# A Behavioural and Non-Behavioural Analysis of the London Gold Market

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A dissertation submitted in fulfilment of the requirements for the Degree of Doctor of Philosophy in Business Studies.

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## Declaration

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## Abstract

This thesis makes a number of contributions to the literature on the economics and finance of the gold market, with a special emphasis on the London gold market.

It provides the first effort to produce a substantiate literature review of the published academic papers relating to the financial economics of gold ignoring any other gold related issues outside this, such as the gold standard. A review of the current state of research on the following issues is given with respect to gold: inflation, interest rates, hedging, diversification, safe havens, gold's relationship to other assets, volatility drivers, market efficiency, speculative bubbles, behavioural issues, market linkages and finally the economics of gold mining. From this broad reading three research questions were formed and investigated.

Firstly, the causal relationship between gold extraction costs and gold prices is analysed using a set of country and company data on gold mining. Strong econometric evidence is found for causality running from gold prices to gold mining costs. The results are supported theoretically by the small amount of annual gold production relative to the total stock and the real options embedded in gold mines. The low flow-stock ratio of gold implies that gold mining firms have low market power and thus an inability to significantly influence gold prices. The real options enable gold mining firms to adjust production conditional on the gold price. Production is therefore led by gold prices. This provides empirical evidence against one of two channels through which gold and inflation are thought to have a long run equilibrium relationship.

Secondly, this thesis tests whether periodically bursting bubbles occur in the spot price of gold using gold's lease rates for the first time in the literature as a measure 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 from gold. Markov Switching Augmented Dickey-Fuller tests for periodically bursting bubbles are employed and gives mixed evidence. No bubble is found to be present if the variance is allowed to switch between regimes, the gold and its lease rate relationship is instead characterised by high and low variance periods. Imposing a constant variance, as

recommended by the literature, gives evidence of a bubble for the 2, 3 and 12 month lease rates, but no bubble when the 1 and 6 month rates are used as determinants.

The first examination of whether the gold forward rate is an unbiased predictor of the future gold spot rate is given in Chapter 8. The evidence strongly suggests that it is not, particularly at longer maturities. Building on Aggarwal and Zong's (2008) approach to allow for investor risk aversion, these deviations from rationality are examined to assess whether they can be explained by behavioural factors such as market optimism and over-reaction to news. Forecast errors in the gold market are shown to generally suffer from over-reaction to observed spot price changes but underreact to outflows of gold from Exchange Traded Funds. Further, the forward premium is found to be a consistently optimistic estimate over the full sample. Finally, while the market mood is shown to vary greatly over time, swinging from pessimism in the 1990s to optimism after 2000, the forecast revision over-reaction is found to be consistently stable over the full sample. These are significant, important, and consistent indications of seemingly non-rational behavioural effects in the gold forward market.

# Acknowledgements

Firstly I would like to thank my supervisor, Prof. Brian Lucey, who has been a massive source of encouragement throughout my 4 years as a PhD student. He has shared his time and thoughts with me very generously and I have found him to be a great source of inspiration for my future research career. My deepest gratitude to him for all his help and guidance.

Secondly I would like to thank my wife Joanne, who has been a wonderful help and support in all things during the last 4 years. Special mention to my rambunctious daughter Isabel, for lightening up our lives at regular intervals throughout.

I would like to thank everyone at the London Bullion Market Association for their financial support, as well as the enhanced access and insight to the real world of the London Gold Market that being their bursary recipient allowed. Especial thanks to Ruth, Aelread and Colette for their willingness to answer a student's emails and provide valuable contacts.

Thanks to all those I have worked with as an academic over this period in University College Cork, the University of Central Lancashire and York St. John's Business School.

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# 1 Introduction

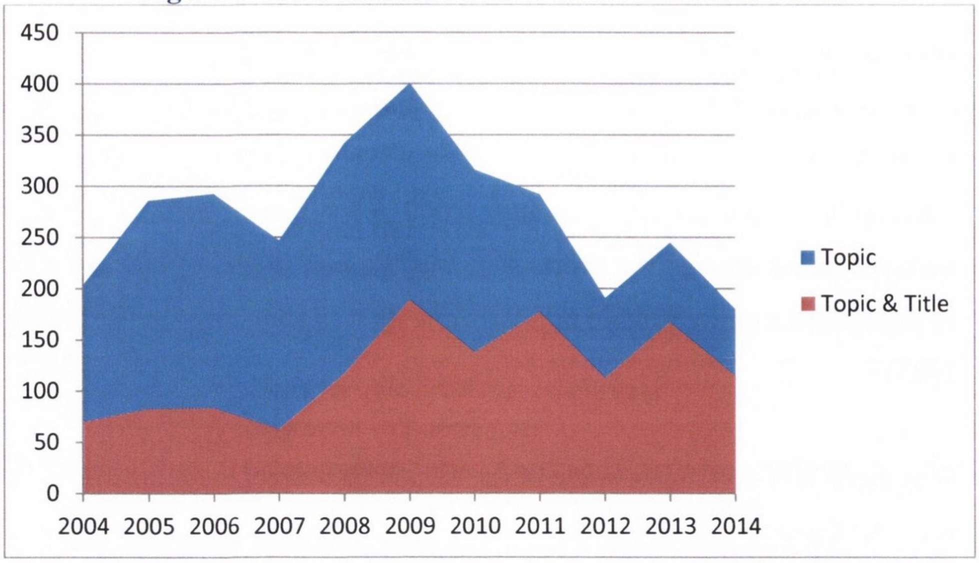
Gold is one of the most malleable, ductile, dense, conductive, non-destructive, brilliant, and beautiful of metals. This unique set of qualities has made it a coveted object for most of human history in almost every civilization, and there have been active gold markets for approximately 6,000 years (Green, 2007). Aristotle is said to have run naked through the streets shouting "Eureka" when he realized a simple way of checking the purity of gold objects while he was taking a bath (Swiss Bank Corp., 1985).

This thesis will investigate some of the factors that affect the price of gold using data from the London Gold Over the Counter (OTC) Market. Many previous studies have concentrated their efforts on data from the COMEX gold futures market as it is more transparent than the London Market, with continuous price and volume data available. However a number of studies, such as Lucey, O'Connor and Larkin (2014), have shown the two markets to be of equal importance in the formation of the gold price.

London has been a dominant centre of the global gold market for most of modern history. The genesis of its leading role was the UK's accidental adoption of a gold standard, which is discussed in the Chapter 2. By 2011 the London OTC Gold Market accounted for about 86% of the gold traded that year (Lucey, Larkin and O'Connor, 2013). The London Market is now changing to a more modern system where all transactions will be centrally cleared following a number of scandals and pressure from regulators to become more transparent (Sanderson, 2014).

The long and intertwined history of gold, financial markets and money, which will be discussed in Chapter 2, has resulted in gold's seemingly perpetual prominence in investment and monetary discussions. It remains a topic discussed regularly in the financial press. Figure 1, below, shows the number of articles published annually in the Financial Times newspaper about gold between 2004 and 2014 from the FT Interactive Database. The total height represents all articles filed under the topic Gold by the Financial Times editors. The red portion show the number filed under Topic: Gold as well as having gold in the title. So the number under the topic gold was 401 in 2009 and 212 of those (53%) also had gold in the title.

**Figure 1- Gold Related Articles in the Financial Times**



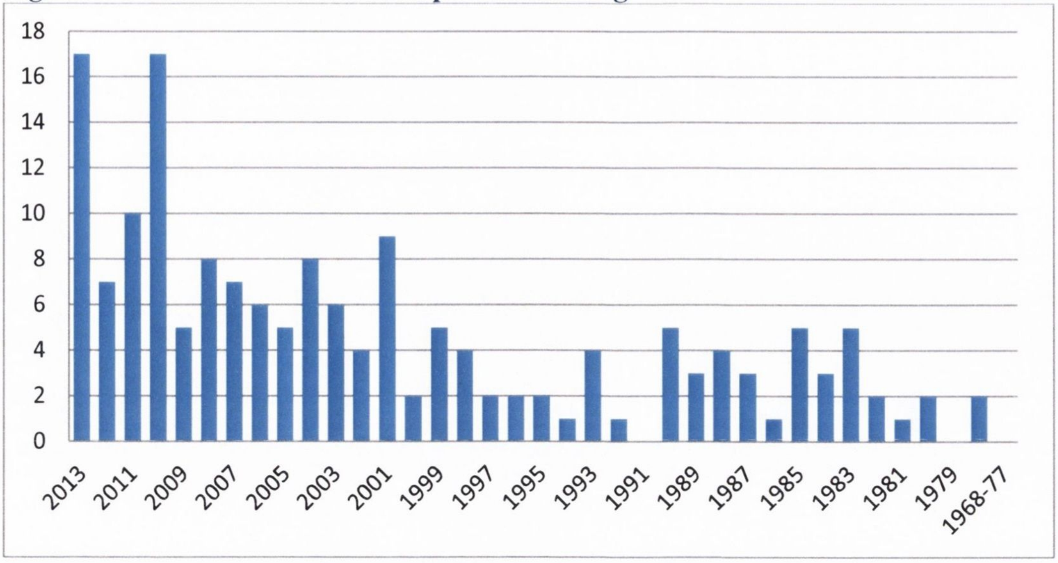

Note: *Searches were carried out on FT.com, Author Calculations*

### 1.1 Focus and Contribution

Chapter 2 will discuss the history of gold and provide some background information giving some reasons for gold's continued prominence as an investment asset over such a long period. It will also discuss the data available on the supply and demand for gold to give readers a view of the broader market for gold.

Chapter 3 will provide the first substantial literature review of the financial economics of gold, focusing on gold as an investment asset, rather than simply as a mined commodity or a monetary unit. This should be a timely undertaking, as the volume of studies on gold has been growing since the price of gold was allowed to float freely in the late 1960's. The volume of peer reviewed papers published is depicted below in Figure 2, showing that the rate of production has increased massively in recent years. The volume of papers now available indicates that a summary of the research undertaken to date would be beneficial for those planning to or undertaking gold research.

**Figure 2- Published Academic Papers discussing the Financial Economics of Gold**




*Source: Author's own calculations*

The empirical work of this thesis will focus on utilising price data from the London OTC Gold Market. There are a number of reasons for this. Firstly this PhD has been undertaken through funding provided by the London Bullion Market Association (LBMA) with a brief to investigate the economics and finance of the London Gold Market. Additionally the London Market is by far the largest by volume, as will be shown in detail in Section 2.3.

This thesis makes 3 empirical contributions to our knowledge and understanding of gold from an investment perspective in Chapters 6 - 8. Chapter 6 gives the first investigation into the relationship between gold prices and the cost of mining gold using a multi-country and company sample over 30 and 24 years respectively. This will address the idea that the cost of extracting gold in some way drives the gold price. In Chapter 7 will use gold lease rates as the fundamental determinant of gold's value, in the same way that dividends would be used for equities, to assess whether bubbles occur in gold prices. We use a Markov Switching Augmented Dickey-Fuller model to test for this, providing a new perspective on gold's value from the cashflows it can generate for investors. Chapter 8 provides the first evidence on whether the London Forward Market is an unbiased predictor of gold spot prices. Finding that this is not the case, it goes on to apply behavioural finance theory to try to explain this deviation from rationality.

Chapter 4 will explain the methodologies used in the empirical studies mentioned above. Chapter 5 details and explains the data used in the empirical chapters.

## 1.2 Publications from this PhD Thesis

While this thesis was being prepared parts of the work have been published and presented in various places, as listed below.

Parts of Chapters 1 and 2 were included in a book chapter "Metals Markets", by Aggarwal, Lucey, and O'Connor (2015).

Chapter 7 was published as "Do Bubbles Occur in Gold Prices? Evidence from Gold Lease Rates and Markov Switching Models" in the Borsa Istanbul Review by Lucey and O'Connor (2013), as well as being presented at the 1st International Conference on the Global Financial Crisis, Southampton UK and the 10th Infiniti Finance Conference, Trinity College Dublin, June 2012.

Chapter 8 was published as "Rationality in Precious Metals Forward Markets: Evidence of behavioral deviations in the gold markets" in the Journal of Multinational Financial Management by Aggarwal, Lucey, and O'Connor (2014), as well as being presented at the 11th Infiniti Finance Conference in Aix en Provence in June 2013.

Part of Chapter 6 was presented at 12th Infiniti Finance Conference, Pareto, June 2014 and is being prepared for submission to a peer reviewed journal.

In addition summaries of some of these pieces of research have been published in The Alchemist, an industry journal published quarterly by the LBMA.

# 2 A Brief History of Gold

Over 6,000 years gold, Keynes' "Barbarous Relic", has maintained a high degree of prominence as a financial asset in the minds of investors, the public and even central bankers. To understand why this is the case it is useful to start by considering its history and basic characteristics.

It is one of the oldest ways to store wealth. In 3000 BC goldsmiths in Sumeria were already working gold into all the various forms of jewellery we still use today (Green, 2007). Excavations at the royal cemetery of Ur (founded about 2500 BC) showed that gold had already become a stock of wealth by this time, as well as money used by traders. Gold has had an impact on the everyday economic activities of ordinary people since at least Egypt in 1400 BC, where it was used as a monetary standard.

### 2.1.1 The Gold Standard

The Modern Gold Standard had its beginnings around the time of the appointment of Sir Isaac Newton as the head of the London Mint in 1696 and the gold rush that occurred in Brazil in the 1700's. Up until this time silver had been the monetary metal due to its abundance relative to gold (Andrei, 2011) but silver coins had been clipped or otherwise devalued to the point that a general re-coinage was needed in the UK. The official prices set by the Bank of England however were not in line with the market's prices at the time - the official purchase price for gold was higher and vice versa for silver.

This encouraged people in England to export their silver holdings to India, where it commanded a premium, while selling their gold to the London Mint. Gold also flowed into the UK from Europe to capture the higher price available. For the first time more gold circulated in England than silver as money, based on Isaac Newton's estimations. The replacement of silver, which had functioned as money for centuries (Craig, 1947) by gold as the main monetary metal then seems then to have been unintentional. Substantial gold shipments from Brazil's new mines directly to the London market allowed this unusual imbalance to hold.

Green (2007) argues that when gold coins were again officially reminted between 1773 - 76, gold had officially become the centre of the monetary scene, on the basis that no re-coinage of silver occurred despite the fact that it had been debased to an even greater extent than gold by then.

The Californian gold rush, set off by John Sutter in 1848, allowed the annual amount of mined gold to increase five-fold in 7 years (Holiday, 1984). This increase in supply allowed another general increase in the minting of gold coins in England, and beyond. In France and the United States silver coins were replaced with gold for everyday transactions by ordinary people due to this massively increased supply.

In the 1850's France and the United States were still officially on a bimetallic standard with silver. However a monetary conference in Paris in 1867, in tandem with the Paris Exhibition, resulted in most countries switching to a gold standard. By 1900 every major nation was on the gold standard except China (Galbraith, 1975).

Silver supporters however did continue to fight its corner. American and Mexican mines contributed 80% to world silver output, creating large groups with a vested interest in maintaining both metals in a monetary role. This push culminated in Williams Jennings Bryan's Presidential campaign and his famous "Cross of Gold" acceptance speech at the 1896 Democratic convention. His campaign's loss ended serious efforts to keep a bimetallic standard, and the United States committed to gold through the US Gold Standard act of 1900.

In 1900 the world monetary system was underpinned by 7,265 metric tonnes of gold, about half minted as coins and the remainder held as reserves by central banks as backing for notes issued (Green, 1999). Further gold discoveries in South Africa, Australia and Canada permitted the stock of gold to continue to increase, allowing for continued economic growth without harmful deflationary pressures. For 25 years before World War I the gold standard formed the basis of most monetary systems and balance-of-payments imbalances between countries were settled in gold (Eichengreen, 1992). There was an understanding between the major national central banks which allowed gold to flow where it was needed giving the system credibility.

The reliability of this system relied heavily on central banks cooperating with each other. As war approached this weakness was exposed as France and Germany ceased conversions of domestic notes into gold and the system of mutual assistance broke down. The US and UK held onto convertibility for a time. But gold flowed from Europe to the US during this time meaning that in 1919, after the war, the US had replaced the UK as the centre of the world monetary system holding the majority of the world's official gold stocks (Brown, 1929). A gold standard was not feasible anymore as countries turned to protectionism, robbing the system of the credibility offered pre-war by central bank agreements.

The UK was returned to the gold standard by Churchill in 1925, but without the use of gold coins as in its previous incarnation. The economist J. K. Galbraith described the decision to return to the gold standard as "the most decisively damaging action involving money in modern times" (Galbraith, 1975:196). By 1930 43 countries were signed up to the gold standard but the new international system was not now characterised by cooperation as before, but by competition for gold reserves by central banks. The banking failures that accompanied the beginning of the Great Depression, such as the collapse of Creditanstalt in Austria, increased the pressure on governments, and without a willingness to help each other the interwar incarnation of the Gold Standard began to collapse in 1931.

The Bank of England soon suspended conversion again followed by Austria, Canada, Finland, Germany, Norway, Sweden and Portugal. The US and some European nations remained, with this group holding 77% of all central bank gold holdings (Eichengreen, 1992). The inauguration of President Roosevelt in 1933 signalled the end of American participation in a gold standard as he cut the link to gold and also banned American citizens from owning gold coins, bars or certificates.

The centrality of gold to the world economy at this time, in or out of a gold standard, cannot be better illustrated than through the fact that the gold price was discussed and set each morning by Roosevelt and his advisors (Schlesinger, 1960). They encouraged the price of gold to rise gradually until it was set at $35 in 1934. This price caused flows of gold from Europe to the US and eventually drove France off the gold standard in 1936. By the outbreak of World War II the gold standard was no more but gold's status as a monetary metal in the minds of investors and the public was still firmly established.

### 2.1.2 Bretton Woods and After

In an effort to try to create a workable monetary system, government representatives of the WWII Allies meet in Bretton Woods in 1944. They set up the International Monetary Fund (IMF) and a system which set a gold price at $35 with the US treasury standing ready to buy or sell at this price. Members of the IMF agreed to set their currency values to within 1% of this price, based on the exchange rates which existed on July 1st 1944.

Once the London gold market reopened in 1954 the market price there could fluctuate above the effective $35 floor imposed by America. In 1960 it reached $40 prompting the creation of the Gold Pool of western countries whose aim was to maintain a price between £35 and $35.20 (Green, 1968). In 1965 the cessation of Soviet gold sales through the London market created a severe negative supply shock. Coupled with increasing speculative demand, cooperation within the gold pool began to break down, with President De Gaulle beginning to turn French held Pound Sterling and US Dollar balances into gold rather than protecting the official price. France finally opted out of the Pool in 1967.

Speculation on whether the $35 gold price would be maintained led to an increasing unwillingness to hold dollars. Demand for gold in London again rose and lead to the US Military flying gold to the London market in order to meet it (Green, 1993). In March, the gold market in London was given a bank holiday due to the massive sales that the gold pool was undertaking.

After this a fiction persisted where, with official help, central banks held and exchanged gold at $35 dollars but the market price floated. And even this failed in August 1971 when President Nixon closed the gold window. After the end of the Bretton Woods era the gold price floated freely. Uncoordinated sales by central banks after this point helped to contribute to significant falls in price especially during the 1990's.

Green (2007:382) describes Nixon's closure of the gold window as follows: "The final link between gold and currency was snapped." However it seems that this has not proved wholly accurate in the long run.

Central bankers have continued to place varying level of emphasis on gold. In 1999 a Central Bank Gold Agreement was signed by the European Central Banks stating that they would be limited to 400 metric tonnes of sales per annum and that these would be coordinated. This agreement was renewed for the fourth time in 2014 along with the statement that "Gold remains an important element of global monetary reserves" (ECB, 2014). This is despite the fact that central banks have recently become net sellers again, to be discussed below in more detail.

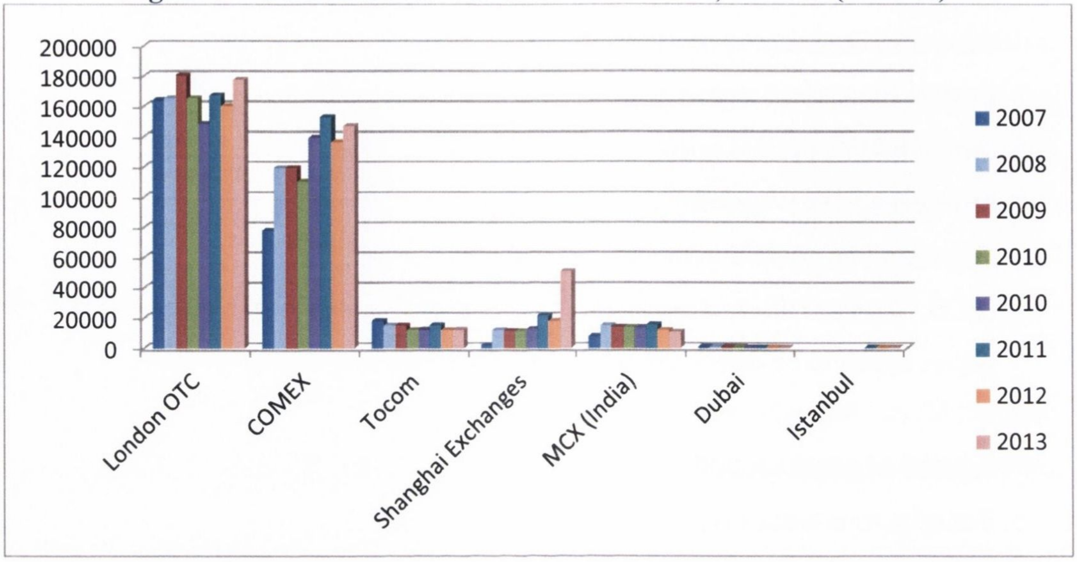
## 2.2 The Modern Gold Market

Today gold is traded on over 7 markets including the London OTC market, COMEX (New York), the three Shanghai Exchanges, TOCOM (Tokyo), MCX (India), Dubai and Istanbul. In terms of turnover, the two major markets for gold are the London OTC market and New York (COMEX). Daily volume on the New York Stock Exchange was just over $34.5bn per day in 2013 (NYXdata.com). The London Stock Exchange had an average daily trading volume of just over £3.8bn ($5.94bn) in the same year (londonstockexchange.com). In 2013 London net OTC and COMEX daily turnover came to $21bn and $18bn at average 2013 prices respectively, based on Gold Fields Minerals Services (GFMS) data and author's calculations. Other markets are much smaller and are shown below in Figure 3, since 2007. China has seen significant growth from a small base to become the third most influential market. In other Asian markets, India has stagnated since 2009 and TOCOM in Japan is seeing falling volumes, possibly due to increasing availability of gold trading centres for Asian investors such as the Shanghai exchanges. Dubai is by far the smallest of those listed at just under 0.2% of all volume.

It is estimated that there has been in total 175,000 tonnes of gold mined in history (www.gold.org). At average 2013 prices this would value the total stock of gold at just under $6 tn. While much of this gold does not circulate as an investment asset, as it is held by central banks in bars or as jewellery by consumers, it still represents a large asset. By comparison, the total market capitalisation of the London Stock Exchange in

December 2013 was £4.23tn ($6.9tn) (LSE, 2014) with the New York Stock Exchange being worth just over $16tn (NYSE.com).

**Figure 3 - Gold markets' turnover 2007 -2012, Annual (Tonnes)**



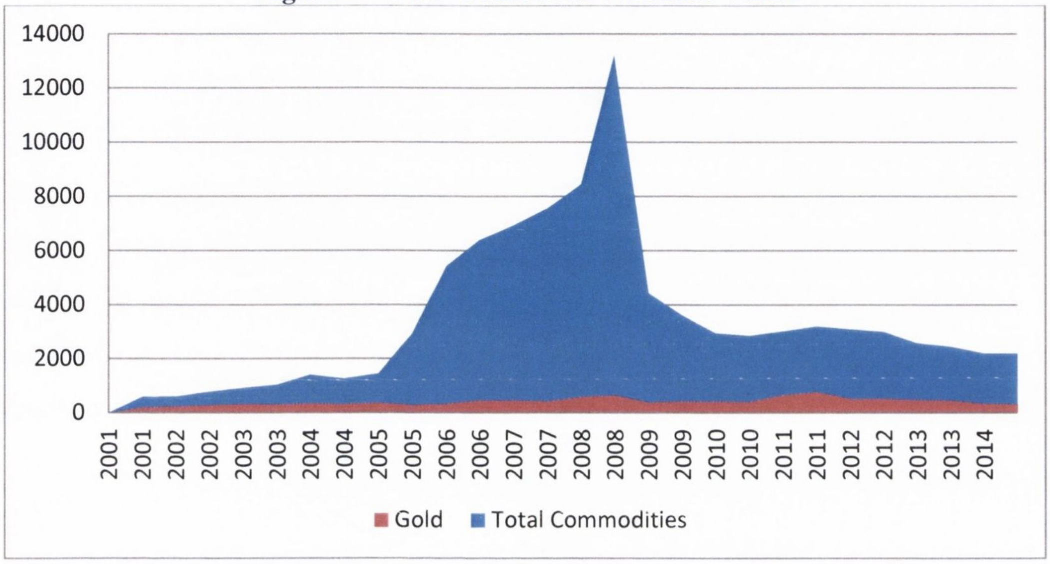

*Note: The London OTC figure represents net transactions, it is estimated that gross is approximately 3 times this number (GFMS, 2014a).*

The accidental move of the UK to a gold standard was the genesis of the dominance of the London gold market, which has lasted up until this day. In the 18th century it absorbed the vast majority of the gold mined in the Brazil gold rush, which went into minting new gold coins; then Russian gold which was the largest producer before the Californian gold rush of the 1840's (Green, 2007). Even the suspension of conversion by the Bank of England in 1931 did not dent London's dominance. In fact as all South African gold was still cleared through the fixing, private hoarders became a major player (BIS, 1938). In the 5 years after the UK came off the gold standard approximately 70% of all mined gold was bought by banks and private investors.

In summary the total available gold stock is similar in value to a major stock market while the turnover of each trading centre shows a similar level of liquidity to major stock exchanges.

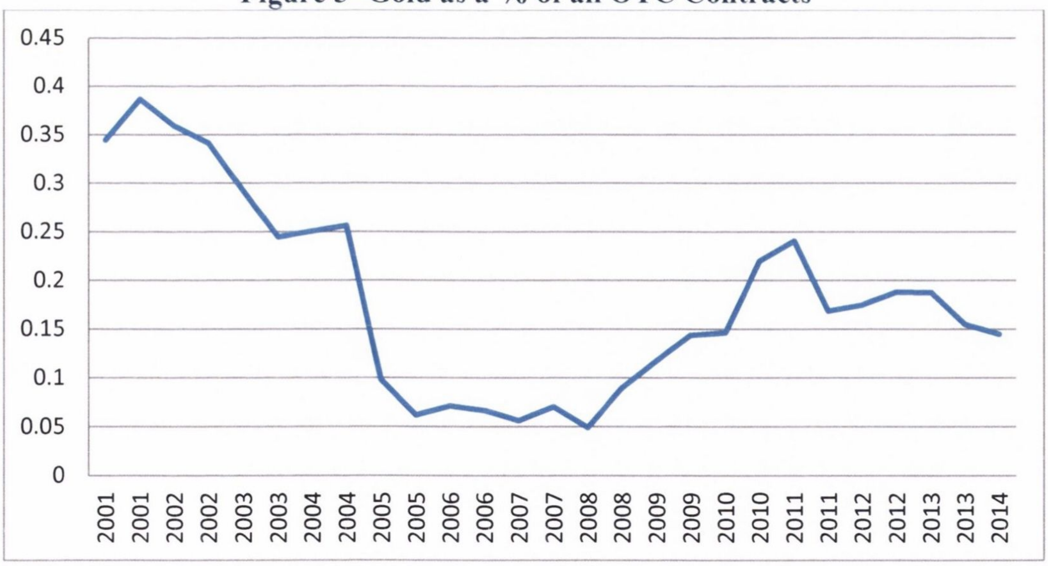
Data from the Bank for International Settlements, shown below in Figures 4 and 5, give the value of all OTC commodities contracts outstanding globally at a semi-annual level. They demonstrate that the demand for gold is much more stable over the period than the demand for other commodities. We see a large spike in commodities demand in the run up to 2008 as a result of the financialisation of consumption commodities (Falkowski, 2011).

**Figure 4- OTC Contracts: Notional Value**




*Source: Bank for International Settlements, OTC derivatives market activity reports 2002 - 2014*

**Figure 5- Gold as a % of all OTC Contracts**




*Source: Bank for International Settlements, OTC derivatives market activity reports 2002 - 2014*

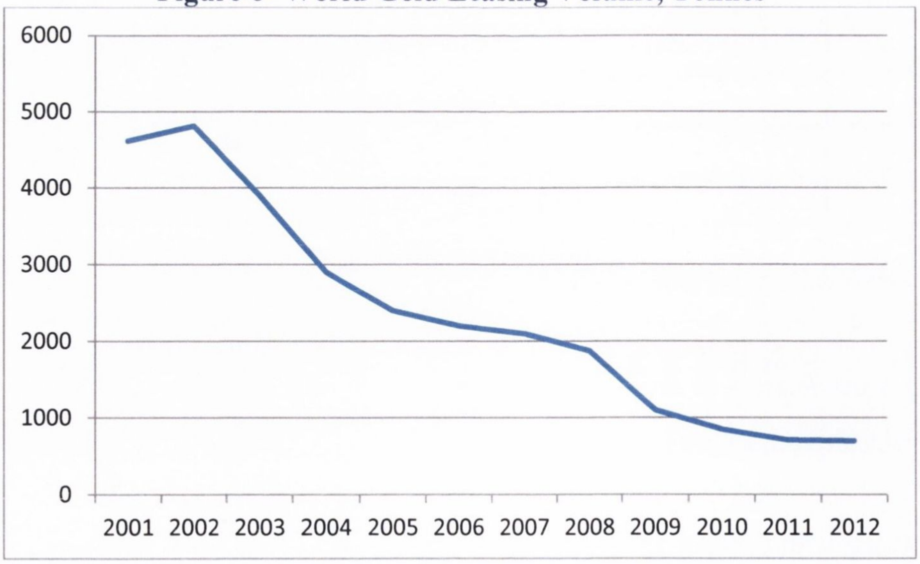
Along with the spot and derivatives markets discussed above, gold can be borrowed in a similar way to normal currencies in the leasing market. Though the modern London gold leasing market was beaten to the idea by Babylonian temples (Green, 2007), it still remains an under researched area. This market began in 1989 with gold leasing maturities available from 1 – 12 months.

The primary sources of gold leasing demand have been jewellers and gold miners. Jewellers borrow gold for fabrication, and return the leased gold once the jewellery has been sold using the proceeds of the sale. Miners can borrow some proportion of their expected mine output which they sell forward in order to finance production. This gives both a natural hedge against gold price movements and, as lease rates are usually lower than dollar interest rates, a cheap source of financing.

Supply into the leasing market comes primarily from central banks who use it to give some income from their gold stocks. Lending by central banks is rarely reported, even after the fact, but it has fallen off in recent years as lease rates have fallen; see Section 5 for details.

An exception is the Reserve Bank of Australia (2012), who stated that out of 80 tonnes in stock only 1 was on loan at that time. GFMS do provide estimates as given in the graph below, but not broken down in any way. The low and falling level of lending in recent times is ascribed to a lack of demand (GFMS, 2013) from the miners and jewellers as well as increased counterparty risk and low available returns.

**Figure 6- World Gold Leasing Volume, Tonnes**



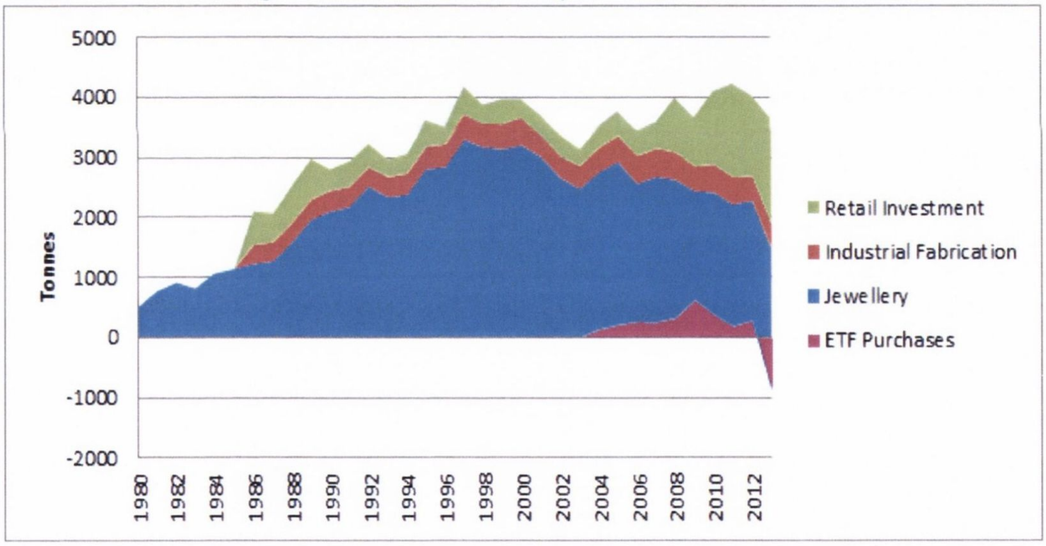

*Source: GFMS Gold Surveys 2000-2013*

2014 has been a year of major changes in the gold market. The gold fixing (as well as silver) which began in 1919 and which had been conducted over two daily conference calls is to be replaced by an electronically run version of these auctions on the 20th of March 2015. These are being held electronically to improve the transparency of the transactions being undertaken (Angwin, 2014).

### 2.3 Physical Gold Demand

While gold does have a number of industrial uses its demand mostly originates from investment demand and jewellery. Figure 7, below, shows the level of demand for physical gold from various sectors beginning in 1980 for jewellery production and from 1986 for all others. Each source is discussed in detail below followed by an overview of the research that exists on physical gold demand in section 2.3.1. We also discuss rehypothecation, a latent form of gold demand.

**Figure 7- Demand for Physical Gold, Tonnes**

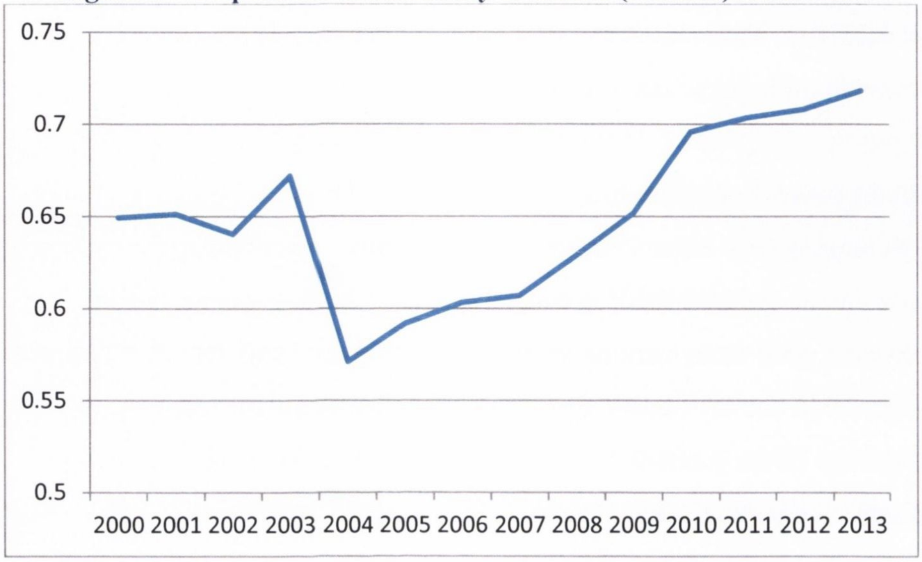



*Source: GFMS Gold Surveys 1989 - 2013*

**Jewellery Production**

Jewellery production represents the most stable long-term source of demand for gold and was one of the earliest uses for gold. Religious and cultural factors mean that the primary sources of demand for jewellery are in Asia, with China and India constituting the largest markets. This long-term demand for precious metals in the East filled the boats of the East India Company in the late 17th and 18th centuries (Green, 2007) on their outward journeys from Europe. Figure 8, below, shows that over 55% of all jewellery was purchased in Asia since 2000 and this has risen to over 70% since 2010.

**Figure 8- Proportion of Jewellery Demand (volume) from Asia**




*Source: GFMS Gold Surveys 2001 - 2013*

**Industrial Fabrication**

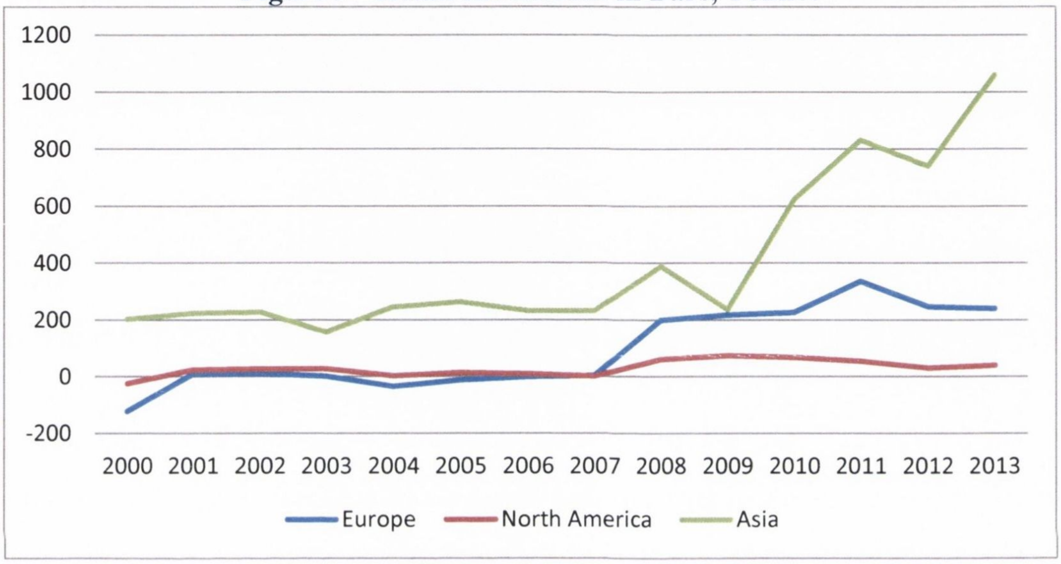
Demand from industrial fabrication is composed of dentistry and electronics, both of whose usage is declining in volume terms. Gold's high price now relative to 10 years ago means that there has been a significant incentive to find cheaper methods in both areas that would allow gold to be replaced. In electronics, gold has been primarily used in bonding wires but advances in technology means that here it is increasingly being replaced by copper. In dentistry, gold is also being replaced by cheaper non-metallic substrates over time. In 2013 the total demand from dentistry was 36.3 tonnes the lowest level ever recorded by GFMS. Gold in electronics also declined due to subdued economic activity, falling below its 2005 level to 278 tonnes in 2013, from a previous high of 321 tonnes in 2007 (GFMS, 2014).

**Retail Investment**

In the run-up to the financial crisis the popularity of retail investment, which can be broken down into gold bars and coins, increased dramatically in contrast to the relatively steady level of demand before this point, over tripling between 2006 and 2013 to 1,377 tonnes (GFMS, 2014). This is a fact that has not been fully realised to date by researchers as the emphasis has been on the development of gold ETF's, see below. But as Figure 7 above showed, the increases in retail investment has been much more pronounced and stable.

Much of this investment has occurred outside of western markets, as gold has flowed east following a long run historical pattern (O'Connor, 2013). Figure 9, below, shows this fact graphically. But the attraction of rising prices and increased concerns about the riskiness of other investments following the 2008 financial crisis saw demand turn positive again in the western world also.

**Figure 9 - Retail Investment in Bars, Tonnes**

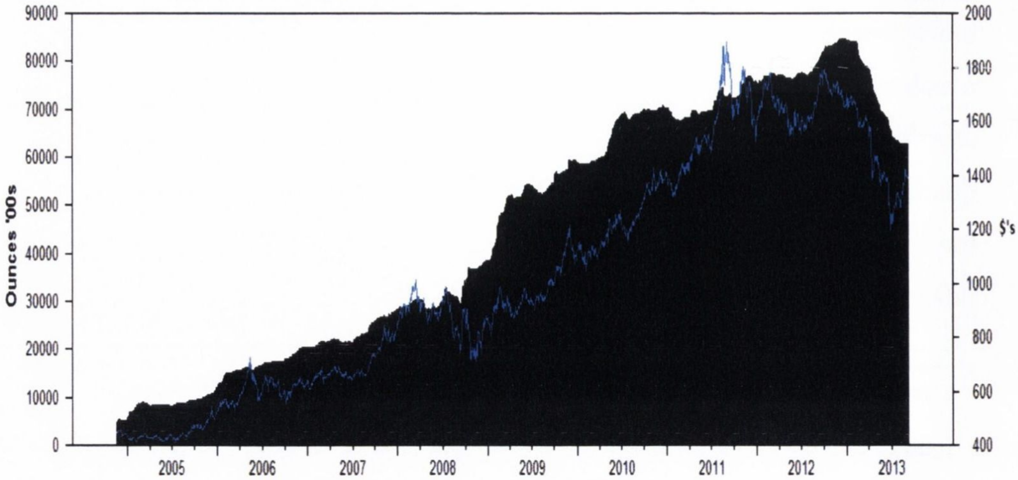



*Source: GFMS Gold Surveys 2001 - 2013*

**Gold Exchange Traded Funds (ETF's)**

A major change in 2003 was the creation of the first gold Exchange Traded Fund (ETF), the Gold Bullion Securities ETF backed by the World Gold Council (GFMS, 2004). This created a new source of investment demand for gold allowing smaller investors to purchase gold more easily. It seems to have been at least partially responsible for the consistent rise in gold prices from about this time, with ETF gold stocks peaking at about 19m ounces in 2012 as shown in Figure 10, below.

**Figure 10 – Total Exchange Traded Fund Gold Holdings (R) and PM Fixing (L)**




*Source: Bloomberg, LBMA*

The steep outflows from Gold ETF's shown in the above graph have been seen as one of the main reasons for the failure of gold prices to recover from prices falls, which may have been the original driver of the outflows caused about this time (Hume, 2013). This fall in demand for "paper" gold, where owners merely have a legal claim on gold which is sitting in a vault somewhere as opposed to owning and holding their own physical bars, occurred despite rising demand for bars and coins which occurred at the same time, as discussed above. The emphasis on ETF flows in commentary on the gold price may be due to their better visibility, as most ETF's report their holdings daily. It may also be the case that these bars and coins represent a reduction in the liquidity of the gold market, as many of these are stored long term rather than traded. ETF outflows by contrast may be sources of day to day supply and have a larger effect on prices. These are issues for further research.

**Latent Demand: Rehypothecation**

The unwinding of ETF positions in 2012-13 and its effect on gold prices has similarities to the Chinese rehypothecation market. Rehypothecation involves the use of inventories of commodities, such as gold or copper, as collateral for loans in a form of the carry trade (Kaminska, 2011). Renminbi are used to buy gold and this is used to borrow dollars. This sets up a natural but partial hedge against dollar risk while allowing for borrowing at lower dollar rates and avoiding some of the capital controls that China has in place.

The World Gold Council (WGC b, 2014) reported that China had 1,000 tonnes of gold tied up in financing deals in 2013, roughly equal to one year of Chinese gold imports. This creates the worry that if these financial deals were unwound a large flow of gold would enter the markets and drive down prices. For example, fears that this would happen in the copper market, which has even larger rehypothecation inventories than gold (estimated to be 1m tonnes in 2014), led to a significant fall in the copper price in March 2014 (Ananthalakshmi, 2014).

The volume of gold being used as collateral in this arrangement also calls into question how much of the physical Chinese gold demand discussed above is an investment in gold (as a speculation or a hedge) and how much is solely for use as collateral. If the primary driver of Chinese physical inflows is rehypothecation rather than investment demand, then it is questionable how much price support this might offer in the medium term.

### 2.3.1 Physical Gold Demand Research

There has been limited academic research on economic issues relating to any of the practical uses for gold. Batchelor and Gulley (1995) provide one such study looking at the relationship between jewellery demand in a number of countries (USA, Japan, Germany, France, Italy, and the UK) and the price of gold. The price elasticity of demand of gold jewellery was found to be between -0.5 and -1, with an average of -0.64. In most cases the full effect occurs in one year. This negative price elasticity of demand points to gold as a discretionary good in these western markets. Whether this relationship holds in economies with different historical relationships with gold, such as China and India, would be an interesting question to address.

Starr and Ky (2008) provide an analysis of the factors which affect the physical demand for gold (such as jewellery and dental) using data from 1992 to 2003. The authors argue that they are significantly different from those that drive investment demand, though this area is not researched here. Their paper finds significant heterogeneity between the drivers of demand in different countries, as might be expected. In developing countries gold consumption rises with falling income pointing to a precautionary motive. The fact that the development of credit markets decreases the demand for gold in these countries reinforces this view. In developed economies gold demand rises with per capita GDP, possibly as gold is viewed as a discretionary expenditure. The paper does however lack some methodological rigor, with no discussion of unit root or co-integration issues despite some of the variables used being commonly seen as non-stationary.

They also find interesting real economic issues through looking at this data: for example what they describe as a dollar illusion for Italy and the UK, where the dollar value of gold has a greater impact than the domestic price. However as there are only 16 years of data available in this study for each country, this observation deserves further attention.

Moses and Cooks (2013) show that the drivers of physical gold demand and gold prices are different using annual and quarterly data from 1992 to 2012. They show that a disconnect exists not only in their drivers but also in the fact that gold prices seem to be unaffected by changes in either consumer or investor demand for gold. They conclude that physical demand will not support gold prices. There is however an issue in the analysis as gold prices will change daily, incorporating information all the time. The data on demand used here is of a significantly different frequency to that and may not be able to capture the effect of physical demand on price changes.

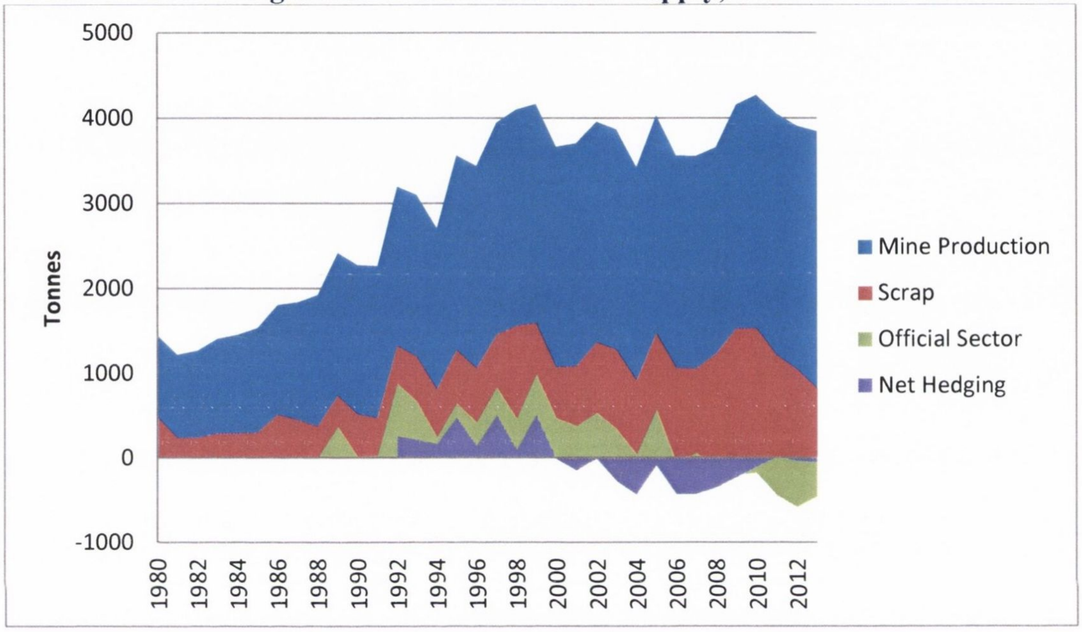
These studies point to interesting areas for future research around physical gold demand, but this is beyond the scope of this thesis.

### 2.4 Physical Gold Supply

Most of the gold ever mined is still in existence and would form a cube with sides of less than 20 meters (gold.org). This is because gold is different from other storable commodities, such as copper, as new gold supply is small relative to its existing stock at about 1% annually. This creates a very large (and ever increasing) stock of gold relative to its flow.

There has been an upward trend in gold supply overall from 1980 to 2013. Total supply has plateaued since 1999 and has hovered around an annual level of 4,000 tonnes only surpassing that level in 2008 and 2009. Even significant increases in scrap supply after the financial crisis, during record nominal gold prices, barely pushed the level above its previous peak. Below we will examine the various sources of supply, examine the life cycle of gold and provide any empirical evidence we have on the different sources of supply. New gold is supplied to the market from 2 main sources: mining and scrap, as shown below. Gold is also sometimes supplied to the market through central bank sales and producer hedging.

**Figure 11- Total World Gold Supply, Tonnes**




*Source: GFMS Gold Surveys, 1989 - 2013*

**Mine Production**

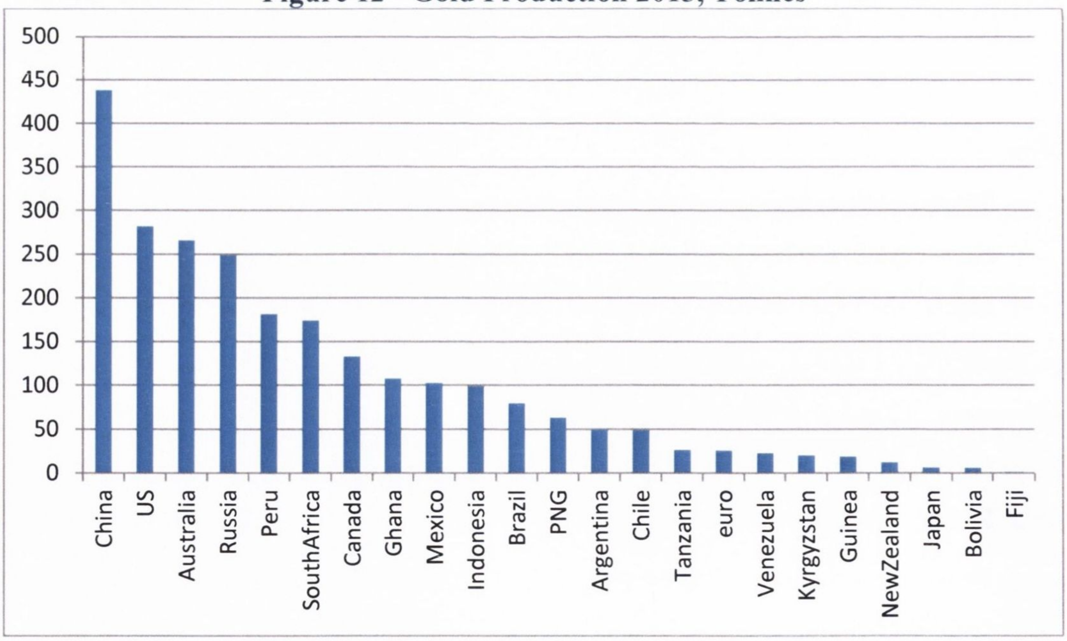
New supplies of gold come to the market in a very different way to other financial assets, such as equities or bonds. While both of the latter are essentially derivative claims on future cashflows or assets, gold represents what can be referred to as a real asset. That is, unlike most assets, it is not also simultaneously a liability for another market participant.

For bonds investors receive coupons over a period of time and par value at the end of its life. Once these are paid the bond ceases to exist. Equity holders lay claim to all cashflows left over after other financial claim-holders (debt, preferred stock etc.) have been satisfied. They receive dividends paid by the company. If a firm is liquidated, the same principle applies, with equity investors receiving whatever is left over in the firm after all outstanding debts and other financial claims are paid off. The principle of limited liability, however, protects equity investors in publicly traded firms if the value of the firm is less than the value of the outstanding debt, and they cannot lose more than their investment in the firm. A share can cease to exist in a number of instances: it is bought back by the firm, the firm is acquired by another or merges with another or the firm enters bankruptcy (Bodie, Kane and Marcus, 2011).

As gold at its most basic is a chemical element it cannot be cancelled out of existence in the same way as most other financial investments. Its life span is permanent. Mine supply will be discussed first below and show from there a characterisation of the lifecycle of gold.

Though gold supply as depicted above peaked in 2010, barely beating the previous peak of 1999, annual gold mine output has continued to increase from 959 tonnes in 1980 to 3,022 in 2013. This has been at a time when the concentration of production has lessened dramatically. South African output has declined from 675 tonnes annually to 174 over the same period; while China has increased production from 112 to 438 tonnes annually between 1992 and 2013 making it the new largest producer of gold. The current distribution of producing countries is as below.

**Figure 12 - Gold Production 2013, Tonnes**




*Source: GFMS Gold Survey 2014*

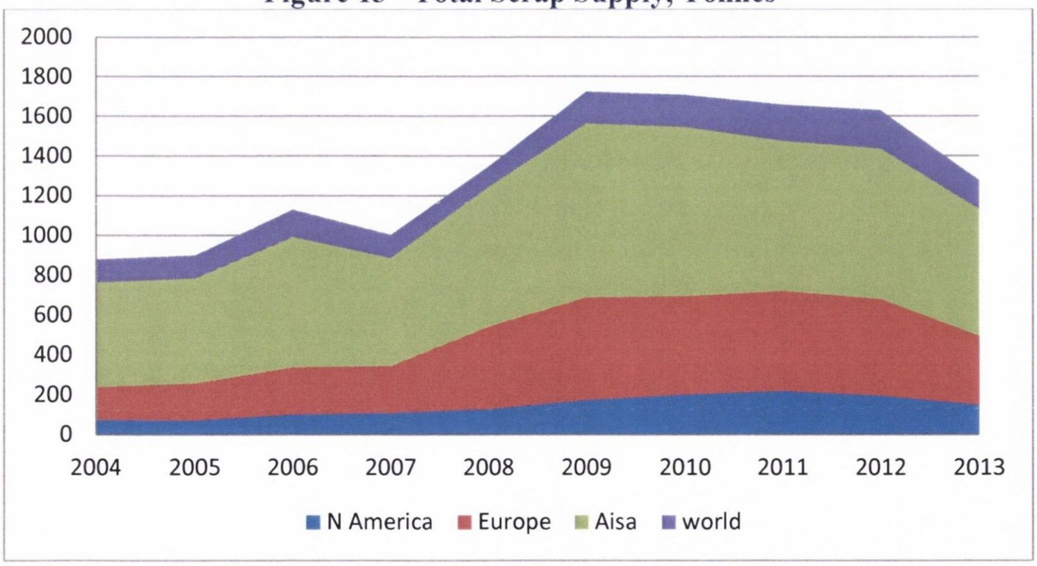
The volume of gold produced from mining a given quantity of ore depends upon on the average grade of ore being processed. Some mines, such as Agnew in Australia, give about 6 grams per tonne of ore processed (GFMS gold mine economics database). This represents about 98% of the gold present in the ore, and is extracted using a process called leaching which uses a cyanide solution (energy.gov). The result is smelted to remove impurities and turned into bullion for further processing into electronics, jewellery etc., or for storage in bar form as an investment.

In order to be held in many official vaults as an investment gold bars must be certified as coming from a refinery on the Good Delivery List maintained and monitored by the LBMA (LBMA.org.uk). The majority of bars will be melted down to create jewellery or smaller bars and coins for investment, as discussed above.

**Scrap supply**

The supply from scrap gold comes from individuals recycling old jewellery and, to some degree, electronics. Some gold is now being lost permanently from the total stock, as it is present in such small quantities in electronic goods that it is not economically viable to recover it. The rate of recovery however is still above 50% (Graedel, Allwood, Birat, Buchert, Hagelüken, Reck, Sibley and Sonnemann, 2011).

**Figure 13 - Total Scrap Supply, Tonnes**




*Source: GFMS Gold Surveys 2005 - 2014*

Based on a visual inspection of Figure 13 above there does seem to be a real correlation with high prices around the financial crisis and jumps in scrap supply. As prices declined after 2011 so did scrap supply. There has however been no academic economic research to date in relation to scrap supply of gold. Söderholm and Ejdemo (2008) investigate the scrap market for steel in Europe and the USA and provide a description of the process. They also discuss the economic fundamentals of the supply which they find to be based on current prices and the fact that scrap can be processed at a fraction of the cost of ore.

But, as gold trades as a primarily financial asset while steel is a simple commodity, there are differences in the markets that warrant further investigation. The Gold Fields Minerals Surveys carried out annually (and providing the basis for this and the previous Section) provide a similar but more detailed analysis of individual countries scrap supply. They also believe that scrap supply changes are based on the price level. However we do not know if a base level exists which is insensitive to price.

**Official Sales/Purchases**

Much of the time period shown in Figure 11, above, saw central bank (official sector) sales of gold holdings. Fieldstein (1980) argues that central bank sales should have a negative effect on gold prices, as they cause a sharp increase in supply, and this did seem to be the case. Green (2007) says that these large central bank sales, which began in the 1990's, originated from central banks leasing gold through the bullion banks. Once they were in regular contact as a result of this market, central bankers saw an opportunity to slowly sell gold and reduce their holdings. When the Bank of England announced that it would sell the majority of its gold in 1999, it seems to have become a trend. Coupled with the rise in production volumes, this was a major driver of the bear market for gold at the time.

However T. Smeeton, a former head of foreign exchange and gold at the Bank of England, is quoted in Green (2007) from a speech at the Financial Times World Gold Conference in 1992, saying that central bankers would and should continue to hold gold for 2 reasons. Firstly, because gold is the ultimate store of value, and secondly, gold should be held as an alternative to national bonds with no credit risk attached.

The global financial crisis proved Mr. Smeeton right in the long term with central banks becoming net buyers of gold again in 2010 for the first time since the 1980's. In

2013 central bank purchases were 409 tonnes, down on the previous year by over 100 tonnes but still very high by modern standards. The effect this might have on gold markets is unclear. Renewed purchases do however point to gold retaining its money like characteristics as it is held increasingly as a monetary reserve.

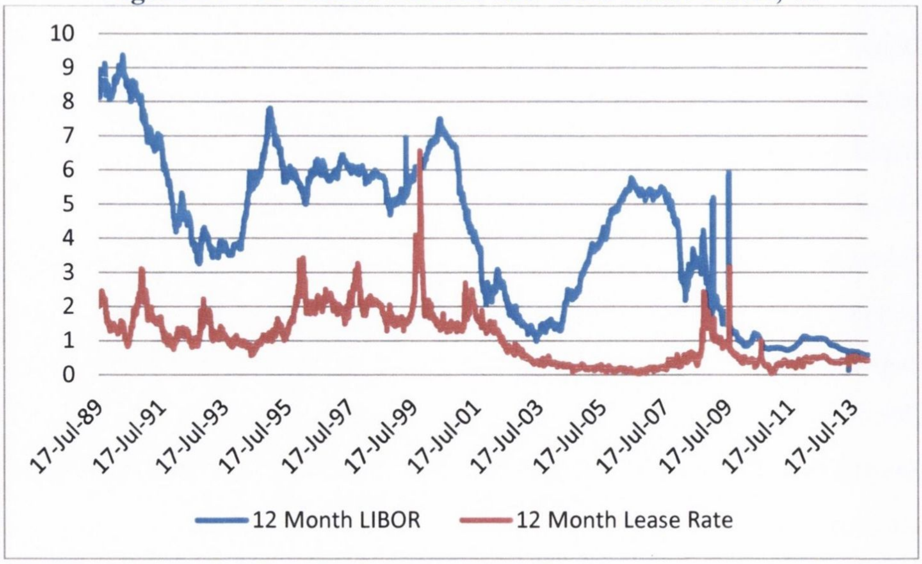
Salant and Henderson (1978) also argued that sales would push down prices, with their analysis based on the Hotellling rule which states that non-renewable resource prices (less the marginal cost) should rise at the rate of interest. In their model prices would then rise at a faster rate than the interest rate when a sale is expected, to compensate investors for the negative price shock cause by the large sale. Recent purchases would cause prices to rise more slowly, so that the positive future impact of anticipated central bank purchases on the gold price is diffused. However this paper has a number of issues. Firstly, according to Livenois (2009), the Hotelling rule does not hold in practice mainly due to technological progress. Secondly it assumes that the only reason to hold gold is price appreciation, but as we will discuss below, it is possible to lease gold.

**Producer Hedging**

Producer hedging by miners can be a source of supply to the market in two ways, through forward sales and leasing. Hedging became common practice as result of Barrick Gold's hedging under Peter Munk (Economist, 2014). It was a source of supply in the 1990's as firms tried to remove their gold price risk.

These positions were not always pure hedges, with evidence that firms tried to sell forward when prices rose and remove positions in the early 1990's (GFMS, 1991). These also do not represent supply to the spot market as no gold is delivered until the end of the contract. Instead it adds liquidity to the derivatives market and allows producers to lock in the prices now of expected future mine output. For the same reasons it does not provide short-term cash for producers.

**Figure 14 - 12 Month LIBOR and Gold Lease Rates, %**




*Source: LBMA.org*

In contrast gold leasing does provide spot market liquidity and immediate financing to the miners. It involves borrowing gold for a fixed period which can then be sold in the spot market for dollars. This gives miners a cheaper source of finance than dollar loans as gold lease rates have typically been lower than dollar interest rates, as shown in Figure 14. Leasing only provides a net supply when more loans are made than repaid in a particular year. Gold lease rates will be discussed in detail in Section 5.4.

# 3 Review of the Investment Literature on Gold

Amongst financial assets gold is quite unique. This literature review will show that it virtually sits as its own asset class different even from the other precious metals: silver, platinum and palladium. One reason is that its usefulness as an industrial metal is negligible, and declining, when compared with its investment and jewellery uses. The other precious metals still however have significant uses in industry: platinum is commonly used in catalysts, palladium is now mixed into many of the alloys that are replacing gold in dentistry and silver can be part of the production of solar panels. This has been a long run historical fact as silver has had significant industrial uses since it became commonly used in photography in the late 1800's (Green, 2007).

As mentioned above in Section 2.4, gold prices, like the prices of other exhaustible resources, are theoretically governed by the Hotelling rule. Again, the Hotelling rule states that the price of the commodity less the marginal cost must increase at the rate of interest in non-renewable resource markets. It forms the theoretical core for understanding the economics of non-renewable resources. However, empirical analysis shows that the Hotelling rule does not hold in practice (Livenois, 2009). As probably the most prominent investment commodity, gold prices are driven by, and related to, a wider range of variables than simply interest rates alone, though interest rates are a significant and complex influence, as can be seen from Section 3.2 below.

Prior to the closure of the gold window in 1971 much of the discussion on gold prices understandably focused on gold's role as a monetary asset. When the price itself was specifically examined the discussion revolved around what level the price should be set at in terms of macroeconomic policy, not based on its characteristics as a financial asset.

For example, Goodman (1956) discusses the recurring conversation as to whether the officially set price of gold during that period should be raised in order to increase international liquidity. While it was by no means a closed question, with Bauchau (1949) arguing for a decrease in the value of all currencies relative to gold and Johnson (1950) the opposite, the reasons for officially adjusting the price of gold were, in general, based on issues around macroeconomic variables, such as trade imbalances and wages. Research on financial asset based issues, such as its ability to hedge risks or diversify a portfolio (areas on which recent literature has focused), were not addressed in any detail.

Early work on speculative or investment view of gold comes from Machlup (1969) which was published just prior to Nixon's decision to sever the link between the gold price and monetary policy. This offers information on the supply and demand for gold in that period in order to form an assessment of the prospects of the gold price in the ensuing years, as well as discussion of the merits of holding god versus other assets. He concludes that the 1969 gold price of $35 would not hold without government intervention and would fall significantly if governments sold their reserves. History has proved this opinion wrong as the price rose to around $200 in the 3 years after the closure of the gold window. As discussed above, central bank gold sales in the 1990's did add to the depressing price pressures at the time but did not permanently damage gold. As the price of gold up to 1971 was fixed, while the general price level continued to increase with inflation, this does raise the question as to whether the rapid rises in the gold price post-1971 were due to a purchasing power parity type adjustment.

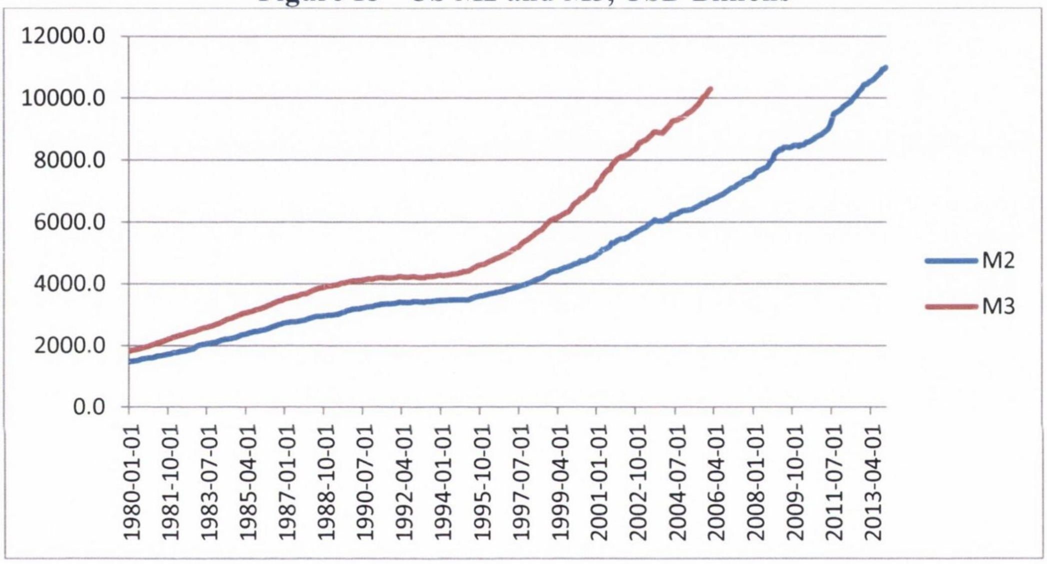
The following Sections in this chapter will discuss the research areas that have drawn the attention of academics over the past 40 years up to and including 2013.

### 3.1 Inflation

A major theme within gold research relates to its ability to hedge inflation, with most of the studies focusing on the US CPI and the US Dollar value of gold. The traditional channel through which this relationship is supposed to come about relates to gold's money like status, as discussed in previous Sections. Gold has a limited stock and a relatively inelastic supply in the short run, as it takes time to increase production through bringing new mines into production. This means that it is not possible to increase the supply of gold at the stroke of a pen or a keyboard in the same way that it is for a fiat currency. It is then seen as a hard currency, holding its value as other currencies purchasing powers decrease in the face of a generally positive inflation rate.

To show the relative growth rates and stocks Figure 15, below, shows US Broad Money (as measured by M3) between 1980 and 2006 and US M2 which the Federal Reserve continue to publish. It has increased approximately 5 fold, at an average annual growth rate of over 6% per year. And while annual mine production increased by 2.5 times over that period, this represents only about a 1-1.5% growth in the total gold stock per annum. This compares with an average world GDP growth, at current prices, of just over 6% over the same period (IMF WEO Database, 2014). While this ignores issues around the unknown velocity of gold it does indicate that gold's supply is much more constrained than normal currencies.

**Figure 15 - US M2 and M3, USD Billions**




*Source: St. Louis Fed, FRED Database*

Below we will examine how this relationship might come about in practise and whether the evidence is, on balance, for or against there being a long run relationship between gold and inflation.

### 3.1.1 Gold-Inflation Channel(s)

Feldstein (1980) looks at the theoretical reasons that *expected* inflation has a relationship with stores of value, such as gold. He argues that this relationship exists because gold is like a currency whose value cannot be diminished by sudden large increases in supply through printing, as is the case for fiat currencies such as the US Dollar or the Euro. He assumes that an increase in expected inflation will cause nominal interest rates to rise. Supposing investors are rational, this means that the

required rate of return on holding gold will also increase, driving up the gold price, in order to compensate investors for the increased opportunity cost.
This paper from 1980 concludes that the gold price will rise faster than the expected rate of inflation. This is because capital taxes will reduce any net payoff from selling gold, so that the gross payoff must be greater than inflation and the net payoff can be the same. It assumes that gold has no marginal product, as other stores of value do, such as land does through rent. While this was true when the paper was written, the London OTC gold leasing market has been in existence since 1989 (LBMA, 2008).

Fortune (1988) develops this by explicitly suggesting a channel through which inflation directly affects gold prices: a substitution effect. This channel works in the following way – the expectation of increases in future prices (inflation) encourages individuals to convert their assets which have a fixed nominal return into gold now. This drives up the price of gold in that currency, protecting its residents from reductions in their purchasing power due to inflation. Using this and interest rate expectations the paper tests a model based on quarterly data from 1973 to 1980 and as expected from theory finds that gold price changes have a positive relationship with inflation.

Levin and Wright (2006) offer an alternative inflation-gold price channel, based on an arbitrage model developed by Levin, Abhyankar and Gosh (1994) which argues that gold lease rates are equivalent to world real interest rates. These papers assume that changes in gold extraction costs are driven by the general rate of inflation, and that in the long term the gold price will rise in order to compensate miners for their increasing costs. This implies that a causal relationship exists: running from inflation to the cost of extraction to gold prices.

The implicit assumption in this argument is that miners are not price takers, and have market power. This is in contrast to many other studies who assume that gold miners are price takers rather than price setters (Blose and Shieh, 1995; and Borenstein and Farrell, 2007) This second hypothesised channel is briefly mentioned by Rockoff (1984) as having its roots in the idea from classic economics that under a stable and perfectly elastic supply curve the cost of extracting gold is the main cause of the gold price level. In analysing the effect of the gold price on production Rockerbie (1999) assumes the same causality hold true.

Chapter 7 of this thesis will address the issue of the gold-inflation channel by discussing why, theoretically, gold prices should instead cause extraction costs, and by examining the direction of causality between gold prices and extraction costs empirically.

### 3.1.2 Empirical Evidence

A number of authors have addressed whether gold and inflation have a long run relationship, which is 1:1, and it is often assumed in models of the gold price to be true. A variety of evidence exists on this issue and is discussed here.

Baker and Van Tassel (1985) find that the US Dollar gold price is positively related to US inflation using annual data from 1973 to 1983. Taylor (1998) uses a much longer data set (monthly, 1914 -1937 and 1968 – 1996) which is broken into sub-periods to try to assess whether a range of precious metals are inflation hedges over the long and short run. They use estimators which are robust to the non-normality of the data used. For the long run analysis they use Johansen (1991) cointegration techniques to look for a long run equilibrium in the relationship between gold and US CPI. This equilibrium relationship is found to exist in both the pre and post war periods.

The division between the long and the sort run is addressed by Gosh, Levin, Macmillan and Wright (2004). They use monthly data from 1976 to 1999 and find a 1:1 cointegrating relationship between the two. This shows that gold is a strong long run inflation hedge. The Error Correction Model (ECM) developed from the long run model is shown to be driven by the gold lease rate, gold's Beta (from the CAPM) and the US trade weighted exchange rates. However the time it takes to return to equilibrium is very long with an ECM parameter of only -0.0228, giving the disequilibrium a half-life of 30 months. The model is shown to predict the gold price relatively well from a visual inspection of actual versus predicted. This could have been carried out in a more robust manner through the use of Root Mean Squared Errors or a similar quantitative measure.

Levin and Wright (2006) provide a further detailed analysis of both the short and long run determinants of gold returns. The authors find that US inflation is the sole determinant of the gold price over the long term, once the short run effects have been washed out. A 1:1 relationship is again found to be within the 95% confidence interval. Here the ECM is -0.017, giving the disequilibrium a half-life of 40 months. While both these half-lives are quite long they are not unusual for a disequilibrium involving inflation. In purchasing power parity modelling the half-life to return to equilibrium is found on average to be between 3 and 5 years (Rogoff, 1996)

Worthington and Pavani (2007) extend the previous datasets for the US (1945 – 2006) and allow for structural breaks to occur both at the closing of the Gold Window and the higher inflation suffered in America during the 1970's. When these breaks are allowed for, as mean shifts in the cointegration tests, gold acts as a strong inflation hedge from the Second World War through the new millennium. There is a clear logic for allowing for a break at the closing of the Gold Window, as there had been a significant change in the operation of the gold market with the gold price free to find its own level in US Dollars. However allowing for a break due to higher inflation, the economic variable which we wish to see if gold can protect investors from seems to go against the tests itself. If gold is an inflation hedge then it should be a hedge also in periods of higher inflation.

Many studies focus on the US dollar price of gold and US inflation ignoring the fact that gold is like a currency without a country. Whether it is a hedge against other inflation rates should then be equally of interest, and more so to non-Americans. To address this gap Sjaastad and Scacciavillani (1996) look at whether gold can be used to hedge against world inflation. They show that gold prices rise with inflation, by about 75% of the change in inflation making it a strong partial hedge. Sjaastad (2008) contradicts this with a finding of a negative, but very small, relationship between gold and world inflation (using data from 1991 to 2004). This paper ascribes the earlier finding to a spike in world inflation in the 1980's.

Wang, Lee and Thi (2011) look for a hedging relationship between gold and inflation in the US and Japan. They find that in the long and short run gold is cointegrated with US CPI but does not in Japan. They attribute this to price rigidity in Japan.

Beckman and Czudaj (2013) expand the range of countries addressed, looking at Japan and the US again but also adding the UK and the Euro Area between 1969 and 2011, and using two measures of inflation – the Purchaser Price Index (PPI) and CPI. This study allows for nonlinearity using a markov switching approach. One regime in the model is shown to approximate abnormal economic times (such as crises and deflation) in the various countries and gold's ability to hedge inflation is higher during these periods. Gold is found to be a partial hedge for inflation with stronger hedging abilities for CPI inflation, and again and its hedging abilities in the Euro Area and Japan are very weak, following Wang, Lee and Thi's (2011) findings. The authors highlight the fact that gold is an effective inflation hedge only over the long term.

Batten, Ciner and Lucey (2014) find that between 1985 and 2012 no cointegrating relationship existed between gold and US CPI using a range of cointegration tests. The authors start at 1985 to avoid a significant structural break in US inflation that occurred in 1984 at the beginning of the Great Moderation, found by both Atkeson and Ohanian (2001) and Stock and Watson (2006). This seems to point to the finding of cointegration in Worthington and Pavani (2007) as stemming from that year.

The theoretical interrelationship between gold, inflation and interest rates espoused by Feldstein (1980) and Fortune (1988) is given strong empirical backing by Batten, Ciner and Lucey's (2014) further analysis. They show that there is significant time variation in the relationship between gold and the CPI. Their relationship is weak in the 80's and 90's, but begins to strengthen in 2002. The relationship is found to be determined by interest rates: falling rates increase the importance of inflation. This possibly reflects a shift in opportunity cost from lost interest payments to declines in purchasing power as US interest rates fall.

Christie-David, Chaudhry and Koch (2000) use intraday data to assess whether macroeconomics news affects the price of gold futures. US Consumer Price Index (CPI) releases were found to have a strong effect on gold returns, which offers the view that at least when the data is announced, gold prices react to inflation. This however would provide very little evidence that gold constitutes a long run inflation hedge.

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 it is US inflation that drives US Dollar gold price and not the world price level, as found also by Sjaastad (2008). Ozturk and Acikalin (2008) find that the gold price in Turkish lira is cointegrated with Turkish CPI. This points to a long run equilibrium but they do not assess whether it is 1:1 as is necessary for an inflation hedge. They also carry out some causality tests but the models seem to be misspecified as they are in levels without an ECM term to account for the cointegrating relationships.

Tandon and Urich (1987) assess whether macroeconomic news *surprises* have a significant impact on gold prices. The find that CPI surprises have no effect but surprisingly high PPI results do causes rises in gold prices. In a related issue surprise increases in the money supply (M1) between October 1982 and December 1985 are shown to increase the volatility of gold prices as implied from options data (Baile, 1988). Blose (2010) updates this and also finds that surprises in US CPI are shown to have no effect on gold spot prices.

Taylor (1998) examines the relationships between the four precious metals and inflation. Pre-World War II silver and platinum are found to be partial hedges but no precious metal, other than gold, is a full hedge. In further sample periods around the two 1970's oil crises gold and silver are shown to be partial hedges. More recent work on the safe haven properties of gold might point to this being the reason for this result rather than gold becoming an inflation hedge in this period.

### 3.1.3 Prediction

Moore (1990) attempts to examine the idea that anticipated inflation has a link to gold returns, using a leading index of US inflation compiled by the Columbia University Business School. Based on this model the investor would buy gold when the index pointed to a rise in inflation, selling holdings of either bonds or equities. When a fall was expected based on the index the investor would do the reverse, moving their assets out of gold. Their strategy leads to an annualised return of over 20% and 18% using stocks and bonds respectively between 1970 and 1988. Simply holding gold would have only yielded 14%, while stocks and bonds would have yielded 11% and 8.7% individually.

The successful use of a predictor of inflation to forecast gold prices seems to give further empirical back-up to Fortune's (1988) suggestion of an asset substitution channel existing driving gold and inflation into a long run equilibrium relationship. However the returns seem to be dominated by a long run appreciation in the gold price at the beginning of the sample, after the closure of the gold window up to the sharp fall in the early 1980's. An update of this piece looking at more recent data would shed more light on the issue. It is also worth noting that the returns are not adjusted for risk.

Mahdavi and Zhou (1997) look at the problem from another direction, assessing whether gold prices can be used to predict inflation. They show that while including gold in an error correction mechanism does improve forecast accuracy, the improvement is not statistically significant, indicating that gold should not be used as a guide for an inflation-focused monetary policy.

Much of the discussion on gold's link to inflation implicitly assumes that gold is a money like commodity. Dubey, Geanakoplos and Shubik (2003) is one of the few studies to argue against gold's money like qualities. They argue that gold is an inefficient commodity to use as money. Gold in this model can provide utility, for instance as jewellery, without reducing its quantity. Therefore those who save using gold but do not gain utility from it through using it as jewellery etc. miss out on the aesthetic benefit. The authors posit that as there is no rental market the owners cannot recoup this but since 1989 gold can be leased on the London market, with rates quoted daily in a similar manner to LIBOR. This would allow utility to be gained from holding gold purely as an investment.

The central issue here is then still unresolved. Inflation news has been shown to have the expected effect on gold prices, a positive relationship, so that at least some market participants trade based on this information as expected. Gold does not seem to be a strong inflation hedge outside the US. While for the US consumer some studies find long run relationships as predicted by theory, where others do not, depending on the length of data set used or assumptions in the models about structural breaks. And the channel through which the relationship might occur is also untested empirically. We will address this last issue in Chapter 7 as mentioned above.

### 3.2 Interest rates

Many commentators view interest rates, whether applied to the dollar, euro or another currency, as representing an opportunity cost of holding gold, a benefit that could have been earned if investors had purchased a bond instead. In some theories, then, it is taken as following from this that there should be a negative relationship between the two, but it is a disputed point. It has been a common variable to include in gold price models in the literature. Below we will discuss the channels through which gold and interest rates might be related as well as the empirical evidence available to resolve whether the relationship is positive or negative.

Fortune (1988) suggests an asset substitution channel through which gold and nominal interest rates are related, for a given level of expected future prices. He argues that increases in expected interest rates should encourage gold owners to sell gold, as it does not provide a cashflow, and buy interest bearing assets, as well as discourage new purchases of gold by investors. Both of these forces should cause gold prices to begin to decline, giving the expected negative relationship. Fortune (1988) states that these sales also happen as market participants expect that the gold price will fall as a direct result of the expectation of higher interest rates in future. But this seems to be making the relationship slightly circular. Using quarterly data from 1973 to 1980 and long term US government bond yields this paper estimates that the relationship between interest rates and inflation is negative and significant as expected.

Abken (1980) disagrees with Fortune's assessment and sees the link between gold and inflation as being the real driver of the gold interest rate link. He argues that an increase in expected inflation will drive up nominal interest rates now by a similar amount. This increased return available through bonds will cause the rate of gold price appreciation to rise at a similar rate; a positive relationship is predicted. This fits with the Hotelling rule discussed in Section 2.4 but this has proven to be a poor predictor of commodity price movements.

The empirical model applied by Abken (1980) is based on the beginning of the month PM fixings price (which are explained in full in Section 5.1 to follow) and the one

month US T-bill rate from 1973-79 on a monthly basis. It found that changes in nominal interest rates have a significant and positive relation to gold price changes. This is explained by first assuming low storage costs and an assumed, but not empirically assessed, negligible convenience yield from holding gold(see Section 3.5.1 for full description of convenience yield). As a non-interest bearing asset investors will only hold it if its price appreciates sufficiently to compensate them for the missed interest from risk free T-bills. Overall the model explains 3.9% of the variation in gold prices and despite the theoretical discussion at the beginning of the article describing the full set of factors that should affect the gold price, extreme uncertainty or central bank actions are not included in the model. In addition interest rates are included in the regression as a level, with the gold price in 1st differences, raising issues around unit root problems.
Using daily data Koutsoyiannis (1983) found a very weak link between gold in US Dollars and nominal US interest rates on commercial paper from 1979-81 (totalling 316 days). He finds a weak but negative relationship, but as in Abken, (1980) there are unit root issues in the analysis. Cai, Cheung and Wong (2001) examine the effect of surprises in interest rates changes and show that they do affect gold prices. In fact the 2nd largest 5 minute return in their sample is an unexpected interest rate change in Europe in 1997 at 0.84%.

But not all studies find that a link exists. Baker and Van Tassel (1985) find no relationship between gold prices and interest rates on using 10 years of annual data, though, again, unit root issues may exist in their analysis. Using quarterly data from 1979 to 2001 Lawrence (2003) finds that there is no statistically significant link between gold and 3 month US Certificate of Deposit rates, as well as many other macroeconomic variables such as inflation. The inclusion of bond yields, 3 month CD interest rates and the M2 measure of the money supply in the same equation may mean that there was some multi-collinearity here. The low frequency of observations in both the above studies also makes it more difficult to analyse the reactions between two financial variables, which, under most sets of assumptions, would react much faster than this to information. More convincingly Tully and Lucey (2007) applied an asymmetric power GARCH model to daily gold prices, in a model including inflation and the trade weighted dollar, and found that interest rates had no significant impact on gold prices. The US Dollar was the sole variable with explanatory power.

Using daily data from 1975-83 Diba and Grossman (1984) found a link to *real interest rates* on corporate paper in the US. They conclude that over this period interest rates corresponded to a fundamental driver of gold value, as an opportunity cost.

Baur (2011) argues that there is a different relationship between gold and long and short term interest rates. Using monthly data over a 30 year period he shows that lower short term rates have a positive impact on gold prices while longer term interest rates have a negative impact. This fits both with the findings of Abken (1980), who found a negative relationship between gold and short term interest rates, and with Fortune (1988), who found a negative relationship with long term rates. This apparent dichotomy is seen to imply that short term interest rates represent an opportunity cost to an investor while long run rates are actually showing inflations expectations, where higher expected inflation (and therefore higher long term interest rates) encourages gold investment and drives prices up. This result points to a need for any short run modelling of gold prices to use short term interest rates, as long term rates are linked to inflation, which is already normally used in the long run gold models (e.g. Levin and Wright, 2006).

Batten, Ciner and Lucey (2014) develop this issue in their study of the time varying hedge relationship between gold and inflation. As discussed in the previous Section they show that when interest rates are at low levels their importance falls and inflation rates become important again.

As a unique paper Levin and Wright (2006) use gold lease rates, the interest rate that can be earned by the holders of physical gold through lending on the London OTC market, as a determinant of gold's value. However, they use gold lease rates as a measure not of the benefit of holding gold but as an opportunity cost of holding gold. This is based on an arbitrage model developed by Levin, Abhyankar and Gosh (1994). The model says that miners have two options: they can extract gold and sell it in the spot market, using the proceeds to invest in a risk free bond; alternatively they can lease gold now, sell the leased gold and buy a risk free bond. In the future they can repay the leased gold with their mined gold, removing any gold price risk. Assuming that mining costs rise with inflation both strategies yield the risk free interest rate of interest less inflation, therefore lease rates are assumed to be the real world interest rate. Levin and Wright (2006) find that gold prices are negatively related to lease rates. The issue with this idea is that gold mining costs are not shown to vary with the rate of inflation, as mentioned in Section 3.1 and to be examined in Chapter 7.

The idea that lease rates can be seen as an opportunity cost of holding gold in your portfolio also seems implausible from a theoretical perspective, as they are the only way to earn interest on gold deposits. This leads to the conclusion that they can be more correctly described as the benefit of holding gold. This thesis will use gold lease rates as the fundamental determinant of gold's price to assess whether bubbles have occurred in the gold price in Chapter 7.

Both this and the previous Section have highlighted the importance of inflation and interest rates in terms of gold pricing. However the picture is more nuanced than simply they are a positive driver or a negative one. Any model of the gold price needs to take into account that long and short term interest rates imply different things for gold prices, as shown by Baur (2011). Their varying explanatory power to drive gold prices depending on their absolute level should be considered in any further work on this topic.

### 3.3 Hedging and Portfolio Diversification

A central reason for holding gold for investors is to add an asset to a portfolio which should have either a negative or no correlation with the real economy on average. This characteristic gives gold the ability to hedge particular risks (such as currency risk) or to perform a diversification role within a portfolio of investments. A hedge is defined as "an asset that is uncorrelated or negatively correlated with another asset or portfolio on average (Baur and Lucey, 2010:220)." Its suitability is partly due to gold not deriving its value from an underlying economic activity. The traditional aim of diversifiers in the literature is to develop a Mean-Variance efficient portfolio, which maximises returns for a given level of variance (risk) (Markowitz, 1952).

Sumner, Johnson and Soenen (2010) look at real return and volatility spillovers between gold, stocks and bonds in the US. They find almost no spillovers to gold from

US stocks and bonds in their sample from January 1970 to April 2009. This seems to highlight the channel, or lack thereof, that allows gold to be a significant diversifying force.

Gold is a volatile asset when held by itself. Jaff (1989) shows that adding it to randomly constructed portfolios gives increased returns and a fall in risk as suggested by modern portfolio theory. It is recommended to hold approximately 10% of a portfolio in gold in order to optimise. Adding a portfolio of gold stocks however is found to increases risk and return in contrast, which, while it may increase the risk-reward ratio overall, does not have the double benefit of simply adding gold.

Using a monthly data set over a longer period (1971-88) Chua, Sick and Woodward (1990) confirm that gold has a low beta, as per the CAPM, and find that it is consistently insignificantly different from zero across different time periods. This shows that gold price movements have no correlation with stock price movements on average over the period examined. This is what gives gold the ability to hedge portfolio risk. Gold stocks are again shown as a poor diversifier relative to gold and to have a time varying beta in contrast to gold's stable beta, in a similar way to Faff and Chan (1998).

Hillier, Draper and Faff (2006) examine the roles of gold, silver and platinum in asset allocation decisions. The paper concludes that all three precious metals provided considerable diversifying benefits in volatile markets when held in a portfolio of U.S. or global stocks, while the diversifying role of precious metals is limited during poor market return periods. The authors then consider two strategies to examine their portfolio's efficiency: a buy-and-hold strategy and a switching strategy. The portfolio efficiency is measured as the relative reward-to-risk ratio. Their results suggest that in a passive buy-and-hold strategy, the optimal weight of gold in broad-based international equity portfolios is approximately 9.5%, significantly higher than the level of gold found in most funds' equity portfolios. It is also higher than any of Bruno and Chincarini's (2010) estimates below. The switching strategy for gold, silver and platinum does not provide significant efficiency gains.

Bruno and Chincarini (2010) look at optimally weighted portfolios to assess how much gold investors in various countries should have in order to maximise their risk return profile. Some results are as follow: 3–8 % in European countries; for South American countries ,Mexico should have about 6% but the remainder should have 0%; in Asia, South Korea gets a 0.1% weighting while India, which have strong cultural links to gold, has a 12% weighting, with the remaining countries between 4% and 7%.

Another characteristic that contributes to gold's diversification abilities is the skewness of its returns distribution. Lucey, Poti and Tully (2006) discuss the importance of considering the moments of a distribution, rather than just mean and variance as is the original portfolio theory. Over the period examined (1988-2003) they show that gold has a positive skew and that when this fact is taken into account the optimal portfolio weights for gold are lower than under a simple mean-variance analysis. It is recommended that investors should hold between 4-6% under traditional optimisation and 2-4% when skewness is accounted for.
Emmerick and McGroaty (2013) update the work of Jaff (1989) using monthly data from 1981 – 2011. They reinforce the finding that the addition of gold to a range of portfolios reduces the portfolio volatility in all periods examined, the main aim of a diversifying asset. However poor gold returns in the 1980's and 1990's mean that risk adjusted returns, as measured by the Sharpe and Treynor ratios, still suffer. The paper also shows that the skew of gold returns moderates the effect of negative skewness, as previously highlighted by Lucey, Poti and Tully (2006), from other assets such as equities when combined in a portfolio. The changes in the benefits to holding gold prompt the authors to suggest that the ability to switch at the correct times into and out of gold would be beneficial. This fact was disputed by Hillier, Draper and Faff (2006) who found no benefits from switching, even with hindsight.

Capie, Mills and Wood (2005) examine whether gold can act as a hedge against currency risk, specifically as a hedge against the Yen/US Dollar and Sterling/US Dollar exchange rates. They show that its ability to act as a hedge is time varying based on unpredictable political and economic events. The theory as to why it would be a dollar hedge is similar to its negative relationship to the US Dollar. It seems sensible that when the dollar is losing value investors might exchange their dollars for gold, raising the price of gold on average. Joy (2011) expanded the sample of dollar pairs to 16 currencies from 1986 – 2008. Using dynamic conditional correlation models he finds that gold is a dollar hedge, and becoming more strongly so, over the 23 year period examined. Reboredo (2013) also finds that gold acts as a dollar hedge using weekly data from 2000 -2011 for 8 currency pairs.

While most papers link gold primarily to the US Dollar, Ozturk and Acikalin (2008) assess whether gold acts as a hedge against the Turkish Lira. They find that the gold price in Turkish Lira is cointegrated with the Turkish Lira US dollar exchange rate. This points there being a long run equilibrium but they do not assess whether it is 1:1 as is necessary for a currency hedge. Soytas, Sari, Hommoudeh and Hacihasanoglu (2009) also find that gold prices in Turkish Lira are unresponsive to the domestic exchange rate, indicating a type of hedge against Lira risk.

Gold's insensitivity to average economic conditions seems to give it the ability to diminish the overall risks faced by financial managers when added to their portfolios, although its ability to increase reward to variability measures, such as the Sharpe ratio, has fluctuated over the last 30 years. It may also help to reduce the overall risk of a portfolio of currencies but to date only studies of the US Dollar and Turkish Lira have been published.

### 3.4 Safe Haven

The attractiveness of gold to investors in times of panic or extreme market stress is widely recognised and mentioned frequently in the financial press (e.g. Sanderson, 2015). This aspect of gold has been included in many models of gold prices but the way studies have measured stress has changed.

Ariovich (1983) includes the impact of political tension on the gold price, dividing them up into those that affect international financial markets, inflation expectations, and the value of the US Dollar. Analysing at monthly data from 1972-1981 an equilibrium price is estimated for gold based on the CAPM. They find that using the Hudson Institute measure of political tension in an explanatory model of the gold price does not increase the power of the model but that there is a positive relationship between the two. US developments are shown to have a larger impact, but as the US dollar gold price is being investigated this is to be expected. Koutsoyiannis (1983) also incorporates an author calculation of "political tension" but it does not provide explanatory power, as does Aken (1980). These "ad-hoc" attempts to show gold's ability to mitigate risk under abnormal stresses do not add much to our understanding.

Baur and Lucey (2010) evolve the underlying idea of what a safe haven is and move it away from the above mentioned works which focused on political tension, rather than gold's relationship to other asset prices at times of extreme market movements. They define it in terms of its ability to protect wealth from financial market crashes. They measure market distress as periods when stock/bond indices fall below 1%, 2.5% and 5% quantile of the return distribution. This also provides a clear separation of the ideas of a hedge and a safe haven. Baur and McDermott (2010:1890) refine the definition of a safe haven to the following, "A strong (weak) safe haven is defined as an asset that is negatively correlated (uncorrelated) with another asset or portfolio in certain periods only, e.g. in times of falling stock markets." Chua, Sick and Woodward (1990) do provide an earlier mention of the benefits of including gold in a portfolio makeup, highlighting it's ability to maintain value during a market crash but focus on its ability to diversify a portfolio on average.

On an empirical level Baur and Lucey (2010) study the relationship between US, UK and German stock and bond returns and gold returns, finding gold is a hedge and a safe haven for stocks but not bonds. However, gold is found to act as a safe haven for only 15 days after a market crash. This might partially explain Ariovich's (1983) finding that it is not a safe haven as their data frequency is monthly. Other reasons would include a different definition of a safe haven. Baur and McDermott (2010) extend this analysis to a more international sample and confirm gold's status as a safe haven for equities but not for all countries examined. In some countries, such as Australia, Canada, Japan and the BRIC's, gold is ineffective in protecting wealth from extreme market movements.

Adding further weight to the argument that gold is a safe haven, Piplack and Straetman's (2010) look at the probability of the prices of different asset classes co-crashing and find that when stock and bond prices crash the price of gold is likely to be rising. Coudert and Feingold (2011) also find a negative or null correlation between gold and a number of major developed world stock markets indexes.

Cohen and Qadan (2010) link gold to the market's constructed measure of risk (VIX, discussed fully in Section 5.3) and find that in times of crisis, such as 2008, gold leads or drives the VIX, making it a better safe haven asset. In normal periods there is a bi-directional causality between the two. Hood and Malik (2013) directly assess whether gold can outperform VIX as a hedge or a safe haven between 1995 and 2010 for US stocks, based on the same methodology and definitions as Baur and McDermott (2010). However Hood and Malik (2013) is based on a much shorter data than Baur and McDermott (2010) which goes from 1979 to 2009. Hood and Malik (2013) find that gold is a hedge and a weak safe haven for equities, that it is uncorrelated with the market in a crash, but not negatively correlated. VIX by contrast is a strong safe haven. Baur and Lucey (2010) have a similar starting point but end in 2005 and do find that gold is a strong safe haven.

Machlup (1969) states that it is only official links, such as gold holding by central banks, which has allowed gold to be seen as a safe asset. Though central banks have again reaffirmed their links to gold in the 2014 Central Bank Gold Agreement their large public sales of gold in the 1990's did not dent gold's safe haven status.

This possible reduction in safe haven status between the time periods studied by these recent papers links to Baur and Glover's (2012b) questioning as to whether gold can remain a safe haven based on behavioural economic issues. They argue that as it is increasingly being held for purely speculative purposes, for example due to the emergence of gold ETF's where it is not only much easier to get an exposure to gold in your portfolio but also to sell, it will suffer in a similar way to other assets when the market panics. Coleman and Dark (2012) show that investors in gold through futures markets are the main drivers of its price over the long term, rather than hedgers. Ivanov (2011) argues that even that has been superseded since ETF's began and that they now drive the spot price of gold.

Internationally, returns from the Malaysian stock market haven been shown to have a low correlation with domestically priced gold returns (Ibrahim, 2012). A weak version of a safe haven is shown to exist as these correlations do not increase on days of consecutive market declines, but extreme markets movements are not directly addressed.

Sumner, Johnson and Soenen (2010) also show that unsurprisingly during financial crises spillovers are higher as systematic risk is prevalent. During the recent financial crisis it is shown that gold volatility and returns spilled over strongly to stocks and more weakly to bonds. This finding fits well with the safe haven literature discussed above.

The risk premium underlying gold prices is examined by Melvin and Sultan (1990) who use a GARCH framework to show that it is time varying based on a number of factors. The conditional variance of spot prices is due to political unrest (specifically in South Africa due to the time period under consideration – 1975 to 1988) and oil price changes. Political unrest is an author calculated figure based on the deaths due to political violence, the number of demonstrations and political arrests reported in the New York Times. Futures price conditional variance is shown to be dependent on spot price forecast errors.

Roboredo (2013) reassesses this issue confirming gold's ability to hedge US dollar risk and finds that in the tails gold does still act to reduce dollar risk across all currency pairs. This paper also shows that in currency portfolios based in dollars gold acts to reduce Value at Risk and Expected Shortfall.

Joy (2011) also evaluates whether gold could act as a safe haven against US dollar risk and find that it does not. They conclude that as gold's correlations with most dollar pairs is less negative in the lower quantiles; gold does not act as a safe haven for extreme dollar depreciations, but as Joy (2011) states earlier in the paper a safe haven exists where an asset has a correlation of 0 or less in times of extreme market movements. A weaker negative correlation at times of stress than on average, does not negate its ability to shield investors in severe market down turns, it still points to a safe haven existing. This less negative correlation may be due to gold and the dollar both being seen to act as safe havens, so that they sometimes co-move during market upheavals.

Ciner, Gurdgiev and Lucey (2013) examine gold's safe haven status in relation to the US Dollar and UK Pound, measured as their trade weighted values, between 1990 and 2010 using dynamic conditional correlations. They show that gold can be considered both as a safe haven for the US dollar from 2000 onwards and also for the UK Pound. They describe this as gold's anti-Dollar characteristic. As this analysis does not relate to the average relationship between gold and the dollar, as in many other studies (an idea criticised by Pukthuanthong and Roll (2011) and O'Connor and Lucey (2012) and detailed in Section 3.5.2) but at extreme points this is an accurate use of this term.

Soytas, Sari, Hommoudeh and Hacihasanoglu (2009) examine gold prices in Turkish Lira relative to their domestic exchange rate. They find the gold price to be highly inelastic with respect to the value of the Turkish Lira and interpret this as a safe haven characteristic without pinpointing time of crisis in the research. This then seems to be more properly defined as a long run hedge.

Whether gold's ability to act as a safe haven has been reduced because it is now being held more and more as a speculative investment through vehicles such as ETF's will require more time and data. The fall in ETF holdings since 2012 may also show this reduction to be a temporary phenomenon. Gold may also act as a safe haven for currencies other than those seen as safe havens themselves, such as the Dollar and the Swiss Franc, but again wider study is required.

## 3.5 Other assets

Gold has been shown to have the ability to mitigate some of the risks faced by investors holding other assets. It has also been shown to have links to specific assets based on both theory and empirical research. Below we detail the theory behind the link to a number of assets as well as the empirical findings of the research in each area.

### 3.5.1 Other Precious Metals

Silver and gold are closely associated throughout history. As discussed Chapter 2 gold replacing silver as the monetary metal of choice in most countries between the 1800's and 1900's was a combination of accident and massive increases in gold supply. Both metals are also very common in jewellery. Silver however has a much longer history as an industrial metal, from its beginnings in photography, up to the present day.

Both gold and silver are also investment assets and it would be expected that their prices would be affected by a wide range of variables in a similar way. It would also be expected that many market participants would be likely to trade in both metals simultaneously. These two factors should lead to information spillover between the four precious metals, not just gold and silver. Garbade and Silber (1983) investigate spot-futures market linkages and show that gold and silver prices are well integrated, over even short periods, in contract to the other commodities examined whose prices were more independent of each other.

Ma (1985) examines the case for gold and silver's value being linked by a long run equilibrium ratio of their prices, as he also expected them to be close substitutes. Historically the ratio of gold to silver prices has varied from 1:1 in ancient Egypt, and was about 13.5:1 for 2000 years until 1837 when the US Congress set it to 16:1. He finds that a short run parity relationship does exist between the two, as expected, between 1978 and 1983. The paper shows that even after transaction costs it is possible to exploit deviations from this relationship to earn positive returns.

Wahab, Cohn, and Lashgari (1994) confirm Ma's (1985) finding of a long run equilibrium relationship between the two and that the gold-silver spread can be used to predict returns in their sample period (1982-1992). Based on this they develop an error correction model and is used this to forecast the spread one week ahead. They test whether it is possible to use this knowledge to beat the market but find that after transaction costs a loss is made.

Koutsoyiannis (1983), using one year of daily data, finds that once other explanatory variables had been accounted for, silver had no power to explain changes in the gold price. In the light of Ma (1985) it is possible to reinterpret this result to say that they may have been close substitutes during this period but whose prices are determined by the same set of explanatory variables, so that silver prices cannot be used to predict the gold price itself.
Chan and Mountain (1988) develop an arbitrage model of gold and silver prices this time based in Canadian dollars where previous studies focused on US dollar prices from 1980-83 with weekly data. The authors find a granger causal relationship, an idea

fully discussed in Section 4.5, between gold and silver prices running from silver to gold in contrast to Koutsoyiannis (1983). At a weekly frequency, however, it is unclear whether this type of relationship can be found with confidence as financial markets react to information very quickly. They use their finding to form a trading strategy allowing for substitution between the two assets. In out-of-sample tests in one-week ahead forecasts using their models outperform a simple random walk, without considering trading costs.

Chan and Mountain's (1988) finding of a leading role for silver in the relationship goes against the theoretical relationship developed by Radetzki (1989). Gold is predicted to lead both silver and platinum prices as it is seen here as more widely held and visible for investors. Its price changes are assumed to spillover onto the other precious metals.

Ma and Soenen (1988) go one step further and show that after transaction costs the parity relationship between gold and silver prices (in both spot and futures markets) allows for what they describe as *arbitrage profits* to be realized, that is risk free profits. However as they also adjust for the risk of the positions this seems to be a mischaracterization of the type of trading necessary to achieve these profits.

Granger and Escribano (1987) find a strong simultaneous relationship between the returns of gold and silver, implying that the information that drives one market may also drive the other. They also find that their models' out of sample predictions about the relationship are less accurate than could be expected indicating that two markets that may have begun diverging around this time. Ciner (2001) re-examines gold and silver futures contracts traded on the Tokyo commodity exchange between 1992 and 1998 and finds that no long run cointegrating relationship exists between the two indicating that the previous relationship may have been as a result of chance or may have broken down as Granger and Escribano (1987) suspected. This is attributed to silvers increased importance as an industrial metal in electronics at that time while gold remained firmly an investment commodity. Lucey and Tulley (2006b) find that the parity did indeed weaken over the 1990's and Batten, Ciner, Lucey and Szilagyi (2013) show, using fractal analysis, that there is a slow mean reversion process within the spread. This information is used to form a trading rule which beats a buy and hold strategy.

Using 15 minute intra-day data over two years on the gold-silver spread Adrangi, Chatrath and David (2000) examine how spillovers between these markets lead to price discovery. Silver is shown to be the asset which is forced to adjust to allow for convergence back to equilibrium, with gold being the dominant partner in the relationship. Chatrath, Adrangi, and Shank (2001) develop this by showing that there is evidence of non-linear dependences which can be explained by ARCH type processes.

Liu and Chou (2003) look at the gold silver spread for cash *and* futures prices using COMEX daily data from 1983 to 1995 and find that both the cash *and* futures spreads are cointegrated. Futures spreads are seen to lead cash spreads, allowing a trading model to be implemented. Using an ECM based on this parity relationship with 5 step ahead forecasts it is shown that the market return can be beaten even after transaction costs.

The correlation between platinum and gold is generally negative but goes through runs of positivity as well (Kearney and Lombra, 2009). Following from Kearney and Lombra (2008) who showed that derivatives usage had non-neutral effects on gold prices this paper assesses whether the gold-platinum relationship might also be affected by derivatives. Hedging book data from gold miners is used to show that increases in forward sales changed the relationship between the two in the late 90'sand early 00's, when hedging activity was very high. An issue with this conclusion is that the hedging activities of platinum producers are not discussed as no data was available. The implicit assumption within this study is that there was no change in the hedging activities of platinum producers, but as the two sets of miners are heavily linked in everyday activities it seems unlikely that a practice adopted in one was not adopted in any way by the other.

Chang and Foster (2012) examine the convenience yield of all four precious metals. The convenience yield is the benefit the holder of a physical commodity gains over the holder of a futures contract, through the assurance of access to the asset when necessary. They find that the convenience yields of gold and silver both have significant effects on platinum and palladium returns. Platinum and palladium's convenience yields seem to not be affected by any of the precious metals, showing gold and silver to be the dominant assets out of the 4.

Some of the above research implies that the precious metals are not the single asset class that they are often assumed to be. Batten, Ciner and Lucey (2015) examine return and volatility spillovers between the 4 precious metals. They show that there are consistent spillovers between gold and silver but that platinum and palladium are relatively separate markets, even from each other.

Between 1986 and 2006 volatility in the 4 precious metals is found to be influenced by each other's volatility (Batten, Ciner and Lucey, 2010). Financial variables such as stock market returns and dividend yields are found to affect gold, platinum and palladium. Monetary variables such as money supply and US CPI are consistently important in driving gold volatility. This is in contract to silver which seems to be the only precious metal to be unaffected by monetary or financial variables.

The sum of this evidence implies that gold is becoming, at minimum, a semi-separate asset class to the other precious metals. It has a driver of its volatility that it does not share with the other precious metals. Its' long run relationship price ratio with silver, which was clearly present in the 1980's, has been shown to have broken down from the 1990's onwards.

### 3.5.2 Currencies

Gold has a long held historical place as a currency, as detailed in Chapter 2. Its relationships with other currencies post-1971 is an area that has received some examination, but has also resulted in some assumptions in models without empirical backup. Here we will discuss the relationships between gold and other currencies. Gold's ability to hedge foreign exchange risk was examined in Section 3.3.

It has been frequently argued that the US Dollar is one, if not the primary, driver of the gold price. The basis for this argument is that gold is traded primarily in dollars. A weaker Dollar (as measured by the dollar's trade weighted exchange rate) makes gold cheaper for other nations to purchase and increases their demand. This then drives up the price of gold explaining their observed negative relationship. Tully and Lucey (2007) find that the trade weighted value of the US Dollar is by far the most significant factor in explaining gold price changes using an APGARCH model. Sari, Hammoudeh and Soytas (2010) confirm their finding.

Sjaastad and Scacciavilliani (1996), however, found that Europe dominated the gold market by analysing the impact of exchange rate changes on the gold price. Sjaastad (2008) finds that 1996 paper pointing to the European currencies giving half the total drive for gold price changes was outdated when looking at longer and more recent data from 1991 – 2004. This data shows that the US Dollar is dominant, followed by the Yen. The currencies of gold- producing countries appear to have no significant impact on the gold price, which fits well with the fact that gold stocks from investments are vastly larger than the annual flows from mining.

Pukthuanthong and Roll (2011) delve into the theory underlying the supposed ability of the Dollar to drive gold price. They argue that this relationship is merely a statistical fact and not a causal one, by looking at bi-lateral exchange rates. They show that positive gold returns measured in a particular currency are a given when that currency is depreciating. O'Connor and Lucey (2012) show that the trade weighted value of 6 currencies have negative relationships with the price of gold when expressed in that currency. Intuitively when a currency, such as the dollar, is tending towards losing value on average against all major currencies, it is also losing value against gold. Viewing gold as a currency-like asset, it would on average would be gaining value against the dollar when on average all other currencies are gaining. These two papers cast doubt on whether the dollar should be considered in models trying to explain gold price changes.

Apergis (2013) assesses whether the gold price can help in predicting the Aussie Dollar/US Dollar nominal and real exchange rates. The models are tested using cointegration and error correction models. The accuracy of the predictions is assessed using root mean square errors and the U-Theil ratios and a random walk is used as a base case to judge their accuracy against. They find that the relationship between the Aussie Dollar/US Dollar and gold is as expected. A 1% increases in the US Dollar price of gold causes a 0.55% appreciation in the exchange rate. The out of sample forecasts of the nominal exchange rate using lagged gold prices as explanatory variables outperforms a random walk at all forecast horizons. Gold prices are also shown to have predictive power for the real exchange rate.

### 3.5.3 Gold Substitutes: Mining stocks and ETFs

Investors wishing to get exposure to the gold price, but for a lower scale of investment, have sometimes looked at gold mining stocks as a way of doing so. McDonald and Solnick (1977) assess whether mining stock returns are related to the gold price and show that there is a statistically significant positive relationship between the two, with a stronger relationship evident for high cost miners, based on 20 South African mining companies. This related to the fact that their profits are more sensitive to gold price changes, as they may be unprofitable unless gold prices are high.

Based on 23 US gold mining stocks Blose and Shieh (1995) find that their exposure to changes in the gold price is greater for high cost miners for the sample period (monthly 1981-1990). Based on OLS regressions of levels data they show that total firm value is positively related to the gold price and its proven reserves, while negatively related to its costs of production. The firms' exposure to the gold price gives an elasticity that is greater than one, so that the sum of the firms market capitalisation and debt is more volatile than the price of gold.

Faff and Chan (1998) look at Australian gold mining stocks between 1979 and 1997 using monthly data to examine their relationship to Aussie and US dollar gold prices, market returns, foreign exchange rates and interest rates. Only the market return and gold prices are important with interest rates (at various maturities) and the trade weighted value of the Aussie dollar not adding to the explanatory power of the regressions. The stocks have a beta of greater than 1 in many of the periods and all of the betas are statistically significantly greater than 0. Coefficients on the stocks exposure to gold prices (in both currencies) is greater than zero and is approximately 0.75 over the full period examined, showing the stocks to be less volatile than the price of gold. However as they have positive and significant relationships with market risk they do not provide the same ability to diversify a portfolio as well as gold, as was shown in Section 3.3.

Borenstein and Farrell (2007) look at the relationship between 17 North American gold miners stock market valuations and gold prices over the longest period, weekly from 1977 to 2004. Again, they show that markets valuation of companies change more than proportionately with the gold price.
The emergence of gold ETF's in 2003 created a new way of gaining exposure to gold at a low cost and low investment scale. Their development, and existence, is discussed in detail by O'Connell (2007) and in an Asian context by Wang, Hussain and Ahmed (2010). Ivanov (2011) examines the influence of Gold and Silver ETFs on price discovery in their respective futures markets. This paper argues that the creation of ETF's has reduced the importance of futures with ETF's now leading price discovery for both markets.

Naylor, Wongchoti and Gianotti (2011) study whether abnormal returns are available through gold ETF's. Through using CAPM the authors show that abnormal returns are not attainable using the GLD fund. Naylor, Wongchoti and Ith (2014) expand the analysis to 4 gold funds with data starting for some in 2004 and others in 2011. They show that gold EFT's track gold prices very closely, as in Ivanov (2011) with an average deviation of only 20 basis points between the two prices. This difference between the two forms of gold investment is maximised when the market is in the top quartile for VIX, raising the question as to whether gold ETF's may not be as useful a safe haven as gold bullion was shown to be in Section 3.4.

Emmrich and McGroarty (2013) examine the diversification benefits of gold ETF's. They find that ETFs decrease portfolio volatility by more than bullion, they however note that the sample period for ETF's was much shorter. This leaves the question about ETF's and safe havens as an area for further examination. They also provide a rare examination of gold mutual funds finding that they are beneficial for diversification but less so than gold bullion.

### 3.5.4 Oil

Oil is a driver of inflation and inflation in turn is a driver of gold, as seen above in Section 3.1. A number of studies have looked at their relationship to one another such as Ewing and Malik (2013) who find that there is significant volatility transmission between the two markets. Silver and gold are both affected by oil shocks (Hammoudeh and Yuan, 2008) with shocks increasing their volatility. This volatility is however susceptible to calming by monetary policy actions. Baffes (2006) shows that a rise in the price of oil by $1 would result in a $0.34 increase in the gold price. However when Soytas, Sari, Hommoudeh and Hacihasanoglu (2009) assess whether US Dollar oil prices affect Turkish Lira gold price and find no relationship between the two.

Narayan, Narayan and Zheng (2010) look at the theoretical link between oil as a driver of inflation and inflation as a driver of gold prices to assess whether oil prices can be used to predict gold price changes. They find that the two are cointegrated at all maturities indicating that the markets are jointly efficient, a finding which is confirmed by Zhang and Wei (2010).

### 3.6 Volatility Drivers

Nowman and Wang (2001) find that the price level of gold has a very strong sensitivity to the conditional volatility of gold using data starting after 1987. Byers and Peel (2001) use a data set covering 2.5 years and address whether gold volatility, measured as daily high/low ratios, has a long memory. They show that this is the case for gold, along with the other assets they examine.

Cai, Cheung and Wong (2001) look at the effects of US news announcements on gold volatility using intraday COMEX data between 1994 and 1997. They find that volatility is higher at the opening and closing of sessions and that there are significant long run autocorrelations present as in Byers and Peel (2001). They also show that news announcements do have significant effects on gold's volatility such as employment reports, GDP and CPI descending in order of importance. That CPI is not the most important is odd as gold's link, at least in theory, to inflation has been seen as one of the main drivers of gold prices.

Between 1986 and 2006 the volatility of the four precious metals is found to be influenced by each others volatility (Batten, Ciner and Lucey, 2010). Financial variables such as stock market returns and dividend yields are found to affect gold and the two Platinum Group Metals (PGM's). Monetary variables such as money supply and US CPI are consistently important in driving gold volatility but not the PGMs.

This is in contract to silver, which seems to be the only precious metal not affected by monetary or financial variables. The type of volatility seen in the gold futures market is shown here to have been more based on these types of macroeconomic variables than in the price discovery actions by traders themselves (Batten and Lucey, 2009). Hammoudeh, Yuan McAleer and Thompson (2010) find that monetary shocks have long run effects on both gold and silver volatility but with a much shorter dataset (1999-2007).

Interestingly Bhar and Hamori (2004) show that increased price returns cause an increase in trading volume in the NYMEX gold market. This is in contrast to agricultural commodities and oil where bi-causality is normally found (Moosa and Silvapulle, 2000) while others find that causality runs from volume to price for other commodities such as oil (Fujihara and Mougoue, 1997).

### 3.7 Gold Market Efficiency

The theory of Market Efficiency revolves around the idea that prices reflect all available information (Fama, 1970). This in turn means that asset prices of gold are not predictable using past information. If we could use information to predict that prices would rise tomorrow, rational agents would buy the asset today with the increased demand driving up the price today. It would be a self-fulfilling prophecy.

In theory the gold market should be one of the most efficiently priced assets available to investors. Firstly it is an homogenous commodity that is traded in 7 major markets globally. This should allow information to be incorporated into the gold price continuously. In addition there were no issues prior to 1989 with trying to assess uncertain cashflows available from gold as there would be with equities, as the gold leasing market did not begin until then. Gold does not have a performance to measure, as shares do in terms of company profitability, or as bonds do in terms of coupon and principal payments. In some ways this makes gold a simpler asset than most but also makes defining the exact source of its value much more difficult.

Tschoegl (1980) gave one of the first assessments of the weak form EMH for gold using spot price data taken from the twice daily London Gold Fixings. The weak form of the EMH says that prices of assets cannot be predicted using past market prices or volumes. The paper shows that while in some cases serial correlation is present - implying the possibility that past prices could be used to forecast future prices – once trading costs are accounted for the trading strategies used are shown to be unprofitable. Solt and Swanson (1981) again find evidence of autocorrelation over a similar time period but find that it is not possible to profit from it. Their sample includes the Hunt Brothers attempt to corner the silver market which may have had an impact on their results. Koutsoyiannis (1983) find some autocorrelation at a daily frequency but only over a 360 day sample period. In a model of the gold price Abken (1980) found that at a monthly frequency one and two month lags of changes in the gold price were insignificant, pointing to market efficiency. It may however be the case that daily data is more appropriate to test this.

The market model is also used by Tschoegl (1980) to see whether positive risk adjusted returns are available, using his findings of autocorrelation. A positive alpha is found, but it is not statistically significant and it does not appear to be possible to beat the market. Smith (2002) finds that London gold prices follow a random walk, using results from the AM and PM Fixings confirm to Tschoegl's (1980) result of autocorrelation. The London closing price however is found to be informationally efficient, giving some circumstantial evidence in favour of the EMH.

Monroe and Cohn (1986) examine the relationship between gold and US T-bill futures markets. They find that it is possible to implement a trading strategy based on deviations away from the equilibrium relationship of the difference between the spot price of gold and its futures price as explained by T-bill interest rates. They show that the inefficiency is driven by the gold futures side of the trade. Garbade and Silber (1983) investigate spot-futures market linkages and show that gold and silver are well integrated over even short periods, in contrast to other commodities examined.

More evidence in this area comes from Basu and Clouse (1993) who evaluate whether the use of the ratio of gold put options to gold call options can be used to predict market returns. If there are more call options we would expect the price to rise as a result of higher demand. They find that while there is a relationship it is not economically significant.

Some studies show that there was a generally increasing efficiency in the global gold market since the 1970's. Muradoglu, Akkaya, and Chafra (1998) look the evolution of the efficiency of the Turkish Gold Market as it transitioned to the Istanbul Gold Exchange from the unregulated Grand Bazar. They found that while efficiency had been increased by the move to a fully regulated exchange, there was still some evidence of inefficiency, as returns were found to be non-random.

Beckers (1984) and Ball, Torous and Tschoegl (1985) assess the efficiency of the gold options market using data from the European Options Exchange, using data from 1981 and 1982. Using the Black Scholes model of option pricing to assess whether options prices were correct Beckers (1984) sees prices which were too high, but not sufficiently so as to allow traders to beat the market. Ball et al. (1985) use Merton's work on options but have a similar finding. They go on to look at whether using deviations from the inferred risk free rate might allow traders to earn arbitrage profits. While deviations are found to happen during the sample used, trading costs eliminate any possible profits. Followill and Helms (1990) do find arbitrage opportunities when the address the put-call-futures relationship between gold options and futures. They find that even after trading costs are accounted for, profits are available, with the most profitable trades resulting from the violations of the relationship which should theoretically hold between these three assets. However they note that not all of the trades in their model are riskless, as is necessary for arbitrage.

Cheung and Lai (1993) found that gold returns suffered from long memory between the early 70's and late 80's. However when they looked at subsamples of their data they found that this was mostly due to data relating to a few days of particularly high Middle Eastern political tension, along with the Hunt Brother's attempt to corner the silver market. This safe haven feature is detailed further in Section 3.4.

Abken (1980) provide the first evidence that futures prices over the period are unbiased predictors of future spot prices using a regression in levels. This estimation procedure has been shown to be less than ideal in more recent studies on this issue for other assets where the regressions are in 1$^{st}$ differences. Kolb (1992) investigates a large set of commodities to assess whether normal backwardation is common. He finds that precious metals futures prices, including gold with data running from 1975 to 1988, are relatively unbiased estimates of future spot prices. Gold is found to be neither consistently in backwardation or suffering from contango and the authors assume that this is because it is a financial asset where there are plenty of opportunities to exploit arbitrage opportunities.

Ho (1985) looks at the relationship between the US Dollar gold price and the US Dollar/Deutsch Mark exchange rate finding that the gold market is incrementally efficient, incorporating information from one asset to the other smoothly.

Neural Networks are applied a few authors in researching gold prices. Grudnitski and Osborn (1993) use this model to try to predict gold futures prices. Rather than assuming a linear relationship between prices and macroeconomic explanatory variables the authors argue that the classes of traders are important and can provide important information. Using the Commitments of Traders in Futures Reports (CFTC) from the Chicago Board of Trade the author gathers the open interest positions of large and small speculative traders between December 1982 and September 1990, on a monthly basis. The US money supply and changes in volatility around the reporting day are also included to predict price movements.

The model developed is able to correctly predict the sign of a price change 61% of the time over the sample period for gold, slightly less than for the S&P500 at 75%. After trading costs this gave a 16% return to the trades, a returns which is statistically significantly greater than that required to compensate for the risk taken. This ability to beat the market points to evidence of a violation of the Efficient Markets Hypothesis over this period. Mirmirani and Li (2004) also use a neural networks model finding short term dependence of up to 36 days in gold price movements. Parisi, Parisi and Diaz (2008) use various neural network models and find that with one they can predict the sign of gold price movements over a week just over 60% of the time with weekly data from 2000 to 2005 as their training sample.

McQueen and Thorley (1997) provide a rare assessment of the semi-strong form of the efficient markets hypothesis in precious metals markets. The Semi-Strong form of EMH states that asset prices cannot be predicted with any publicly available information. They use a portfolio of gold mining stocks as a possible source of information which the market may not have fully incorporate into gold's price, in order to assess whether a 1979 Wall Street Journal piece arguing that gold stocks lead gold prices was correct. The information gleaned from the portfolio of gold stocks is shown to help investors beat the market, especially prior to the 1979 article. After this point the market appears to learn as the inefficiency decreases as the sample progresses.

Smales (2013) provides another semi-strong assessment analyzing the effect of news on gold mentioned in the public press on the gold futures market. Text analysis is used to assess whether news items relating to gold are positive, negative or neutral. This information is then weighted based on the probability that it will be understood in that way by investors, the prominence of the mention in the article and how "new" the information is. A strong relationship is shown to exist between all news and returns, with results suggesting no change in the gold price in the absence of news. Increased trading volumes on the futures exchange are found to increase the impact of news on returns and in the sample as a whole continues to show a more powerful reaction to negative news, while positive news becomes insignificant. However some evidence is shown in favour of the idea that speculative positioning on futures exchanges has the ability to predict future returns.

Caminschi and Heaney (2013) provide new a insight into the real time efficiency of the gold futures market in conjunction with what they describe as a leaky spot price fixing. The gold spot price has been set or "fixed" twice daily in London by a telephone auction between the 6 market making banks. During the telephone auction Caminschi and Heaney (2013) show that the COMEX gold futures price reacts to the PM Fixings spot price auction, even though the conversation is not made open to the public. Only the market clearing price is published and not the various bidding stages. Informed traders are able to beat the market during this time by trading gold futures. They show that after the auction the two prices are again in equilibrium pointing to short term violation of the strong form of the EMH while the fixing takes place.

### 3.7.1 Seasonality

Though the above studies on the efficiency of gold find that it is at least relatively so after trading coast are accounted for, there is a growing literature on anomalies that can potentially allow traders to earn supernormal profits from publicly available information. There is a particularly well developed literature on seasonal anomalies.

Ball, Torous and Tschoegl (1982) look at the effect of days of the week and the weekend on gold returns in the 1970's. Using the AM and PM fixings as intraday prices they show that gold's returns on certain days is systematically higher, such as negative returns on Tuesdays and positive on Wednesdays. But no weekend effect is found, as had been the case in studies on equities which found negative weekend returns. Ma (1986) examines the same question with a first subsample between 1975 – 1981, and again finds significant ositive Wednesday returns. But in the post 1981 subsample Tuesdays negative and Wednesday's positive returns disappear, while Monday returns become significant and negative. This is explained by the authors as a result of changes in procedures for settlement in 1981.

But Herbst and Maberly (1988) argue that post 1981 this result is caused by four no-consecutive days of return in 1982. Ma, Wong and Maberly (1989) reply to this and show that even with the inclusion of the four days Ma's (1986) findings hold. In a more recent study running from 1982 to 2002, Lucey and Tully (2006) find that Monday returns are negative, significant, and not driven by differing risks across days. They do however find significant differences in the daily variances, though it is not shown whether this is a day of the week or a weekend effect. The size of the coefficients on the significant results found is small, however, reducing their economic significance.

Yu and Shih (2011) provide recent evidence to argue that increasing gold market efficiency has changed the day of the week effects again. They find that returns are significantly higher on a Thursday and lower on a Tuesday, pointing to the possibility that as traders became aware of the profit possibility they pushed the days back from Friday and Monday in an attempt to profit from the anomaly.

Blose and Gondhalekar (2012) use data over a 30 year period and find that while the cumulative returns from the 5 weekdays of trading are significant and positive; weekend returns are insignificantly different from zero. These authors also divide the sample between bull and bear markets to assess whether these phases affect the answer. The bear market examined does exhibit significantly negative Monday returns but the following bull market reverses the trend becoming positive and significant.

The possibility of seasonality in returns is higher for gold than for most financial assets as there are periods where the demand for physical gold is higher, such as around festivals in India and China. Tschoegl (1987) looks for cyclicality and seasonality in gold returns from 1975-1984. No cyclicality is discovered, nor is a January Effect. They do however see some evidence of below average returns in September.

Seasonal and monthly anomalies have also been shown to exist by Baur (2013) using the London Fixings spot price between 1981 and 2010. September (in keeping with Tschoegl, 1987) and November have significantly different returns than other months, with the same finding for autumn vis-à-vi the other seasons. The volatility of gold is also higher at these times. Naylor Wongchoti, and Ith (2014) confirm that there are monthly effects on gold bullion prices but show higher returns in November and lower in September, January and February but using a much shorter data set. They have similar findings for gold ETF's.

Qi and Wang (2013) examine the Shanghai Gold Exchange price data (2002-2012) and find that gold returns are higher in September and November, as in Baur (2013), and also in February. These abnormal returns are attributed to Chinese public holidays, called Golden weeks by the authors, when gold demand is higher. In relation to gold mining stocks Coutts and Sheikh (2002) find no evidence to support the January effect on the All Gold Index of the Johannesburg Stock Exchange.

Lucey (2010) investigated whether lunar seasonality has any effect on precious metals prices, as has been shown in other asset classes. They find that while there is some evidence of this for silver prices, no significant relationship is shown to exist.

### 3.8 Gold Price Bubbles

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 that is above the present value of discounted dividends, making the high price an equilibrium price. Testing for bubbles in gold prices is a common area to study, possibly owing to some prominent economists saying that gold is a 6,000 year old bubble - as it is commonly thought to have no available cashflow as equities do through dividends.

This has led researchers to look at gold's value in a number of ways in order to assess whether its price is sustainable at realised levels. Diba and Grossman (1984) test whether rational bubbles exist in the price of gold using the real US Commercial Paper interest rate as a measure of gold's fundamental value, but not as a benefit. Instead they use this to look at the opportunity cost of holding gold – the cost of not buying bonds instead which would provide an investor with a stream of cashflows from the bond coupons. Using traditional unit root tests they find that the market price of gold corresponds to this market based measure of its opportunity cost. However it is not shown that the two investments, gold and commercial bonds, are at a similar level of risk which is a necessary condition for commercial paper to represent an opportunity cost.

Diba and Grossman's (1984) method of testing for bubbles was criticised by Pindyck (1993), see a fuller discussion of the methodological critique in Section 4.5. In his model Pindyck (1993) also links gold prices with a measurable benefit of owning gold. He develops a present value model of gold prices, where the value of gold is based on its Convenience Yield (CY). CY is the benefit that the holder of a commodity earns relative to the holder of a futures or forward contract on that asset. It reflects the market's view about its future supply of the commodity (Hull, 2006). The benefits can include prevention of hold up problems in production. He finds a rational price bubble to have occurred somewhere within the sample he examines (1975 – 1990), but is not able to pinpoint the exact time.

However, it can be argued that while CY is appropriate for consumption commodities, such as oil, it is inappropriate for an investment commodity, such as gold. Benefits to investors of owning physical gold do not stem from ease of access allowing for smooth production but from gold's ability to hold its value over time (as in Section 3.1). Possibly for gold the CY may also reflect the value it brings as a safe haven asset, a factor discussed in detail in Section 3.4

The convenience yield has been implemented in a number of recent studies trying to assess whether golds price is fundamentally justified by a measurable benefit. Went, Jirasakuldech and Emekter (2009) do find evidence of a bubble in gold (along with a number of other commodities) 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, Bohl, Stephan, and Wisniewski (2011) find the deviations of gold price from its fundamental value based on a CY approach using a markov switching model (see Section 4.5 for fuller details) and they see no evidence of a bubble in the period between 1978 and 2010. However Casassus and Colllin-Dufresne (2005) found that a negligible causal relationship existed between gold price and its convenience yield, in either direction. Instead interest rates are shown to drive gold's convenience yield. Chapter 7 of this thesis argues that gold lease rates represent a better market based measure of the benefit of holding gold in a portfolio.

Another approach is to model gold's value based on a number of measures, dictated by economic theory and previous empirical findings. Bertus and Stanhouse (2001) build an explicit model of the supply and demand for gold, based on the macroeconomic drivers of gold. They then use dynamic factor analysis to look for bubbles in the quarterly futures price of gold. Using this model they derive a fundamental gold price and use this time series to estimate a time series variable representing the bubble component in the gold price. The bubble component is, however, found to be insignificant, leading the authors to conclude that no bubble was present in the price of gold between 1975 and 1998.

Bialkowski, Bohl, Stephan and Wisniewski (2015) build an approximation of gold's true value in a similar manner to Bertus and Stanhouse (2001) but apply a markov-switching ADF bubble test. They find no evidence of a bubble when the European sovereign debt crisis is accounted for. Ma and Patterson (2012) develop another model of the gold prices (based on inflation, GDP, US trade weighted index, the oil price and the T-bill rate) and assess whether gold was overpriced between 2009 and 2012. They show that while a regression does find gold to be over priced during this period, when a quantile regression is used no over pricing is found to be present. This squares well with gold's safe haven property where gold acts differently in extreme economic situations.

There is, however, a weakness of the approach used by the three previously mentioned papers, over-specification. If enough variables are included in a model, particularly with the use of hindsight to determine what factors were most salient, the estimated equation will always explain the price well. Baur and Glover (2012b) also argue that some of the variables used in these types of models do not represent fundamental drivers but rather factors that attract speculative investors, which could in fact be the cause of a bubble in an assets price.

Baur and Glover (2012a) attempt to circumvent the problem of over specification and trying to find an appropriate fundamental determinant of gold's value. They apply Philips, Wu and Yu's (2011) sup-ADF tests (forward recursive ADF tests) for explosive price behaviour to the gold price alone. They conclude that the gold price was in a bubble between 2002 and 2012, except in 2008-9 during the sub-prime mortgage crisis due to its explosive price behaviour at these times. Explosive price behaviour is however a necessary but not sufficient condition for a price bubble. If gold's fundamental determinant(s) were also acting explosively at the same time then no bubble would be present in gold at that time. As this issue is not addressed it cannot be said to prove a bubble in gold prices.

An issue in this area, then, is to find a fundamental determinant which does provide a market based approximation of gold's fundamental value, and avoids the issue of over specification. Chapter 7 of thesis will suggest gold lease rates, discussed fully in Section 5.4, as the best candidate for this, as they are the only market based cashflow available to the owners of gold. In addition, Barone-Adesi, German and Theal (2010) find that the lease rates are a good approximation of gold's CY, the previous variable suggested in the literature to fill the role of gold fundamental determinant. This would follow theoretically from Levin and Wright (2006), who say that gold lease rates are composed of gold's CY and the default risk that exists in the lease rate, as they represent an over the counter transaction.

### 3.9 Behavioural Issues

While many of the investment characteristics of gold, such as its ability to act as a safe haven, must surely be caused by the way investors' beliefs and perceptions about gold lead to behavioural issues in gold pricing, this remains a severely under-researched area. This is surprising, as gold is an asset which is commonly linked with investor psychology in the financial press.

Psychological barriers have been shown to exist in gold prices by Aggarwal and Lucey (2007) indicating behavioural based inefficiency. They show that at the 100's level gold reaches a point where it is less likely to continue an upward or downward price path, as traders views these numbers as being significant is some psychosocial way. In particular it is shown that gold's volatility changes when its price is near or has just crossed a barrier, especially if the price is falling.

Lucey and Dowling (2011) assesses whether mood has an effect on precious metals prices. They use proxies such as days of the week, the weather and biorhythms, all of which have been shown to be as useful explanatory variables in equity research. Only the proxy for Seasonal Affective Disorder is shown to be positive and significant for gold. They conclude that mood is not a significant variable in equity pricing.

In Smales (2015) evidence of initial overreactions to news is also found. When news is broken in good and bad ways to assess whether the market's reaction is symmetric, negative news is found to have twice the effect of positive news. The paper also finds that news during recessions is assimilated differently. Negative news loses its significance, while positive news has a highly significant impact. Interestingly, as speculators increase their long positions, the reaction to negative news becomes even more marked.

In order to develop this aspect of the literature on gold, in Chapter 8 we will assess whether mood, this time proxied by the markets assessment for future gold prices versus spot price, can help to explain the fact that forward prices are not an unbiased predictor of future spot prices.

### 3.10 Market linkages

Laulajainen (1990) studies three gold markets (London, New York and Hong Kong) building a 24 hour trading day with daily prices from each market in order to rank them in terms of importance. Using a VAR model in levels it is shown that New York affects the other two markets more than it is affected by them, making it either dominant or independent according to the author. An issue with this analysis is that London's importance is possibly understated as the PM Fixings is used. The PM Fixings price overlaps with US trading, unlike the AM Fixing, and it is possibly more related to the New York price, where the closing price is at 19.30 GMT is used. Also, the specification in level ignores statistical problems such as unit roots and integration. Sjaastad and Scacciavilliani (1996) find that Europe dominates the gold market by analysing the impact of exchange rate changes on the gold price.

Xu and Fung (2005) look at US and Japanese daily trading in gold, silver, and platinum between 1994 and 2001. The US is shown to lead Japan for returns but feedback between the two markets is shown to be present. US gold returns affect returns on TOCOM 6 times more than Japanese returns affect the US. The pattern is even more pronounced for Silver (36 times) and is weaker for platinum (2 times). Where volatility is concerned, the relationship between the markets is more symmetric. These findings are particularly interesting as the trading days for TOCOM and COMEX/NYMEX do not overlap, allowing the authors to look at how closing prices from one affect opening prices for the other.

Lucey, Larkin and O'Connor (2013) examine the contribution that different geographical markets of gold trading make to price formation. They look at London Fixings and COMEX futures prices as the two largest centres of gold trading (86% and 10% volume respectively; Murray (2011) and GFMS Gold Survey (2013). They find that both contribute to price discovery dominating the process at different times with no obvious macroeconomic or political links.

Lucey, O'Connor and Larkin (2014) expand this by growing the number of markets examined to four to find which market is dominant in forming the gold price. They look at both returns and volatility spillovers to produce the first study of the four largest markets for gold. In keeping with earlier findings, London and New York are found to be consistently dominant as the drivers of returns and volatility in the four markets throughout the sample, with each taking a leading role at different times. Interestingly, the Shanghai gold market is quite insulated from the others with little spillover into or out of it throughout the sample period. Tokyo is affected by the two major markets, but does not significantly and consistently affect the others.

Pavabutr and Chaihetphon (2010) look at the price discovery process of the Multi Commodity Exchange of India between 2003 and 2007 using daily observation. Within this developing market they assess which of three contracts is most important in price discovery: standard and mini futures contracts, and spot prices. Though the volume of mini contracts is very small at 2%, the authors show that they contribute to 3% of the price discovery in this market. As in other studies, here both types of futures contract prices are shown to lead spot prices.

Pavabutr and Chaihetphon (2010) also find that for the futures and spot contracts traded on the Multi Commodity Exchange of India, futures prices changes tend to drive spot prices. Ivanov (2011) examines the influence of Gold and Silver Exchange Traded Funds on price discovery in the futures market. This paper argues that the creation of ETF's has reduced the importance of futures with ETF's now leading price discovery for both markets.

### 3.11 The Gold Price and Gold Mining

Many studies, such as Bertus and Stanhouse (2001), discuss gold prices in terms of supply and demand factors. However, including gold supply as a variable is more difficult than might be expected due to the previously-mentioned issue of gold's stocks dwarfing new gold inflow from mining. The relationship between gold prices and mining activities is then a factor to be considered in any modelling.

Gold shares a negative short-run relationship between price and mining output with other exhaustible resources. As Keynes (1936) and others have pointed out, an increase in the price of an exhaustible resource like gold, can, in the short term, lead to declines in its output now. The fixed nature of ore processing capacity in the short term and a higher price of gold will induce the mining of lower grades of ore, which reduces the total volume of output. Thus, while the amount of ore processed remains steady, the final output of gold declines, leading to a further price increase.

This inverse relationship between the gold price and mining output has been documented empirically both for the 1930s (Keynes, 1936), and for the 1970s (Marsh, 1983). Fortunately, it has been noted that the long-term relationships between price and output do seem to be positive and stabilizing, as ore processing capacity restrictions can be overcome in the long term.

Selvanathan and Selvanathan (1999) provide recent evidence on this through an empirical test of whether Western Australian gold production between 1948 and 1994 had a positive relationship to price. They find that in the short term (one year) there is no real measurable response in production level to price changes. However over 5 years a 1% increase in the real price of gold results in a roughly 1% increases in the volume produced. Rockerbie (1999) provides a similar analysis for South African data between 1970 and 1995, with annual data. He finds that the adjustment speed of production was slow, taking eight years to feed through. This is one of the few occasions in the literature where production costs are considered, but they were found to be an insignificant factor in explaining production volume changes. Once again it is shown that an increase in gold prices results in an increase in production. Erb and Harvey (2012), however, suggest that gold mine production is not significantly affected by the rise of prices since 2000, from a visual inspection of data. Rockoff (1984) shows that the long run supply of gold is relatively elastic with respect to gold's price.

Many other studies argue that gold miners are price takers rather than price setters (Blose and Shieh, 1995; Borenstein and Farrell, 2007). Borenstein and Farrell (2007) find no mention of supply shocks of any kind having an effect on gold price from a search of 28 years of the Wall Street Journal. Nor was it mentioned in interviews they held with mining executives.

Another factor from mining affecting gold prices is the idea that the marginal costs of gold mining drive gold prices. Rockoff (1984) points to this having its roots in the idea from classic economics that under a stable and perfectly elastic supply curve the cost of extracting gold is the main cause of the gold price level. In analysing the effect of the gold price on production, Rockerbie (1999) assumes this causality holds true. Paul Krugman stated, "Placing a ceiling on the value of gold is mining technology, and the prospect that if its price gets out of whack for long on the upside a great deal more of it will be created." (New York Times, December 28, 2013).

The other possibility is that the causality runs from prices to production costs, as explained by David Ricardo's Law of Rent (Ricardo, 1817). At any given price it can be expected that mines will supply the market up to the point where marginal costs equal marginal benefits, and the industry as a whole maximises its economic profit. Ricardo notes that mines are of various qualities. As gold prices rise, marginal mines, which were previously unprofitable, will be brought into production. These would be deeper mines or mines yielding a lower quality of ore. This means that the average cost of production for the industry as a whole would rise after prices do, and because of the rise, making low cost mines even more profitable and allowing overall production to expand to meet demand. Similarly, if gold prices fall, it would force high-cost mines to shut down and decrease supply. The opening and closing of mines conditional on the gold price is consistent with the "real option" characteristic embedded in gold mines as analysed theoretically in Brennan and Schwartz (1985) and empirically in Krautkraemer (1989) and Moel and Tufano (2002). For example, Krautkraemer (1989) finds that as prices rise, miners tend to mine lower quality ore.

There is also some industry based discussion that gold prices drive production costs and not the other way around. The GFMS Gold Survey 2013 Update 1 (2014:22) states that "Over the last decade rising gold prices enabled producers to adjust mine plans to incorporate lower grade material, thereby optimising assets' lives, but this practice also served to push costs higher when expressed on a unit dollar per ounce basis." In contrast, some analysis argues that production costs provide a price floor below which gold prices cannot fall, as reported in Barron's by Conway (2014).

We will test this issue empirically in Chapter 6 when we at look whether a causal relationship exists between mine extraction costs and the gold price. This will build on Rockerbie's (1999) finding that gold extraction costs are not related to production volume to create a fuller picture around the lifecycle of gold.

## 3.12 Questions arising

Following the above review of the literature on gold as a financial asset, a number of issues seem appropriate for further investigation as part of this thesis.

Gold's relationship to national interest rates has been examined by a number of studies (see Section 3.2 above). Interest rates have been used to represent the opportunity cost of holding gold, the interest income forgone from not holding government or commercial bonds. This has been used to assess whether bubbles have occurred in the gold price, e.g. Diba and Grossman (1989). Within other asset classes the benefit of holding the asset is more commonly used to look for speculative bubbles, for instance Shiller (1981) uses dividends as the ultimate benefit, and thereby the fundamental value of holding shares. For gold the only cashflow available from holding it in a portfolio are gold lease rates, which are discussed in detail in Section 5.4. Some studies, such as Levin and Wright (2006) have used gold lease rates but have included it as an opportunity cost of holding gold. This is following Levin, Abhyankar and Gosh (1994)'s arbitrage model which argues that gold lease rates are a proxy for world real interest rates.

This gives rise to two related issues that require examination. One is to test the underlying assumption of Levin, Abhyankar and Gosh (1994) that gold prices are driven by the cost of mining, which leads to the conclusion that gold lease rates are a cost and not a benefit of holding gold. This will be undertaken in Chapter 7 using Granger Causality tests (detailed in Section 5.5) using times series and panel data at a country and company level.

Researching this question will also allow an examination of one of the hypothesized channels through which gold and inflation may have a long run equilibrium relationship. If costs are not found to have a positive causal relationship with gold prices, then it is not the miners who drive gold prices and inflation into equilibrium by demanding increased gold prices from the market to compensate themselves for inflation based increases in costs.

Based on the above study as well as the theoretical reasons for treating gold lease rates as a benefit of holding gold, as discussed in Section 3.2, the first assessment of whether bubbles occur in the gold price will be undertaken using gold lease rates as a fundamental driver. We will apply a markov-switching ADF test to assess this question, with this methodology fully detailed in Section 4.6.

As a third issue this thesis will add to the literature on the efficiency of the London OTC market, specifically the forward market, which to date has not been investigated in the literature. Studies of gold derivatives have focused on futures prices from various exchanges, mostly COMEX. An essential question about this market is whether it represents an unbiased estimate of future spot prices. Abken (1980) provide evidence that gold futures prices are unbiased predictors of future spot prices. Kolb (1992) updates this finding that gold futures are relatively unbiased estimates of future spot prices with data ending in 1989. We will address this question with daily data running from 1989 to 2013. If they are found to be biased, we propose to test whether behavioural factors can be used explain the deviations from rationality, using methodologies developed by Easterwood and Nutt (1999) and Aggarwal and Zong (2008).

# 4 Methodology

This chapter will describe this thesis's research philosophy in Section 4.1, a brief discussion of the development of econometrics will be covered in Section 4.2 and the methods employed to address the questions posed following the above literature review will be covered in Sections 4.3 - 4.7.

## 4.1 Research Methodology

The most common approach in modern financial economics research, and in the area of precious metals discussed in this thesis, is the positivist approach. Positivism stresses that reality is particular and exists independently of the researcher. This is in contrast to the socially constructed view of reality that characterises the interpretive position, described by Guba and Lincoln (1982). Positivist researchers believe that reality is composed of independent variables and that these can be studied separately. As reality is particular and independent it is possible through this form of enquiry to progress towards finding an absolute truth which answers the question for everyone, not just for the researcher.

Guba and Lincoln (1982) state that positivism is an objective method of observing phenomena, the researcher and the researched are independent of each other. This seems appropriate to the quantitative methodology described below where the researcher gathers secondary data and has no direct interaction with the phenomenon as it occurs in time. Knowledge is then seen to develop by observing objective facts.

Within positivism results can be explained through causal relations. This idea has its basis in the philosophy of Hume (1739). Observed occurrences can be explained as the result of a cause(s) that precedes an outcome, or is simultaneous to it. The aim of finding these causal relations is to create generalisations that will allow us to make predictions about the future based on these relationships.

Finally the answers given by positivist research should be free of any values held by the researcher prior to the investigation beginning. Against these points, researchers using subjectivist methods argue that no research can be value free as researchers' values have an influence even on the question asked. This implies that two positivist

observers of one event should come to the same conclusion if the research is carried out correctly (Blumberg, Cooper and Schindler, 2008).
The usefulness of the results gathered under the positivist paradigm are traditionally assessed under 3 criteria: Reliability, Validity and Generalisability.

The idea of reliability is related to the consistency of the answers found in the research, for example a ruler is a more reliable measure of length than hand spans. This implies that the findings from a measurement or test must be repeatable with identical or at least insignificantly different answers. A reliable test gives as precise an answer as possible (Gujarati, 2008). There are various ways to assess the reliability of a test such as test-retest. For test-retest, the test would be undertaken twice to see whether both observed measurements are the same regardless of when or where they were taken (Sekaran and Bougie, 2010).

Validity represents the extent to which inferences made from a test are appropriate, meaningful and useful. It asks whether the test used is analysing the phenomenon that we want it to. Again this can be broken down into different types. Internal validity assesses whether the test is well designed and implemented. External validity requires the researcher to examine their findings in order to ask whether there are other possible explanatory variables that could explain the results found.

Based on this philosophical stance it is sensible for me to choose a quantitative research method to address my research questions. Also, as I am distinctly separate from the phenomena that I plan to study (such as gold spot or forward price formation and the cost of extracting gold), and have had no direct interaction with the gold market over the sample used, one of the main criticisms of positivism does not apply here. I apply econometric techniques, a brief history of which is discussed below followed by a detailed description of the econometric models employed.

However, much of the discussion that occurs relating to the economics and finance of gold in the investment community is driven by the "Goldbugs", for want of a better term. This portion of the investment community view gold in a variety of ways but to simplify – gold is seen as the truest of assets. These beliefs are rarely, if ever, based on the type of research that this thesis proposes to undertake; of forming hypotheses and testing them with real market data.

The properties attributed to gold by Goldbugs do sometimes relate to tested ideas, such as whether it can hedge inflation. However based on these tested hypothesis come firmly held beliefs that the rapid rise in gold prices after 2008 signalled that runaway inflation (Bullionvault, 2009). The failure of the prediction of runaway inflation also does not seem to lead to a revision of ideas, as would be the case if positivist research was taking place (Krugman, 2013). Instead, falls in the gold price are regularly interpreted by prominent voices, such as Max Keisser, as conspiracies by central banks against gold (Weisenthal, 2013).

## 4.2 The Development of Econometrics

A number of histories of econometrics are available concentrating on different aspects of the area. Works such as Epstein (2014) chart the development from economics using statistics through to econometrics becoming a discreet discipline.

Keynes (1891) major work on economic methodology holds that while not able to replace the experimental method, statistics had a vital inductive role in economics. Its uses were said to include data description, suggesting empirical laws and testing deductive laws.

According to Epstein (2014) the earliest example of applied econometrics is Moore (1914). This was an examination of the American labour market which aimed to statistically test theories of the marginal productivity theory of wages. This utilised the probability theory developed by Pearson (1900). Moore believed that by employing mathematics and statistics, economics could become an exact science in the same class as biology and chemistry.

Robbins (1932) argued that the use of statistics within economics was a fundamentally flawed idea. This was due to the changing nature of the variables being examined. He argued that nothing in the social sphere is ever uniform over time. Schumpeter (1933), however, said that as long as statistics and mathematics were combined together in econometrics, it could be a useful tool for economic study. Its usefulness was thought to be in disproving theories, rather than proving them by Tinbergen's work in the 1930's.

Deistler (1996) focuses on the period beginning with the Cowles Commission in 1932. Tinbergen had provided the encouragement to try to apply statistical methods to address issues around the business cycle. This resulted in a debate with Keynes through a number of journal articles, such as Tinbergen (1940). The work of the Cowles commission investigated the best methods of using economic theory with statistics on real world data to estimate parameters of general equilibrium models to show how the macro-economy functions (Hoover, 2004). This was in order to show how economics could be used to manage the economy more effectively (Christ, 1994). Issues such as lag length selection received less attention.

Many of the techniques discussed below are a part of the revolution in econometrics that was inspired by the work of the Cowles commission. Some of the techniques such as VAR's and granger causality represent the redevelopment of process analysis that originated with Hermann Wold (see Hoover (2004) for a fuller discussion).

### 4.3 Unit Roots (Stationarity)

Nelson and Plosser (1982) started a debate on whether or not time series variables are dominated in the long run by a random walk component, which is to say that they have a unit root. A random walk can be expressed as below in Equation 1 below:

$$y_t = \beta y_{t-1} + \mu_t \qquad \mathbf{1}$$

If $\beta$ is equal to 1 then it can be shown that shocks, measured by $\mu_t$, never die away. This creates a serious issue for economists as it implies that there are no long run equilibrium relationships between these non-stationary variables.

Nelson and Plosser (1982) found unit roots in many US macroeconomic time series at an annual level. Since then many more macroeconomic, and financial, times series at higher frequencies have also been shown to contain unit roots. According to Banerjee, Dolado, Galbraith and Hendry (1993) these studies relied upon the methodology developed by Dickey and Fuller (1979), which is discussed in the next section. While this method was criticised and modifications were made to improve it, the general finding of a unit root did not change.

Since then there has been a wide range of tests proposed. Here the focus is on the most commonly used tests in time series and panel data applications.

### 4.3.1 Time Series Unit Root Testing

Based on the above discussion prior to using any of the variables, which are fully discussed in Chapter 5, we pre-test for the stationarity or otherwise of variables in all cases. The Augmented Dickey-Fuller (ADF) methodology to test for the presence of a unit root in a time series variable as set out in Enders (2004) is discussed below.

1. Begin by estimating an Autoregressive model with the appropriate number of lags (AR(p)) as found through minimising a selection criteria such as Akaike Information Criteria (AIC) or Schwarz Information Criteria (SIC), with constant and trend terms as in Equation 2 below.

$$\Delta y = \delta + \gamma t + \pi y_{t-1} \sum_{j=1}^{p} \beta_i y_{t-i} + \mu_j \qquad 2$$

Test for $\pi$=0. If the series is found to be non-stationary move on to step 2 below and re-test. If it is found to be stationary the process is stopped.

2. Now estimate Equation 2 again but without the trend term. $\pi$=0 is tested for again. If the series is found to be non-stationary move on to step 3 and re-test. If it is found to be stationary the process is stopped.

3. Lastly estimate an AR(p) model as in Equation 2 with no constant or trend term. No further testing is required at this point. If the null hypothesis of a unit root is rejected one can conclude that the series is stationary [I(0)]. Otherwise the series is non-stationary [I(1)].

If a series if found to be non-stationary it cannot be included in an OLS regression as a level, unless the set of variables in the regression is found to be cointegrated, see next section for further details. To be included the variable must be transformed into first differences.

This adjustment is made for a number of reasons. Firstly, using non-stationary data can lead to a spurious regression where two unrelated variables are found to have a statistically significant relationship due to their non-stationarity. In addition the t-ratios and F-ratios for non-stationary variables will not follow a normal distribution, and the standard assumption for asymptotic analysis will not be valid (Brooks, 2014).

While other unit root tests can be implemented, such as the KPSS or Andews-Zivot (which can be used to take account of structural breaks), here we use the ADF as the standard tool in the literature to assess whether a unit root exists in a time series.

### 4.3.2 Panel Unit Root Testing

A variety of panel unit root tests are discussed by Breitung and Pesaran (2008), however, in the presence of dynamic heterogeneity and to avoid issues around cross sectional independence we use the Im, Pesaran and Shin (2003) (IPS) test. The IPS unit root method is a heterogeneous panel unit root test. This means that it allows for heterogeneity in the dynamics of the autoregressive coefficients for all members of the panel. This is in contrast to other panel unit root tests such as Levin, Lin and Chu (2002). The IPS is based on the same basic ideas as traditional ADF tests while allowing for different lag lengths for the panel member and slope heterogeneity.

The source of the heterogeneity is unobserved but can be related to the different economic conditions and level of economic development in the countries or companies being examined. Im, Pesaran and Shin (2003) have shown that the IPS test has increased power relative to other panel unit root tests. It is carried out through equation 3 below:

$$\Delta y_{i,t} = \delta_i + \pi_I y_{I,t-1} + \sum_{j=1}^{p} p_{i,j} \Delta y_{I,t-j} + \epsilon_{i,t} \quad (3)$$

where i = 1,….,N for each panel member and the error terms $\epsilon_{i,t}$ are assumed to be independently and normally distributed for all i's and t's with finite heterogeneous variances and 0 means. The null hypothesis is that each series in the panel has a unit root, versus the alternative that at least one of the series in the panel is stationary as in equations 4 and 5 below.

$$H_0: \pi_i = 0, \forall_i \quad (4)$$

$$H_1: \begin{cases} \pi_i = 0, for\ some\ i's \\ \pi_i < 0, for\ at\ least\ one\ i \end{cases} \quad (5)$$

T-bar test statistics developed by IPS are then employed. This test is so called because it is the average of the individual t-stats calculated for the $\pi_i$'s from the separate ADF regressions as in equation 6.

$$\tilde{t} - bar_{NT} = \frac{\sum_{t=1}^{N} t_{i,T}(\pi_i)}{N} \quad (6)$$

where $t_{i,T}$ is the ADF statistic calculated for each panel member. The t-bar statistic is normally distributed under the null hypothesis. Im, Pesaran and Shin (2003) then calculate a normalised z-bar statistic using the variance and mean estimates from the t-bar stat. For 0-lags it is defined as below in Equation 7.

$$z_{\tilde{t}-bar} = \frac{\sqrt{N}(\tilde{t}-bar_{NT}-E[\tilde{t}_T|\pi_i=0]}{\sqrt{VAR\{\tilde{t}-bar_{NT}|\pi_i=0]}} \quad (7)$$

where $E[\tilde{t}_T|\pi_i = 0]$ and $\sqrt{VAR\{\tilde{t} - bar_{NT}|\pi_i = 0]}$ are the mean and variances of $t_{i,T}$.

### 4.4 Co-integration

The finding of the presence of unit roots in many time series by Nelson and Plosser (1982) implied the possibility that there were no long run relationships in these sets of economic time series data. This would have called into question many of the theoretical underpinnings of economics and financial research around long run equilibrium relationships. This disagreement between data and theory was resolved by Engle and Granger (1987) who introduced the concept of co-integration into the literature. This allowed for sets of variables which were individually non-stationary to have a long run equilibrium (Hall, 1996). This is as explained below in detail.

If a series is found to be I(1) it cannot be used in many common types of econometric analysis. This is because when the regression is undertaken the residuals of the regression will normally be equal to the largest order of integration of the variables, here I(1), which violates the assumptions underpinning OLS. However it is possible for the linear combination of I(1) variables to be I(0) if they are co-integrated, making the residuals of the regression I(0), even though the variables in the regression may all be I(1).

This can happen within financial variables, as while many are non-stationary, they do co-move due to common forces, such as arbitrage opportunities in linked markets. The market may create a push factor that drives the two variables to have a long run equilibrium relationship, which is a common way to describe co-integration. Next the methods that are employed within this thesis will be discussed below.

### 4.4.1 Time Series Co-integration Testing

Testing for co-integration can be done in a number of ways. A common way by which it can be assessed is by following the Engle and Granger 2 step method. Here the residuals of a regression of the dependant on the independent variable(s) is estimated and the residuals are saved. Following the earlier ADF tests we estimate:

$$\Delta \mu_t = \pi \mu_{t-1} + \sum_{j=1}^{k} \beta_j \, \Delta \mu_{t-1} + \epsilon_j \qquad \mathbf{8}$$

where $\mu_t$ are the residuals from the regression of the dependant on the independent variables. Engle Granger critical values are then applied to the results in the same way as the ADF tests above, testing, against a null of $\pi = 0$, which, if not rejected, would indicate that the variables are co-integrated.

However this procedure suffers from a number of weaknesses. One is that this approach forces the researcher to specify an independent variable, though the causality may be bi-directional. In small samples there is also a lack of power which means that even if we estimate a number of different regressions where each variable is considered as the independent variable in turn, we may not receive a consistent answer. That is, the saved residuals of the regressions may be interchangeably either I(0) or I(1).

The Johansen (1991) method solves the issue of specifying causality through implementing a Vector Auto-Regression (VAR) system. A set of g variables, where g≥2, which are I(1) and are thought to be co-integrated can be shown as a VAR with k lags as follows:

$$y_t = \beta_1 y_{t-1} + \beta_2 y_{t-2} + \cdots + \beta_k y_{t-k} + \mu_t \qquad \textbf{9}$$

To use the Johansen test we estimate a Vector Error Correction Model (VECM) based on the VAR in Equ. 9 above, as follows in Equ. 10:

$$\Delta y_t = \Pi y_{t-k} + \Gamma_1 \Delta y_{t-1} + \Gamma_2 \Delta y_{t-2} + - \cdots + \Gamma_{k-1} \Delta y_{t-(k-1)} + \mu_t \qquad \textbf{10}$$

where $\Pi = \left(\sum_{i=1}^{k} \beta_i\right) - I_g$ and $\Gamma_i = (\sum_{j=1}^{i} \beta_j) - I_g$. The VAR then contains g variables on the left and K-1 lagged differences of the dependant variables on the right and a $\Gamma$ coefficient matrix for each (Brooks, 2014).

$\Pi$ is the long run coefficient matrix as, when the variables are in equilibrium the differences lags of $y_t$and the error term will all be equal to 0. The rank of the $\Pi$ matrix is assessed by its eigenvalues, $\lambda_i$. These are placed in ascending order. If the variables are not co-integrated $\Pi$'s rank will be insignificantly different from zero, written as $\lambda_i \approx 0$ .

The Johansen tests are implemented in this thesis through the Cointegration and Time Series (CATS) software and end by calculating the following statistic:

$$\lambda_{trace}(r) = -T \sum_{i=r+1}^{g} \ln(1 - \widehat{\lambda_i}) \qquad \textbf{11}$$

where r represents the number of co-integrating vectors under the null and $\widehat{\lambda_i}$ is the estimated $i^{th}$ eigenvalue from the $\Pi$ matrix. Equation 11 is used to test jointly whether the number of co-integrating vectors is less than or equal to r, against the general alternative hypothesis that the number of co-integrating vectors is greater than r.

In practice, if the test value for each eigenvalue is greater than the critical value calculated by Johansen (1991), we reject the null hypothesis. The testing starts with the hypothesis of no co-integrating vectors (r=0) versus the alternative that it is greater than zero but less than g. If this is not rejected then it can be concluded that there is no co-integration. Otherwise we consecutively increase the value of r until we do reject the null. If we reach r = g-1 and the null is rejected we have a co-integrated set of variables. If we find that r=g this implies that the original variables were stationary to begin with.

### 4.4.2 Panel Co-integration Testing

Time series co-integration testing can be carried out using Johansen's (1991) procedure, however this does not deal with co-integration for panels. Following the literature, such as Apergis and Payne (2009), Pedroni's (1999, 2004) co-integration tests for heterogeneous panels are used in Chapter 6, below, allowing heterogeneity in the slope and the intercept of the regressions. To construct a test with a null of no co-integration in panels Pedroni (1999) first finds the residuals from a regression of the hypothesised co-integrating variables as in equation 12 below.

$$y_{i,t} = \alpha_i + \delta_i + \beta_{1i}x_{1\,i,t} \dots + \beta_{mi}x_{m\,i,t} + e_{i,t} \qquad \mathbf{12}$$

for t=1,….,T; i=1,…..,N and m=1,….,M. T refers to time, N to the individual observations and M to the number of regression variables. This is used to construct 7 test statistics grouped into within and between statistics.

The within statistics are referenced to as panel co-integration statistics and are referred to as the panel-v, ρ, PP and ADF statistics. The panel-v stat is a variance ration style test, panel-ρ stat is a non-parametric panel version of the Phillips and Peron rho-stat, the panel-PP stat is similar to the traditional Phillips and Peron t-statistic and the panel-ADF follows the normal parametric ADF test. The between statistics are group mean panel statistics. The first is analogous to the Phillips and Perron rho-statistic, second to the Phillips and Perron t-statistic and the last follows the ADF t-statistic. See Pedroni (1999) for further details on each test.

### 4.4.3 Other Co-integration Tests

A wide range of co-integration tests, for both panel and time series data exist within the literature. These include an approach that uses a single equation error correction model derived from an ARDL developed by Pearsan, Shin and Smith (2001) and Kanioura and Turner (2005), and utilised by Batten Ciner and Lucey (2014) to examine the relationship between gold and inflation. Subject to the condition of exogeneity this approach allows for the long and short run aspects of a relationship to be estimated simultaneously. Structural breaks in the data can also be accounted for using methods such as Saikkonnen and Lutkepohl (2000) and implemented again to look at gold and inflation by Worthington and Pahlavani (2007).

While there are various benefits to using these new techniques, this thesis uses the standard test in the literature, the Johansen co-integration method, as this is the first assessment of the questions asked in relation to gold, such the Forward Rate Unbiasedness Hypothesis. Further examination of these questions may utilise these tools to further examine the answers given here.

## 4.5 Granger Causality

Granger Causality focuses on what is, according to Hoover (2004), the major difference between econometrics and statistics. Econometrics focuses on establishing whether causation exists between a set of variables rather than simply association, and, if it does exist, asks in what direction and over what timescale?

### 4.5.1 Time Series Causality

Before causality can be assessed all data needs to be tested for the presence of a unit root using an ADF test as above. In a second step, if any I(1) pairs of time-series variables are found they need to assessed to see if they are co-integrated. If co-integration does not exist between the two variables being tested the following VAR is appropriate (Granger, 1988). For a system of two variables, as will be implemented in Chapter 6, it can be represented as follows:

$$\Delta y_{1t} = \alpha_0 + \sum_{i=1}^{k} \alpha_{1i} \Delta y_{1t-i} + \sum_{i=1}^{k} \alpha_{2i} \Delta y_{2t-i} + \varepsilon_{1t} \qquad \textbf{13}$$

$$\Delta y_{2t} = \beta_0 + \sum_{i=1}^{k} \beta_{1i} \Delta y_{1t-i} 3 + \sum_{i=1}^{k} \beta_{2i} \Delta y_{2t-i} + \varepsilon_{2t} \qquad \textbf{14}$$

where $y_1$ and $y_2$ represent variables 1 and 2. Engle and Granger (1987) show that rejecting $H_0: \alpha_{21} = \alpha_{22} \ldots. = \alpha_{2k} = 0$ implies that variable 1 does Granger-cause variable 2. Rejecting $H_0 = \beta_{11} = \beta_{12} \ldots. = \beta_{1k} = 0$ implies that variable 2 does Granger-cause variable 1.

Granger (1988) also shows that in the presence of co-integration, causality tests require an error correction term $(\delta_i \epsilon_{t-1})$ to be added which is derived from the co-integrating relationship. Granger (1988) also demonstrates that co-integration implies some form of long run Granger causality. Equation 13 and 14 then become as below in equations 15 and 16.

$$\Delta y_{1t} = \alpha_0 + \delta_1 \epsilon_{t-1} + \textstyle\sum_{i=1}^{k} \alpha_{1i} \Delta y_{1t-i} + \sum_{i=1}^{k} \alpha_{2i} \Delta y_{2t-i} + \varepsilon_{1t} \quad \textbf{15}$$

$$\Delta y_{2t} = \beta_0 + \delta_2 \epsilon_{t-1} + \textstyle\sum_{i=1}^{k} \beta_{1i} \Delta y_{1t-i} + \sum_{i=1}^{k} \beta_{2i} \Delta y_{2t-i} + \varepsilon_{2t} \quad \textbf{16}$$

Rejecting $H_0: \alpha_{21} = \alpha_{22} \ldots. = \alpha_{2k}$ and $\delta_1 = 0$ in this situation implies that variable 2 does Granger cause variable 1. Rejecting $H_0 = \beta_{11} = \beta_{12} \ldots. = \beta_{1k}\ and\ \delta_2 = 0$ implies that variable 1 does Granger cause variable 2.

### 4.5.2 Panel Causality Testing

Panel causality testing follows a very similar pattern to the time series approach. If we find that the series are co-integrated (based on the tests in Section 4.3.2) we then run a panel vector error correction model in order to carry out the granger causality test as in 17 and 18 below. In the first step we find the error correction term through Fully Modified OLS (FMOLS) as in Pedroni (2007) followed by the below model testing for causality.

$$\Delta y_{1\,i,t} = \alpha_{o,i} + \delta_{1i} \epsilon_{i,t-1} + \sum_{i=1}^{k} \alpha_{11i} \Delta y_{1t-i} + \sum_{i=1}^{k} \alpha_{12i} \Delta y_{2t-i} + \varepsilon_{1it} \quad \textbf{17}$$

$$\Delta y_{2\,i,t} = \beta_{o,i} + \delta_{2i} \epsilon_{i,t-1} + \sum_{i=1}^{k} \beta_{21i} \Delta y_{1t-i} + \sum_{i=1}^{k} \beta_{22i} \Delta y_{2t-i} + \varepsilon_{2it} \quad \textbf{18}$$

If the series are not co-integrated we drop the ECM terms from equations 17 and 18 and estimate a VAR in first differences. The VECM or VAR style estimations are carried out by Generalised Method of Moments (GMM) (Arellano and Bond, 1991) allowing for general serial correlation within each individual. If this test were carried out as a fixed effects panel estimation, Woodridge (2002) points out that it would be biased as a lagged dependant variable is included with a small T (in Chapter 6 we only have 14 observations per individual for panel estimations).

### 4.5.3 Other Causality Tests

As discussed above, for co-integration and unit roots a variety of methods to test for causality exist in the literature. Sims (1972) suggests a similar test to Granger Causality but also proposes including lead or future terms in the regressions. The test for causality would then be to assess whether or not the sum of the estimated coefficients on the lagged and lead terms are jointly equal to zero, as the lead terms should have no predictive power. However studies such as Chamberlain (1982) point out that neither has a particular advantage over the other.

It is also possible to assess whether or not non-linear causality exits between variables using tests developed by Baek and Brock (1992) and later modified by Hiemstra and Jones (1994). This testing is done by first estimating the causal relationships in a linear form, saving the residuals and assessing whether non-linear causality exists based on these.

However these methods are not applied in Chapter 6 as this is the first set of tests on the question asked and Granger Causality remains the most common method of assessing causality in the literature.

## 4.6 Testing for Asset Price Bubbles

A broad literature exists on methods for testing for Rational Speculative Bubbles, defined in Section 3.8, in financial asset prices. These generally focus on assessing whether an assets price is explained by some variable which is thought *a prioi* to be its fundamental determinant. A bubble occurs when their relationship breaks down, with the assets price rising rapidly without a fundamentally justified reason and then collapsing. The basis of all these tests is the Present Value Model, where future expected benefits are discounted back to today's value based on the opportunity cost of capital (Gurkaynak, 2008).

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:

$$P_t = \sum_{i=1}^{\infty} \frac{E_t(C_{t+i})}{(1+r)^t} \qquad \textbf{19}$$

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 measured as the discounted value of expected future cash flows given by equation 19; and a bubble term, $b_t$. The true value of the asset is then given by equation 20:

$$P_t = \sum_{i=1}^{\infty} \frac{E_t(P_{t+i}+C_{t+i})}{(1+r)^t} + b_t \qquad \textbf{20}$$

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

$$p_t = p_t^* + b_t \text{ where } E_t(b_{t+1}) = (1+r)b_t \qquad \textbf{21}$$

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.

Below we discuss some of the early models of bubble detection and then examine the most prominent recent examples, followed by a justification of the choice of the Markov Switching Augmented Dickey-Fuller (MSADF) bubble test in this thesis.

### 4.6.1 Early Bubbles Tests

Early attempts to look at bubbles include variance bound tests, as in Shiller (1981). These tests essentially looked at whether the actual volatility of asset prices, in Shiller's case equity prices, is greater than the bound imposed by the variance of the price that is estimated through actual dividends based on the present value model. This test has however been criticised by a number of authors. Marsh and Merton (1986) showed that in the presence of non-stationary data this test is not a reliable way to detect bubbles.

Diba and Grossman (1984) develop an alternative way to test for bubbles by exploiting the theoretical statistical properties that they should exhibit. As the model used in this thesis is a development of this approach it will be discussed in some detail. In addition it is the earliest employed empirical test for bubbles in gold prices mentioned in the literature.

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. The first of these is the Fundamental Component (FC) of the value of gold and is given by Equation 21 below.

$$s_t + p_t = \beta(E_t(p_{t+1}) - p_t) - \gamma E_t r_{t+1} + o_t \qquad \textbf{22}$$

where: $p_t$ is the log of the gold price, $s_t$ is the log of the stock of gold at t, $\beta$ is a positive constant, showing the relationship between the portfolio demand for gold and the real return on gold, $\gamma$ is a positive constant, showing the relationship between the portfolio demand for gold and the real return on other assets, $E_t(.)$ denotes the rational expectations operator, $r_{t+1}$ represents the rate of return on other assets, $o_t$ is other factors that affect gold's fundamental value that are not observable.

The FC of the value of gold, given by Equation 21 above, states that the total value of the stock of gold is based on what is expected to happen to its price in the future, as well as being negatively related to what you can earn on other assets. Diba and Grossman (1984) use real interest rates, from US commercial paper, in their model as the return on other assets.

The other parts of what determines the price of gold in their model are the Stochastic Bubble Component (SBC), a random variable with a zero mean whose value falls to zero as time progresses and the Deterministic Bubble Component (DBC). If DBC is found to be present within the asset's price then a rational bubble is seen to be present. These are shown in equation 22 below.

The DBC is a constant, times an eigenvalue raised to a power greater than 1, i.e. $(1+\beta^{-1})^t$. This implies that as t increases the DBC increases. The SBC is a constant, times an 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 22.

$$p_t = \underbrace{(1+\beta)^{-1}\sum_{i=0}^{\infty}(1+\beta^{-1})^{-i}E_t(u_{t-i} - \gamma r_{t+1-i} - s_{t+i})}_{FC} + \underbrace{c(1+\beta^{-1})^t}_{DBC} + \underbrace{\sum_{i=1}^{t}(1+\beta^{-1})^{t-i}z_i}_{SBC} \qquad \mathbf{22}$$

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 Equation 22 the stationarity properties of the process that generates $p_t$ can be investigated for evidence of bubbles. As we cannot observe the DBC we must make inferences about the process that generates it. If c in equation 22 is non-zero it will be mean that the DBC is non-stationary as it grows at $(1+\beta^{-1})^t$, 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 would then be the number of times it is necessary to make $p_t$ stationary, if $p_t$ is the fundamental value determined by its fundamental determinant, in Chapter 7 gold lease rates. Evans (1991) argues 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. Essentially then, the asset price and its fundamental determinant would be tested for unit roots and if both are integrated to the same order, e.g. both are found to be I(1), then no bubble is present. If however they are integrated to different orders then a bubble is present.

Diba and Grossman (1988) develop this idea showing that if found to be non-stationary the variables must also co-integrate in order to rule out a bubble (see Section 4.4 for a full discussion of co-integration). They argue that it is unlikely that an unobserved fundamental will be I(2), meaning that failing to reject a co-integrating 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 co-integration tests.

### 4.6.2 Periodically Bursting Bubbles

Evans (1991) shows that Diba and Grossmans tests are only applicable for bubbles that continue to grow in the asset's price from t=0, as the c component is not time varying and must be present from the start in order to be present in the series. Traditional Unit root and co-integration tests do not have any ability to detect periodically bursting bubbles. Evans (1991) also points out that it is more likely that bubbles appear and disappear over time, 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 and this class of bubbles is what we would expect to most worry and therefore interest investors. Evans also assumes that a bubble cannot be negative, but, unlike earlier work, bubbles in this model can now collapse to a low but positive value. The bubble can then be in one of two different states at any time as in equation 23 and 24 below.

$$B_{t+1} = (1 + r)B_t U_{t+1} \qquad \text{if } B_t \leq \alpha \qquad \textbf{6}$$

$$B_{t+1} = [(\partial + \pi^{-1}(1 + r)\theta_{t+1}] * [B_t - (1 + r)^{-1}] * U_{t+1} \quad \text{if } B_t > \alpha \qquad \textbf{24}$$

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 Independently identically distributed (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.

### 4.6.3 Markov Switching Augmented-Dickey Fuller (MSADF) Test

Hall, Psaradakis and Sola (1999) use simulation and an empirical example to put Evans' (1991) idea into practice using a Markov Switching Augmented Dickey-Fuller (MSADF) test following Hamilton's (1989) method. This method has been applied to bubble detection as in Liu, Margaritis, and Wang (2012) and in other contexts such as studying real exchange rate nonlinearities in Kruse, Frömmel, Menkhoff and Sibbertsen (2012).

We adjust the ADF equation (**2**) as in Hall, Psaradakis and Sola (1999) so that it is now time varying, changing with an unobserved indicator, the stochastic regime variable (st), which takes on a value of 0 or 1 giving equation 25 below:

$$\Delta y = \pi_{st} + \Phi_{st} y_{t-1} + \sum_{i=1}^{k} \beta_{st,i} \Delta y_{t-j} + \sigma_{st}^2 \epsilon_t \qquad \textbf{25}$$

where $\pi_{st} = \pi_0 + s_t(\pi_1 - \pi_0)$, $\Phi_{st} = \Phi_0 + s_t(\Phi_1 - \Phi_0)$, $\beta_{st,i} = \beta_{0,i} + s_t(\beta_{1,i} - \beta_{1,i})$ and $\sigma_{st}^2 = \sigma_0^2 + s_t(\sigma_1^2 - \sigma_0^2)$. $\epsilon_{s_t}$ is normally distributed and k is the lag order of the model. We assume that 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. This model is therefore a random sequence to a homogenous markov chain with transition probabilities as defined as below, allowing the data to determine whether or not we are in a particular state:

$$\begin{aligned} Pr(s_t = 1 | \, s_{t-1} = 1) &= p \\ Pr(s_t = 0 | \, s_{t-1} = 1) &= 1 - p \\ Pr(s_t = 1 | \, s_{t-1} = 0) &= q \\ Pr(s_t = 0 | \, s_{t-1} = 0) &= 1 - q \end{aligned} \qquad \textbf{267}$$

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), and these are designated as the transition probabilities.

We estimate the parameters using maximum likelihood procedures as in Hall et al. (1999) to test the null hypothesis of a bubble in either regime (i.e. that $\Phi_{st}>0$, a right tailed test for explosiveness) against the alternative of a regime which is either stationary or has a unit root. If $\Phi_{st}>0$ in any state then we can say that a bubble is present in the data for that state. The process gives inferences about the probability of being in a particular state [$\Pr(s_t = 1 | I_t, \vartheta)$, where $I_t=(y_1,\ldots,y_t)$ and $\vartheta=(\pi_1, \pi_2, \Phi_1, \Phi_2, \beta_{0,1}\ldots \beta_{0,k}, \beta_{1,1}\ldots \beta_{1,k})$], the filter probabilities that we are in state 1 at any time. These allow us to make inferences about which of the unobserved regimes we are in at any time as in Hamilton (1990) and Hall et al. (1999). We use the Broyden–Fletcher–Goldfarb–Shanno (BFGS) algorithm, following Shi (2012) who finds this outperforms the alternative expectation-maximization (EM) algorithm in estimating this type of model.

We can also allow the variance in each regime to switch between the two states, as in Brooks and Persand (2001) or remain constant as in Shi (2012). Shi (2012) argues that imposing a constant variance can improve the power of the test, though it may lead to the rejection of the null too often when the differences between the residual variance of the different regimes is large. It also makes the results more robust to model misspecification. We carry out both a constant variance (MSADF-CV) and regime switching variance ADF (MSADF-RV) test to assess the sensitivity of our results to these factors but more emphasis is put on the MSADF-CV due to its increased power.

Nelson, Zivot and Piger (2001) chose their lag length using the backward lag-length selection procedure as found in Campbell and Perron (1991) with the lag length, k, set equal to a maximum of the lower integer bound of $T^{1/3}$ as proposed in Said and Dickey (1984). Camacho (2011) uses the AIC and SCB in formations criteria. Here we apply the three methods and, when they disagree we test all suggested models, only reporting the most parsimonious model if the results are qualitatively the same.

Camaco (2011) points out that the distribution of the t-statistic used to test the null is nonstandard. We follow Hall et al. (1999) by bootstrapping the model under the null hypothesis in order to calculate the simulated critical values, using the estimates of the model parameters from this realisation of $y_t$. The number of bootstrap replications is 50,000. The steps of the estimating procedure are given in Camaco (2011).

### 4.6.4 Other Bubble Tests

A number of other ways to test for bubbles are present in the literature. Philips, Wu and Yu (2011) provide a new method within this general ADF type approach used for the MSADF, the sup-ADF. They use forward recursive right-tailed ADF tests and state that this method can also be used to anticipate bubbles, making it very useful for policy makers. Homm and Breitung (2012) test the power of Philips et al.'s (2011) sup-ADF against a number of alternatives including a version of the sup-ADF test including a Chow test modification, the sup-ADFC. They find that for randomly starting bubbles their new sup-ADFC test out performs the sup-ADF in terms of bubble detection. However the sup-ADF is by far the most powerful in detecting periodically collapsing bubbles in the sample of tests addressed in the paper. The MSADF test was not investigated.

Another class of bubble test are Counting Models, also known as Hazard Models. These are different to the ADF style tests discussed above in that they do not compare the time series behaviour of the determining factors of the value of the asset with its price. 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 19, allowing the bubble to be estimated as a time series variable. The weakness of this approach and relationship models in general is common to much finance research. That is, it really involves testing a joint hypothesis; is there a bubble and is our model of the assets price correct which is similar to the problems found when testing EMH (Lo, 2007). Any misspecification of the present value 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.

The decision to use the MSADF in this thesis to assess whether bubbles occur in the gold price is motivated by the fact that it has been used to look for bubbles in gold by 2 previous papers [Bialkowski, Bohl, Stephan, and Wisniewski (2011) and Bialkowski, Bohl, Stephan, and Wisniewski (2015)]. As they used other fundamental drivers, the convenience yield and a model with a number of other explanatory variables as discussed in Section 3.8, using lease rates here allows us to compare whether a bubble was present considering a new and market based fundamental determinant, while holding the model used constant. This range of variables within the one framework may help create a clearer picture as to whether a bubble has occurred in gold prices.

### 4.7 The Forward Rate Unbiasedness Hypothesis (FRUH)

Chapter 8 is based on firstly testing for the presence of the FRUH. This assumes that if rational expectations hold and investors are risk neutral the forward rate is an unbiased predictor of the expected future spot. It can be expressed as:

$$E_t(s_{t+1}) = f_t \qquad 27$$

where $E_t$ represents the expectation conditional on information available to the market t, $s_t$ is the spot rate and $f_t$ is the forward rate (Zivot, 2000). Baillie (1989) refers to this hypothesis as observable expectations. In levels we can express the hypothesis as:

$$s_{t+1} = f_t + \epsilon_{t+1} \qquad 28$$

Where $\epsilon_{t+1}$is the rational expectations forecast error with an expected value of zero. This leads to a regression in levels which allows us to test for unbiasedness in the forward rate.

$$s_{t+1} = \alpha + \beta f_t + \mu_{t+1} \qquad 29$$

The null hypothesis is that $\beta$=1, $\alpha$=0 and $E_t(\mu_{t+1}) = 0$. As $S_t$ and $F_t$ are generally found to have unit roots testing the FRUH requires assessing whether $S_{t+1}$ and $F_t$ are co-integrated with a (1, -1) vector.

Engle (1994) also shows the difference version of this regression equation as follows:

$$s_{t+1} - s_t = \alpha + \beta(f_t - s_t) + \mu \qquad \textbf{30}$$

where the null hypothesis that the forward premium is an unbiased predictor of the change in the spot rate is found to be true if β=1, α=0 and $E_t(\mu_{t+1})$=0.

MacDonald and Taylor (1992) also suggest testing the efficiency of the forward market by using the forecast error (FE), the difference between the forward rate ($F_t$) and the realised spot rate at t+1 ($S_{t+1}$). The FE is regressed on lagged values of itself as in equation 30 below.

$$s_{t+1} - f_t = \alpha_0 + \sum_{i=0}^{p} \beta_i(s_{t-i} - f_{t-i-1}) + \mu \qquad \textbf{30}$$

with the null hypothesis α=0 and $\sum_{i=0}^{p} \beta_i$=0. This provides a test of weak form market efficiency, as a finding against implies that, using freely available market information, it is possible to outperform the market.

We test empirically for the FRUH in two ways. Firstly we test for cointegration between the forward rate and the future spot rate as in equation 28. If $F_t$ and $S_{t+1}$ are cointegrated with a (1, -1) cointegrating vector we have evidence in favour of the FRUH. Zivot (2000) argues that $F_t$ and $S_t$ also need to be cointegrated with a (1, -1) cointegrating vector. If these relationships are found to exist we have found a long run equilibrium relationship between the two prices, upholding the FRUH.

We also regress the change in the spot rate on the forward premium as in equation 30 and test the null hypotheses that β=1, α=0 and $E_t(\mu_t)$ = 0. If the null hypotheses are rejected, we reject the FRUH. This involves regressing a long horizon dependant variable, the change in the spot rate over 1, 3, 6 and 12 month periods, on an explanatory variable, the change in the spot rate predicted by the forward premium. The dependant variable can therefore suffer from serious autocorrelation. Valkanov (2003) finds that regressions using long horizon returns can have poor statistical power due to the autocorrelation inherent in the data.

This is dealt with here using Newey-West (1987) heteroskedasticity and autocorrelation consistent (HAC) standard errors as in Evans and Lyons (2005), who examine exchange rate forecasting. Britten-Jones, Neuberger and Nolte (2011) find that the Newey-West estimator does suffer from a downward bias when the forecast horizon is long and the number of observations is small (until about 100 observations). As we have over 6000 daily observations and over 1000 weekly observations to utilise in Chapter 8 (as discussed in Section 5.3) this issue not a substantial one here. Testing at the weekly level, where this issue of autocorrelation would be less of a factor, should also help to assess whether this is a problem for the results of this thesis.

Other methods to deal with this problem include Hodrick's (1992), who uses a structured covariance estimator generalising the work of Richardson and Smith (1991). Ang and Bekaert (2007) use Hodrick's (1992) correction for long-horizon returns and find that previous methodologies had led to the too frequent rejection of the null hypothesis of Forward Rate Unbiasedness. Autocorrelation can also be dealt with through pre-whitening as in Sul, Philips and Choi (2005). But as Britten-Jones et al. (2011) find that these three methods perform equally well the standard Newey-West methodology is used in this thesis.

## 4.8 Testing for Behavioural Biases

### 4.8.1 Forecast Errors and Revisions

In Section 8 we begin by assessing whether gold forward prices are an unbiased estimate of future spot prices using the unit root and cointegration techniques discussed above. If they are not found to be unbiased estimates we address two possible factors that could affect the markets forecast from a behavioural standpoint. These are: that as the market processes new information its general outlook (optimism vs. pessimism); and its response to that information (under vs. over-reaction) are independent of whether the information received is positive or negative. This, and the following sections, details various approaches based on and developed from Easterwood and Nutt (1999) and Aggarwal and Zong (2008).

Forecast Errors (FE's) that tend to be positive reflect general optimism in the market while negative forecast errors show a general pessimism on the part of participants.

Optimism can also be found based on the market's reaction to different types of information: if it underreacts to bad information and overreacts to good information. Overreaction occurs when the market's FR's are of the opposite sign to its FE's; i.e., a negative revision is too large and we observe a positive FE. Under-reaction happens when the FR and FE are of the same sign.

All of the dependant variables in the equations in Section 4.8 below are expected to suffer from autocorrelation due to a similar overlapping problem as for the FRUH regression. Consequently, Newey-West heteroskedasticity and autocorrelation consistent (HAC) standard errors are used for all regressions to deal with this with the appropriate number of lags. We also test all models at a weekly frequency. If significant autocorrelation still exists we would expect the $R^2$'s to decline as the frequency is reduced but do not observe a significant reduction for any model.

To control for market risk aversion as a possible explanatory variable for FE's, FR's and the forward premiums in all models in the equations in Section 4.8 are estimated with and without $VIX^2$ (following Banerjee, Doran and Peterson (2007)), but it did not change the results significantly. The COMEX Gold VIX was also considered but as it only exists from 2008 and is highly correlated with VIX (approximately 90%), and so we employ the broad VIX measure here.

Following Aggarwal and Zong (2008) we begin by attempting to distinguish between the markets general outlook and the markets strength of response to new information with the equation 31 below. It examines the relationship between the markets mistake (the FE) on a particular day and the revisions to its expectations (FR's) on that day.

$$FE_t = \alpha + \beta(FR_t) + \mu_t \qquad \textbf{32}$$

The null of no behavioural biases is tested by: $\alpha = \beta = 0$. A positive alpha points to optimism as when FR's are 0 there is still a FE, while a negative alpha implies pessimism. A positive beta reflects over reaction by the market as the FE and FR are both of the same signs as discussed above and a negative beta shows general under reaction.

Due to data restrictions Aggarwal and Zong (2008) implicitly assume that the relevant FR for any FE is the one with the most similar time period e.g. in our case the FR,12m-6m would be regressed on the FE,12m. As we have 4 forward prices rather than 2 we can regress all FR's on each FE and, as in equation 33 below. This allows us to assess whether relationships exist between different maturities.

$$FE_t = \alpha + \beta_1(FR12m6m) + \beta_2(FR6m3m) + \beta_3(FR3m1m) + \mu_t \quad \textbf{33}$$

### 4.8.2 Past Information and Market Forecasts

We can also examine how observed changes in the spot price over a prior time period predicts the markets FE which is made at t but not observed until t+1.

$$FE_t = \alpha + \beta(PSCH_{t-1}) + \mu_t \quad \textbf{34}$$

Where $PSCH_{t-1}$ is the prior period spot rate change ($S_{t-1} - S_{t-2}$) over a given maturity. For a given FE, e.g. FE6m, we assess first how the change in the spot rate over the same period (6 months) that is observed on the prior day affects the markets FE over a 6 month duration (as in Aggarwal and Zong, 2008). This allows us to examine whether the way in which the market incorporates this news causes FE's. If the slope coefficient is negative it indicates over reaction to prior information and vice versa.

We also test equation 35 to assess if the market is affected by long, medium or short run spot changes in making its predictions, rather than just the same maturity as in equation 34.

$$FE_t = \alpha + \beta_1(PSCH12m_{t-1}) + \beta_2(PSCH6m_{t-1}) + \beta_3(PSCH3m_{t-1}) + \beta_4(PSCH1m_{t-1}) + \mu_t \quad \textbf{35}$$

Easterwood and Nutt (1999) develop a test, originally discussed in Abarbanell and Bernard(1992), to separate out market mood from its reaction to new information. They point out that the over-reaction observed may be simply that, or market optimism. If the market overreacts to good information this is optimism. They should then also overreact to good prior information. Therefore, we also separate the market's reaction to news from its mood using prior period changes by grouping the prior period spot changes into low, medium and high quartiles. This will allow us to distinguish between reactions of different strengths based on the type of news. The effect of news type on both FEs (as in Eq. 36) and the markets forecast, the forward premium (FP) in Eq. 37.

$$FP_t = \alpha + \beta_1 LoPSCH_{t-1} + \beta_2 HiPSCH_{t-1} + \beta_3 PSCH_{t-1} + \beta_4 DLPSCH_{t-1} + \beta_5 DHPSCH_{t-1} + \mu_t \quad \textbf{36}$$

$$FE_t = \alpha + \beta_1 LoPSCH_{t-1} + \beta_2 HiPSCH_{t-1} + \beta_3 PSCH_{t-1} + \beta_4 DLPSCH_{t-1} + \beta_5 DHPSCH_{t-1} + \mu_t \quad \textbf{37}$$

where the $FP_t = {}_{t-1}F_t - S_{t-1}$, $LoPSCH$ and $HiPSCH$ are dummy variables: $HiPSCH$ is equal to one when $PSCH$ is in the upper quartile for changes and zero when not. $LoPSCH$ is equal to one when $PSCH$ is in the lower quartile for changes and zero when not. $DLPSCH$ and $DHPSCH$ are interactive terms equal to $PSCH$ times $LoPSCH$ and $PSCH$ times $HiPSCH$ respectively.

$\beta_3$ in equations 35 and 36 measures the impact of prior period changes in spot prices on the FP and FE for the average values found in the middle quartiles. To measure the effect of prior spot rate changes in the lower quartile on the predicted changes $\beta_3 + \beta_4$ are examined, while for the effect of an upper quartile change $\beta_3 + \beta_5$ is used. Systematic pessimism exists if a significant negative summed coefficient is found in the lower quartile (overreaction) and a significant positive $\beta_3 + \beta_5$ for the upper quartile. Optimism is found to be present if signs are reversed on the summed coefficients. This gives the ability to assess both the attitude and reaction of the markets to new information. The null of no behavioural biases can then be stated as $\beta_3 + \beta_4 = 0$ and $\beta_3 + \beta_5 = 0$.

This regression is carried out for all maturities of the FP and FE coupled with all maturities of the PSCH in order to assess whether differing lengths of spot price changes have different effects on the dependant variable at a given maturity.

### 4.8.4 Past Information and Forecast Revisions

Next we examine the effect of prior FE's on the markets FR's, again using upper and lower quartile observations but this time of the markets prior prediction errors, the FE's.

$$FR_t = \alpha + \beta_1 LoFE_{t-1} + \beta_2 HiFE_{t-1} + \beta_3 FE_{t-1} + \beta_4 DLFE_{t-1} + \beta_5 DHFE_{t-1} + \mu_t \qquad \textbf{38}$$

$LoFE_{t-1}$and $HiFE_{t-1}$ are dummy variables where $HiFE_{t-1}$ is equal to one when $FE_{t-1}$ is in the upper quartile for changes and zero when not. $DLFE_{t-1}$ and $DHFE_{t-1}$ are interactive terms equal to $FE_{t-1}$ times $LoFE_{t-1}$ and $FE_{t-1}$ times $HiFE_{t-1}$ respectively. Under-reaction to information about previous forecast errors in precious metals markets would show as positive slope coefficients and negative if over-reaction is the norm. If the markets attitude is generally optimistic then $\beta_3$ +$\beta_4$ should be significant and positive and $\beta_3$ +$\beta_5$ should be negative and significant. We carry out this regression for all maturities of the FR coupled with all maturities of the prior FE.

### 4.8.5 ETF Flows

We use the EFT data discussed in Section 5.3 to assess whether investors mood is affected by learning about changes in total ETF gold holdings, developing on from the tests proposed by Easterwood and Nutt (1999) and Aggarwal and Zong (2008). Information on changes in the gold holdings of ETFs are generally updated the day after trading closes (spdrgoldshares.com) but some funds do report a day or more after that. This means that the information on changes in how much gold is held by ETFs is generally assimilated by the market in London on the day after the change in ETF holdings actually occurs.

Most funds gold holdings data were delayed by one day to reflect the lag in information that could affect GOFO or the PM fixing. As in previous sections we use upper and lower quartile observations of changes in ETF gold holdings to assess the effect on the markets prediction errors, the FEs as in Eq. 39 below.

$$FE_t = \alpha + \beta_1 LocETF_{t-1} + \beta_2 HicETF_{t-1} + \beta_3 cETF_{t-1} + \beta_4 DLcETF_{t-1} + \beta_5 DHcETF_{t-1} + \mu_t \qquad \textbf{39}$$

where $cETF_{t-1}$ is the change in aggregate reported holdings of gold by all ETFs on the evening before GOFO is set and the PM gold fixing occurs. $LocETF_{t-1}$ is a dummy variable which equal 1 when $cETF_{t-1}$ is in the upper quartile for changes and zero when not. $DLcETF_{t-1}$ and $DHcETF_{t-1}$are interactive terms equal to $cETF_{t-1}$ times $LocETF_{t-1}$ and $cETF_{t-1}$ times $HicETF_{t-1}$ respectively. Under-reaction to information about changes in ETF holdings by precious metals markets would show as positive slope coefficients and negative if over-reaction is the norm. If the markets attitude is generally optimistic then $\beta_3 + \beta_4$ should be significant and positive and $\beta_3 + \beta_5$ should be negative and significant. We carry out this regression for all maturities of the FE as in Eq. 39 and finally the same regression with the $FR_t$ as the dependent variable.

# 5 Data

This Chapter will describe and explain the data used in the empirical sections of this thesis. The gold price data is common to Chapters 6, 7 and 8 and is discussed in Section 5.1. Section 5.2 will discuss the data used in Chapter 6 on the cost of mining gold for a sample of countries and companies. Section 5.3 will discuss the Gold Offer Forward rate (GOFO), how this is converted into gold forward prices and the other data used in Chapter 8. Finally Section 5.4 will describe the gold lease rate data (which is derived from GOFO) used in Chapter 7.

## 5.1 The London Gold Fixing

The London Gold Price Fixings is interesting in that it reflects an almost ideal example of Walrasian auction pricing. Prices in the London market have been set since 1919 (September 8) at the twice daily "fixings" by representatives of the bullion dealers (Harvey, 2012). Buy and Sell orders are received by these representatives over the telephone from their clients and proprietary traders during the fixings and the price is adjusted by the chairperson until supply and demand are in balance. While sellers receive the "fixed" price, buyers are charged a fixing commission of a quarter per cent (minimum $100) LBMA (2008).

The first London Price Fixing took place in 1919 involving four brokers: Mocatta and Goldsmith, Pixley and Abell, Sharps and Wilkins, and Samuel Monetgue and Co (Harvey, 2012). London's original advantage came from its monopoly to purchase all gold from South Africa, then the world's largest producer, its ability to handle large volumes of purchases and sales as a result of its close association with the Bank of England (Green, 2007). The London market was suspended in 1939 and only allowed to reopen in 1954 with all gold being dealt with by the Bank of England in between these times. It only lost the South African monopoly in 1968 after a 2 week closure due to the collapse of the gold pool, followed by the failing of the officially set price of $35.

Recent scandals have pushed the market to move away from a telephone based Fixing as it results in information asymmetries in the market, as shown by Caminschi and Heaney (2013) and discussed fully in Section 3.7. The first auction took place on 20 March 2014. The basic structure of the Walrasian auction remains but orders will now be inputted electronically by the Market Makers. This means that the fixing will be visible as it progresses towards an equilibrium price.

**Figure 16- London PM Gold price, $'s**


*Source: LBMA.org*

From 1983 to 2004 the gold market is best described as sideways. The price in nominal terms fluctuated up and down but no long run upward or downward trend was apparent. In general, however, prices did fall from the beginning of the 1990's until the new millennium, with much of the decline in gold prices from 1990 happening after 1995. New sources of investment around the new millennium have been given the credit for the rises in price, and as discussed in previous sections.

Kearney and Lombra (2008) offer another suggestion for these price changes in terms of the derivatives usage volume over this time and see it rising rapidly for gold miners. These were necessarily short positions as they were selling the supply forward into the market. Using a real interest rate model to find predicted vales of gold prices over this period they find that actual price was consistently below their forecast up to 2006. They also attribute large falls in hedging by miners after this time with the rapid gold price rises seen in the second half of the 00's. They cite these higher prices as then more correct over the long term, and a movement back towards equilibrium. Cai, Cheung and Wong (2001) found that 6 of the 25 largest absolute one day gold returns were associated with central banks' selling their gold.

**Table 1- Descriptive statistics: Gold Price, Daily Data**

| | 1968-2013 | | 1968-1990 | | 1991-2013 | |
|---|---|---|---|---|---|---|
| | AM Spot | PM Spot | AM Spot | PM Spot | AM Spot | PM Spot |
| **Mean** | 441 | 441 | 262 | 261 | 619 | 619 |
| **Standard Deviation** | 378 | 239 | 170 | 169 | 439 | 439 |
| **Skewness** | 1.886 | 1.998 | 0.208 | 0.212 | 1.358 | 1.356 |
| **Kurtosis** | 3.288 | 3.724 | -0.988 | -0.984 | 0.486 | 0.476 |
| **Jarque-Bera** | 14371 | 14244 | 282 | 281 | 2372 | 2339 |
| **ADF Statistic-Level** | -0.608 | -0.649 | -1.975 | -2.017 | -0.427 | -0.433 |
| **ADF Statistic-** | -108.90 | -105.33 | -79.51 | -80.54 | -76.21 | -72.29 |
| **Obs.** | 11569 | 11498 | 5758 | 4928 | 5811 | 5770 |

Above some descriptive statistics for AM and PM Fixings gold prices are presented from the 2nd of April 1968 until December 31st 2013. We show some subsample statistics by breaking the sample in 1990. Unsurprisingly, it can be seen that the Am and PM fixings give very similar results. As the PM fixing is anecdotally the more liquid due to overlapping with US trading time this thesis focuses on this as the gold price in analysis to follow. There are generally more observations for the AM fixing as there are trading days around Christmas and New Year where the London market closes at 1pm.

While many other metals prices are generally negatively skewed, we can see here that over the full sample running from the freeing of the gold market following the failing of the gold pool in 1968, gold has been positively skewed. This fact, highlighted by Lucey, Poti and Tulley (2006) contributes significantly to its ability to diversify a portfolio. However this skewness is less pronounced prior to 1990.
In addition, the kurtosis coefficients for both the AM and PM fixings over the full sample are significantly leptokurtic so that the tails of their distribution are fatter than tails of a normal distribution of the same variance. However in the first sample period we see that the distribution of prices is platykurtic, with thin tails.

These results indicate that gold prices are non-normally distributed and the Bera–Jarque test confirms this by rejecting the null hypothesis of a normal distribution. Modes of fluctuation for gold price changes also exhibit significant non-normality and non-stationarity with significant skewness and kurtosis in their means and variances

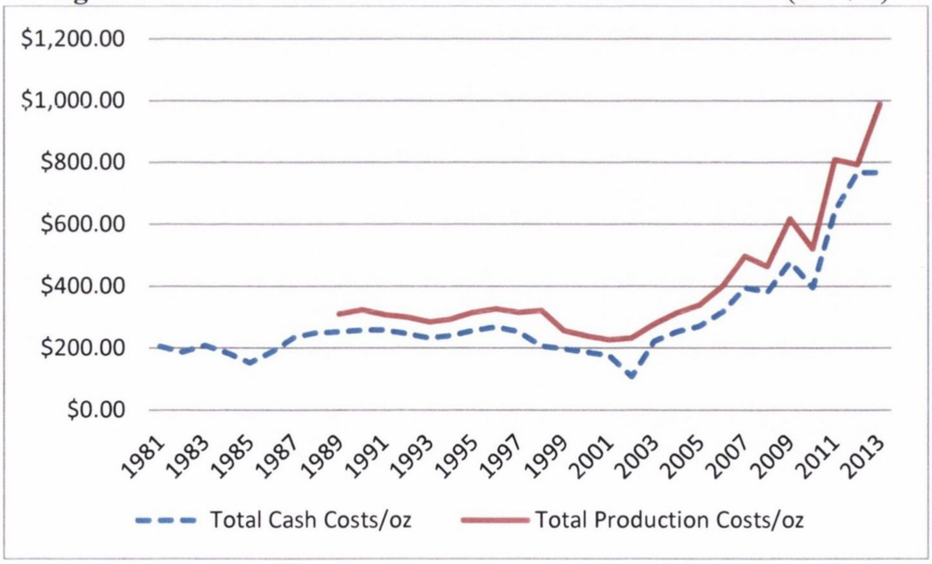
(Aggarwal and Soenen, 1988; Solt and Swanson, 1981). Gold prices are shown to be I(1) over all sample periods.

## 5.2 Cost of Gold Extraction

Chapter 6 assesses for the first time in the literature the causal links between gold prices and the cost of mining new gold. The data set for extraction costs was taken from the Thompson Reuters Gold Fields Minerals Services (GFMS). Some of the data is also available from the GFMS Annual Gold Surveys over a longer period and is used to lengthen the data sets where available. Two measures of extraction costs are used: Cash Costs and Total Production Costs.

Cash Costs are defined as "Mine cash expenses (mining, ore, processing, on site general administrative costs), refining, charges, royalties and production taxes, net of by-product credits" (GFMS, 2014b:52). Total Production Costs are Cash Costs plus depreciation, amortisation and reclamation of cost provisions. These are both measured as the US dollar cost of extracting one ounce of gold. The world average for Cash Costs and Total Production Costs are presented below in Figure 17 and can be seen to strongly co-move. These world averages represent the production volume weighted average of the individual mines' costs.

**Figure 17:** Total Cash Costs versus Total Production Costs (US $'s)



Mining costs for this thesis are collected from two related GFMS sources and are provided in nominal US Dollars. Longer term data is available for some larger gold producing countries in the annual GFMS Gold Surveys (1989 – 2014), with World Average Cash Costs available from 1981 – 2013 and the longest country data available (for South Africa) between 1983 and 2013. Data is also available for a wider selection of countries not covered in the GFMS Gold Surveys from the Thomson Reuters GFMS Mine Economics Database over a period covering 2000-2013 at an annual level. Firm-level data is also obtained from the Thomson Reuters database between 2000 and 2013.

24 countries and 32 companies are covered by this analysis, all the countries and companies for which time-series data is available from at least 2000 on. These are listed in the tables of results in Chapter 6. GFMS gather data at a mine level and aggregate the data based on mine location for country level statistics and mine ownership for companies. The annual data is on a calendar and not fiscal year basis. Selvanathan and Selvanathan (1999) have examined the relationship between gold production volume and gold prices in Western Australia and show that changes in production volume in response to price changes happen over a number of years so that annual data seems to be appropriate to capture the relationship between changes in costs and prices.

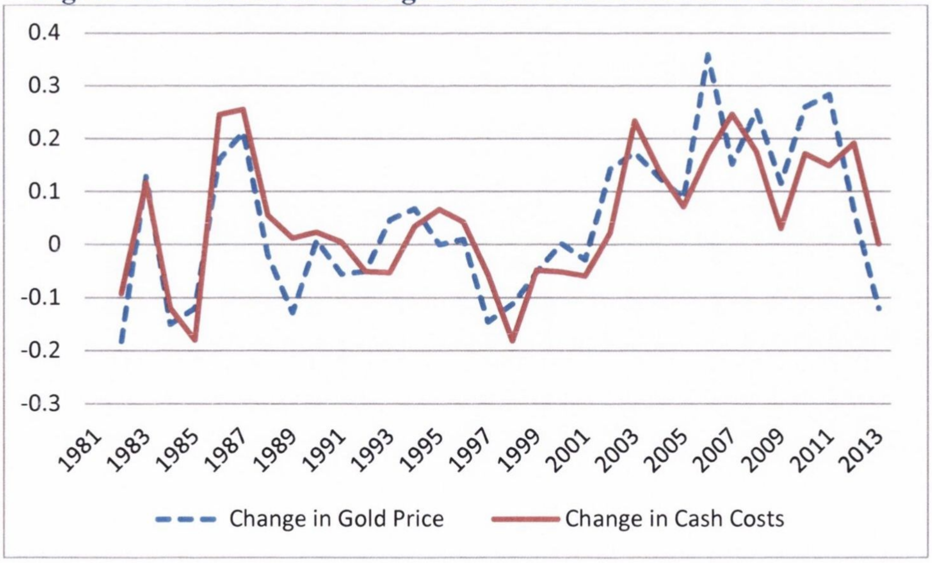
The two sets of data (country and company) are then based on the same underlying dataset with the country and company data representing a total production of 48 and 32 million troy ounces in 2013 respectively. 2013 World Average Cash Costs and Total Production Costs are broken down into their constituent parts in Table 2 below.

**Table 2 - Breakdown of Cash and Total Production Costs. 2013 $'s per ounce**

| | |
|---|---|
| Mining | 353 |
| Ore Processing | 249 |
| General & Administration | 129 |
| **Mine Site Cash Cost** | **731** |
| Smelting and Refining | 15 |
| By-Product Credits | -23 |
| Royalties | 44 |
| **Cash Cost** | **767** |
| Depreciation/Amortisation, Inventory Change | 222 |
| **Total Production Cost** | **989** |

The figure below presents changes in the US Dollar gold price and changes in average world cash costs and seems to provide a preliminary indication that gold prices do in fact move first.

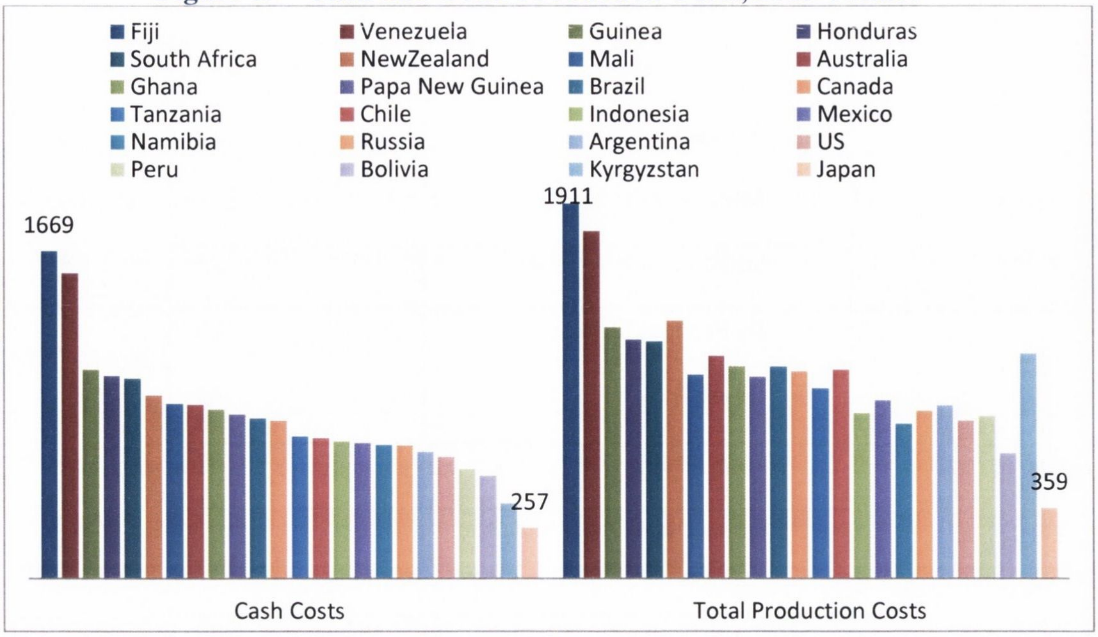
**Figure 18 - Annual % Change in Gold Price and Total Cash Costs**




*Source: GFMS gold Surveys 2014-1989*

Figure 19, below, shows the 2013 cash and total production costs of all countries in the sample. We can see that there is wide variation between countries.

### Figure 19 - Cash and Total Production Costs, 2013 Tonnes




### Table 3- ADF Tests for Country Level Costs Data

| | Level | Δ | Level | Δ |
|---|---|---|---|---|
| Gold Price | 0.60581 | -4.062** | | |
| | Cash Costs | | Total Prod. Costs | |
| **Panel A: Between 34-23 Observations** | | | | |
| World | 1.329 | -6.681*** | 1.329 | - 10.917*** |
| Australia | 1.604 | -4.157** | 1.422 | -4.157** |
| Canada | 1.465 | -4.098** | 1.261 | -2.059** |
| South Africa | 2.454 | -6.716*** | 0.926 | -4.023** |
| United States | 1.150 | -4.386*** | 1.431 | -3.650** |
| Other | 0.632 | -4.126** | 1.637 | -4.312** |
| **Panel B: 14 Observations** | | | | |
| Argentina | 2.238 | -4.236** | 3.445 | -5.850*** |
| Brazil | 1.714 | -4.713** | 2.056 | -1.671* |
| Bolivia | 0.274 | -2.618** | 0.028 | -2.581** |
| Chile | 1.814 | -7.013*** | 0.561 | -6.223*** |

| | | | | |
|---|---|---|---|---|
| Ghana | 2.436 | -4.030** | 2.606 | -3.636* |
| Guinea | 1.487 | -5.288*** | 1.326 | -4.123** |
| Honduras | 3.562 | -3.395** | 3.492 | -3.400** |
| Indonesia | 1.716 | -3.920** | 1.610 | -3.902** |
| Japan | 0.904 | -1.994** | 3.125 | -5.433*** |
| Kyrgyzstan | 0.110 | -2.775** | 1.444 | -3.026* |
| Mali | 0.722 | -1.481* | 1.388 | -1.177* |
| Mexico | 1.290 | -3.389* | 1.165 | -2.782* |
| New Zealand | 3.067 | -2.484** | 3.006 | -2.322** |
| Peru | 4.712 | -2.898* | 1.932 | -4.612** |
| PNG | 1.895 | -2.045** | 1.068 | -4.039** |
| Russia | 3.024 | -3.495* | 2.534 | -3.013* |
| Tanzania | 1.283 | -3.943** | 2.354 | -5.933*** |

*Note: t-statistics given with ***, ** and * indicating significance at 1%, 5% and 10% levels. "Other" represents all other countries cover by Thomson Reuters GFMS but not listed in Panel A.*

Above, in Table 3, the ADF tests for all cash and total production costs for all countries in the sample are presented, firstly as time series variables and then as a panel. The time series test statistics shows that all variables exhibit a unit-root in levels and are stationary if measured in first differences. The same pattern holds for the panel unit root test results.

**Table 4 - Country Panel Unit Root tests - IPS**

| Variable | Without Trend | With Trend |
|---|---|---|
| **Annual Gold Price** | -0.234 (1) | 6.0366 (2) |
| **Δ Annual Gold Price** | -2.918** (1) | -8.250** (2) |
| **Annual Cash Costs** | 10.360 (2) | 0.830 (2) |
| **Δ Annual Cash Costs** | -6.750** (1) | -7.835** (2) |
| **Annual Total Production Costs** | 12.035 (2) | 0.397 (2) |
| **Δ Annual Total Production Costs** | -8.067** (2) | -7.931** (2) |

*Note: IPS statistic with the maximum lag length for each panel member in brackets. Where **and * indicates significance at 1% and 5% level.*

The below tables (5 and 6) show the ADF tests for a sample of the company level data as time series followed by the IPS unit root tests for the data as a panel. Variables are again found to be I(1) in levels and I(0) in differences.

**Table 5 - ADF test results – Company Level Data**

| | Country | Level | 1st Difference | Level | 1st Difference |
|---|---|---|---|---|---|
| **Gold Price** | - | 0.605 | -4.062** | | - |
| **Panel A: Top 10 Producers by volume** | | | | | |
| | | **Cash Costs** | | **Total Production Costs** | |
| **Barrick Gold** | CAD | 0.737 | -5.438*** | 0.255 | -5.521*** |
| **Newmont Gold** | USA | 1.039 | -4.716** | 0.885 | -4.139** |
| **Anglo Gold Ashanti** | RSA | 1.651 | -3.398* | 1.497 | -3.232 |
| **Goldcorp** | RSA | 1.630 | -3.038* | 1.107 | -2.719* |
| **Kinross Gold** | CAN | 1.799 | -3.828** | 3.540 | -4.510** |
| **Newcrest** | AUS | 2.826 | -4.036** | 2.551 | -3.830** |
| **Gold Fields** | RSA | 0.870 | -2.707* | 0.822 | -2.725* |
| **Harmony Gold** | RSA | 1.657 | -3.045* | 1.619 | -3.073* |
| **Yamana Gold** | CAN | 3.086 | -4.535** | 1.583 | -5.939*** |
| **Iamgold** | CAD | 3.296 | -2.962 | 3.197 | -3.773** |
| **Panel B: 5 Smaller Producers** | | | | | |
| **Claude Resources** | CAD | 2.539 | -2.937* | 2.456 | -3.873** |
| **IFC** | Swiss | 3.986 | -3.871** | 4.319 | -4.854** |
| **PT Antam** | Indo | 1.136 | -4.288** | 1.849 | -4.257** |
| **Kingsgate Consolidated** | AUS | 1.990 | -3.629** | 3.195 | -3.170** |
| **DRD Gold** | RSA | 0.391 | -2.395 | 0.138 | -1.672* |

****, ** and * indicates significance at 1%, 5% and 10% level.*

**Table 6 - Company Panel Unit Root tests - IPS**

| Variable | Without Trend | With Trend |
|---|---|---|
| Annual Cash Costs | 12.956 (2) | 0.124 (1) |
| *Δ* Annual Cash Costs | -10.639** (1) | -11.48 ** (1) |
| Annual Total Production Costs | 12.862 (2) | 0.293 *(1) |
| *Δ* Annual Total Production Costs | -8.444** (1) | -10.157** (1) |

*Note: IPS statistic with the maximum lag length for each panel member in brackets. Where **and * indicates significance at 1% and 5% level.*

## 5.3 Spot-Futures

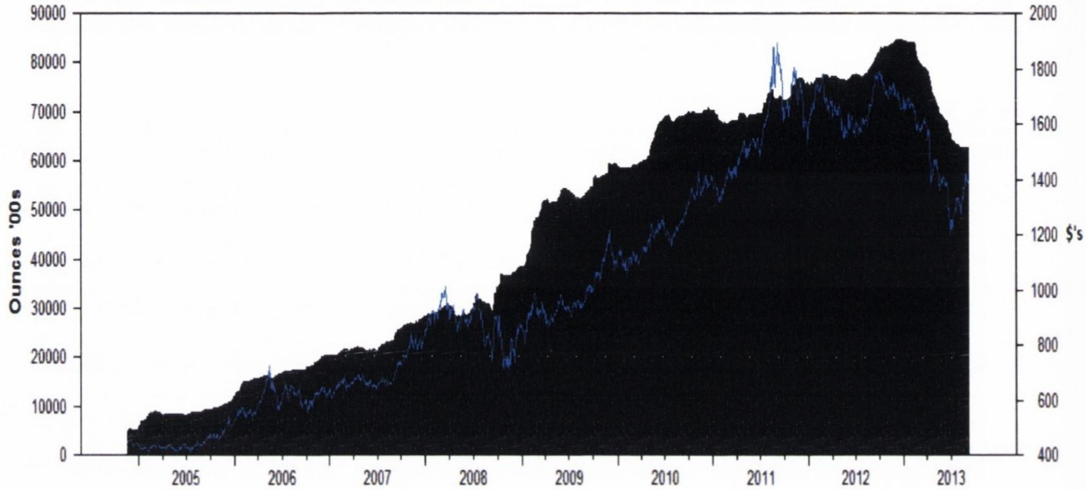
Forward prices for gold are calculated using the Gold Offer Forward Rate (GOFO) in conjunction with the London fixings spot price. GOFO represents the annualised percentage premium over (or under) the spot gold price that market making members of the London gold market will lend as a swap for US Dollars (LBMA, 2008). It is formed in an equivalent manner to the London Interbank Offer Rate (LIBOR). Market Makers submit their mean GOFO quotes, the highest and lowest are dropped and an average is calculated from the remaining quotes. This is published at 11am each morning by the LBMA.

We use the 1, 3, 6, and 12 months Gold Offer Forward Rate's (GOFO) at a daily frequency with data available for over about a quarter century running from the markets official inception on 17$^{th}$ of July 1989 until the end of June 2013.

The forward prices are calculated following the market convention of a 360 day year and a 30 day month (LBMA, 2008). Where the delivery date for a forward contract is a non-business day, the value used for delivery is the next good business day as is done in normal trading. This means that at times the delivery price can be constant for 2 or 3 days at a time. As in Aggarwal and Zong (2008), to make our results robust to this fact we estimate all models at a daily frequency corrected to show the market price for delivery on a given day and at a weekly frequency taking the Wednesday value which does not require correction.

To control for risk aversion in some of the models used in Chapter 8 the Chicago Board Options Exchange market volatility index, commonly referred to as the VIX, is used. Whaley (2000) provides a detailed explanation of the VIX. It measures the expected future volatility over the next 30 calendar days implied by the market, using S&P500 100 index options as a proxy for the market. This data point gives a good measure of the level of risk aversion in the market at any given time. This data is used from the beginning of its availability, from 1990 to June 2013.

**Figure 20 –**
**Total Exchange Traded Fund Gold Holdings and PM Fixing, Ounces '000s**




*Source: Bloomberg, LBMA*

The emergence of Gold ETFs in 2004, discussed in Chapter 2, created a very visible new source of demand for gold. As shown in Figure 2 above ETF gold holdings have increased dramatically since their inception with a peak in their combined stocks of over 84 million ounces in early 2013. Outflows from ETFs since then have coincided with large falls in the gold price raising the possibility that this provides easily accessible information for investors about the general market for gold to use in their decision making. Total ETF gold holdings data were downloaded from Bloomberg and run from November 2004 to June 2013.

This data is used to assess whether changes in ETF gold holdings contain information on investor mood. Below we provide descriptive statistics in Table 7 for gold forward prices, VIX and changes in Gold ETF holdings over our sample at the daily frequency. For this study we examined 67 ETFs reported gold holdings on a daily basis, all downloaded from Bloomberg. This data was corrected so that it reflected information coming to the market as discussed in 4.8.5.

**Table 7 -Descriptive statistics for gold daily data**

| | 1 Month Gold | 3 Month Gold | 6 Month Gold | 12 Month Gold | VIX | Change in ETF Holdings |
|---|---|---|---|---|---|---|
| **Mean** | 591.47 | 593.51 | 596.93 | 604.08 | 20.29 | 25.29763 |
| **ST. Deviation** | 400.01 | 400.09 | 400.24 | 399.56 | 8.079 | 189.5209 |
| **Skewness** | 1.718 | 1.717 | 1.71 | 1.694 | 1.998 | 1.888 |
| **Kurtosis** | 1.811 | 1.813 | 1.797 | 1.747 | 7.064 | 22.63 |
| **Obs.** | 6250 | 6250 | 6250 | 6250 | 6134 | 2291 |

Forecast Errors (FE) and Forecast Revisions (FR) are calculated following Aggarwal and Zong (2008) but due to the work in this thesis using 4 forward maturities rather than 1 a slightly different notation is needed. The FE for the 12 month forward rate (FE, 12m in Table 8 below) is calculated as the difference between the predicted spot rate at t and the realised rate at t+1 (${}_tF_{t+1}$ - $S_{t+1}$). The $FE_t$ is the forecast error made in the markets prediction of the spot rate at time t, but not observed until t+1.

FR's are calculated as the change in the *prediction* of a future spot price at t+1, calculated as follows. At t-1 market participants form an expectation of the spot rate at t and t+1, which are ${}_{t-1}F_t$ (which is the forward rate, formed at t-1, which predicts the spot rate at t) and ${}_{t-1}F_{t+1}$ respectively. At t the market revises its expectation of the spot rate for t+1 based on new information. The forward rate for t+1 then changes and is now expressed as ${}_tF_{t+1}$. The change can be shown as the $FR_t = {}_tF_{t+1}.- {}_{t-1}F_{t+1}$.

For example assume that at t-1 the 12 month forward price for gold is $1500 (${}_{t-1}F_{t+1}$) and the 6 month forward price is $1400 (${}_{t-1}F_t$). After 6 months the forward price for gold deliverable at t+1 is the new 6 month contract (${}_tF_{t+1}$). This forward price will be different from the original expectation of $1500 at t-1, say $1450 and this represents ${}_tF_{t+1}$. The FR is then the change in the markets expected price for between t-1 and t calculated as ${}_tF_{t+1}$ - ${}_{t-1}F_{t+1}$, -$50 in this case. This FR is denoted as FR, 12m-6m in table 2 below showing descriptive statistics for all FE's and FR's.

**Table 8 - Descriptive statistics for Forecast Errors and Revisions**

| | FE, 12m | FR, 12m-6m | FE, 6m | FR, 6m-3m | FE, 3m | FR, 3m-1m | FE,1m |
|---|---|---|---|---|---|---|---|
| **Mean** | -38.26 | -17.77 | -17.26 | -8.32 | -7.58 | -5.53 | -2.20 |
| **STDEV** | 116.5 | 80.86 | 83.460 | 57.718 | 60.45 | 50.307 | 38.00 |
| **Skew** | -1.399 | -0.657 | -0.353 | -0.677 | -0.2362 | -0.872 | 0.1671 |
| **Kurt** | 2.857 | 4.618 | 5.669 | 6.228 | 7.167 | 8.437 | 9.102 |
| **Obs.** | 5997 | 6103 | 6125 | 6168 | 6190 | 6189 | 6233 |

Table 9, below, shows the ADF tests for the variables in the section. As expected, the spot and all forward rates are I(1). All forward premiums, changes in spot exchange rates, FE's, FR's and $VIX^2$ are I(0).

**Table 9 - ADF tests**

| | Level | *1st Difference* | | Level | *1st Difference* |
|---|---|---|---|---|---|
| **$VIX^2$** | -9.611*** | - | **$S_3$-$S_1$** | -7.766*** | - |
| **Forward: 1m** | 2.908 | *-37.03**** | **$S_6$-$S_1$** | -4.940*** | - |
| **Forward: 2m** | 2.355 | *-27.11**** | **$S_{12}$-$S_1$** | -3.225*** | - |
| **Forward: 3m** | 2.996 | *-35.41**** | **FE, 12m** | -3.519*** | - |
| **Forward: 6m** | 3.010 | *-35.11**** | **FR, 12m-6m** | -5.509*** | - |
| **Forward: 12m** | 2.612 | *-35.74**** | **FE, 6m** | -4.848*** | - |
| **FP: 1m** | -28.15*** | - | **FR, 6m-3m** | -10.96*** | - |
| **FP: 2m** | -19.70*** | - | **FE, 3m** | -7.811*** | - |
| **FP: 3m** | -17.72*** | - | **FR, 3m-1m** | -15.45*** | - |
| **FP: 6m** | -17.64*** | - | | | |
| **FP: 12m** | -13.43*** | - | | | |

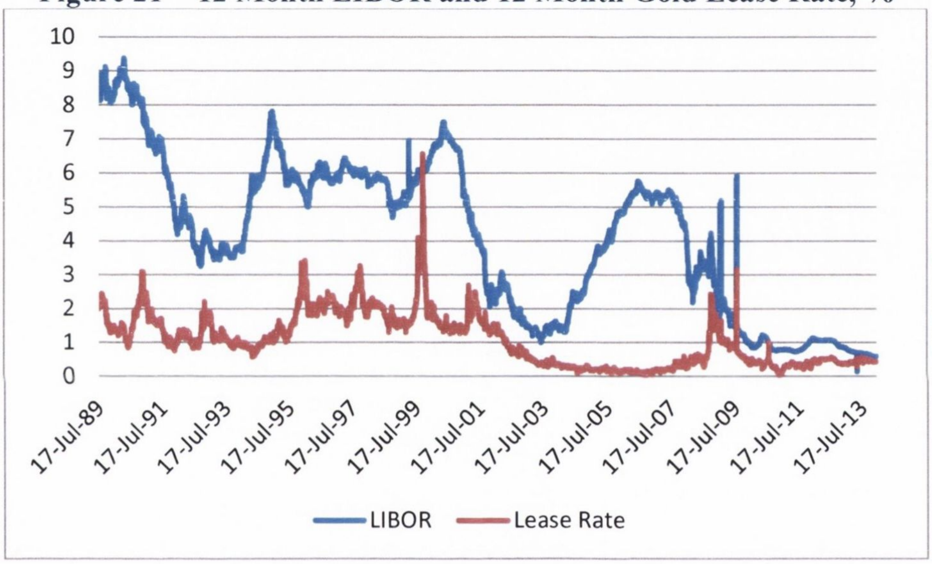
Note: **(***) represent significance at the 5% (1%) levels

## 5.4 Gold Lease Rates

In Chapter 8 it is argued that gold lease rates are the only cashflow available to the holders of gold that represent a market based return. Gold lease rates have not previously been used to assess gold's value from the perspective of a fundamental microeconomic driver. Gold lease rates are the annualised Over The Counter interest rates that can be earned by lending gold over 1, 2, 3, 6 or 12 months. They are technically referred to as derived lease rates, which are calculated daily as the London Interbank Offer Rate (LIBOR) at a given maturity minus the Gold Offer Forward Rate (GOFO) at that maturity (LBMA, 2008). This can be used by an owner of gold to earn a cashflow similar to the dividends or coupon payments that can be earned by owning equities or bonds.

Gold lease rates are derived in theory as follows: A lends US Dollars to B at LIBOR and B lends gold to A at GOFO. At the end of the period both parties return the amount of gold or dollars borrowed plus the interest agreed. The difference is the lease rate (LBMA, 2008). As GOFO is generally lower than LIBOR dollars can usually be borrowed more cheaply in this way. From this we see that the lease rate can be viewed as the market's valuation of gold's worth as collateral for a US Dollar loan. In reality offsetting loans are not necessary; gold is simply lent and borrowed at the lease rate. The evolution of the 12 month LIBOR and gold lease rates are shown below.

**Figure 21 - 12 Month LIBOR and 12 Month Gold Lease Rate, %**




*Source: LBMA.org*

Lease rates normally follow a term structure as can be seen in the below graph of the different gold lease rate maturities from their inception in 1989.

**Figure 22- Gold Lease Rates, %**

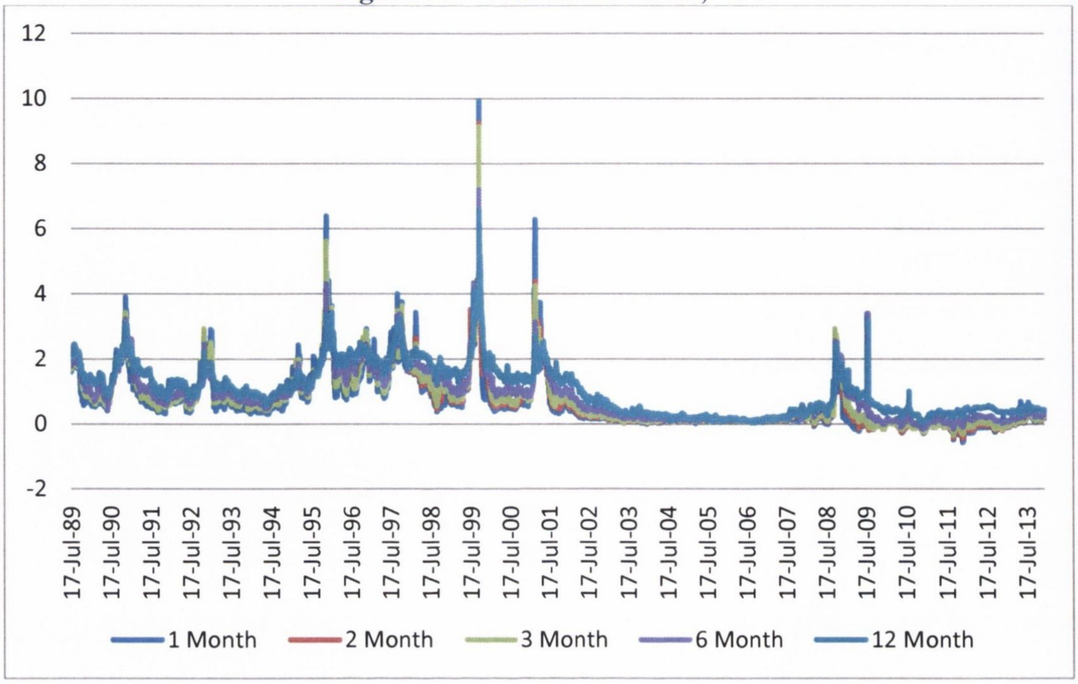



Table 10, below, shows the descriptive statistics for daily gold lease rate data. Data is available from 17th of July 1989 up to the 31st of July 2013 for all variables except the 2 month lease rate which begins on the 2nd of January 1998. The lease rates are all annualised figures. The data is available from the London Bullion Market Association (LBMA) website.

**Table 10- Descriptive statistics for gold lease rates daily data**

| | 1 Month Gold | 3 Month Gold | 6 Month Gold | 12 Month Gold |
|---|---|---|---|---|
| **Mean** | 591.47 | 593.51 | 596.93 | 604.08 |
| **Standard Deviation** | 400.01 | 400.09 | 400.24 | 399.56 |
| **Skewness** | 1.718 | 1.717 | 1.71 | 1.694 |
| **Kurtosis** | 1.811 | 1.813 | 1.797 | 1.747 |
| **ADF Statistic - Level** | -2.632 | -1.383 | -1.746 | -1.003 |
| **ADF Statistic -** | -41.53 | -31.628 | -50.443 | -35.52 |
| **Obs.** | 6250 | 6250 | 6250 | 6250 |

# 6 The Gold and Its Cost of Extraction

This chapter provides the first empirical evidence on the causal relationship between commodity prices and their cost of production. This is possible for gold as the gold mining industry gives very detailed information on a wide variety of data, such as production costs and production volume. The existing literature generally focussed on the gold price exposure of gold mining firms and their hedging strategies [e.g. see Brown, Crabb and Haushalter (2006), Tufano (1996) and Tufano (1998)]. Paish (1938) provided a detailed discussion on the reasons for changes in the costs of production over the past two centuries and their effect on the volume of production, but does not analyse the relationship between the two variables.

Within the literature on gold price formation production costs are rarely considered as a variable, mainly due to the non-availability of a comprehensive and high-frequency data set. This study contributes to the literature by addressing this gap with a previously unused sample of country and firm-level data to provide an analysis of the causal relationship between 2 measures of gold extraction costs and the price of gold. An analysis of the nature and direction of the causal relationships is important to understand the factors that drive gold prices and also, in another research vein, to understand the operations of gold mining firms.

This analysis will also allow us to provide a solution to a dispute in the literature on which of the two hypothesised channels through which gold is linked in the long run to inflation (discussed in detail Section 3.1.1), based on the direction of causality.

## 6.1 Gold and its Production Costs

The two competing theories regarding the causality between prices and production costs were discussed in detail in Section 3.11 and the impact this has on the gold-inflation channel is detailed in Section 3.1.1, so these will only be summarised here.

One theory assumes that production costs lead and determine gold prices, based on the link between gold and inflation (see Levin, Abhyankar and Gosh (1994) and Levin and Wright (2006)). This assumption is also the basis of a theory for the channel through which gold prices are driven by inflation. These authors assume that changes in gold production costs are equal to general inflation over the long-run, allowing them, under this assumption, to build an arbitrage model showing that gold lease rates are a proxy for the real world interest rate. They follow this by positing that in the long term the gold price will rise in order to compensate miners for the increasing costs. This implies a causal relationship running from inflation to the cost of production and on finally to gold prices. Rockoff (1984) and Rockerbie (1999) also argue that the causality runs from production costs to prices. If this relationship is not present or not positive it gives some evidence against this channel, making the alternative of an asset substitution channel the more plausible answer.

This thesis proposes an alternative hypothesis, that gold prices lead and determine production costs. The idea stems from David Ricardo's Law of Rent (Ricardo, 1817). At any given price it can be expected that mines will supply the market up to the point where marginal costs equal marginal benefits and the industry as a whole maximises its economic profit. Ricardo notes at the beginning of chapter 3 that mines are of various qualities. As gold prices rise previously marginal mines, which would previously have been unprofitable, will be brought into production. These would be deeper mines or mines yielding a lower quality of ore. This means that the average cost of extraction for the industry as a whole should rise *after* prices do and *because* of the rise. This would make low cost mines even more profitable and allow overall production to expand to meet demand. Similarly, if gold prices fall it would force high-cost mines to shut down and decrease supply. The opening and closure of mines conditional on the gold price is consistent with the "real option" characteristic embedded in gold mines as described by Brennan and Schwartz (1985).

In addition to the theoretical and academic empirical discussion in 3.1.1 there are practical data based reasons to assume that gold miners do not have the power to determine gold prices. The reaction of gold miners to gold price changes tends to stabilize the price of gold by increasing the supply in rising gold price regimes and decreasing the supply in decreasing gold price regimes.[1] Another argument that gold prices lead production costs is based on the special stock-flow ratio of gold in comparison with other commodities and the implied low market power of gold mining

[1] Paul Krugman states "Placing a ceiling on the value of gold is mining technology, and the prospect that if its price gets out of whack for long on the upside a great deal more of it will be created." (New York Times, December 28, 2013).

firms. Gold is unusual among commodities in having a vastly larger accumulated stock than its annual flow from mines, a fact which is due to the very small amounts of gold that are used up each year to reduce the stock. This is in contrast to other perishable commodities where the annual supply from production is roughly equal to the total supply available that year. It follows that gold miners have low market power and are likely to be price takers rather than price setters (Borenstein and Farrell, 2007 and Blose and Shieh, 1995). Any attempt to run an OPEC-style cartel to try and set prices would be swallowed up by both large historical stocks and market flows coming into the market as prices rose. From the perspective of historical gold stock levels gold miners' supply accounts for about 1.6% of the total estimated stock of gold available as at 2010 (World Gold Council, 2010; GFMS, 2013). Recycled gold allows illiquid jewellery back into circulation to meet increased demand. Indeed as gold prices increased dramatically between 2003 and 2010 the supply of gold from this channel doubled. The total supply from miners in 2014 was 3,022 tonnes while an average day of trading on the London Market is 680 tonnes, not enough to supply that market for one week (GFMS, 2014).

Based on the above theoretical discussion the relationship will be tested empirically and strong support for causality running from gold prices to production costs is found both at a country and firm level. The findings also contribute to the literature on the real option characteristics of mines. The identified direction of causality provides new evidence that real options are regularly exercised, i.e. rising gold prices lead to the opening of new mines and falling prices lead to the closure of existing mines. It is also apparent that in some cases production costs lead gold prices but not in the direction predicted by Levin, Abhyankar and Gosh (1994) and Levin and Wright (2006). These findings are explained through mining companies incorrectly predicting future gold price rises thereby increasing their production and their costs.
This chapter is structured as follows: Section 6.2 presents the country level data results, 6.3 the Company-level data results and discusses the main findings and Section 6.4 summarises the results and provides concluding remarks.

### 6.2 Country-level Results

This section presents the co-integration tests and the Granger causality tests for country level data. The time series estimations for the individual companies will be discussed and followed by the results from the panel estimations as described in Section 4.5. As seen in Chapter 5 all variables are non-stationary, exhibiting a unit-root in levels and are stationary in first differences.

Table 11, below, presents the results of the Johansen co-integration tests between the dollar gold price and each country's cash costs and total production costs, individually. It shows that gold and either cash cost or total production costs are rarely co-integrated. For the longer time-series presented in Panel B none of the series are co-integrated. Considering the large number of individual time-series estimations, it is unlikely that production costs and gold prices have a long-run equilibrium relationship. In addition, it is theoretically unclear which forces would create such equilibrium.

A long-run relationship would also imply that there is a long-run profit margin, the difference between costs and prices. Over time this is likely to have changed; for instance as a result of a change in industry hedging practices, as begun by Barrick Gold under Peter Munk (see Economist, 2014).

## Table 11 - Johansen Co-integration – Country Data

| | r | Total Cash Costs | Total Production Costs | | r | Total Cash Costs | Total Production Costs |
|---|---|---|---|---|---|---|---|
| **Panel A: 14 Observations** | | | | **Panel B: Between 34-23 Observations** | | | |
| Argentina | 0 | 0.158 | 0.215 | World | 0 | 0.258 | 0.124 |
| | 1 | 0.515 | 0.525 | | 1 | 0.265 | 0.800 |
| Australia | 0 | 0.156 | 0.158 | Australia | 0 | 0.123 | 0.370 |
| | 1 | 0.760 | 0.515 | | 1 | 0.313 | 0.624 |
| Brazil | 0 | 0.159 | 0.007 | Canada | 0 | 0.180 | 0.156 |
| | 1 | 0.717 | 0.535 | | 1 | 0.613 | 0.605 |
| Bolivia | 0 | 0.027 | 0.205 | South Africa | 0 | 0.228 | 0.293 |
| | 1 | 0.962 | 0.432 | | 1 | 0.371 | 0.343 |
| Canada | 0 | 0.040 | 0.008 | United States | 0 | 0.619 | 0.575 |
| | 1 | 0.584 | 0.266 | | 1 | 0.764 | 0.898 |
| Chile | 0 | 0.121 | 0.063 | Other | 0 | 0.113 | 0.449 |
| | 1 | 0.153 | 0.192 | | 1 | 0.147 | 0.960 |
| Ghana | 0 | 0.089 | 0.465 | | | | |
| | 1 | 0.275 | 0.460 | | | | |
| Guinea | 0 | 0.040 | 0.044 | | | | |
| | 1 | 0.451 | 0.470 | | | | |
| Honduras | 0 | 0.116 | 0.049 | | | | |
| | 1 | 0.379 | 0.915 | | | | |
| Indonesia | 0 | 0.643 | 0.835 | | | | |
| | 1 | 0.626 | 0.594 | | | | |
| Japan | 0 | 0.474 | 0.776 | | | | |
| | 1 | 0.868 | 0.820 | | | | |
| Kyrgyzstan | 0 | 0.487 | 0.139 | | | | |
| | 1 | 0.890 | 0.583 | | | | |
| Mali | 0 | 0.048 | 0.004 | | | | |
| | 1 | 0.848 | 0.343 | | | | |
| Mexico | 0 | 0.334 | 0.236 | | | | |
| | 1 | 0.568 | 0.520 | | | | |

| | | | |
|---|---|---|---|
| New Zealand | 0 | 0.006 | 0.004 |
| | 1 | 0.599 | 0.720 |
| Peru | 0 | 0.002 | 0.006 |
| | 1 | 0.234 | 0.594 |
| PNG | 0 | 0.160 | 0.222 |
| | 1 | 0.220 | 0.758 |
| Russia | 0 | 0.100 | 0.632 |
| | 1 | 0.379 | 0.738 |
| Tanzania | 0 | 0.000 | 0.006 |
| | 1 | 0.399 | 0.931 |

*Note: Values shown are p-values. "Other" is a GFMS constructed variable and represents all other countries covered by Thomson Reuters GFMS but not listed in Panel A or B.*

**Table 12- Country Panel Cointegration Tests – Costs and Gold price - Pedroni**

| **Statistic – Within Dimension** | **Cash Costs** | **Total Production Costs** |
|---|---|---|
| *Panel-v Statistic* | 4.46 | 5.29 |
| *Panel- ρ Statistic* | 2.13 | 2.06 |
| *Panel- PP Statistic* | 1.24 | 1.23 |
| *Panel- ADF Statistic* | -5.15*** | -4.77*** |
| **Statistic – Between Dimension** | | |
| *Group- ρ Statistic* | 3.68 | 3.86 |
| *Group - PP Statistic* | 2.54 | 2.72 |
| *Group - ADF Statistic* | -4.76*** | -4.62*** |

*Where ***, ** and * indicates significance at 1%, 5% and 10% level.*

From Table 12, above, it is concluded that gold and extraction costs are not co-integrated as a panel, as 5 of the 7 panel cointegration measures are insignificant, following Apergis and Payne (2009). However the panel causality tests which follow were also run as VECM's to assess if this assumption affects the results. The conclusions remain unchanged and the ECM term is insignificantly different from zero.

The Granger causality test results are presented in Table 13 below. Panel A presents results for the countries with longer time-series available, Panel B discusses the shorter time-series countries and Panel C presents the results from the panel estimations. The F-value assesses whether the estimated coefficients on the lags are jointly statistically significantly different from zero. $\delta$ represents the p-value of the ECM term, which is only estimated if the pair are cointegrated. This p-value needs to be significant in order for causality to exist as per the earlier discussion in Section 4.4. The final column shows the sum of the lags in the model which is interpreted below. The symbol "->" represents causes.

The longest available time-series is World Cash Costs. The series starts in 1981 and covers the widest cross-section of gold production, as all mines surveyed are included in this aggregated figure not just those for whom a continuous data set is available over the full sample period. The world average is weighted on the basis of the level of production. The results show that the price of gold causes the cost of production and not vice versa. For every $1 increase in the gold price, average world cash costs are shown to increase by just over $0.36 over the following two years. For World Production Costs the increase is $0.44 which makes sense as total production costs are always higher than cash costs (see Section 5.2). In fact when we look at the data for the countries with the longer time-series all have a very similar finding with significant F-statistics and positive coefficients for the gold price causing production costs.

Table 13 - Granger causality between Gold Price and Production Costs

| | F- Value | $\delta$ | Lags | Σ coeff. |
|---|---|---|---|---|
| **Panel A: Longer Data set - 23-30 Observations** | | | | |
| World Cash Costs -> Gold Price | 1.007 | - | 2 | - |
| Gold Price -> World Cash Costs | 7.332*** | - | 2 | 0.365 |
| World Total Production Costs -> Gold Price | 0.209 | - | 2 | - |
| Gold Price -> World Total Production Costs | 7.962*** | - | 2 | 0.442 |
| | | | | |
| Australia Cash Costs -> Gold Price | 3.887* | - | 1 | -1.071 |
| Gold Price -> Australia Cash Costs | 23.711*** | - | 1 | 0.592 |
| Australia Total Production Costs -> Gold Price | 3.329* | - | 1 | -0.847 |
| Gold Price -> Australia Total Production Costs | 24.895*** | - | 1 | 0.748 |
| | | | | |
| Canada Cash Costs -> Gold Price | 1.999 | - | 2 | - |
| Gold Price -> Canada Cash Costs | 9.851*** | - | 2 | 0.500 |
| Canada Total Production Costs -> Gold Price | 3.001 | - | 1 | - |
| Gold Price -> Canada Total Production Costs | 12.485*** | - | 1 | 0.584 |
| | | | | |
| South Africa Cash Costs -> Gold Price | 0.017 | - | 1 | - |
| Gold Price -> South Africa Cash Costs | 10.873*** | - | 1 | 0.554 |
| South Africa Total Production Costs -> Gold Price | 0.035 | - | 1 | - |
| Gold Price -> South Africa Total Production Costs | 10.996*** | - | 1 | 0.638 |
| | | | | |
| United States Cash Costs -> Gold Price | 0.067 | - | 1 | - |

| | | | | |
|---|---|---|---|---|
| Gold Price -> United States Cash Costs | 5.072** | - | 1 | 0.137 |
| United States Total Production Costs ->Gold Price | 0.094 | - | 1 | - |
| Gold Price -> United States Total Production Costs | 5.273** | - | 1 | 0.127 |
| | | | | |
| Other Cash Costs -> Gold Price | 3.633* | - | 1 | -1.574 |
| Gold Price -> Other Cash Costs | 26.67*** | - | 1 | 0.428 |
| Other Total Production Costs -> Gold Price | 4.135* | - | 1 | -1.079 |
| Gold Price -> Other Total Production Costs | 26.785*** | - | 1 | 0.4670 |
| **Panel B: Shorter Data set - 14 Observations** | | | | |
| Argentina Cash Costs -> Gold Price | 4.006 | - | 1 | - |
| Gold Price -> Argentina Cash Costs | 2.400 | - | 1 | - |
| Argentina Total Production Costs -> Gold Price | 6.007** | - | 1 | -0.884 |
| Gold Price -> Argentina Total Production Costs | 3.935* | - | 1 | 0.578 |
| | | | | |
| Brazil Cash Costs -> Gold Price | 1.330 | - | 2 | - |
| Gold Price -> Brazil Cash Costs | 3.970* | - | 2 | - |
| Brazil Total Production Costs -> Gold Price | 1.737 | [0.536] | 2 | - |
| Gold Price -> Brazil Total Production Costs | 2.968 | [0.918] | 2 | - |
| | | | | |
| Bolivia Cash Costs --> Gold Price | 0.573 | [0.325] | 3 | - |
| Gold Price -> Bolivia Cash Costs | 0.573 | [0.145] | 3 | - |
| Bolivia Total Production Costs -> Gold Price | 3.476 | - | 3 | - |
| Gold Price -> Bolivia Total Production Costs | 0.281 | - | 3 | - |
| | | | | |

| | | | | |
|---|---|---|---|---|
| Chile Cash Costs -> Gold Price | 2.732 | - | 3 | - |
| Gold Price -> Chile Cash Costs | 6.187* | - | 3 | 0.740 |
| Chile Total Production Costs -> Gold Price | 9.876* | [0.220] | 3 | 0.856 |
| Gold Price -> Chile Total Production Costs | 33.976** | [0.051] | 3 | 1.225 |
| | | | | |
| Ghana Cash Costs -> Gold Price | 1.940 | - | 1 | - |
| Gold Price -> Ghana Cash Costs | 5.372** | - | 1 | 0.378 |
| Ghana Total Production Costs -> Gold Price | 6.319** | [0.029] | 1 | -2.029 |
| Gold Price -> Ghana Total Production Costs | 1.771 | [0.554] | 1 | - |
| | | | | |
| Guinea Cash Costs -> Gold Price | 6.364** | [0.212] | 1 | -1.613 |
| Gold Price -> Guinea Cash Costs | 0.050 | [0.031] | 1 | - |
| Guinea Total Production Costs -> Gold Price | 4.190* | [0.362] | 1 | -1.279 |
| Gold Price -> Guinea Total Production Costs | 0.456 | [0.125] | 1 | - |
| | | | | |
| Honduras Cash Costs -> Gold Price | 1.426 | - | 3 | - |
| Gold Price -> Honduras Cash Costs | 8.514* | - | 3 | 1.835 |
| Honduras Total Production Costs -> Gold Price | 2.178 | [0.552] | 2 | - |
| Gold Price -> Honduras Total Production Costs | 0.842 | [0.249] | 2 | - |
| | | | | |
| Indonesia Cash Costs --> Gold Price | 1.483 | - | 3 | - |
| Gold Price --> Indonesia Cash Costs | 24.957** | - | 3 | 1.243 |
| Indonesia Total Production Costs -> Gold Price | 0.488 | - | 3 | - |

| | | | | |
|---|---|---|---|---|
| Gold Price -> Indonesia Total Production Costs | 10.494* | - | 3 | 2.149 |
| | | | | |
| Japan Cash Costs -> Gold Price | 0.091 | - | 1 | - |
| Gold Price -> Japan Cash Costs | 0.0007 | - | 1 | - |
| Japan Total Production Costs -> Gold Price | 2.861 | - | 3 | - |
| Gold Price -> Japan Total Production Costs | 0.460 | - | 3 | - |
| | | | | |
| Kyrgyzstan Cash Costs -> Gold Price | 2.767 | - | 1 | - |
| Gold Price -> Kyrgyzstan Cash Costs | 0.201 | - | 1 | - |
| Kyrgyzstan Total Production Costs -> Gold Price | 11.774*** | - | 1 | -0.610 |
| Gold Price -> Kyrgyzstan Total Production Costs | 5.021** | - | 1 | 1.037 |
| | | | | |
| Mali Cash Costs -> Gold Price | 0.391 | [0.654] | 2 | - |
| Gold Price -> Mali Cash Costs | 0.206 | [0.408] | 2 | - |
| Mali Total Production Costs -> Gold Price | 0.857 | [0.791] | 2 | - |
| Gold Price -> Mali Total Production Costs | 0.164 | [0.281] | 2 | - |
| | | | | |
| Mexico Cash Costs -> Gold Price | 0.045 | - | 1 | - |
| Gold Price -> Mexico Cash Costs | 4.949* | - | 1 | 0.270 |
| Mexico Total Production Costs -> Gold Price | 0.060 | - | 1 | - |
| Gold Price -> Mexico Total Production Costs | 3.681* | - | 1 | 0.345 |
| | | | | |
| New Zealand Cash Costs -> Gold Price | 4.925* | [0.022] | 1 | 1.561 |
| Gold Price -> New Zealand Cash Costs | 3.264* | [0.000] | 1 | -0.557 |

| | | | | |
|---|---|---|---|---|
| New Zealand Total Production Costs -> Gold Price | 1.065 | [0.130] | 1 | - |
| Gold Price-> New Zealand Total Production Cost | 0.888 | [0.001] | 1 | - |
| Peru Cash Costs -> Gold Price | 1.742 | [0.505] | 1 | - |
| Gold Price-> Peru Cash Costs | 3.417 | [0.011] | 1 | - |
| Peru Total Production Costs -/--> Gold Price | 0.0009 | [0.231] | 1 | - |
| Gold Price -/--> Peru Total Production Costs | 0.162 | [0.018] | 1 | - |
| PNG Cash Costs -/--> Gold Price | 1.742 | [0.505] | 1 | - |
| Gold Price -/--> PNG Cash Costs | 3.417 | [0.011] | 1 | - |
| PNG Total Production Costs -> Gold Price | 0.700 | - | | - |
| Gold Price -> PNG Total Production Costs | 5.955* | - | | 0.708 |
| Russia Cash Costs -> Gold Price | 0.677 | - | 1 | - |
| Gold Price-> Russia Cash Costs | 0.165 | - | 1 | - |
| Russia Total Production Costs-> Gold Price | 1.251 | - | 1 | - |
| Gold Price -> Russia Total Production Costs | 0.004 | - | 1 | - |
| Tanzania Cash Costs-> Gold Price | 35.53*** | [0.000] | 1 | -1.615 |
| Gold Price-> Tanzania Cash Costs | 0.962 | [0.874] | 1 | - |
| Tanzania Total Production Costs -> Gold Price | 17.025*** | [0.004] | 1 | -1.395 |
| Gold Price -> Tanzania Total Production Costs | 2.786 | [0.962] | 1 | - |
| **Panel C: Panel Data Results** | | | | |
| Cash Costs -> Gold Price | 17.05*** | - | 1 | -0.337 |
| Gold Price -> Cash Costs | 26.21*** | - | 1 | 0.329 |
| Total Production Costs -> Gold Price | 25.02*** | - | 1 | -0.353 |
| Gold Price -/--> Total Production Costs | 38.28*** | - | 1 | 0.492 |

****, ** and * indicates significance at 1%, 5% and 10% level. Lags for the panel results were chosen via likelihood ratio tests described by Sims (1980). A maximum number of 4 lags were considered and the restriction that a lower-order system compared to a higher-order was tested, indicating one lag.*

For Australia and the Other[2] group of countries we also see that costs are driving gold prices, but only at the 10% level. In addition, the relationship is negative where Levin and Wright (2006) predicted a positive relationship. This implies that if cash costs rise in a given year gold prices fall in the following one. While this could be interpreted as a causal relationship it seems unlikely that miners would aim to increase their extraction costs before a price fall intentionally. Instead this result is interpreted here as indicative of an inability to predict prices on the part of miners; with some miners opening new expensive mines before subsequent price falls. However this is not shown to be the case in the US, Canada or South Africa, three of the largest gold mining countries over the period examined.

For the shorter time series results presented in Panel B we can see that for many countries, such as Chile, the same pattern holds with changes in cash costs or total production costs caused by gold price changes. However, in many cases no causality is found, possibly due to the shorter dataset. On a number of occasions, such as for Argentina, total production costs are shown to lead gold prices but with a negative sign, i.e. a $1 increase in Argentina's total production costs is causing or preceding a $0.88 fall in the gold price. This again points to a lack of forecasting ability on the part of Argentinian miners. A number of other countries also show a negative relationship running from costs to price but they are significant only at the 10% level.

The panel data results shown in Panel C cover the period 2000 to 2013 for all the above countries listed in Panels A and B. Here we again see clearly that changes in gold prices cause extraction costs and in the expected direction. We see evidence that there is a negative causal relationship running from extraction costs to prices and due to the increased power of the tests the results are significant at the 1% level.

[2] *"Other" is a GFMS constructed variable and represents all other countries covered by Thomson Reuters GFMS but not listed in Panel A or B of table 13.*

The panel data results are, however, unweighted for the level of production in any given country so that Kyrgyzstan, with 11.3 tonnes of gold production, and the US, with 231.3 tonnes of gold produced in 2013 (GFMS, 2014a), enter the calculations as equally important. These results together with the Others in Panel A, a group of smaller producer countries, may imply that the negative relationship running from costs to prices is more common in small producer countries. When the world average production costs are used only prices are shown to drive costs and these seem more believable for a number of reasons.

The World Cash Costs and World Total production Costs time series is a more complete dataset, covering all mines in the GFMS survey not just those in the countries listed above, with weightings for levels of production in each country. In addition it reflects the effect of average global costs on the world gold price, which it seems would be of more interest to the global investment community.

### 6.3 Firm-level Results

For the company data we present time-series results for the top 10 producers in our sample by volume as well as 5 of the smaller producers, with their 2013 production levels shown in Figure 23 below. The full set of 30 companies is used in the panel estimations. Figure X below gives a graphical representation of their relative levels of production, with a significant drop from Iamgold (the 10th largest producer in the sample) to Consolidated Goldfields, the first of the smaller producers.

Figure 23 - Annual company gold production, Tonnes

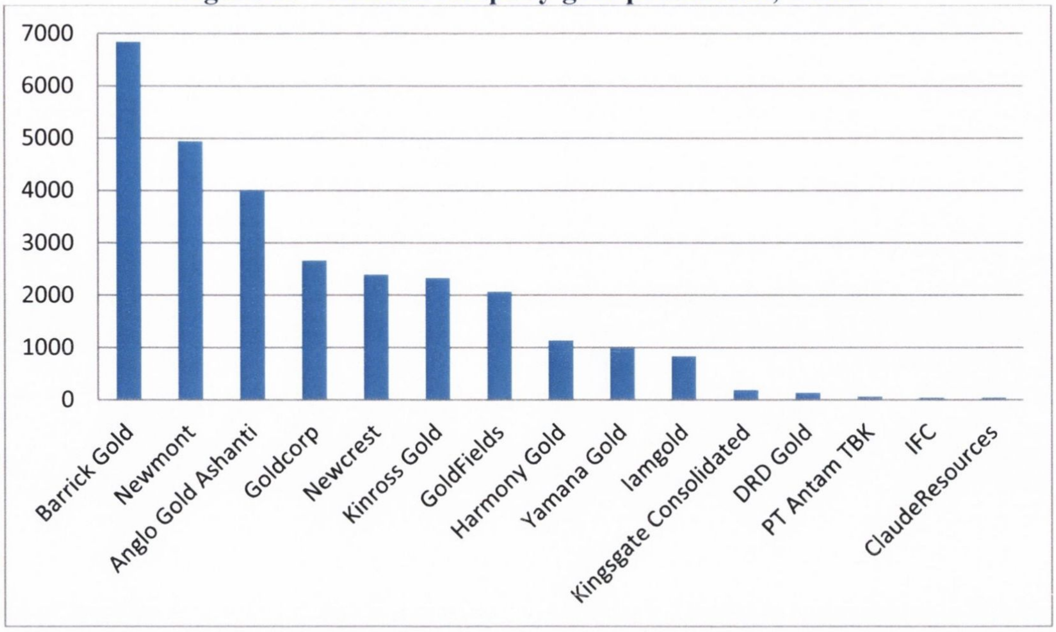



Table 14 -Co-integration results for costs and the gold price: Company data

| | Country | r | Cash Costs | Total Prod. Costs |
|---|---|---|---|---|
| Panel A: Top 10 Producers by volume | | | | |
| **Barrick Gold** | CAD | 0 | 0.019 | 0.030 |
| | | 1 | 0.566 | 0.575 |
| **Newmont Gold** | USA | 0 | 0.350 | 0.052 |
| | | 1 | 0.380 | 0.656 |
| **Anglo Gold Ashanti** | RSA | 0 | 0.256 | 0.382 |
| | | 1 | 0.530 | 0.699 |
| **Goldcorp** | RSA | 0 | 0.013 | 0.051 |
| | | 1 | 0.611 | 0.131 |
| **Kinross Gold** | CAN | 0 | 0.001 | 0.000 |
| | | 1 | 0.256 | 0.227 |
| **Newcrest** | AUS | 0 | 0.484 | 0.572 |
| | | 1 | 0.611 | 0.922 |
| **Gold Fields** | RSA | 0 | 0.581 | 0.185 |
| | | 1 | 0.466 | 0.247 |
| **Harmony Gold** | RSA | 0 | 0.683 | 0.634 |
| | | 1 | 0.919 | 0.980 |
| **Yamana Gold** | CAN | 0 | 0.120 | 0.418 |
| | | 1 | 0.134 | 0.823 |
| **Iamgold** | CAD | 0 | 0.000 | 0.024 |
| | | 1 | 0.102 | 0.436 |

| Panel B: 5 Smaller Producers | | | | |
|---|---|---|---|---|
| Claude Resources | CAD | 0 | 0.542 | 0.506 |
| | | 1 | 0.341 | 0.724 |
| IFC | SWISS | 0 | 0.918 | 0.027 |
| | | 1 | 0.798 | 0.342 |
| PT Antam | INDO | 0 | 0.548 | 0.670 |
| | | 1 | 0.669 | 0.634 |
| Kingsgate Consolidated | AUS | 0 | 0.298 | 0.111 |
| | | 1 | 0.129 | 0.164 |
| DRD Gold | RSA | 0 | 0.150 | 0.534 |
| | | 1 | 0.220 | 0.606 |

*Note: Values shown are p-values.*

As the variables are all I(1), as seen in Section 5.2, we test for co-integration between each extraction cost and the gold price as time series variables in Table 14 and as a panel in Table 15. Some time series pairs are found to be cointegrated and so an ECM term is added to their granger causality tests which follow. The panels are not found to cointegrate as 5 of the 7 panel cointegration statistics are insignificant, see 6.2 for fuller justification. As above for the country level data, the panel causality tests which follow were also run as VECM's to assess if this affects the results. The conclusions remain unchanged and the ECM term is insignificantly different from zero.

**Table 15 - Company Panel Cointegration Tests – Costs and Gold price**

| Statistic – Within Dimension | Cash Costs | Total Production Costs |
|---|---|---|
| *Panel-v Statistic* | 4.02 | 3.57 |
| *Panel- ρ Statistic* | 1.59 | 1.10 |
| *Panel- PP Statistic* | -1.60* | 2.22** |
| *Panel- ADF Statistic* | -6.16*** | -6.48*** |
| **Statistic – Between Dimension** | | |
| *Group- ρ Statistic* | 3.746 | 3.31 |
| *Group – PP Statistic* | -0.025 | 0.45 |
| *Group – ADF Statistic* | -5.714*** | -6.45*** |

*All estimations include trend. Where ***, ** and * indicates significance at 1%, 5% and 10% level. Maximum 3 lags used, all including intercept and trend.*

Table 16, below, shows a number of companies where gold prices do indeed drive costs, such as in the examples of Anglo Gold Ashanti and Newcrest. Again, in some cases costs cause prices with a negative sign: e.g. Barrick Gold's cash costs cause changes in the gold price with a $1 rise in cash costs followed by a $2.38 fall in the gold price. This again seems to point to a lack of predictive ability among some gold producers and potentially poor hedging strategies with long-term commitments. However, as the data for the companies is only available for 14 years the results need to be treated with some caution.

**Table 16**
**Granger Causality between Gold Prices and Production Costs – Company**

| | F- Value | $\delta$ | Lags | Σ Coeff. |
|---|---|---|---|---|
| **Panel A: Larger producers** | | | | |
| Barrick Cash Costs -> Gold Price | 15.714*** | [0.006] | 1 | -2.386 |
| Gold Price -> Barrick Cash Costs | 0.788 | [0.666] | 1 | - |
| Barrick Total Production Costs -> Gold Price | 8.427** | [0.018] | 1 | -1.726 |
| Gold Price -> Barrick Total Production Costs | 1.684 | [0.737] | 1 | - |
| Newmont Cash Costs -> Gold Price | 1.250 | - | 1 | - |
| Gold Price -> Newmont Cash Costs | 3.975* | - | 1 | 0.219 |
| Newmont Total Production Costs -> Gold Price | 1.246 | [0.098] | 1 | - |
| Gold Price -> Newmont Total Production Costs | 1.215 | [0.103] | 1 | - |
| Anglo Gold Ashanti Cash Costs -> Gold Price | 3.766* | - | 1 | - |
| Gold Price -> Anglo Gold Ashanti Cash Costs | 15.013*** | - | 1 | 0.454 |
| Anglo Gold Ashanti Total Production Costs -> Gold Price | 1.315 | - | 1 | - |
| Gold -> Anglo Gold Ashanti Total Production Costs | 9.770** | - | 1 | 0.537 |
| Goldcorp Cash Costs -> Gold Price | 11.53*** | [0.040] | 1 | -2.594 |
| Gold Price -> Goldcorp Cash Costs | 2.046 | [0.361] | 1 | - |
| Goldcorp Total Production Costs -> Gold Price | 6.598** | [0.014] | 1 | -1.449 |
| Gold Price -> Goldcorp Total Production Costs | 0.790 | [0.337] | 1 | - |
| Kinross Cash Costs -> Gold Price | 0.712 | [0.223] | 1 | - |
| Gold Price -> Kinross Cash Costs | 0.028 | [0.052] | 1 | - |
| Kinross Total Production Costs -> Gold Price | 0.049 | [0.055] | 1 | - |

| | | | | |
|---|---|---|---|---|
| Gold Price -> Kinross Total Production Costs | 0.149 | [0.111] | 1 | - |
| Newcrest Cash Costs -> Gold Price | 1.267 | - | 1 | - |
| Gold Price -> Newcrest Cash Costs | 4.700** | - | 1 | 0.585 |
| Newcrest Total Production Costs -> Gold Price | 0.551 | - | 1 | - |
| Gold Price -> Newcrest Total Production Costs | 5.487** | - | 1 | 0.657 |
| Gold Fields Cash Costs -> Gold Price | 0.010 | - | 1 | - |
| Gold Price -> Gold Fields Cash Costs | 1.285 | - | 1 | - |
| Gold Fields Total Production Costs -> Gold Price | 0.095 | - | 1 | - |
| Gold Price -> Gold Fields Total Production Costs | 1.565 | - | 1 | - |
| Harmony Cash Costs -> Gold Price | 0.739 | - | 1 | - |
| Gold Price -> Harmony Cash Costs | 0.666 | - | 1 | - |
| Harmony Total Production Costs -> Gold Price | 1.248 | - | 1 | - |
| Gold Price -> Harmony Total Production Costs | 0.225 | - | 1 | - |
| Yamana Cash Costs -> Gold Price | 0.176 | - | 1 | - |
| Gold Price -> Yamana Cash Costs | 0.913 | - | 1 | - |
| Yamana Total Production Costs -> Gold Price | 0.303 | - | 2 | - |
| Gold Price -> Yamana Total Production Costs | 0.334 | - | 2 | - |
| Iamgold Cash Costs -> Gold Price | 0.021 | [0.043] | 1 | - |
| Gold Price -> Iamgold Cash Costs | 1.434 | [0.009] | 1 | - |
| Iamgold Total Production Costs -> Gold Price | 0.391 | [0.024] | 1 | - |
| Gold Price -> Iamgold Total Production Costs | 0.029 | [0.116] | 1 | - |
| **Panel B: Smaller Producers** | | | | |
| Kingsgate Cash Costs -> Gold Price | 0.846 | - | 1 | - |
| Gold Price -> Kingsgate Cash Costs | 0.201 | - | 1 | - |
| Kingsgate Total Production Costs -> Gold Price | 2.266 | - | 1 | - |

| | | | | |
|---|---|---|---|---|
| Gold Price -> Kingsgate Total Production Costs | 1.204 | - | 1 | - |
| DRD Cash Costs -> Gold Price | 2.500 | - | 1 | - |
| Gold Price -> DRD Cash Costs | 0.308 | - | 1 | - |
| DRD Total Production Costs -> Gold Price | 2.270 | - | 1 | - |
| Gold Price -> DRD Total Production Costs | 0.310 | - | 1 | - |
| PTAntam Cash Costs -> Gold Price | 0.277 | - | 1 | - |
| Gold Price -> PT Antam Cash Costs | 0.445 | - | 1 | - |
| PT Antam Total Production Costs -> Gold Price | 2.545 | - | 1 | - |
| Gold Price -> PT Antam Total Production Costs | 0.158 | - | 1 | - |
| IFC Cash Costs -> Gold Price | 4.181* | - | 1 | 1.770 |
| Gold Price -> IFC Cash Costs | 0.033 | - | 1 | - |
| IFC Total Production Costs -> Gold Price | 0.311 | [0.189] | 1 | - |
| Gold Price -> IFC Total Production Costs | 1.927 | [0.026] | 1 | - |
| Claude Resources Cash Costs -> Gold Price | 0.744 | - | 1 | - |
| Gold Price -> Claude Resources Cash Costs | 1.9064 | - | 1 | - |
| Claude Resources Total Production Costs -> Gold Price | 1.611 | - | 1 | - |
| Gold Price -> Claude Resources Total Production Costs | 3.880* | - | 1 | 0.507 |
| **Panel C: Panel Data Results** | | | | |
| Cash Costs -> Gold Price | 13.32*** | - | 1 | -0.346 |
| Gold Price -> Cash Costs | 43.36*** | - | 1 | 0.295 |
| Total Production Costs -> Gold Price | 8.761*** | - | 1 | -0.291 |
| Gold Price -> Total Production Costs | 44.81*** | - | 1 | 0.392 |

****, ** and * indicates significance at 1%, 5% and 10% level. Lags for the panel results were chosen via likelihood ratio tests described by Sims (1980). A maximum number of 4 lags were considered and the restriction that a lower-order system compared to a higher-order was tested, indicating one lag.*

The panel data results in Panel C confirm the finding from the earlier tables that gold prices cause extraction costs with a positive relationship. As with the country data panel we again see a negative causal relationship running from costs to prices. Again as the results in Panel C are unweighted by producer production volume they seem less reliable than the world average time series results in Table 13. This may imply an inability generally on the part of producers over the period being examined to predict gold price changes, increasing (decreasing) costs in expectation of higher (lower) gold prices in future, with the opposite actually occurring.

## 6.4 Summary and Concluding Remarks

This chapter is motivated by the scarcity of studies on the relationship between gold prices and gold production costs, as well as any other mined commodities. It utilises a new and hand-collected data set to describe two competing theories regarding the causal relationship between prices and production costs. One theory is based on the role of general inflation on production costs ultimately affecting gold prices whilst the other is based on classical laws of rent and the "real option" character of gold mine operations. Our empirical analysis for a comprehensive set of country and firm-level data provides strong evidence for causality running from gold prices to production costs with the expected sign and not the other way around. Higher gold prices lead to the opening of previously unprofitable mines increasing the average production costs, whilst lower gold prices lead to the closure of previously profitable mines, thereby decreasing the average production costs.

The study contributes to the literature on gold in general, gold mining firms in particular and to a better understanding of the link between production costs and gold prices. The data set also enables an analysis of real optionality both on the aggregate country level and the firm-level avoiding a common focus on changes in the gold exposures of listed gold mining firms.

Industry analysis sometimes argues that production costs provided a floor below which gold prices cannot fall such as reported in Barron's in July 2014. While this study does not test this issue directly we do show that costs do not provide a long term price floor as falling gold prices lead to falling in production costs over time.

# 7 Periodically Collapsing Bubbles in the Gold Price: Markov-Switching models and Gold Lease Rates

The re-emergence of gold as a prominent investment asset in the run up to the financial crisis in 2008, at least partly due to its safe haven status, and the long run rises in the gold price from 2000 have led to a general renewed interest in gold price bubbles. With both investors and the official sector increasingly investing in this asset class again (see Section 2), new nominal highs in the gold price being reached and followed by large price falls, it seems appropriate that an attempt is made to assess whether gold's price is justified by a market based fundamental determinant, that is, by the income that can be earned by owning it.

This thesis uses gold lease rates, the interest that can be earned by lending physical gold at various maturities, as a way to measure gold's true value (see Section 5.4 for a full description of gold lease rates). Despite these being the only directly observable market measures of a cash flow that can be earned from gold existing since 1989, lease rates have never been used to assess whether bubbles occur in the gold price. Previous papers in this area have used convenience yield and real interest rates. This thesis argues that lease rates are a superior way to examine whether bubbles occur in gold prices for a number of reasons.

Deciding which of factors that have been shown to drive of gold price changes are fundamental determinants of its price and which are spurious, or speculative, factors represents a real issue, as mentioned in Section 3 and in Baur and Glover (2012a). Focusing on assessing gold's true value from a fundamental microeconomic perspective rather than from the macroeconomic standpoint allows us to use an undisputed measure of the benefit of holding gold, the income that can be earned from it.

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, Bohl, Stephan and Wisniewski (2011). A commodity's convenience yield is the benefit the holder of the physical commodity receives relative to the owner of a futures or forward contract on the asset and reflects the markets view about its future supply (Hull, 2006).

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. It can be thought of intuitively as the indirect benefits the holder of a commodity receives such as ease of access for production, preventing hold up problems and, from a financial asset perspective for gold, having the metal in your portfolio as a hedge against market risk or safe haven in a financial crisis as discussed in Baur and Lucey (2010).

The concept of convenience yield is primarily intended for 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. Investment assets are assumed to have a zero convenience yield; if they do not, arbitrage opportunities present themselves for investors (Hull, 2006). While gold is consumed in electronics and dentistry, it is primarily held for investment with annual jewellery and pure investment demand accounting for over 80% of annual demand between 2000 and 2011 (GFMS Gold Survey, 2012). This leaves it in a slightly grey area where the convenience yield applies, but not perfectly.

In contrast gold lease rates 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, or two futures prices of different maturities. This raises the problem that as a measure of gold's value convenience yield is derived from two gold prices, the variables that it seeks to explain.

Finally, Barone-Adesi, Geman and Theal (2011) find that lease rates are a good proxy 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, given that gold lease rates are an over the counter transaction and subject to the risk that one party may default.

We test for rational speculative bubbles by assessing the statistical properties of gold prices and lease rates that can be indicative of bubbles, detailed in Section 4.6. This involves applying tests for periodically bursting bubbles using Markov-Switching Augmented Dickey-Fuller (MSADF) tests. The rest of the paper is organised as follows. Section 7.1 discusses the results of the tests. Section 7.2 provides the conclusions of the work.

## 7.1. Markov-Switching Augmented Dickey-Fuller tests for periodically bursting bubbles

In Tables 17 and 18, below, the results of both the MSADF-RV and MSADF-CV models derived from Equation 25 in Section 4.6.3 are shown, for the residuals of the PM Fixing and each lease rate maturity in turn. The results for the AM fixings are not shown as they are qualitatively identical. $\Phi_1$ and $\Phi_2$ are the means of regime 1 and 2 respectively, Variance 1 and Variance 2 are the regimes respective variances (where applicable) and $P_{12}$ and $P_{21}$ are the probabilities of switching from regime 1 to regime 2 and vice versa. All estimations include a constant term and the appropriate number of lags as determined from the procedures discussed in Section 5 but the coefficients are not reported here.

**Table 17 - Maximum Likelihood Estimates:**
**Residuals of Gold Price and Lease Rates: MSADF-RV**

| | 1 Month | 2 Month | 3 Month | 6 Month | 12 Month |
|---|---|---|---|---|---|
| $\Phi_1$ | -0.0104<br>[-1.742] | -0.0001<br>[-0.010] | -0.0046<br>[-0.981] | -0.005<br>[-0.891] | -0.0053<br>[-1.003] |
| Variance 1 | 0.6215*** | 0.643*** | 0.481*** | 0.450*** | 0.346*** |
| | | | | | |
| $\Phi_2$ | -0.0045<br>[-4.609] | -0.0061<br>[-5.579] | -0.003<br>[-5.695] | -0.002<br>[-3.956] | -0.0014<br>[-2.345] |
| Variance 2 | 0.1073*** | 0.0952*** | 0.1090*** | 0.1028*** | 0.0996*** |
| | | | | | |
| $P_{12}$ | 0.2883*** | 0.2636*** | 0.2550*** | 0.2581*** | 0.3424*** |
| $P_{21}$ | 0.0694*** | 0.0464*** | 0.0579*** | 0.0472*** | 0.0456*** |

Note: *, ** and *** represent significance at the 10%, 5% and 1% level, t-stats are given below in parentheses with a null of $\Phi_{st} = 0$.

We can see in Table 17, above, that when we allow the variance to differ across regimes (MSADF-RV) two regimes exist for all lease rate maturities. However regardless of the lease rate maturity no bubble is found to be present. Based on a right tailed test for explosiveness with a null of $\Phi_{st} > 0$ all equations fail to find a bubble. Regime 1 is stationary, i.e. . $\Phi_1$is not significantly different from zero and while regime 2 has a unit root ($\Phi_2$ is significantly different from zero) it is not explosive as $\Phi_2$ is not significantly greater than 0.

We find that the two regimes are characterised not by one having a bubble but by sizeably different variances. Regime 1 has the higher variance by a multiple of between approximately 3 and 6 times depending on which maturity of lease rate is used as the fundamental determinant in the equation. The residuals of the relationships between the gold price and measures of the benefit of holding gold are then characterised by periods of stability (regime 1) and increased volatility (regime 2), that is times when lease rates are not as powerful an explanatory variable for gold prices.

The results of the estimations when we restrict the variance to be the same in both regimes (MSADF-CV) are shown in Table 18, below. This approach finds in favour of a bubble in the gold price when the 2, 3 and 12 month lease rates are used as the fundamental determinant of gold prices.

$\Phi_1$ is significantly greater than 0 at the 1% level for 2 and 3 month maturity and at 10% for 12 months, indicating an explosive unit root and so a periodically collapsing bubble in the gold price. For 1 and 6 month maturities no bubble is found as regime 1 is stationary and regime 2 is not explosive. The probability of switching from the bubble regime to regime 2 is very high and once in regime 2, it switches much more infrequently. The results shown in table 18 are more robust than those under the MSADF-RV tests in Table 17 above, based on Shi's (2012) work as discussed in Section 4.6.3 in full. For this reason we focus on the MSADF-CV results for the remainder of this chapter.

**Table 18 - Maximum Likelihood Estimates:
Residuals of Gold Price and Lease Rates: MSADF-CV**

| | 1 Month | 2 Month | 3 Month | 6 Month | 12 Month |
|---|---|---|---|---|---|
| $\Phi_1$ | -0.007<br>[-0.258] | 0.225***<br>[8.687] | 0.256***<br>[8.807] | 0.0458<br>[1.383] | 0.1071*<br>[2.196] |
| $\Phi_2$ | -0.004***<br>[-5.646] | -0.010***<br>[-.4.893] | -0.005***<br>[-6.607] | -0.0046***<br>[-5.293] | -.0032***<br>[-3.999] |
| | | | | | |
| $P_{12}$ | 0.925*** | 0.775*** | 0.814*** | 0.639*** | 0.718*** |
| $P_{21}$ | 0.018*** | 0.015*** | 0.010*** | 0.007*** | 0.010*** |

Note: *, ** and *** represent significance at the 10%, 5% and 1% level, t-stats are given below in parentheses with a null of $\Phi_{st} = 0$.

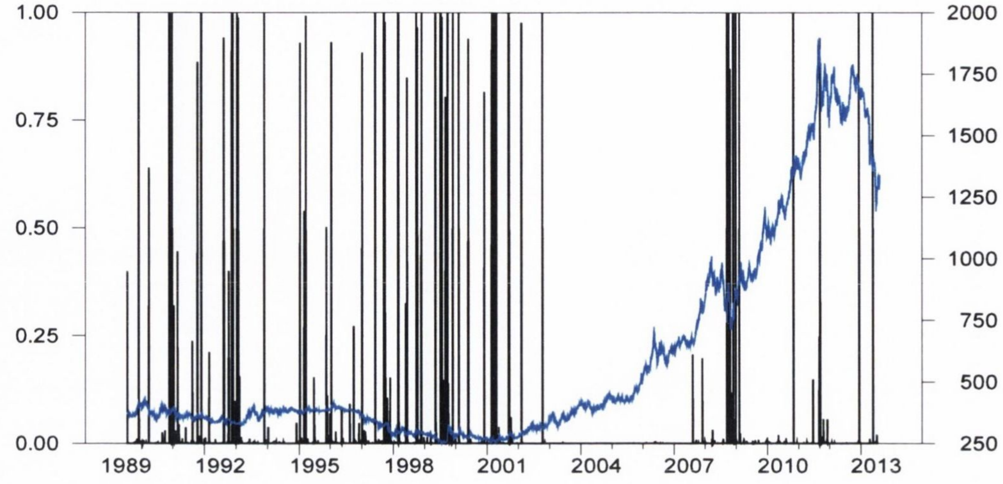
Following Hamilton (1989), Figure 24, below, plots the inferred filter probabilities of being in regime 1 at any given time between 1989 and 2013 based on the information available at that particular time, for all maturities under the MSADF-CV estimations. The gold price is shown as a blue line and plots to the right hand axis for reference.

When the probability is less than 0.5 we are in regime 1 (shown to have a bubble using some maturities above) and when greater than 0.5 we can say that we are probably in regime 2.

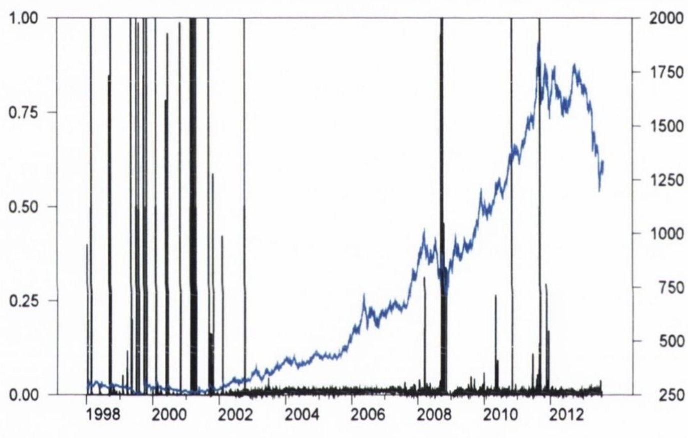
From this we can see a long period of stability in the mid-2000s where the gold price was fundamentally justified based on the 2 and 3 month lease rates. The relationship between gold prices and lease rates frequently switches into a bubble at the beginning of the sample but quickly moves out of it each time. We consistently find a bubble to be present during the 2008 financial crisis.

Figure 24 - The probability of being in regime 1 at t, MSADF-CV

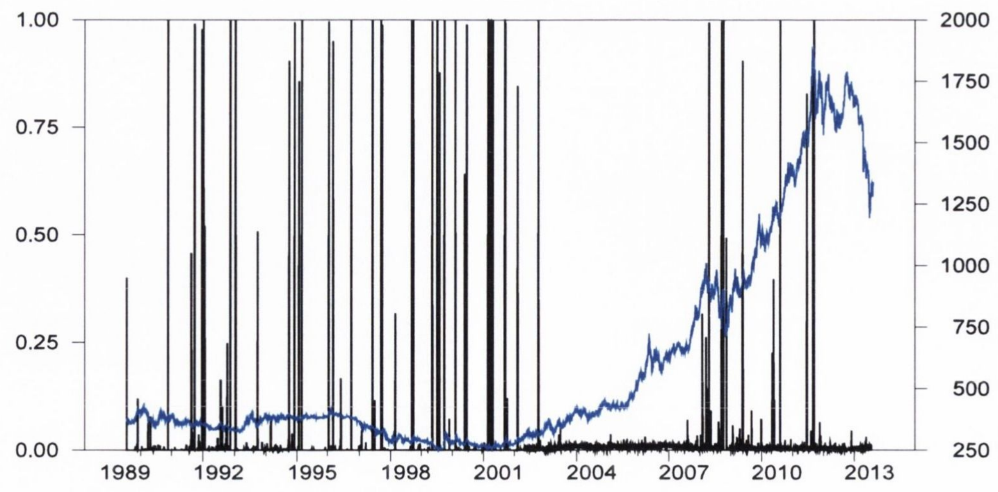
1 Month Lease Rate



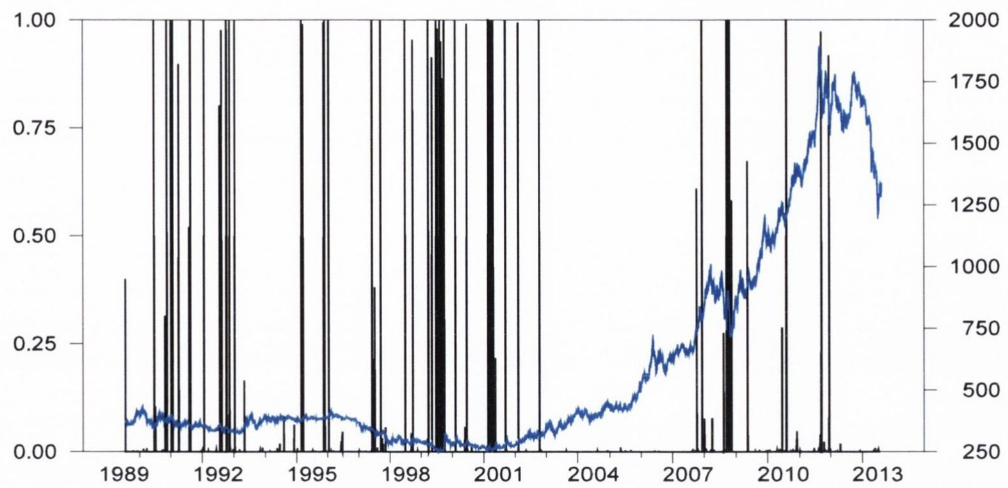

2 Month Lease Rate




3 Month Lease Rate




6 Month Lease Rate




**12 Month Lease Rate**

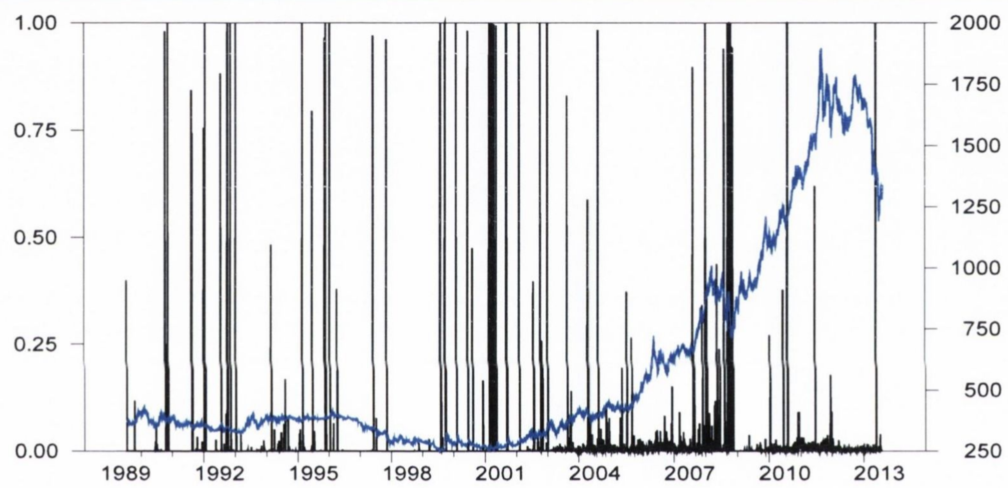



Table 19, below, shows a cross-correlation matrix for the filter probabilities for all lease rate maturities based on the MSADF-CV. We see the highest correlation between the 2 and 3 month estimations where we find a bubble with the highest degree of confidence.

**Table 19 -Cross-Correlation Matrix: probabilities of being in regime 1, for all maturities MSADF-CV**

| | 1 month | 2 month | 3 month | 6 month | 12 month |
|---|---|---|---|---|---|
| **1 Month** | 1 | - | - | - | - |
| **2 Month** | 0.556 | 1 | - | - | - |
| **3 Month** | 0.491 | 0.727 | 1 | - | - |
| **6 Month** | 0.500 | 0.556 | 0.565 | 1 | - |
| **12 Month** | 0.399 | 0.480 | 0.534 | 0.644 | 1 |

## 7.2 Conclusions

In attempting to answer whether bubbles occur in the price of gold we use gold lease rates as a measure of gold's fundamental value for the first time in the literature, testing for periodically bursting bubbles using two types of regime switching models. Using Markov Switching ADF tests for cointegration to allow the assumption of a single long run relationship to be relaxed: two different regimes are allowed to exist to assess whether bubbles form and then burst over time.

We run these tests twice: once to allow for the variance to be a switch between the two regimes and again holding it constant, as recommended by Shi (2012). Allowing the variance to switch between regimes results in no bubble being found. Instead the two regimes are characterised by switching between two states: high and low variance. This indicates that in the high variance regime the lease rates' power as explanatory variables decreases significantly.

When we restrict the variance between regimes we do find some evidence of a bubble when using the 2, 3 and 12 month lease rates as gold's fundamental determinant. A stable period in the mid-2000s shows the gold price as fundamentally determined by its lease rates but at other times bubble phases occur frequently if only for short periods. As the constant variance model is more powerful and robust we must conclude that there is some evidence of bubbles in gold prices.

Further research in applying lease rates to gold prices as a fundamental determinant to assess whether bubbles occur are necessary to get a clearer picture, asking the question using different approaches such as Philips et al.'s (2011) sup-ADF test or McQueen and Thorley's (1994) non-parametric duration dependence test for bubbles. This Chapter's use of a market based measure of the economic benefit of holding gold however does provide new and theoretically strong evidence that gold has been through some bubble phases at certain times over the last 20 years.

# 8 Rationality in Precious Metals Forward Markets - Evidence of Behavioural Deviations from the FRUH

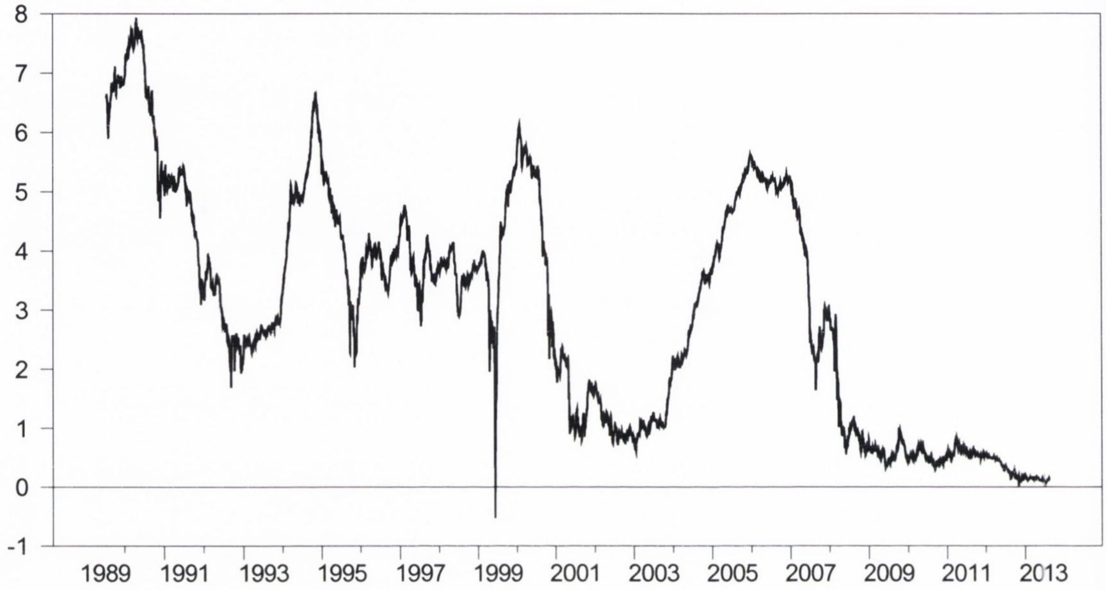
The issue of the relationship between spot and forward prices is a significant one for market participants, whether from a hedging or a speculative perspective. This chapter offers the first assessment of the ability of the gold forward price to act as a predictor of the future gold spot price, assessing whether precious metals markets are characterised by rational expectations.

The only previous research that addresses a similar question is Abken (1980) who researches whether gold futures prices are unbiased predictors of future spot prices. Using 6 years of monthly data Abken (1980) finds that rational expectations holds in this market. However, the results are based on a regression in using variables in levels, and the paper does not address unit root issues, making the results questionable. Here we use a much longer dataset (1989 – 2013) at a daily and weekly level to address the question for the London gold forward and spot OTC markets.

If rational expectations hold true, the forward market provides an unbiased estimate of the future spot rate, with the two prices being perfectly positively correlated and with an expected value for prediction errors of zero. Results from other markets such as equity and foreign exchange have documented systematic deviations from rationality (Aggarwal, 2004). Surveys of the literature (e.g. Engle, 1992) have been unsuccessful in explaining such deviations using foreign exchange models of risk premia, such as the capital asset pricing model, or trade frictions. The failure of this Forward Rate Unbiasedness Hypothesis (FRUH) could be as a result of one of two issues, or both.
Firstly, the market may not be risk neutral as assumed by the FRUH. Over the sample examined here the spot price of gold on a given day is generally less than the forward prices, as shown in Figure 25, below, through the 12 Month GOFO rate. This forward premium can be viewed as compensation for the cost of carrying gold in your portfolio. These costs include storage and insurance as well as the opportunity cost of interest forgone. A benefit can be earned from holding gold by leasing it (see Section 5.4 and Chapter 7 for further details). Keynes (1930) argued that forward prices will either be above or below the expected futures spot prices depending on whether speculators hold short or long positions respectively. This is because they require a

risk premium in order to hold purely speculative positions. As there is no long or short positions data on the OTC forward gold market, here we will control for the general level of risk aversion in the market.

**Figure 25 - 12 Month GOFO, %**




*Source: LBMA.org*

Or, secondly, a number of behavioural factors could explain failures of financial markets to rationally anticipate future prices. These include behaviours such as systematic under or over-reaction to news in the market, which has been documented in equities by Jackson and Johnson (2006) and in foreign exchange markets by Aggarwal and Zong (2008).

Evidence on the behavioural aspects of the gold market is more limited than would be imagined for an asset that has such an impact on the emotions of investors (see Section 3.9 for a full discussion). This chapter will apply and develop the behavioural analyses used by Easterwood and Nutt (1999) and Aggarwal and Zong (2008) to assess whether the precious metals markets are characterised by optimism or pessimism, and whether they over- or under-react to new information. The information assessed here includes changes in the following variables: spot prices, forecasted spot prices, the forward premium, and changes in the holding of gold by Exchange Traded Funds (ETFs). These possible behavioural explanations of the failure of the FRUH are assessed while controlling for investor risk aversion.

The evolution of the markets risk aversion and behavioural dynamics over time is also examined to assess whether the markets outlook is stable over time. Our data set contains a wider range of maturities than previous studies with 1, 3, 6 and 12 month maturities used. This allows an assessment of whether long run factors affect the short run factors and vice versa, rather than solely looking at the issue for the same maturity. The sections to follow in this chapter present the results of the estimations of the equations detailed in Sections 4.7 - 4.10

## 8.1 Evidence on Forecasting, the FRUH and Market behaviour

A large amount of research testing the FRUH has been carried out on the foreign exchange market based on the theoretically elegant rational expectations hypothesis (REH), which has very little evidence to support it in practice. Estimates of $\beta$ for Eq. (2.4) are frequently and puzzlingly found to be closer to $-1$ rather than the +1 required by the REH (such as Gospodinov, 2009). Froot and Thaler (1990) look at estimates of $\beta$ from over 75 papers and find an average value of $-0.88$. While still not providing evidence to support the hypothesis, Frankel and Rose (1994) argue that an estimate of $\beta < 0$ 0 may only apply to floating exchange rate regimes, as when they look at European countries participating in the Exchange Rate Mechanism they find an estimate much closer to zero.

Evidence on whether spot and forward exchange rates are cointegrated is mixed. MacDonald and Taylor (1989) test for cointegration between the spot and forward rate for 10 sets of exchange rates over a 12 year period and find no strong evidence for cointegration. Hakkio and Rush (1989) test the UK Pound/US Dollar and the Deutsche Mark/US Dollar exchange rates and find that cointegrating relationships do exist. Aggarwal and Zong (2008) find mixed evidence when testing 9 currencies, but in general the evidence found refutes the idea that currency markets are characterised by rational expectations. Deviations from FRUH are particularly puzzling as these should provide opportunities for traders to profit from the deviations (Kirtzman, 1993).

Forecasts by equity analysts also seem to fail the rational expectations test. Kang et al. (1994) find that analysts forecasts are biased upwards. There has been conflicting evidence on whether analysts under- (Elliott et al., 1995) or over-react to new information (DeBondt and Thaler, 1990). Easterwood and Nutt (1999) find that analysts underreact to negative information and overreact to positive news indicating systematic optimism resolving inconsistencies in earlier work on the issue. Gu and Xue (2007) find that analysts over react to good news, but once earning uncertainty following extremely good news is controlled for, only their general under-reaction remains. This evidence of biases in equity analysts' forecasts can however be at least partially explained by their economic incentives. To gain access to the companies they are following, analysts need to make sure that their reports cannot be seen as negative and, as sales employees, they are incentivised to encourage customers to purchase stocks.

However, such perverse economic incentives should not exist in the forward markets for foreign exchange or precious metals where participant errors can result in financial losses. There have been many papers which have tried to explain the bias found in forward exchange rates. Engle's (1992) survey documents a number attempts utilising models that account for potential problems such as risk premia and trade frictions but they conclude that these have not resolved the issue. Other attempts have looked at peso problems and learning (Frankel and Rose, 1994), but the general conclusion that forward currency markets do not fully conform to the FRUH remains (Aggarwal, 2004).

Recent work has examined if behavioural biases can help to explain this non-rationality across a number of markets. Amir and Ganzach (1998) find that security analysts under react to new information. Aggarwal and Zong (2008) find that forward exchange rates are characterised by systematic pessimism and under-reaction to new information. Ball and Croushore (2001) look at macroeconomic news and find that market responses to new information on inflation are consistently pessimistic. Daniel, Hirshleifer, and Subrahmanyam (1998) explain the theoretical underpinnings of under-reaction as overconfidence by market participants who put too much weight behind their private information and fail to make full use of public information.

Keynes (1930) and Hicks (1939) argued that forward prices will either be above or below the expected future spot depending on whether speculators hold short or long positions. This is due to the risk premium they require in order to hold their purely speculative positions. Lewis (1989) examined predictions regarding the US Dollar using forward rates and attributed 50% of the errors to a learning issue and the remaining 50% to a risk premium. Mohanram and Gode (2013) find a strong link between the cost of equity, as a measure of risk, and analysts forecast errors for stocks. However Gurkaynak and Wolfers (2006) examine the market for macroeconomic derivatives and find only a very small risk premium. This evidence points to the need to include a control variable to account for risk as an explanatory factor in forecast errors.

There is already a body of research on deviations from rationality in the precious metals market. Aggarwal and Sundararaghavan (1987) find that changes in silver futures prices are predictable in a markov matrix framework using both the direction and magnitude of price changes. Aggarwal and Lucey (2007) show that psychological barriers exist at round numbers, such as 100s. Cavaletti, Factor and All (2004) discuss the importance of psychological issues in the gold market.

Chapter 7 of this thesis assessed whether bubbles occur in the price of gold and finds that gold is priced rationally in relation to its lease rates when the variance of the relationship does not have to be a constant. Smales (2014) examines the effect of the flow of news into the gold market by classifying news stories into good and bad news. The market is shown to have an asymmetric response to news, with greater reaction to bad news. Further, deviations from rationality are examined by Lucey (2010) who documents differences in the mean returns of precious metals depending on the stage of the lunar cycle, although these differences are not statistically significant. Behavioural research on the gold market is still in its infancy and warrants further scholarly research.

## 8.2 Testing the FRUH

Firstly cointegration between the forward rate and the spot rate is tested for in levels, as in Equation 29 following Johansen's (1991) method, with the results presented in Table 20, below. In order for the FRUH to be accepted the $S_{t+1}$ and $F_t$, as well as $S_t$ and $F_t$, must be co-integrated with a $(1, -1)$ cointegrating vector. Table 20 shows that a co-integrating relationship exists between gold spot and forward rates at all maturities, but that the cointegrating vector is not $(1, -1)$ for any maturity. This is the case for $S_t$ and $F_t$ also and at a weekly frequency.

**Table 20 - Johansen Cointegration between $S_{t+1}$ and $F_t$**

| | Eigenvalue | Trace | 5% Crit. Value | P-Value | r | (1, -1) |
|---|---|---|---|---|---|---|
| **$S_{t+12m}$ Vs. 12m Forward** | 0.008 | 49.297 | 25.731 | 0.000 | 0 | |
| | 0.001 | 4.014 | 12.448 | 0.739 | 1 | No |
| **$S_{t+6m}$ Vs. 6m Forward** | 0.007 | 47.721 | 25.731 | 0.000 | 0 | |
| | 0.001 | 4.199 | 12.448 | 0.714 | 1 | No |
| **$S_{t+4m}$ Vs. 3m Forward** | 0.016 | 100.690 | 25.731 | 0.000 | 0 | |
| | 0.003 | 3.589 | 12.448 | 0.795 | 1 | No |
| **$S_{t+1m}$ Vs. 1m Forward** | 0.155 | 148.08 | 25.731 | 0.000 | 0 | |
| | 0.001 | 3.406 | 12.448 | 0.818 | 1 | No |

Table 21, below, shows mixed evidence on the FRUH based on Equation 30. At longer horizons the null of FRUH is rejected at the 1% and 5% significance levels for daily and mid-week data. However the relationship between spot and forward rates at 1 month conforms to the null of unbiasedness. This long run/short run divide becomes more pronounce at a weekly frequency with 3 and 1 month maturities becoming unbiased.

Overall, the levels and differences methods used to test if the FRUH holds in the gold market seem to suggest it does not hold in the gold market. The co-integration tests are unanimous and the results from the regression analysis suggest that a relationship between spot and forward prices cannot be said to exist with much confidence for the gold forward–spot market as a whole. There is how ever some evidence that there is predictive power at short horizons.

**Table 21- Differences test for FRUH**

| Variables | α | β | Null |
|---|---|---|---|
| **S Vs. F: 12m** | 45.44<br>[0.133] | 0.526<br>[0.674] | 0.135 |
| **S Vs. F: 6m** | 25.20<br>[0.035] | -0.191<br>[0.064] | 0.091 |
| **S Vs. F: 3m** | 10.81<br>[0.066] | -0.002<br>[0.041] | 0.100 |
| **S Vs. F: 1m** | 3.425<br>[0.064] | -0.083<br>[0.000] | 0.000 |

*Note: Equation 30 was estimated using OLS with Newey-West HAC standard errors, showing α and β as the coefficient estimates. P-values for the null hypotheses (β=1, α=0) are given in parenthesis next to the coefficient estimate. P-values for jointly testing the null of β=1, α=0 are given in the null column. Maximum lag length set =* $4(t/2100)^{2/9})$ *as suggested by Newey and West (1987).*

## 8.3 Testing for Behavioural biases

Table 22 shows the results of Equs. 32, and 33 which expands the independent variables to include all maturities. We see negative and significant constant estimates for all time periods and specifications pointing to pessimism, and negative betas indicating under-reaction by the market to news, though they are only significant between the FE,12m and the FR,12m–6m. The joint test for no behavioural biases is rejected in all cases at the 5% significance level for daily data. Weekly data in general agrees, but finds no pessimism or behavioural biases for FE,3m. FRs seem to have some explanatory power at 12 month horizons but no real significance at the shorter horizon as the $R^{2}$'s are almost indistinguishable from zero, which is similar to the findings of Aggarwal and Zong (2008).

**Table 22 - Test for Behavioural Biases**

| Dependant Variable | α | FR, 12M-6M | FR, 6M-3M | FR, 3M-1M | $R^2$ | Null |
|---|---|---|---|---|---|---|
| FE,12m | -30.79*** | -0.429*** | | | 0.075 | 0.000 |
| | *4.625* | *0.119* | | | | |
| | -30.74*** | -0.482*** | 0.032 | 0.104 | 0.076 | 0.000 |
| | *4.631* | *0.140* | *0.215* | *0.231* | | |
| FE,6m | -16.541*** | | -0.059 | | 0.001 | 0.000 |
| | *3.404* | | *0.096* | | | |
| | -16.19*** | -0.095 | 0.041 | -0.018 | *0.005* | |
| | *2.971* | *0.114* | *0.185* | *0.151* | | |
| FE,3m | -7.267*** | | | -0.033 | 0.000 | 0.009 |
| | *2.481* | | | *0.112* | | |
| | -5.868** | -0.106 | 0.035 | 0.024 | *0.010* | *0.0335* |
| | *2.520* | *0.065* | *0.102* | *0.102* | | |

*Note: SE's are given below the coefficient estimates in italics with ***, **, and * indicating significance at 1%, 5% and 10% level. All regressions use Newey-West HAC standard errors.*

A control variable for risk aversion is then added to these regressions with the results shown in Table 23, below. We find that the constant estimates become universally insignificant at 1% and 5% with only 2 significant at 10%, and these two disagree in their signs. For the FE,12m regression $R^2$ almost doubles due to the inclusion of risk, though the power of the model is still low at shorter horizons. Evidence is still in favour of behavioural biases at longer horizons but is now firmly rejected at short horizons. This fact is not surprising as at short horizons there was some evidence that the FRUH did hold.

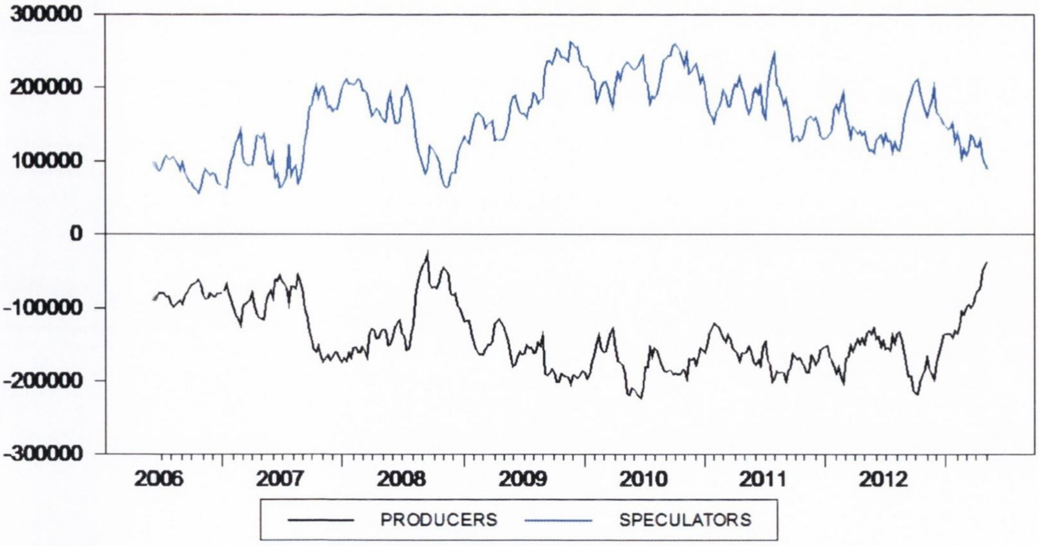
## Table 23- Test for Behavioural Biases, with Risk

| Dependant Variable | α | FR, 12M-6M | FR, 6M-3M | FR, 3M-1M | $VIX^2$ | $R^2$ | Null |
|---|---|---|---|---|---|---|---|
| FE,12m | -4.013 | -0.439*** | | | -0.054*** | 0.126 | 0.000 |
| | *6.684* | *0.122* | | | *0.012* | | |
| | -3.481 | -0.513*** | 0.047 | 0.143 | -0.055*** | 0.129 | 0.004 |
| | *6.417* | *0.135* | *0.191* | *0.217* | *0.011* | | |
| FE,6m | -7.312* | | -0.062 | | -0.020*** | 0.015 | 0.198 |
| | *4.417* | | *0.097* | | *0.007* | | |
| | -6.085 | -0.104 | 0.042 | -0.006 | -0.020*** | 0.019 | 0.482 |
| | *4.075* | *0.114* | *0.184* | *0.150* | *0.006* | | |
| FE,3m | 0.890 | | | -0.028 | -0.016*** | 0.018 | 0.924 |
| | *3.778* | | | *0.086* | *0.006* | | |
| | 2.658* | -0.114 | 0.038 | 0.036 | -0.017*** | 0.030 | 0.470 |
| | *3.851* | *0.064* | *0.099* | *0.100* | *0.006* | | |

*Note: SE's are given below the coefficient estimates in italics with ***, **, and * indicating significance at 1%, 5% and 10% level. All regressions use Newey-West HAC standard errors.*

$VIX^2$ is negatively related with FEs and significant at all maturities. A negative relationship between FEs and risk aversion implies that as risk aversion rises the market consistently underestimates future spot prices, indicating that speculators are long gold futures contracts. While no explicit data exists on speculative holdings for the forward market, when we look at the Commitment of Traders reports on futures positions from 2006 to 2013 we can see this is the case as in Figure 26, below.

**Figure 26 - Producers and Speculators Futures Positions, No. of Contracts held**

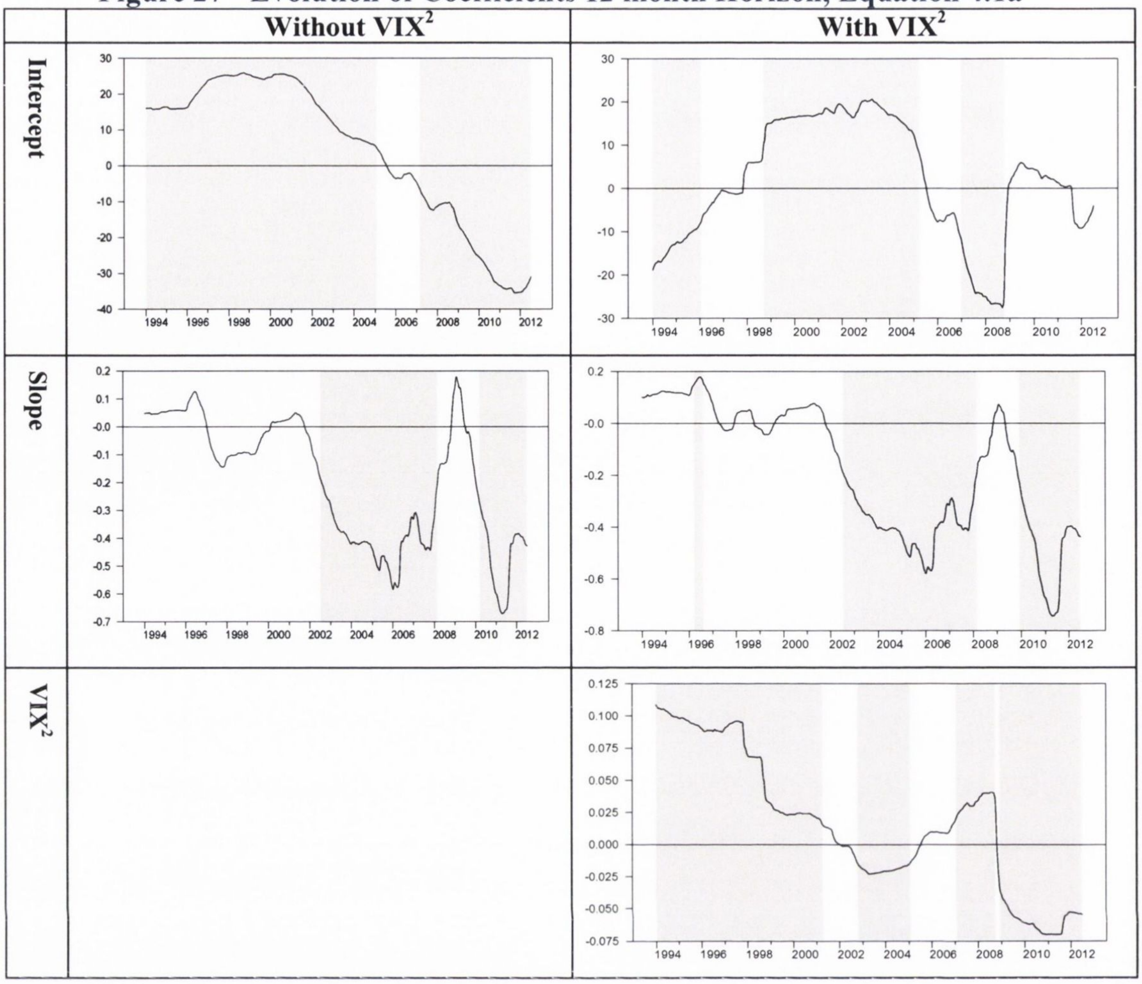



*Source: Commodities Futures Trading Commission (http://www.cftc.gov)*

We can also examine the stability of our estimates over the period of our sample by running the same regressions on a rolling basis as discussed in Section 4.8. In Figure 27, below, we show the evolution of our intercept and slope terms from regressions 32 and 33 with FE,12m with and without our control for risk aversion We begin by running the regressions for 1000 observations and increase the length of the sample up to the full 6000 observations saving the coefficient estimates and their level of significance at each point. When estimates are significant at 1% they enter a shaded area.

Based on the intercept, without controlling for risk, the market is shown to be optimistic until the mid-2000s when it began to change; and became pessimistic for the late 2000s and continued to be so over the sample as a whole. When we control for risk aversion we see that the market switches between moods over the sample period but reflects a more balanced mood over the whole period. The slope estimates that points to systematic under-reaction are relatively consistent with or without the control for risk. The market is characterised by under-reaction for much of the sample, though when we control for risk a short period of significant over-reaction is present in the mid-1990s. The markets risk aversion also changes significantly over the period.

**Figure 27 - Evolution of Coefficients 12 month Horizon, Equation 4.1a**




## 8.4 Past Information and Market Forecasts

Table 24 gives the results of estimating Equs. 34 and 35 for daily data. Estimates of the slope coefficient for the 12 month prior spot change ($PSCH_{t-1}12m$) are negative and significant for 12 and 6 month FEs, indicating that the market is overreacting to this information to a significant extent in relation to longer run forecasts. This suggests that analysts concentrate on longer run changes in spot rates in making their longer term forecast predictions but at shorter maturities FEs are independent of prior spot changes.

This relationship breaks down at the shortest 1 month forecast horizon. Here only the one month prior spot change is significant and a positive beta reflects under-reaction. These findings are replicated at a weekly frequency. This finding of under-reaction at short and over-reaction at longer horizons is consistent with Jackson and Johnson (2006).

**Table 24- Prior Spot Rate Change as a Determinant of Forecast Error**

| Dependant Variable | $\alpha$ | $PSCH_{t-1}$ 12m | $PSCH_{t-1}$ 6m | $PSCH_{t-1}$ 3m | $PSCH_{t-1}$ 1m | $R^2$ |
|---|---|---|---|---|---|---|
| FE,12m | -22.046*** | -0.338*** | | | | 0.096 |
| | *4.472* | *0.075* | | | | |
| | *-21.97**** | *-0.276**** | -0.182 | 0.002 | 0.363* | 0.108 |
| | *4.311* | *0.096* | 0.183 | 0.203 | 0.220 | |
| FE6m | -15.85*** | | -0.072 | | | 0.004 |
| | *2.899* | | *0.0717* | | | |
| | -9.319*** | -0.290*** | 0.228 | -0.010 | 0.148 | 0.068 |
| | 2.925 | 0.075 | 0.148 | 0.175 | 0.153 | |
| FE3m | -6.736*** | | | -0.048 | | 0.001 |
| | *2.577* | | | *0.076* | | |
| | -3.447 | -0.101* | 0.024 | -0.017 | 0.139 | 0.043 |
| | *2.418* | *0.060* | *0.107* | *0.102* | *0.113* | |
| FE1m | -2.700** | | | | 0.124** | 0.019 |
| | *1.380* | | | | *0.070* | |
| | -1.062 | -0.015 | -0.030 | -0.043 | 0.207*** | 0.037 |
| | *1.366* | *0.032* | *0.055* | *0.064* | *0.069* | |

*Note: SE's are given below the coefficient estimates in italics with ***, **, and * indicating significance at 1%, 5% and 10% level. All regressions use Newey-West HAC standard errors.*

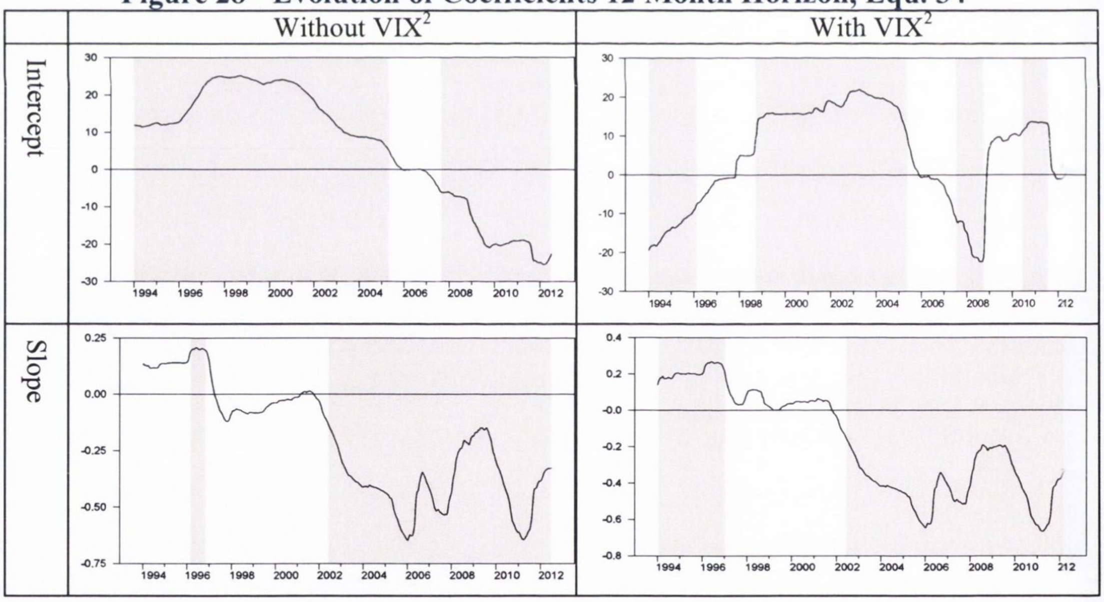
Including risk, as shown in Table 25, below, does not alter the above findings but does change the constant estimates and removes their significance. Without controlling for risk in the model it points to pessimism as before. Including risk once again turns the constant estimates insignificant with negative forecast errors explained through risk aversion rather than behavioural factors. VIX2 is significant at all maturities bar 1 month. Allowing for risk aversion increases the adjusted $R^2$ for all models. Figure 29 shows how these coefficients evolve over time. It can again be seen that they are not stable and that the market goes through different moods as time passes. However, since the early 2000s the market has consistently overreacted to prior spot price change information.

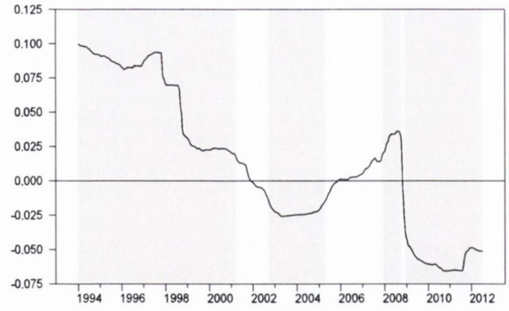
**Table 25 - Prior Spot rate change as a determinant of forecast error, with risk**

| Dependant Variable | α | $PSCH_{t-1}12m$ | $PSCH_{t-1}6m$ | $PSCH_{t-1}3m$ | $PSCH_{t-1}1m$ | $Vix^2$ | $R^2$ |
|---|---|---|---|---|---|---|---|
| FE12m | 2.690 | -0.325*** | | | | -0.051*** | 0.143 |
| | 6.793 | 0.078 | | | | 0.010 | |
| FE12m | 3.921 | -0.263*** | -0.222 | 0.0294 | 0.375* | -0.053*** | 0.143 |
| | 6.606 | 0.088 | 0.165 | 0.198 | 0.217 | 0.011 | |
| FE6m | -5.866 | | -0.074 | | | -0.020*** | 0.017 |
| | 4.084 | | 0.072 | | | 0.006 | |
| | -0.264 | -0.284*** | 0.215 | -0.004 | 0.152 | -0.018*** | 0.080 |
| | 4.016 | 0.073 | 0.146 | 0.177 | 0.155 | 0.005 | |
| FE3m | 1.327 | | | -0.047 | | -0.016*** | 0.019 |
| | 3.858 | | | 0.076 | | 0.006 | |
| | 4.623 | -0.096* | 0.012 | -0.009 | 0.142 | -0.016*** | 0.044 |
| | 3.858 | 0.059 | 0.104 | 0.102 | 0.115 | 0.006 | |
| FE1m | -1.137 | | | | 0.125* | -0.003 | 0.016 |
| | 2.162 | | | | 0.069 | 0.004 | |
| | 0.339 | -0.014 | -0.031 | -0.041 | 0.208** | -0.002 | 0.033 |
| | 2.383 | 0.031 | 0.055 | 0.065 | 0.069 | 0.004 | |

*Note: SE's are given below the coefficient estimates in italics with ***, **, and * indicating significance at 1%, 5% and 10% level. All regressions use Newey-West HAC standard errors.*

**Figure 28 - Evolution of Coefficients 12 Month Horizon, Equ. 34**



| | | |
|---|---|---|
| $VIX^2$ | |  |



Equs. 36 and 37, discussed in detail in Section 4.8.2, are estimated for all maturities of the FP and FE coupled with all maturities of the PSCH, in order to assess whether differing lengths of spot price changes have different effects on the dependant variable at a given maturity. Table 26 presents the results of Equation 36 coupling each FP with each PSCH for all horizons, examining the impact of prior period spot changes on the predicted change in the future spot rate.

**Table 26 - Determinants of the Forward Premium**

| Dependant Variable | PSCH | Low | | Normal | | High | | |
|---|---|---|---|---|---|---|---|---|
| | | α | β | α | β | α | β | $R^2$ |
| FP12m | 12m | 13.322 | 0.049 | 14.100 | -0.063 | 25.370 | 0.043 | 0.073 |
| | | *0.000* | *0.000* | *0.000* | *0.000* | *0.000* | *0.000* | |
| | 6m | 15.549 | 0.040 | 13.125 | -0.020 | 18.800 | -0.031 | 0.026 |
| | | *0.000* | *0.000* | *0.000* | *0.365* | *0.000* | *0.025* | |
| | 3m | 15.783 | 0.054 | 13.350 | -0.090 | 18.020 | -0.034 | 0.029 |
| | | *0.000* | *0.000* | *0.000* | *0.002* | *0.000* | *0.035* | |
| FP 6m | 12m | 6.354 | 0.018 | 6.888 | -0.041 | 14.247 | -0.031 | 0.040 |
| | | *0.000* | *0.059* | *0.000* | *0.000* | *0.000* | *0.000* | |
| | 6m | 7.327 | 0.016 | 6.429 | -0.017 | 11.220 | -0.033 | 0.020 |
| | | *0.000* | *0.033* | *0.000* | *0.137* | *0.000* | *0.009* | |
| | 3m | 7.652 | 0.025 | 6.550 | -0.043 | 10.783 | -0.048 | 0.027 |
| | | *0.000* | *0.012* | *0.000* | *0.012* | *0.000* | *0.001* | |
| FP 3m | 12m | 3.213 | 0.013 | 3.390 | -0.019 | 6.723 | -0.015 | 0.020 |
| | | *0.000* | *0.003* | *0.000* | *0.000* | *0.000* | *0.000* | |
| | 6m | 3.800 | 0.012 | 3.198 | -0.010 | 4.680 | -0.012 | 0.09 |
| | | *0.000* | *0.000* | *0.000* | *0.118* | *0.000* | *0.026* | |
| | 3m | 3.786 | 0.016 | 3.244 | -0.023 | 4.490 | -0.016 | 0.009 |
| | | *0.000* | *0.000* | *0.000* | *0.016* | *0.000* | *0.013* | |

*Note: P-values' are given below the coefficient estimates in italics. All regressions use Newey-West HAC standard errors.*

The sums of $\beta_3 + \beta_4$ and $\beta_3 + \beta_5$ in Table 26 are found to be positive and negative respectively and almost all significantly different from 0 at the 5% level, indicating systematic optimism. The market underreacts to negative prior period changes in the spot rate, giving a positive sign and over-reacts to positive information, with a negative sign. This is consistent across all pairings. The overall explanatory power of the models is small with low $R^2$s; as found in Aggarwal and Zong (2008).

These full sample results would be very much influenced by when this study was undertaken. Figure 29 below showsa that $\beta_3 + \beta_4$ (bad news) are negative for much of the sample period and the estimates of $\beta_3 + \beta_5$ (good news) are very volatile. This means that a consistent outlook is not apparent over the longer run and for long periods, like the late 2000s, the signs on the summed coefficients point to pessimism. Results are similar using weekly data although estimates of $\beta_3 + \beta_4$ are not universally significant. Including risk as an explanatory variable does not have a significant effect on the results presented above and the risk coefficient itself is generally insignificant.

**Figure 29 - Evolution of Coefficients (FP, 12m on PSCH 12m), Equ. 36**

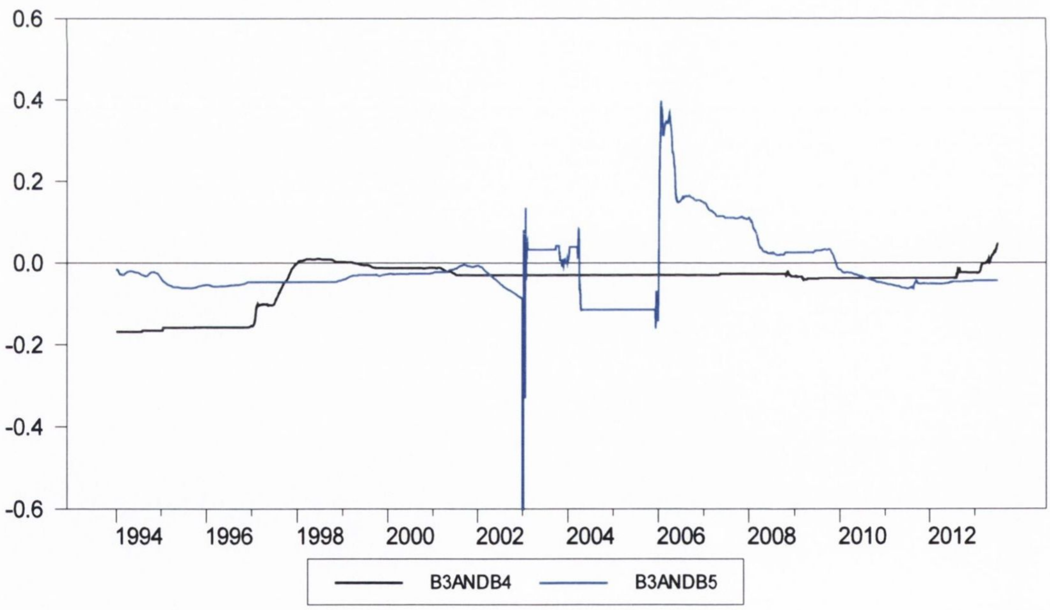



Table 27 below, shows the results of estimating Equation 37. No significant optimism or pessimism in the markets assimilation of prior spot changes for FEs is observed. Estimates of the sums of $\beta_3 + \beta_4$and $\beta_3 + \beta_5$ are generally insignificant. When they are significant the coefficients are positive indicating over-reaction to upper or lower quartile prior spot changes. The middle quartiles' results for $\beta_3$ are all negative and significant pointing to under-reaction to average changes. Once again the inclusion of a control for risk aversion as a factor has no material effect on the results.

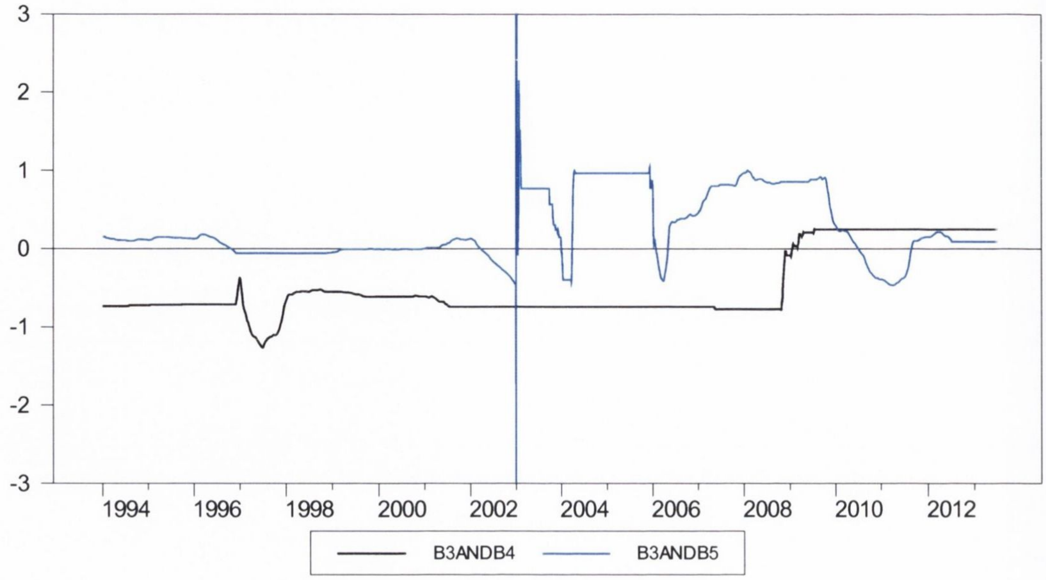
**Table 27 - Determinants of FE**

| Dependant Variable | PSCH | Low | | Normal | | High | | $R^2$ |
|---|---|---|---|---|---|---|---|---|
| | | α | β | α | β | α | β | |
| FE 12m | 12m | 6.837 | 0.247 | -2.168 | -1.079 | -131.5 | 0.090 | 0.149 |
| | | *0.551* | *0.511* | *0.564* | *0.000* | *0.000* | *0.441* | |
| | 6m | 27.882 | 0.809 | -7.439 | -1.034 | -154.2 | 0.254 | 0.189 |
| | | *0.006* | *0.022* | *0.015* | 0.000 | *0.000* | *0.104* | |
| | 3m | -10.659 | 0.316 | -15.260 | -1.730 | -94.47 | 0.058 | 0.076 |
| | | *0.335* | *0.379* | *0.000* | *0.000* | *0.000* | *0.798* | |
| FE 6m | 12m | -3.946 | -0.154 | 1.999 | -0.694 | 60.939 | 0.031 | 0.070 |
| | | *0.462* | *0.295* | *0.441* | *0.000* | *0.000* | *0.701* | |
| | 6m | 20.969 | 0.801 | -4.137 | -0.539 | -56.740 | 0.123 | 0.064 |
| | | *0.000* | *0.000* | *0.033* | *0.000* | *0.000* | *0.258* | |
| | 3m | -4.785 | 0.247 | -8.377 | -0.787 | -48.570 | 0.204 | 0.022 |
| | | *0.459* | *0.279* | *0.000* | *0.000* | *0.000* | *0.103* | |
| FE 3m | 12m | 0.820 | -0.131 | 1.283 | -0.296 | -53.847 | 0.119 | 0.057 |
| | | *0.923* | *0.605* | *0.403* | *0.000* | *0.000* | *0.038* | |
| | 6m | -1.532 | 0.011 | -1.726 | -0.076 | -38.112 | 0.121 | 0.025 |
| | | *0.811* | *0.964* | *0.211* | *0.348* | *0.000* | *0.120* | |
| | 3m | -3.879 | -0.047 | -2.794 | -0.369 | -35.270 | 0.203 | 0.022 |
| | | *0.470* | *0.801* | *0.052* | *0.001* | *0.000* | *0.031* | |

*Note: P-values' are given below the coefficient estimates in italics. All regressions use Newey-West HAC standard errors.*

Figure 30 shows the evolution of the summed coefficients when we regress the FEs,12m on the prior year spot change. As in the previous graph long periods of pessimism can be seen (when $\beta_3 + \beta_4$ is positive and $\beta_3 + \beta_5$ are negative) and unstable coefficients.

**Figure 30 - Evolution of Coefficients (FE, 12m on PSCH 12m), Equ. 37**




## 8.5 Past Information and Forecast Revisions

Table 28, above, examines whether prior FEs are explanatory drivers of FRs. The results are that the combined of coefficients for $\beta_3 + \beta_4$ and $\beta_3 + \beta_5$ are always negative for all combinations with all lower quartile estimates of FE,1m failing to be significant for longer run FR's. This implies that the market's revisions to its spot price forecasts overreact to the FEs that they observe on the previous day. However, no systematic optimism or pessimism is observed as the reactions do not seem to be dependent on the type of information the market receives, it is always an over-reaction. The $R^2$s are also of a relatively high value indicating good explanatory power. As in the previous models, including risk as a control variable has no material effect on the results and is not reported.

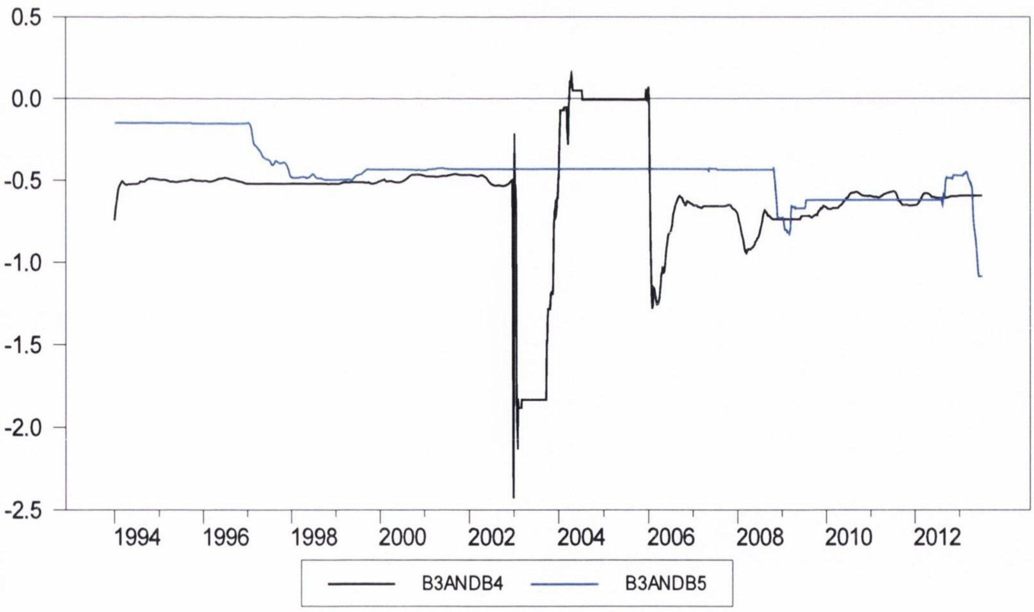
**Table 28- Determinants of Forecast Revision**

| Dependant Variable | $FE_{t-1}$ | Low α | Low β | Normal α | Normal β | High α | High β | $R^2$ |
|---|---|---|---|---|---|---|---|---|
| FR, 12m6m | 12m | -22.686 | -0.593 | 2.222 | -0.434 | 30.382 | -1.082 | 0.600 |
| | | 0.053 | *0.000* | 0.227 | *0.000* | *0.000* | *0.000* | |
| | 6m | 4.408 | -0.951 | -0.565 | -1.020 | -0.697 | -1.009 | 0.964 |
| | | 0.015 | *0.000* | 0.005 | *0.000* | 0.291 | *0.000* | |
| | 3m | 14.468 | -1.037 | 0.592 | -1.170 | 11.162 | -0.839 | 0.553 |
| | | 0.035 | *0.000* | 0.692 | 0.094 | *0.000* | *0.000* | |
| | 1m | 12.090 | -1.433 | -2.160 | -1.100 | 9.570 | -0.268 | 0.302 |
| | | 0.098 | *0.000* | 0.183 | *0.000* | 0.261 | 0.423 | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| FR6m3m | 12m | -26.087 | -0.362 | 1.233 | -0.213 | 19.843 | -0.617 | 0.334 |
| | | 0.038 | *0.000* | 0.379 | *0.000* | 0.146 | *0.000* | |
| | 6m | -14.886 | -0.590 | -0.086 | -0.404 | 7.554 | -0.636 | 0.532 |
| | | 0.069 | *0.000* | 0.927 | *0.000* | 0.003 | *0.000* | |
| | 3m | 0.843 | -0.960 | -0.013 | -1.004 | -1.317 | -0.949 | 0.942 |
| | | *0.399* | *0.000* | *0.939* | *0.000* | *0.083* | *0.000* | |
| | 1m | 4.938 | -1.076 | -1.969 | -0.946 | 2.266 | -0.516 | 0.349 |
| | | *0.363* | *0.000* | *0.060* | *0.000* | *0.715* | *0.041* | |
| FR3m1m | 12m | -29.445 | -0.309 | 0.435 | -0.153 | 18.145 | -0.508 | 0.262 |
| | | *0.025* | *0.000* | *0.727* | *0.000* | *0.093* | *0.015* | |
| | 6m | -22.686 | -0.493 | -0.986 | -0.285 | 12.484 | -0.518 | 0.373 |
| | | *0.022* | *0.000* | *0.319* | *0.000* | *0.000* | *0.000* | |
| | 3m | -11.155 | -0.779 | -1.025 | -0.654 | -0.232 | -0.580 | 0.578 |
| | | *0.026* | *0.000* | *0.197* | *0.000* | *0.942* | *0.000* | |
| | 1m | 2.092 | -1.023 | -0.961 | -0.963 | -3.193 | -0.589 | 0.440 |
| | | *0.698* | *0.000* | *0.22* | *0.000* | *0.339* | *0.000* | |

The relationship between FRs and prior FEs is much more stable than the others examined. While $\beta_3 + \beta_4$ is hovering around zero at times, both summed coefficients are generally negative pointing to a strong systematic bias towards market over-reaction to past FEs over the whole period examined (Fig. 31 below).

**Figure 31 - Evolution of Coefficients (FR, 12m-6m, FE, 12m), Equ. 38**



## 8.6 Role of ETF Flows

**Table 29 - Forecast Errors, Forecast Revisions and ETF flows**

| Dependant Variable | Low | | Normal | | High | | |
|---|---|---|---|---|---|---|---|
| | α | β | α | β | α | β | $R^2$ |
| FE12m | -137.00 | -0.144 | -111.0 | -0.027 | -102.700 | -0.013 | 0.026 |
| | *0.000* | *0.018* | *0.000* | *0.932* | *0.000* | *0.655* | |
| FE6m | -45.863 | -0.012 | -48.78 | -0.089 | -52.060 | -0.132 | 0.022 |
| | *0.000* | *0.032* | *0.000* | *0.758* | *0.009* | *0.566* | |
| FE3m | -1.027 | -0.111 | -18.69 | -0.202 | -26.444 | -0.007 | 0.061 |
| | *0.929* | *0.010* | *0.000* | *0.285* | *0.004* | *0.756* | |
| FE1m | 0.063 | 0.007 | -5.437 | -0.235 | -0.108 | -0.040 | 0.017 |
| | *0.993* | *0.117* | *0.196* | *0.024* | *0.110* | *0.633* | |
| FR12m6m | 63.53 | 0.068 | 55.797 | 0.649 | 68.873 | -0.015 | 0.012 |
| | *0.000* | *0.167* | *0.000* | *0.005* | *0.000* | *0.704* | |
| FR6m3m | 18.49 | 0.054 | 21.26 | 0.322 | 36.322 | -0.004 | 0.012 |
| | *0.090* | *0.119* | *0.000* | *0.005* | *0.000* | *0.884* | |
| FR3m1m | 12.792 | 0.080 | 11.79 | 0.156 | 22.957 | -0.002 | 0.019 |
| | *0.155* | *0.000* | *0.000* | *0.005* | *0.006* | *0.952* | |

The results for the effect of ETF flows are that the combined slope coefficients are negative at the 12, 6 and 3 month maturities. Only large outflows (lower quartile changes) of gold from the ETFs have a statistically significant effect on the markets FEs, normal flows and large inflows importance seem to be discounted by the market. This points to market under-reaction to large outflows of gold in the ETF data over the sample. The upper and lower quartile ETF flows have no significant effect on the markets forecast revisions while the average reaction is to consistently overreact to this type of information. The shorter time horizon due to the new nature of ETF's results in stable estimates of the coefficients given in Table 29 under a rolling analysis, as was carried out in previous sections.

## 8.7 Economic Significance

Table 30, below, shows the economic significance of the intercept and slope coefficient estimations made in the earlier sections. This is done for the first estimation from each of the previous tables to give indications as to the economic size of the coefficient estimates. For regressions where dummy variables are used, we take the central (normal) estimate to assess the economic significance of the model. The significance of each estimated coefficient is assessed by forcing it to take a value of zero. This simulated estimate is then compared with the estimate where no restrictions were placed on alpha or beta. The mean FE12m, FR12m,6m, FR12m, VIX2, PSCH12m and Change in ETF Holdings used are as reported in Section 5.3.

From Equation 33 we can see that using FRs has a very large impact on the estimation of the FE. The prior spot change also has a significant impact as measured through Equ. 35. Using $VIX^2$ consistently changes the estimate of FE by 40% in both Equs. 33 and 35. Despite the beta estimated for the PSCH in Equation 36 being highly statistically significant it appears to be much less economically significant causing only a 7% change in the FP when it is dropped. The estimated betas in Equs. 37 and 38 also have highly significant impacts, while dropping the coefficient on change in ETF holdings from Eq. 39 causes a 23% change in the estimated FR. Some estimates of alphas also have large economic effects such as in Equations 33, 36 and 39

## Table 30- Sample of the Economic Significance of Estimates

$\overline{FE12m}$, $\overline{PSCH12m}$, $\overline{cETF}$, $\overline{Vix^2}$ and $\overline{FR12m6m}$ are the means of the: 12 month forecast error, prior 12 month spot price change, daily change in ETF gold holdings, $VIX^2$ and forecast revision between 12 and 6 months. Estimates of alphas and betas are from the regression indicated in column (1). The average estimates given in column (7) are found using the averages from column (2) and (3) and the estimates of alpha and betas given in columns (4), (5) and (6). Columns (8), (10) and (12) report the estimates with one coefficient held to zero. Columns (9), (11) and (13) report the change of estimate with a zero imposed coefficient.

| **Average Values and Model Estimates of the Coefficients** | | | | | | **Average** | ***Economic Significance of Estimate*** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **(1)** | **(2)** | **(3)** | **(4)** | **(5)** | **(6)** | **estimate (7)** | ***(8)*** | ***(9)*** | ***(10)*** | ***(11)*** | ***(12)*** | ***(13)*** |
| **Equ 33** | $\overline{FR}$**12m6r** | $\overline{Vix^2}$ | **A** | **β(FR)** | **β($VIX^2$)** | **Est. of FE** | **β(FR)=0** | **Change** | ***α =0*** | ***Change*** | ***β (Vix)=0*** | **Change** |
| **FE,12m** | -17.77 | 20.294 | -4.01 | -0.439 | -0.054 | 2.692 | -5.108 | 290% | *6.705* | *149%* | *1.596* | 41% |
| **Equ 35** | $\overline{PSCH12n}$ | $\overline{Vix^2}$ | **A** | **β(PSCH)** | **β($VIX^2$)** | **Est. of FE** | **β(PSCH)=0** | **Change** | ***α =0*** | ***Change*** | ***β (Vix)=0*** | **Change** |
| **FE, 12m** | 52.37 | 20.294 | 2.69 | -0.325 | -0.51 | -24.680 | -7.650 | 69% | *-27.370* | *11%* | *-35.030* | 42% |
| **Equ 36** | $\overline{PSCH12n}$ | | **A** | **β(PSCH)** | | **Est of FP** | **β(PSCH)=0** | **Change** | ***α =0*** | ***Change*** | | |
| **FP,12m** | 13.82 | | 14.1 | -0.063 | | 13.229 | 14.100 | 7% | *-0.870* | *107%* | | |
| **Equ 37** | $\overline{PSCH12n}$ | | **A** | **β(PSCH)** | | **Est of FE** | **β(PSCH)=0** | **Change** | ***α =0*** | ***Change*** | | |
| **FE, 12m** | 52.37 | | -2.16 | -1.079 | | -58.675 | -2.168 | 96% | *-56.507* | *4%* | | |
| **Equ 38** | $\overline{FE12m}$ | | **A** | **β(FE)** | | **Est of FR** | **β(FE)=0** | **Change** | ***α =0*** | ***Change*** | | |
| **FR12m,6m** | -38.26 | | 2.22 | -0.434 | | 18.826 | 2.222 | 88% | *16.604* | *12%* | | |
| **Equ 39** | $\overline{cETF}$ | | **A** | **B(ETF)** | | **Est of FR** | **β (ETF)=0** | **Change** | ***α =0*** | ***Change*** | | |
| **FR12m,6m** | 25.297 | | 55.7 | 0.649 | | 72.214 | 55.797 | 23% | *16.417* | *77%* | | |

### 8.8 Conclusion

This chapter examines rationality in the gold market. It shows that the gold forward and spot markets in general do not conform to rational expectations especially at horizons longer than a month (there is some evidence in favour at the 1 month horizon). The forward price is generally not an unbiased predictor of the future spot price.

Drawing on the earlier work of Easterwood and Nutt (1999) and Aggarwal and Zong (2008), two possible reasons for these deviations from rationality are examined, risk aversion and behavioural factors. Based on these models, we examine optimism, pessimism, under-reaction, and over-reaction in the gold forward market. The findings documented and discussed here are established as economically significant in most cases.

The gold market's forecast errors are generally found to be pessimistic. However, as expected, when risk aversion is controlled for using $VIX^2$, we see a fall in forecast errors when volatility rises, indicating that speculators are long gold futures contracts. This is partially confirmed by Commitments on Trader's data from the Commodities Futures Trading Commission. Further, when we allow for differing reactions to positive and negative prior information we fail to find optimism or pessimism. Forecast errors in the gold market are only affected by large gold outflows in ETF holdings, but under-react to this news.

In fact, the market's mood and reaction to information has not been a constant over time. The market's forward premiums overreacted to all news in the late 1990s and were systematically pessimistic in the mid-2000s. However, forward premiums over the full sample are found to be optimistic, over reacting to good information and under-reacting to bad. Forecast Errors are shown to be a major driver of the markets forecast revisions with a high level of explanatory power. The market's forecast revisions are fairly stable with over-reaction dominating over the almost the whole period examined. Strong evidence is found that over the full sample period the gold market overreacts to prior spot price changes.

In summary, in this chapter we document that gold spot and forward markets do not conform to rational expectations. In general, they over-react and are optimistic. These deviations from rationality are systematic, economically significant, and not explained by other plausible economic factors such as market risk or ETF gold demand. Behavioural factors are clearly shown to be important in the gold forward markets.

# 9 Final Discussion

This thesis has been divided into a selection of chapters. The first gives a brief introduction to the topic as well as the contributions that will be made by the research. Chapter 2 provides a brief history of gold with an emphasis on the London gold market, up to current supply and demand trends to give context to the rest of the thesis. Chapter 3 provides a substantive review of the literature on the economics and finance of gold. Chapter 4 describes the philosophical approach and methodology that was implemented to answer the questions posed. Chapter 5 summarised the data used in the three empirical chapters. Chapter 6 - 8 provided the empirical contributions of the thesis, as described in the following paragraphs.

Chapter 6 addressed the issue of the direction of causality between gold prices and their cost of production. This is done for two reasons. Firstly in order to judge between two competing hypotheses of the channel through which gold and inflation may be kept in a long run equilibrium. One of these, based on classical economics, suggests that extraction costs are led by inflation and in part determine gold prices through miners demanding higher gold prices to compensate them for increased prices. The hypothesis favoured here is that mining firms are price takers and that gold prices lead and in part determine extraction costs. This idea fits well with Ricardo's Law of Rent as well as more recent work on Real Options. Secondly, the idea that extraction costs lead and cause gold prices has led some authors to the conclusion that gold lease rates are the opportunity cost of holding gold, as discussed in Section 3.2. As gold lease rates are used in Chapter 7 to represent the benefit of holding gold it is useful to disprove this idea.

The above question is addressed with Granger Causality tests using global survey data from Thompson Reuters GFMS broken down into 24 countries and 30 companies. This data covers a maximum timespan of 1981 to 2013, but the country and company data used more commonly runs from 2000 and 2013. It is shown that for the gold price clearly leads world average extraction costs with a positive and significant relationship, as predicted through theory by this thesis. These results are confirmed for all countries with longer data sets, which represent the major gold producers over the period. For the countries and companies with shorter data sets in many cases no significant

relationships are found, but as we only have 14 observations here this may be to a lack of power in the tests.
Some evidence is also found of a causal relationship running from extraction costs to gold prices, but not using the world average costs figures. Also, the relationship is negative which is not as predicted for an inflation channel by Levin and Wright (2006). Instead this is interpreted as a failure on the part of miners to predict gold prices accurately, consistently increasing their extraction costs prior to a gold price fall or vice versa. This finding is most common for the countries with shorter samples. In longer samples only Australia and the smaller producer countries, grouped together as "Other" by GFMS show this result.

Chapter 7 investigates whether periodically bursting bubbles occur in gold prices based on Markov-Switching Augmented Dickey-Fuller tests. All maturities of gold lease rates are used as the fundamental determinants of gold prices for the first time in the literature. It is argued that this data represents an improvement on previous models as lease rates are the only market based measure of the benefit of holding gold. Earlier studies had resorted to a number of less optimal methods such as: domestic interest rates as gold's opportunity cost; gold's convenience yield which it is argued above is more suited to consumption commodities; or attempts to create a true gold price based on a number of drivers of the gold price, which could suffer from over specification.

Based on the results from the more empirically valid version of the Markov-Switching Augmented Dickey-Fuller test, which have a constant variance across regimes, it is shown that bubbles may have formed and burst during the sample period examined (1989 – 2013) based on the 2, 3 and 12 month lease rate maturities. However no bubble is seen to be present when the 1 and 6 month lease rates are used. As it is unclear which of the lease rates are the best representation of the fundamental value of gold this remains a question to be addressed by future research.

Chapter 8 provides the first tests of the Forward Rate Unbiasedness Hypothesis (FRUH) for the gold OTC market; though there was one previous study using gold futures. The hypothesis is not accepted based on tests in levels and first differences. This implies that there must be a factor not included in rational expectations that can explain this deviation.

This thesis tests for two possible explanations for this failure: risk aversion and behavioural biases. We find that risk aversion, as proxied by the VIX index, does not explain away the failure of the FRUH, though it does have some explanatory power. Instead we look for under or over reaction to previous changes in gold prices to assess whether we could find optimism or pessimism in forward gold prices as predictions of future spot prices. Some findings include: the forward premium is consistently optimistic; forecast revisions overreact to news consistently; but many other findings indicate that the markets mood in general is not stable. Instead it is shown to swing from pessimism in the 1990's to optimism in the 2000's. This points to some irrationality being present in the London gold market.

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