measured by the trade weighted exchange rate) is found to be a strong short term determinant by Levin and Wright (2006) and Kaufmann and Winters (1989). A strong dollar makes gold cheaper for other nations to purchase and increases their demand. This then drives up the price of gold explaining their negative relationship, as is found also by Tully and Lucey (2007) and Sari, Hammoudeh and Soytas (2010). However O'Connor and Lucey (2012) argue that the trade weighted value of a currency has a negative relationship with the price gold of gold in that currency. It means that when the dollar on average is losing value against all major currencies, it is also losing value against gold, which can been viewed as just another currency and on average would be gaining value against the dollar as well at that time.

Interest rates also figure as an important explanatory variable. Koutsoyiannis (1983) found a strong link to nominal US interest rates and Diba and Grossman (1984) found a link to real interest rates in the US. The underlying economic theory points to the fact that the opportunity cost of holding gold is the interest that could have been earned from holding another currency on deposit. Lawrence (2003) argues against these points and using quarterly data from 1979 to 2001 finds that there is no statistically significant link between gold and these of macroeconomic variables.

Baur and Lucey (2010) examine gold's relationship market crashes, its safe haven property. They study the relationship between U.S., U.K. and German stock and bond returns and gold returns. They find that gold is a hedge and a safe haven for stocks. However gold only acts as a safe haven for 15 days after a market crash. Baur and McDermott (2010) extend this analysis to a more international sample with similar results. Coudert and Feingold (2011) find a negative or null correlation between gold and a number of major stock markets indexes.

Overall, there is a surprising lack of analysis of the fundamental macroeconomic drivers of gold. As a consequence, there have been few papers that have examined bubbles in the traditional manner, of consistent deviations from fundamentally justified levels.

3 Rational Speculative Bubbles in Asset Prices

What is a bubble? In common parlance we are aware that it means an asset price which is "too high", relative to some fundamental driver, and which must inevitably burst. We can distinguish between types of bubbles. More formally, Gurkaynak (2008:166) defines a rational speculative bubble (for equities) as being when "investors are willing to pay more for the stock than they know is justified by the value of the discounted dividend stream." They do this in expectation of being able to sell at a price in the future above the present value of discounted dividends, making the high price an equilibrium price. Irrational bubbles in asset prices, where investors believe the market to be overvalued but do not go short focus on the difference between investor actions and beliefs are used in studies such as Vissing-Jorgensen (2004) but are outside the scope of this research.

Gurkaynak (2008) shows that for a normal asset with an observable yield it's fundamental, no arbitrage, value is equal to the discounted stream of future cash receipts or:

$$P_t = \sum_{i=1}^{\infty} \frac{E_t(p_{t+1}+c_{t+i})}{(1+r)^t} \quad \textbf{(3.1)}$$

Where P_t is the value of the asset at time t, C_{t+i} is the cash flow derived from owning the asset earned at time t+i and r is the risk free rate of interest.

If a rational bubble exists, then the value of the asset is made up of two components: the fundamental market value, the discounted value of expected future cash flows, as given by equation **(3.1)** and a bubble term, B_t. The true value of the asset is then given by equation **(3.2)**:

$$P_t = \sum_{i=1}^{\infty} \frac{E_t(c_{t+i})}{(1+r)^t} + b_t \quad \textbf{(3.2)}$$

Where b_t is the value of bubble component at time t such that:

$$p_t = p_t^* + b_t \, where \;\; E_t\,(b_{t+1}) = (1+r)b_t \quad \textbf{(3.3)}$$

This implies that rational speculative bubbles can exist in financial markets as long as the rate of growth of the value of the bubble is equal to its discount factor. The price of the asset including the bubble is then still an equilibrium value and investors can rationally invest in it *as long as they believe* that the bubble will grow at the discount rate r.

3.1 Tests for Asset price bubbles

There are three main approaches used to test empirically in the literature for the presence of rational speculative bubbles in asset prices: Relationship models, Counting models and tests of explicit models for pricing assets.

Relationship models look at statistical relationships that exist for the assets in question and their fundamental driver. Shiller (1981) used the variance bound tests of the equity prices to show that their variance was too large to be justified by fundamentals. Tests for long run relationships between prices and fundamentals use Unit Roots and Cointegration tests which will be outlined in more detail below and used in this research.

Counting models, also known as hazard models, are different in that they do not compare the time series behaviour of the determining factors of the value of the asset with its price, meaning that we do not need to worry about correctly specifying the underlying model for pricing the asset. These models include McQueen and Thorley's (1994) non-parametric duration dependence test which they applied to equity markets.

Explicit models such as Wu (1999) treat bubbles strictly as deviations from the present value model shown in equation **(3.2)**, allowing the bubble to be estimated as a time series variable. The issue with this approach is that any misspecification of the PV model is included in the bubble component so that it cannot be shown decisively if a bubble is present or the model used by the researcher needs correction.

3.2 Bubbles in Gold Prices

3.2.1 Early Model

Diba and Grossman (1984) form an equation for the price of gold based on an investor's portfolio demand for gold composed of three parts.

$$s_t + p_t = \beta(E_t p_{t+1} - p_t) - \gamma E_t r_{t+1} + o_t \quad \textbf{(3.4)}$$

Where: p_t is the log of the gold price,

s_t is the log of the stock of gold at t,

β is a positive constant, showing the relationship between the portfolio demand for gold and the real return on gold,

γ is a positive constant, showing the relationship between the portfolio demand for gold and the real return on other assets

Et denotes rational expectations

r_{t+1} represents the rate of return on other assets

o_t is other factors that affect gold's fundamental value that are not observable

s_t is the log of the stock of gold

The fundamental component (FC) of the value of gold is 3.4 above. It says that gold is valued based on what is expected to happen to its price in future as well as being negatively related to what you can earn on other assets. They use real interest rates in their model as the return on other assets. Here we will also include the lease rate on gold as another reason to hold gold other than expected price changes. Gold lease rate data begins in 1989 and therefore fell into the u_t category of unobservable variables in their 1984 model.

Other parts of what determines the price of gold are the Stochastic Bubble Component (SBC) which is a random variable with a zero mean whose value decreases to zero as time progresses. The deterministic bubble component (DBC) is what we are looking for in testing for the presence of bubbles here and if it is found to be present then we have a rational bubble. These are shown in equation 3.5 below.

The DBC is a constant, times an eigenvalue raised to a power greater than 1 $[(1+\beta^{-1})^t]$. This implies that as t increases the DBC increases. The SBC is a constant, times and eigenvalue raised to a power less than one, so that it decreases with t $[(1+\beta^{-1})^{t-i}]$. Their equation for the time path of the price of gold is shown below in equation 3.5.

$$p_t = \underbrace{(1+\beta)^{-1}\sum_{i=0}^{\infty}(1+\beta^{-1})^{-i}E_t(u_{t-i} - \gamma r_{t+1-i} - s_{t+i})}_{\text{FC}} + \underbrace{c(1+\beta^{-1})^t}_{\text{DBC}} + \underbrace{\sum_{i=1}^{t}(1+\beta^{-1})^{t-i}z_i}_{\text{SBC}} \quad \textbf{(3.5)}$$

Where c is a constant determined by an initial condition and z_i is a random variable representing new information with a zero mean and is uncorrelated with all variables. In the analysis z_t is treated as an unobserved variable.

Diba and Grossman (1984:8) state that "the intuitive distinction between FC and the bubble components is that, if the market collectively misunderstands FC, individuals can gain by contradicting the market, whereas if the market does not expect a price bubble, individuals who act on the basis of price forecasts incorporating a bubble will lose". The bubble components are rational when the market collectively incorporates them in price forecasts.

From this equation we can investigate the stationarity properties of the process that generates p_t that can give evidence for or against bubbles. As we cannot observe the DBC we must make inferences about the process that generates the DBC. If the c in 4.2 is non-zero it will be mean that the DBC is non-stationary as it grows at $(1 + \beta^{-1})^j$, regardless of how many times it is differenced (Gurkaynak, 2008). If we find that the process generating the FC components is stationary, p_t would also be stationary if no bubble is present.

The number of times it is necessary to difference the determinants of gold's value to make them stationary should also be the number of times it is necessary to make p_t stationary, if p_t is the fundamental value and is determined by its lease rate and leasing cashflows. As Evans (1991) says the argument is that if the price series of an asset is not more explosive than its fundamental determinant then it can be said that no bubble is present, as the fundamental component is what gives us the price series.

This tests only for bubbles that continue to grow in p_t from t=0 as the c component is not time varying and must be present from the start in order to enter the series, and will not be able to find periodically bursting bubbles, as shown by Evans (1991), see section 3.3.4.

3.2.2 Cointegrating relationships

Diba and Grossman (1988) test for a bubble in the price of shares using the idea that if two series are found to be I(1) from both sets of ideas above, and their linear combination cointegrates, then there is an equilibrium relationship between them, implying that no bubbles exist. They argue that it is unlikely that the unobserved fundamental will be I(2), meaning that failing to reject a cointegrating relationship for variables is proof of a fundamentally determined price. Rejection however may not prove that a bubble exists due to differing power and size properties of cointegration tests.

3.2.3 Periodically bursting bubbles

Evans (1991) extends this area by looking at periodically collapsing bubbles. He also assumes that a bubble cannot be negative but unlike earlier work such as Diba and Grossman (1988) can collapse to a low but positive value. The bubble can then be in one of two different states at any time.

$$B_{t+1} = (1+r)B_t U_{t+1} \qquad if\ B_t \leq \alpha \qquad \textbf{3.7a}$$

$$B_{t+1} = [(\partial + \pi^{-1}(1+r)\theta_{t+1}] * [B_t - (1+r)^{-1}] * U_{t+1} \quad if\ B_t > \alpha \qquad \textbf{3.7b}$$

Where δ and α are positive parameters such that 0< δ<(1+r)α and $U_{t+1}$is an exogenous identically and independently distributed (iid) random variable with $\Sigma(U_{t+1})=1$. θ is an exogenous and iid Bernoulli process independent of U_t which takes on a value of 1 with a probability of π and a value of 0 with a probability of 1- π.

Thinking of bubbles in this way increases our ability to identify them, as under Diba and Grossman's (1988) model the bubble would need to be present over the period being examined. Evans (1991) points out that it is more likely that bubbles appear and disappear, making it more likely that the process will appear stationary but in reality still contain speculative bubbles. Testing for this class of bubbles represents a more realistic test of what we would expect to see in reality.

3.3 Evidence for Bubbles in the Price of Gold

Diba and Grossman (1984) found that the price of gold was entirely based on market fundamentals using conventional unit root and co integration tests with real interest rates on commercial paper as the measure of gold's value. Evans (1991) criticised these results on the basis that they do not detect periodically bursting bubbles.

A number of researchers have used gold's CY to find a true fundamental value for gold, in the same way as is normal for storable consumption commodities, such as oil or copper. Pindyck (1993) assumes that the fundamental value of a commodity is the present value of expected future payoffs. A gold price bubble is found between 1975 and 1990, but when it occurs cannot be specified. Went, Jirasakuldech and Emekter (2009) find evidence of a bubbles using a duration dependence test on the monthly interest-adjusted basis, a measure of the potential excess returns earned on commodities through their CY. Bialkowski et al. (2011) find the deviations of gold price from its fundamental value based on a CY approach, and use a Markov regime-switching Augmented Dickey- Fuller test to whether and when speculative gold price bubbles occur. They find no evidence in the period between 1978 and 2010.

Bertus and Stanhouse (2001) use dynamic factor analysis to look for bubbles in the quarterly futures price of gold. They build an explicit model of the supply and demand for gold to derive a fundamental price and use this to estimate a time series for the bubble component in the price. This is however found to be insignificant so that they conclude that no bubble is present. Baur and Glover (2012) apply tests developed by Philips Wu and Yu (2011) based on explosive price behaviour that does not require any assumption about the fundamental value of an asset. They conclude that the gold price has been in a bubble between 2002 and 2012, except in 2008-9 during the sub-prime mortgage crisis.

4. Methodology

4.1 Unit roots and Cointegration

Diba and Grossman (1984) test for unit roots in gold prices by looking at the Auto Correlation Function of the gold price and real interest rates, as well as their 1st and 2nd differences. We use Augmented Dickey-Fuller (ADF) tests provide a more rigorous way of looking for unit roots in the variables, as employed by Diba and Grossman (1988) and shown in equation 4.1 below.

$$\Delta y = \pi y_{t-1} + \sum_{j=1}^{p} c_j \beta y_{t-j} + \epsilon_j \qquad \textbf{4.1}$$

Where y is the gold price and we test for π=0.

Following Diba and Grossman (1988) we test for cointegrating relationships between gold and its fundamental determinants. Following the earlier ADF tests we estimate:

$$\Delta v_t = \pi v_{t-1} + \sum_{j=1}^{k} \beta_j \, \Delta v_{t-1} + \epsilon_j \qquad \textbf{4.2}$$

where v_t are the residuals from the regression of gold prices on the relevant leasing cashflow or lease rate.

4.2 Markov Switching ADF

Authors such as Hall, Psaradakis and Sola (1999) extended these tests of asset prices using a Markov Switching ADF framework, as discussed in Hamilton (1989, 1990). This provides a form of the ADF tests described above to take into account the critique of Evans (1991), that traditional unit root and cointegration tests do not account for periodically collapsing bubbles.

We assume that equation **(4.1)** is time varying, changing with an unobserved indicator s_t, the stochastic regime variable, which takes on a value of 0 or 1 so that:

$$\Delta y = \pi_1 s_1 y_{t-1} + \pi_2 s_2 y_{t-1} + \sum_{j=1}^{p} \beta_j s_t \Delta y_{t-j} + \epsilon_{s_t} \qquad \textbf{4.3}$$

As is general for markov switching processes we assume the probability that the process is in a particular regime at time t depends only upon the probability of which regime the process was in at time t-1, and not on earlier periods as well. We therefore model this random sequence to a homogenous markov chain with switching probabilities defined as below:

$$\begin{aligned} \Pr(s_t = 1 | \, s_{t-1} = 1) &= p \\ \Pr(s_t = 0 | \, s_{t-1} = 1) &= 1 - p \\ \Pr(s_t = 1 | \, s_{t-1} = 0) &= q \\ \Pr(s_t = 0 | \, s_{t-1} = 0) &= 1 - q \end{aligned} \qquad \textbf{4.4}$$

We also required that ϵ_{s_t} is independent of the state variables for all observations.

To test the null hypothesis of a unit root in either regime (i.e. that π_1=0 or π_2=0) we estimate equation 4.3 in RATS using maximum likelihood procedures as in Hall et al. (1999). From this we will also find the probability that the series is in regime 1 at any time (p) or in regime 2 (1-p), the filter probabilities.

We also allow the variance in each regime to switch between the two states. This is in order to take into account the findings of Tully and Lucey (2007) and Capie, Mills and Wood (2005) that gold is best modeled in a framework that allows for a variance that can change over time.

5 Data

Table 5.1 below shows the daily and monthly average data used in this study. It is available from 17th of July 1989 up to the 19th of December 2011 for all variables except the 2 month lease rate which begins on the 2nd of January 1998. The lease rates are all annualised figures. Data is available from the London Bullion Market Association (LBMA) website. The price data are the LBMA PM Fixings.

The leasing cashflow numbers are the authors' own calculations. They are the relevant lease rate times the PM Fixings spot price on that day (LBMA, 2008).

[Insert table 5.1 about here]

6. Results

6.1 ADF Unit Root tests

ADF tests for all variables in levels and first differences are shown in Table 6.2 below. Both the Akaike Information Criteria (AIC) and Schwarz Information Criteria (SIC) were used to apply the appropriate number of lags for each ADF test in all tests to follow. As neither is optimal where they provided different answers both were tested.

For daily data the AM and PM Fixings as well as all lease rates and leasing cashflows are all I(1) and I(0) in 1st differences. These tests imply that gold prices are fundamentally determined by their lease rates indicating no bubble.

For monthly data the same pattern follows for gold spot prices. However 1, 2 and 3 month lease rates and 2 month cashflows are all I(0) in levels. The other fundamental determinants are I(0) in 1st differences. Due to the lower number of observations for the 2 month maturities it is possible that these results are due to low power in the tests. However these results do imply the possibility of a bubble in gold prices due to mixed evidence at this monthly frequency.

[Insert table 6.1 about here]

6.2 Cointegration Tests

Below the pairs of variables found to be I(1) above for daily and monthly average data are tested for cointegration. Only PM pairs are reported as the results from the AM fixings data were the same.

[Insert table 6.2 about here]

No cointergating relationships are found to exist between any of the I(1) pairs. The lack of a cointergating relationship between the variables implies that a long run equilibrium relationship may not exist between the London Gold Fixings prices and gold lease rates or gold leasing cashflows, so that rational speculative bubbles may occur in the price of gold. While this is not proof of a bubble due to issues of size and power for this type of test, it does imply the possibility.

6.3 Markov-Switching Augmented Dickey Fuller tests for Periodically Bursting Bubbles

We now test for a cointegrating relationship between gold prices and lease rates or leasing cashflows as in Section 6.2 above but allowing for a switch between two unobserved regimes with two unknown means and two unknown variances. In tables 6.3 and 6.4 $\pi_1$and $\pi_2$are the means of regime 1 and 2 respectively, Variance 1 and Variance 2 are the regimes respective variances and P_{12} and P_{21} are the probability of switching from regime 1 to regime 2 and vice versa. All regressions included the appropriate number of lags, but the coefficients on the lagged residuals are not reported here.

We can see from Tables 6.3 and 6.4 that regardless of frequency or how we measure the benefit of holding gold no bubble is found to be present under this test. A cointergating relationship exists with the means of all equations significantly different from 0 at the 1% level. This change happens as we allow the variances to differ between the two regimes. Regime 1 has the lower variance by a multiple of between 3 and 7 times depending on which maturity is used as the fundamental determinant. The residuals of the relationships between the gold price and measures of the benefit of holding gold are then characterised by periods of stability or increased volatility.

[Insert Tables 6.3 and 6.4 about here]

Figure 1 below graphs the probability of moving from the low variance regime 1 to the high variance regime 2 at the 1 month and 12 month maturities along with the PM fixings price.. Figures for the other maturities are given in Appendix A. At 1 month maturity switches are more frequent between regimes but a prolonged period in regime 1 can be seen between 2002 and 2007, which is also the case for the 2, 3 and 6 month maturities. For all these maturities we then see increased switching between regimes during the global financial crisis. At 12 months maturity regime 1 is predominant in the beginning of our sample and moves into regime 2 in the latter part, with a very similar pattern for the other 4 maturities.

All figures seem show a move to the higher variance regime at times of market stress such as the dotcom bubble in 2001, with the relationship between gold and shorter maturities being more likely to be affected at such times.

[Insert Figure 3 about here]

The cross-correlation matrix for these probabilities for all maturities and fundamental determinants is shown below in Table 6.5. All cross-correlations are above 90% showing a high degree of consistency in answering whether gold is in regime 1 at any time regardless of how we measure golds value or what maturity is used. This indicates that the results are robust to changes in both maturities and fundamental determinants.

[Insert Table 6.5 about here]

7. Conclusions

In attempting to answer whether bubbles occur in the price of gold we use 2 related measures of gold's fundamental value, gold lease rates and gold leasing cashflows measured in dollars, as well as 2 methods, testing for rational speculative bubbles and regime switching tests for periodically bursting bubbles.

If we allow the assumption that once a bubble is present in an asset it remains, as in Sections 6.1 and 6.2, we obtain mixed answers. ADF tests say that gold lease rates and the dollar leasing cashflows that can be earned by leasing gold are both stationary by first differencing, indicating no bubble is present when daily data is used. Monthly data provides a less clear picture with the fundamental determinants pointing to the possibility of a bubble at some maturities. As these are both financial variables we would expect that they incorporate information quickly, and as we have far more observations in the daily tests it seems likely that the weight of evidence from the ADF tests points towards a fundamentally determined price.

When we use the same data to test for cointegrating long run relationships between the spot price of gold and measures of its fundamental value, no fundamental measure is found to cointegrate. This indicates the possibility of bubbles being present in the gold price as no long run equilibrium relationship is found.

Markov Switching ADF tests for cointegration shown in Section 6.3 allow the assumption of a single long run relationship to be relaxed and different regimes are allowed to exist with different means and variances. This allows us to look for periodically bursting bubbles as well as whether golds variance is constant or varying over time. These tests find that two cointegrating regimes exist for each set of variables. These two regimes are differentiated by periods of lower and higher variance which fits with previous research on modelling gold such as Tully and Lucey (2007) and Capie et al. (2005) who find that modelling golds returns requires relaxing the assumption of a constant variance.

Baur and Lucey (2010), and Baur and McDermott (2010) both show that gold is not a single purpose asset, in that it serves as a safe haven in times of extreme market stress. This helps to explain why a low and a high variance regime might exist between gold and its price determinants. Figure 1 and Figure A both show switching that seems to have a relationship to times of market stresses, showing a higher probability of being in the higher variance regime around the dotcom crash in 2001 and after the financial crisis as gold takes its role as a safe haven and hedge against general market risk. The volume of news affecting the gold price increases at these times may accounts for the increased variance of the residuals from the relationship of the gold price and fundamentals determinants. Overall the evidence therefore is mixed – allowing for regime switching we see no evidence of bubbles, but some indications when we impose a single regime.

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Appendix A:

Figure A: The probability of being in regime 1 for 2, 3 and 6 month lease rate and leasing cashflows, Daily data

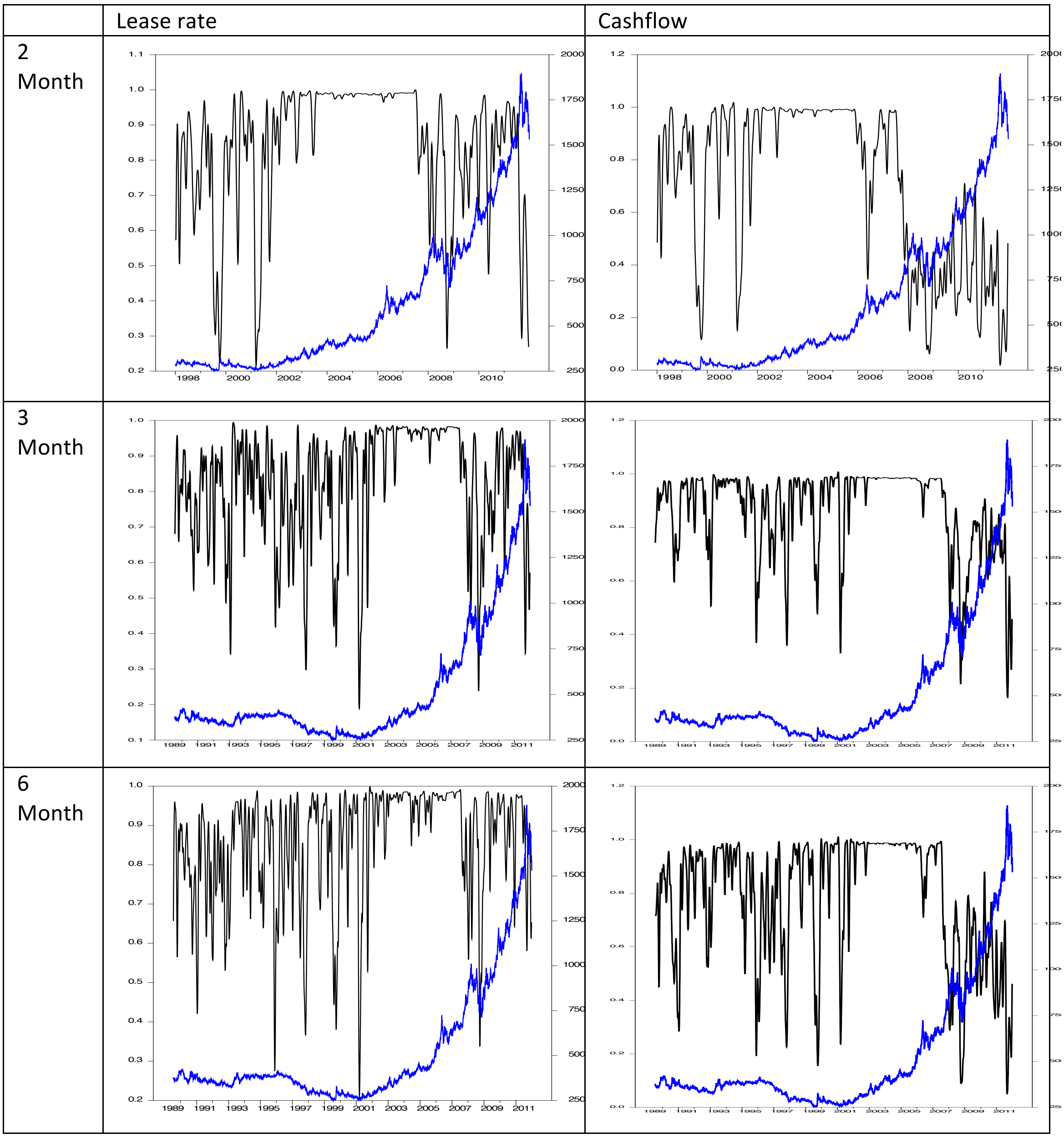


Table 5.1: Data

	Observations			
Fixings				
	Daily	Monthly Average	Mean	Standard Deviation

AM Fix	5495	261	482.57	334.34
PM Fix	5451	261	482.22	334.07
Lease Rates				
1 Month Lease Rate	5495	261	0.0074	0.71%
2 Month Lease Rate	3357	159	0.0050	0.40%
3 Month Lease Rate	5495	261	0.0083	0.81%
6 Month Lease Rate	5495	261	0.0094	0.92%
12 Month Lease Rate	5495	261	0.0113	1.11%
Leasing Cashflows ($'s)				
1 Month	5495	261	$2.44	$3.20
2 Month	3357	159	$1.58	$2.93
3 Month	5495	261	$2.92	$2.92
6 Month	5495	261	$3.51	$3.51
12 Month	5495	261	$4.5	$4.50

Table 6.1: Augmented Dickey Fuller (ADF) tests

Data:	No. of Lags	Daily Data	No. of Lags	Monthly Data
Fixings				
AM	1	Non-Stationary	2	Non-Stationary
Am Return	1	Stationary at 1%	2	Stationary at 1%
PM	1	Non-Stationary	2	Non-Stationary
Pm Return	2	Stationary at 1%	2	Stationary at 1%
Lease Rates				
1 Month	0	Non-Stationary	2	Stationary at 1%
1st Dif -1 Month	3	Stationary at 1%	2	Stationary at 1%
2 Month	1	Non-Stationary	2	Stationary at 1%
1st Dif -2 Month	5	Stationary at 1%	5	Stationary at 1%
3 Month	1	Non-Stationary	2	Stationary at 1%
1st Dif -3 Month	6	Stationary at 1%	5	Stationary at 1%
6 Month	1	Non-Stationary	2	Non-Stationary
1st Diff 6 Month		Stationary at 1%	5	Stationary at 1%
12 Month	1	Non-Stationary	2	Non-Stationary
1st Dif-12 Month	3	Stationary at 1%	4	Stationary at 1%
Leasing Cashflows				
1 Month	14	Non-Stationary	2	Non-Stationary
1st Dif -1 Month	2	Stationary at 1%	2	Stationary at 1%
2 Month	15	Non-Stationary	2	Stationary at 1%

1^{st} Dif -2 Month	2	Stationary at 1%	12	Stationary at 1%
3 Month	14	Non-Stationary	2	Non-Stationary
1^{st} Dif -3 Month	5	Stationary at 1%	5	Stationary at 1%
6 Month	12	Non-Stationary	3	Non-Stationary
1^{st} Dif -6 Month	3	Stationary at 1%	13	Stationary at 1%
12 Month	13	Non-Stationary	2	Non-Stationary
1^{st} Dif-12 Month	12	Stationary at 1%	11	Stationary at 1%

Table 6.2: Cointegration - Daily data

Cointegrating Pair	Lags	Daily Data	Lags	Monthly Data
	Lease rates			
PM Fix & 1 month	6	Not Significant		NA
PM Fix & 2 month	6 14	Not Significant Not Significant		NA
PM Fix & 3 month	6 9	Not Significant Not Significant		NA
PM Fix & 6 month	6 9	Not Significant Not Significant	2 5	Not Significant Not Significant
PM Fix & 12 month	6 9	Not Significant Not Significant	2 4	Not Significant Not Significant
	Leasing Cashflows			
PM Fix & 1 month	14	Not Significant	2	Not Significant
PM Fix & 2 month	3 17	Not Significant Not Significant		NA
PM Fix & 3 month	19 20	Not Significant Not Significant	2	Not Significant
PM Fix & 6 month	18 19	Not Significant Not Significant	2	Not Significant
PM Fix & 12 month	7 18	Not Significant Not Significant	2 7	Not Significant Not Significant

Table 6.3: Maximum likelihood Estimates of Markov-Switching ADF Tests – *Daily Data*

PM Fixing and Lease Rates					
	1 Month	2 Month	3 Month	6 Month	12 Month
π_1	1.0003 ***	1.0001 ***	1.0000 ***	0.9997 ***	1.0002 ***
Variance 1	0.1108 ***	0.0986 ***	0.1144 ***	0.1053 ***	0.1044 ***
π_2	0.9864 ***	0.9942 ***	0.9912 ***	0.9922 ***	0.9907 ***
Variance 2	0.6160 ***	0.6578 ***	0.4983 ***	0.4570 ***	0.3583 ***
P_{12}	0.0736 ***	0.0458 ***	0.0551 ***	0.0451 ***	0.0386 ***
P_{21}	0.2774 ***	0.2365 ***	0.2500 ***	0.2583 ***	0.2430 ***
PM Fixing and Leasing Cashflows					
	1 Month	2 Month	3 Month	6 Month	12 Month
π_1	1.0011 ***	1.0012 ***	1.0004 ***	1.0006 ***	0.9995 ***
Variance 1	6.6772 ***	4.9633 ***	9.5047 ***	8.9060 ***	3.4963 ***
π_2	0.9987 ***	0.9997 ***	0.9954 ***	0.9980 ***	1.0007 ***
Variance 2	51.257 ***	43.394 ***	85.425 ***	53.991 ***	16.626 ***
P_{12}	0.0589 ***	0.0467 ***	0.0988 ***	0.0532 ***	0.0225 ***
P_{21}	0.1836 ***	0.1019 ***	0.4826 ***	0.1777 ***	0.0445 ***

Note: *, ** and *** represent significance at the 10%, 5% and 1% level.

Table 6.4: Maximum likelihood Estimates of Markov-Switching ADF Tests– *Monthly average data*

PM Fixing and Lease Rates					
	1 Month	2 Month	3 Month	6 Month	12 Month
π_1	0.9984 ***	1.0112 ***	1.0081 ***	1.0030 ***	1.0123 ***
Variance 1	0.2146 ***	0.3350 ***	0.3871 ***	0.3522 ***	41.575 ***
π_2	0.9267 ***	0.7475 ***	0.7087 ***	0.7681 ***	0.9537 ***
Variance 2	1.3425 ***	1.2904 ***	1.0592 ***	0.9254 ***	183.43 ***
P_{12}	0.0973 **	0.0233	0.0289 **	0.0374 **	0.0442 ***
P_{21}	0.0672 **	0.0668	0.0467 **	0.0885 **	0.1560
PM Fixing and Leasing cashflows					
π_1	1.0141 ***	1.0235 ***	1.0059 ***	1.0041 ***	1.0115 ***
Variance 1	20.010 ***	19.017 ***	21.940 ***	23.870 ***	39.854 ***
π_2	1.0060 ***	0.9891 ***	0.9956 ***	0.9862 ***	0.9979 ***
Variance 2	124.81 ***	123.33 ***	134.72 ***	139.33 ***	169.85 ***
P_{12}	0.0995 ***	0.0749 ***	0.0705 *	0.0509 **	0.0472 *

P_{21}	0.1078 **	0.1163 **	0.0697	0.0570 **	0.1502 *

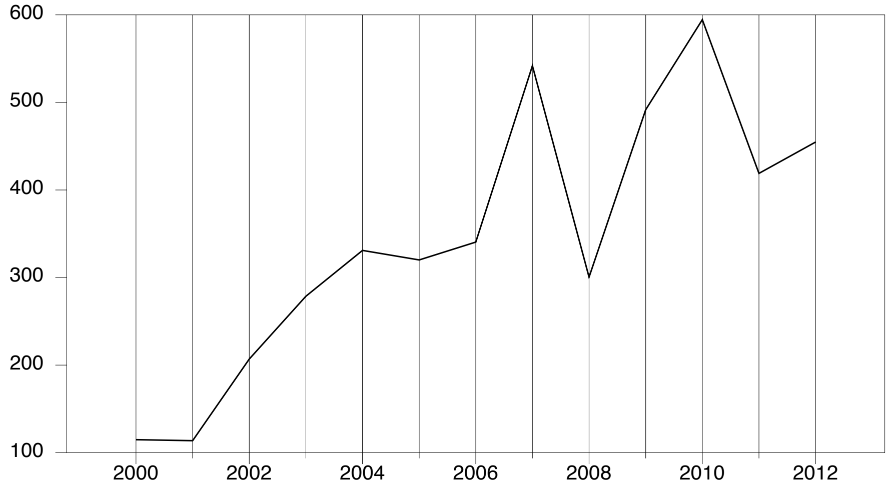
Note: *, ** and *** represent significance at the 10%, 5% and 1% level.

Table 6.5: Cross-Correlation Matrix of probabilities of being in regime 1, for all fundamental determinants-

12 month Leasing cashflow	0.964	0.969	0.978	0.964	0.982	0.986	0.992	0.992	0.998
12 month Lease Rate	0.963	0.967	0.979	0.965	0.982	0.986	0.992	0.990	1.000
6 month Leasing cashflow	0.964	0.96699 0.96943	0.973	0.959	0.980	0.983	0.997	1.000	-
6 month Lease Rate	0.964	0.969	0.976	0.962	0.981	0.983	1.000	-	-
3 month Leasing cashflow	0.967	0.973	0.978	0.964	0.995	1.000	-	-	-
3 month Lease Rate	0.972	0.976	0.973	0.959	1.000	-	-	-	-
2 month Leasing cashflow	0.936	0.939	0.983	1.000	-	-	-	-	-
2 month Lease Rate	0.951	0.954	1.000	-	-	-	-	-	-
1 month Leasing cashflow	0.991	1.000	-	-	-	-	-	-	-
1 month Lease Rate	1.000	-	-	-	-	-	-		
	1 month Lease Rate	**1 Month Leasing Cashflow**	**2 month Lease Rate**	**2 Month Leasing Cashflow**	**3 month Lease Rate**	**3 Month Leasing Cashflo w**	**6 month Lease Rate**	**6 Month Leasing Cashflow**	**12 month Lease Rate**

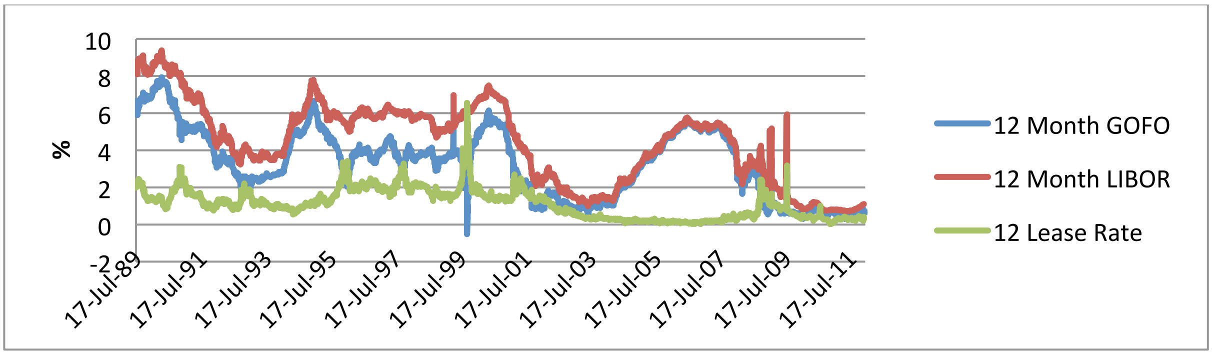
12 Month Leasing Cashflow		-	-	-	-	-	-	-	-	1.000

Figure 1: Open interest in gold futures contracts on COMEX



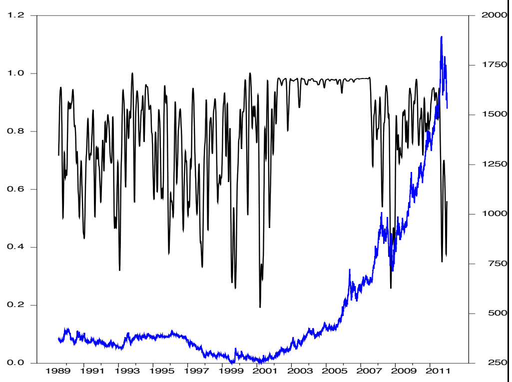
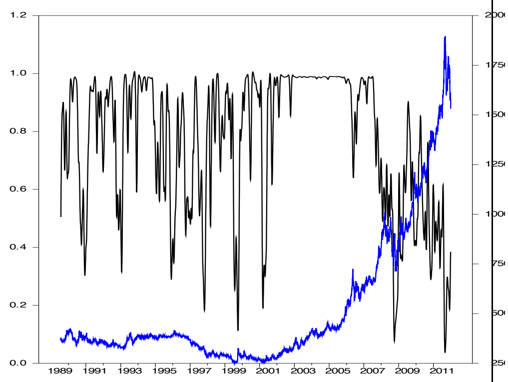
Source: CFTC, Commitment of traders

Figure 2: 12 Month GOFO, LIBOR and Gold Lease Rates



Source: LBMA Website

Figure 3: The probability of being in regime 1 for 1 and 12 month lease rate and leasing cashflows, Daily data

Maturity	Lease rate	Cashflow
1 Month		
12 Month