The Financial Economics of Gold - a survey

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The Financial Economics of Gold – A Survey

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Abstract

We review the literature on gold as an investment. We summarize a wide variety of literature, including the papers in this special issue of International Review of Financial Analysis to which this survey acts as an editorial introduction. We begin with a review of how the gold markets operate, including the under researched leasing market; we proceed to examine research on physical gold demand and supply, gold mine economics and move onto analyses of gold as an investment. Additional sections provide context on gold market efficiency, the issue of gold market bubbles, gold's relation to inflation and interest rates, and the very nascent literature on the behavioural aspects of gold.

Keywords: Gold, survey, review

JEL Codes: E44, F33, G15, L72, Q31

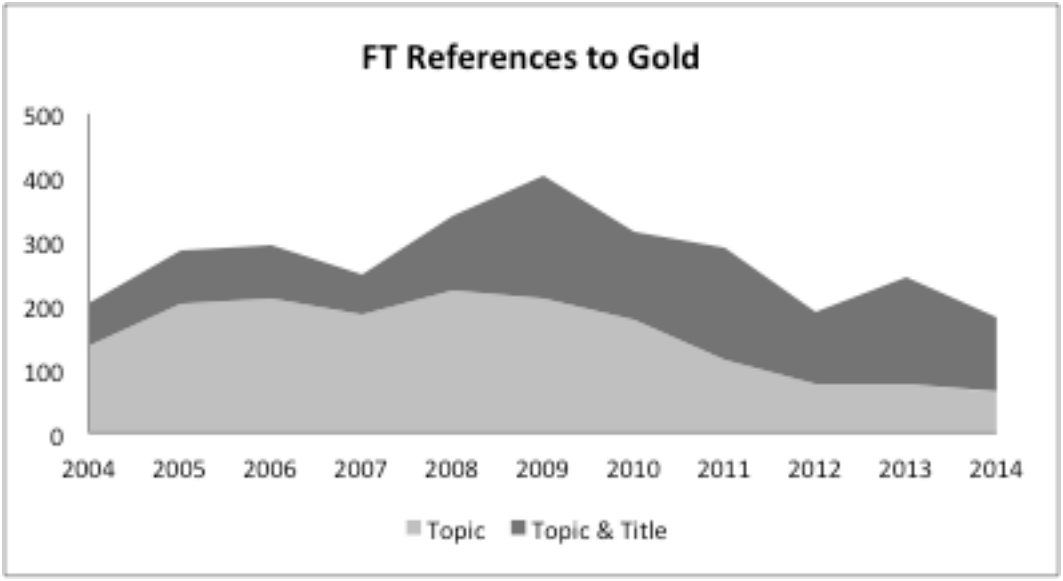
The Financial Economics of Gold – A Review

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 over 6,000 years Green (2007). As money, as an investment, as a store and source of value, hundreds of papers have been written on Gold. This review provides a state of the art overview of this voluminous research, and acts as an introduction to this special issue of the International Review of Financial Analysis, while also assisting as a source of reference for future research.

The long and intertwined history of gold, financial markets and money has resulted in gold's regular prominence in investment and monetary discussions. 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 represents all articles filed under the topic Gold by the Financial Times editors, with the lighter portion showing the number filed under Topic: Gold as well as having gold in the title. Thus, the number under the topic gold was 401 in 2009 and 212 of those (53%) also had gold in the title.

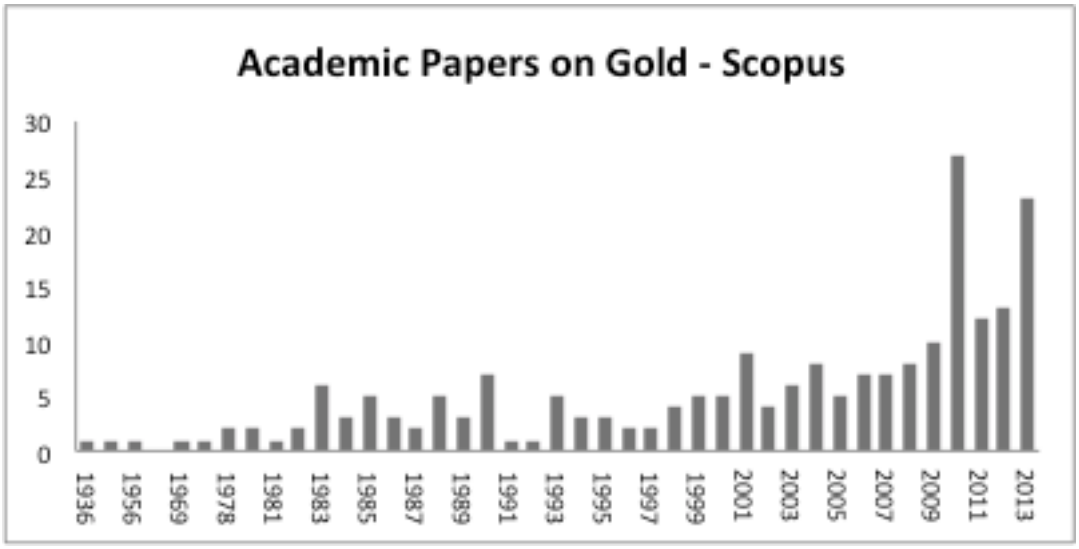
Figure 1- Gold Related Articles in the Financial Times



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

The volume of academic studies on gold has been growing since it was allowed to float freely in the late 1960's. While gold prices rose after this period, the drivers and mechanics of changes in the price of gold also attracted the attention of academic researchers. The volume of peer-reviewed papers published, depicted below in Figure 2, shows that the number of published papers has increased significantly in recent years highlighting the relevance of both this special issue and the need for a comprehensive survey of the existing literature.

Figure 1- Published Academic Papers discussing the Financial Economics of Gold



Source: Author's own calculations, from Scopus

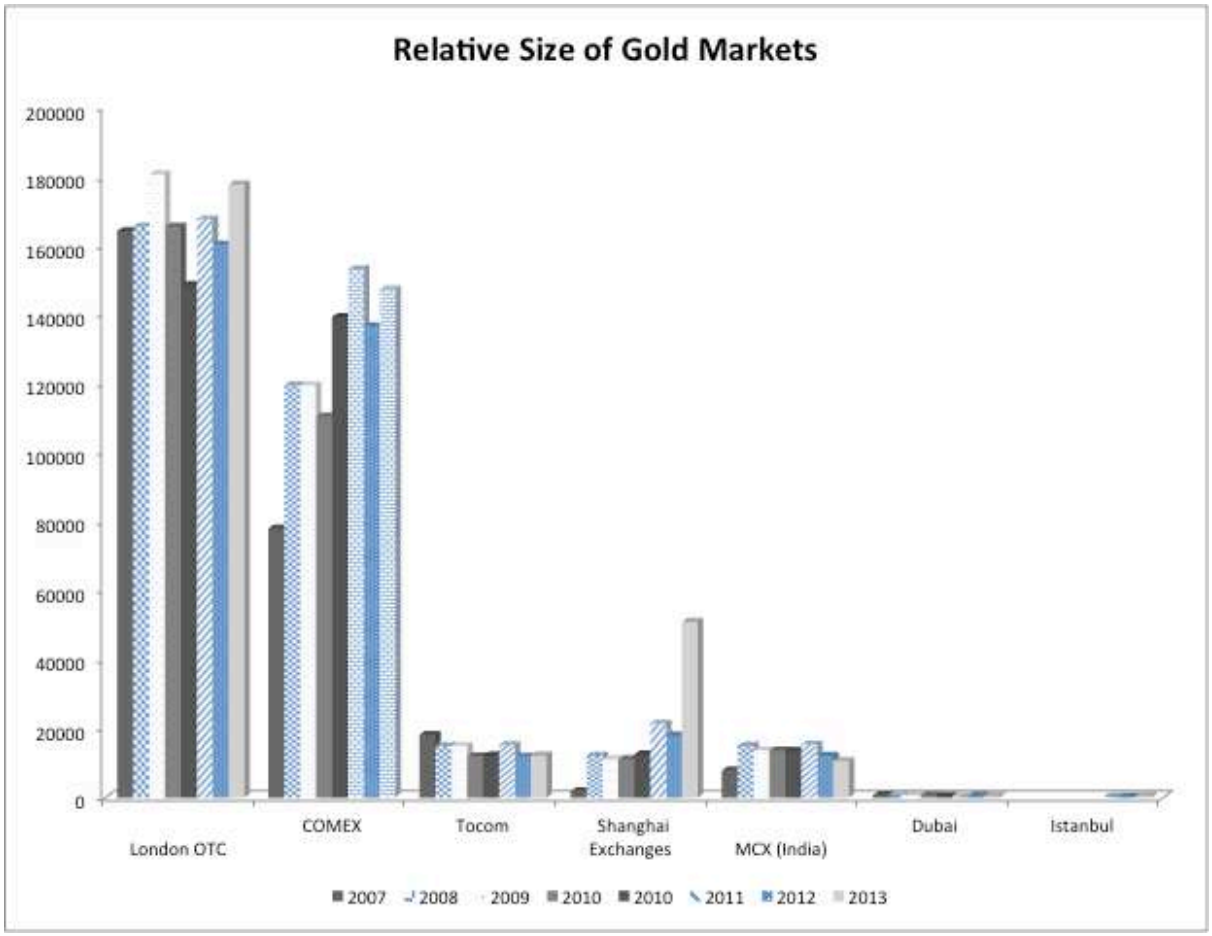
A Brief History of Gold

Gold is one of the oldest ways to store wealth. In 3000 BC goldsmiths in Sumeria were already working gold into the various forms of jewellery still used today. Excavations at the royal cemetery of Ur (founded about 2500 BC) showed that gold had already become a store of wealth by this time, as well as being utilized as money 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. Perhaps the most famous usage of gold was as money under various gold standards.

Today gold is traded on seven 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 U$34.5bn per day in 2013. 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 was U$21bn and U$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. It is estimated that there has been in total 175,000 tonnes of gold mined in history. At average 2013 prices this would value the total stock of gold at just under US$6 trillion. 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 remains a sizeable and important financial asset. By comparison, the total market capitalisation of the London Stock Exchange in December 2013 was £4.23tn (U$6.9tn) with the New York Stock Exchange being worth just over U$16tn .

Figure 2 - 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 (2014)).

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 this market absorbed the vast majority of the gold mined in the Brazil gold rush that then went into minting new gold coins; then Russian gold, which was the largest producer before the Californian gold rush of the 1840's. Even the suspension of conversion by the Bank of England in 1931 did not dent London's dominance.

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

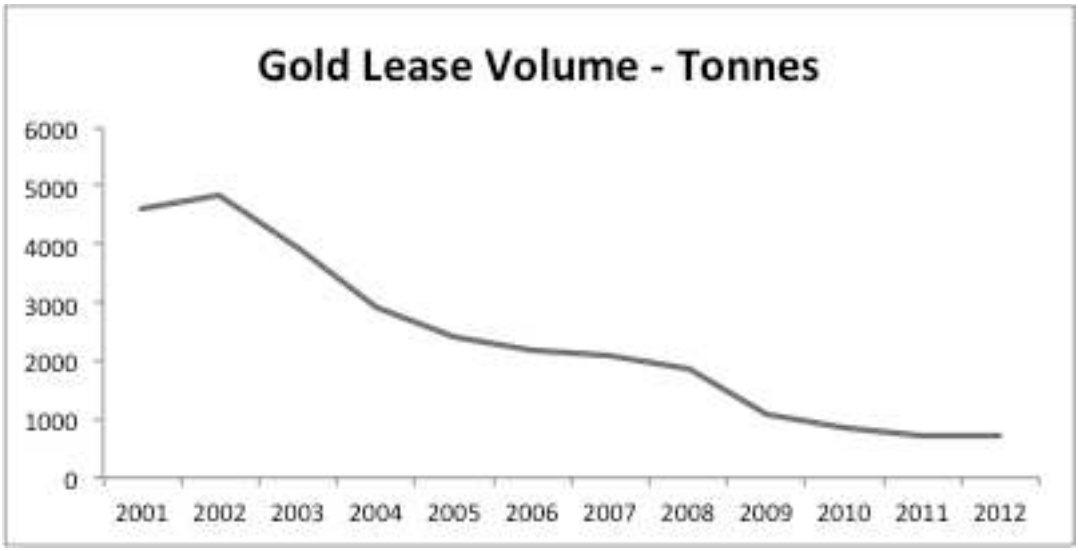
Along with the spot and those derivatives markets discussed above, gold can be borrowed in a similar way to normal currencies. There is very little research published on the operations of the leasing markets. Gold itself has an interest rate, the lease rate. Levin & Wright (2006) find that gold prices are negatively related to lease rates. This analysis is based on an arbitrage model developed by Levin, E., Abhyankar, A. and Ghosh (1994). Here miners have two options: firstly 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. 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. This of course depends on the relationship between mining and inflation. 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. Gold Lease rates should perhaps be more correctly described as the benefit of holding gold.

The primary sources of gold leasing demand have traditionally 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 and a few large trading banks that use it to provide income from their physical gold holdings. Lending by central banks is rarely reported (although the Bundesbank has now begun to report) but it has fallen off in recent years as lease rates have decreased.

An exception is the Reserve Bank of Australia (Reserve Bank of Australia (2012)), who stated for 2012 that out of 80 tonnes in stock only one was on loan at that time. The low and declining level of lending in recent times is ascribed by market participants to a lack of demand from miners and jewellers as well as increased counterparty risk and low available returns.

Figure 4- World Gold Leasing Volume, Tonnes



Source: GFMS Gold Surveys 2000-2013

Gold Market linkages around the world

As noted, and more so in latter years, gold is an asset traded widely around the globe. A natural question then is the relationship between the prices and price information flows as between the markets. 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 effects the other two markets more than they, making it either dominant or independent according to the author, affect it. An issue with this analysis is that London's importance is possibly understated as the PM Fixings are used. The PM Fixings price overlaps with US trading, unlike the AM Fixing, and it is possibly more to be related more to the New York price, whose closing price of 19.30 GMT is used.

Xu & Fung (2005) look at US and Japanese daily trading in gold, and also in 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 affects the US 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.

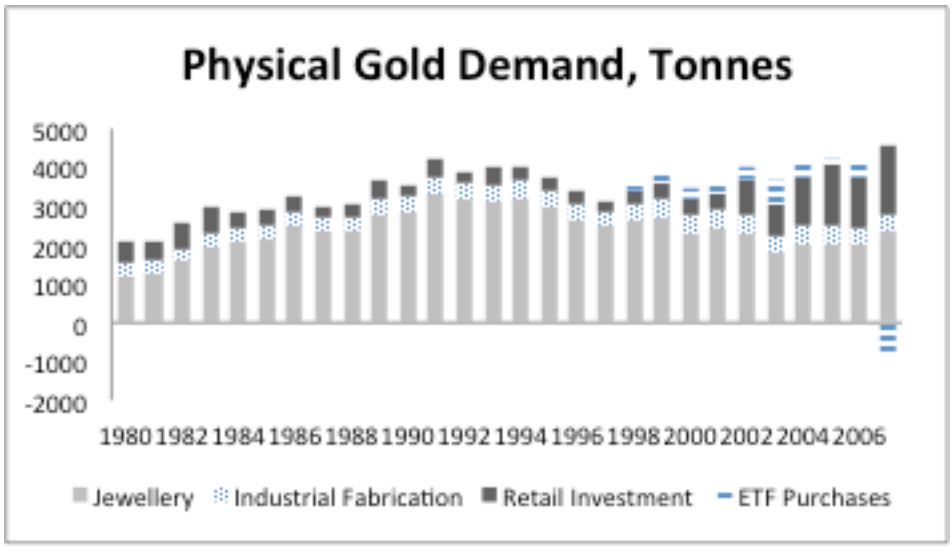
Lucey et al. (2013) examine the contribution that different geographical markets of gold trading make to price formation. They look at London Fixings and COMEX futures prices as the two largest centres of gold trading (86% and 10% volume respectively; Murray (2011) and GFMS Gold Survey (2013). They find that both contribute to price discovery dominating the process at different times with no obvious macroeconomic or political links. Lucey et al. (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 & Chaihetphon (2008) 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.

As econometric methodologies evolve so too do the findings of researchers. The consistent takeaway from all papers is that no one market is dominant at all times. More recently, papers have examined information transmission formally. Pavabutr & Chaihetphon (2008) look at the price discovery process of the Multi Commodity Exchange of India between 2003 and 2007 using daily observations. 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. Lucey, Larkin, and O'Connor (2013) apply Gonzalo and Granger (1995) and Hasbrouck (1995) measures and conclude that although significant time variation exists in information transmission London may be dominant. These measures have however been critiqued by Putniņš (2013), who derives a new measure which accounts for market specific noise. Applying this measure, and to a longer run of high frequency data, Hauptfleisch, Putniņš, and Lucey (2015) confirm the time variation but suggest that New York leads. We also see in this issue from Chai, Lee, and Wang (2014) that this New York dominance also holds when a nonparametric approach is taken, and in fact the two hour (on average) period when both New York and London are open provides a further very large contribution to global price information formation.

Physical gold demand and supply issues

While gold does have industrial uses its demand mostly originates from investment demand and jewellery. Figure 5 below shows the level of demand for physical gold from various sectors beginning in 1980 for Jewellery production and from 1986 for all others.

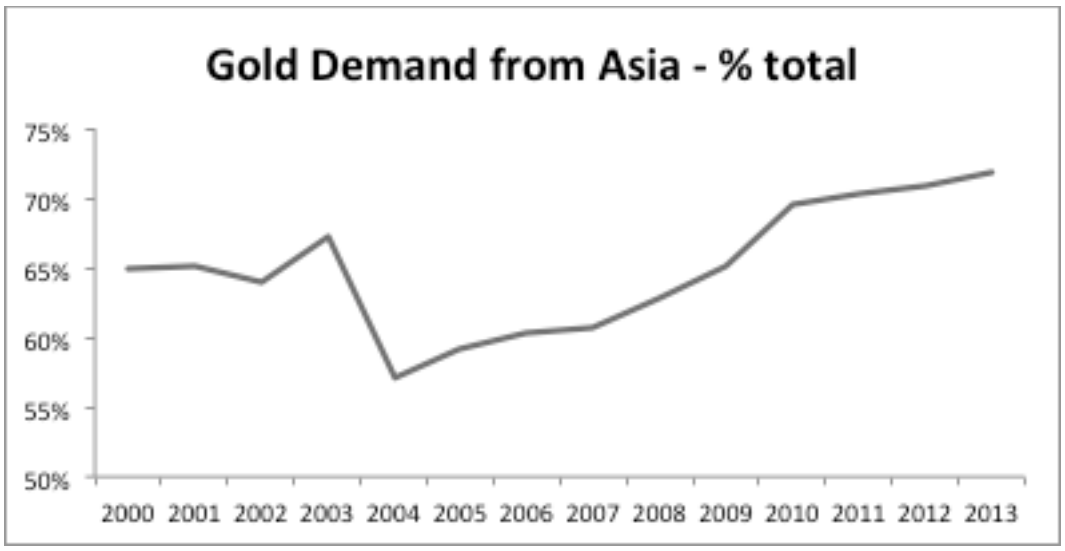
Figure 5- Demand for Physical Gold, Tonnes



Source: GFMS Gold Surveys 1989 - 2013

Jewellery production represents the most stable long-term source of demand for gold and was one of the earliest uses for gold. Sociocultural 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 Asia filled the boats of the East India Company in the late 17th and 18th centuries on their outward journeys from Europe. Figure 6 below shows that over 55% over all jewellery is purchased in Asia since 2000 and has risen to over 70% since 2010.

Figure 6- Proportion of Jewellery Demand (volume) from Asia

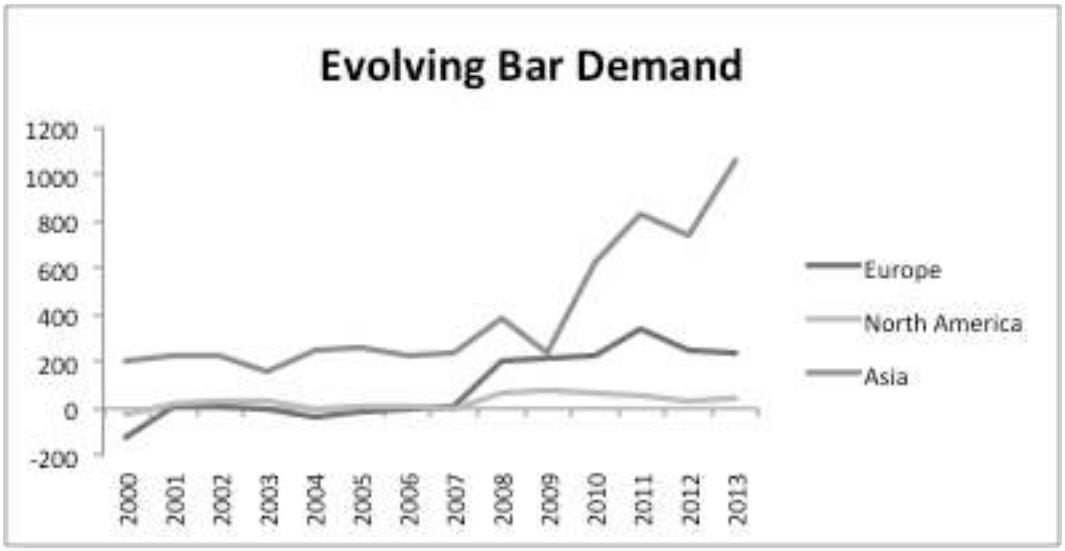


Source: Gold Fields Mineral Services Ltd (GFMS) GFMS Gold Surveys 2001 - 2013

Demand from industrial fabrication arises mainly from dentistry and electronics, both of whose usage are 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 t is being increasingly replaced by copper. In dentistry, gold is being replaced by cheaper non-metallic substrates such as plastics. In 2013 the total demand from dentistry was 36.3 tonnes the lowest level ever recorded by GFMS. Gold in electronics has 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..

With jewellery demand stable and industrial demand declining, demand has increased by retail investment. In the run-up to the financial crisis the popularity of retail investment of gold bars and coins, increased dramatically tripling between 2006 and 2013 to 1,377 tonnes. Much of this investment has occurred outside of western markets, as gold has flowed to Asia following a long run historical pattern. Figure 7 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 also saw increased demand in the western world.

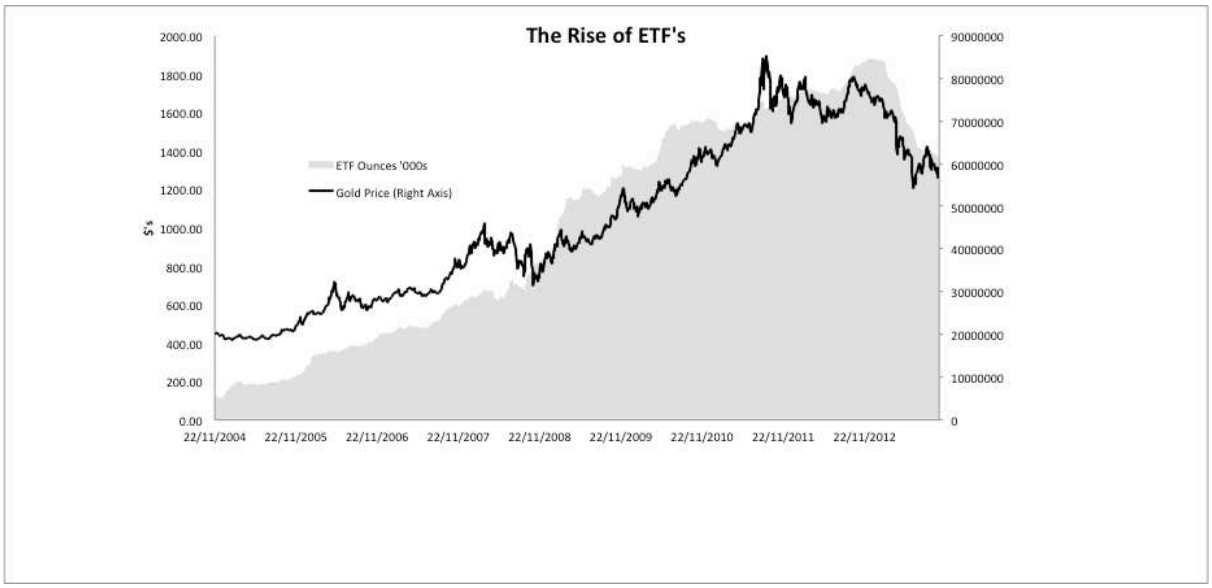
Figure 7 - Retail Investment in Bars, Tonnes



Source: GFMS Gold Surveys 2001 - 2013

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. 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 8 below.

Figure 8 – Total Exchange Traded Fund Gold Holdings and PM Fixing



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 recent price falls. As will be shown

later, the bivariate relationship between the price of gold and ETF demand has attracted some, but curiously limited, research attention.

This fall in demand for "paper" gold, where owners merely have a 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 reporting the 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.

The unwinding of ETF positions in 2012-13 and its effect on gold prices has similarities to events in 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. Renminbi are used to buy gold and this is in turn 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 (eee Kaminska, 2011).

The World Gold Council (WGC (2014)) estimates that China had 1,000 tonnes of gold tied up in financing deals in 2013, roughly equal to about one year of Chinese gold imports. This overhang creates the concern that if these financial deals were suddenly 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, as per Ananthalakshmi (2014), which has even larger rehypothecation inventories than gold (estimated to be 1million tonnes in 2014), led to a significant fall in the copper price in March 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.

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 jewelry 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 jewelry 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 Tran (2008) provide an analysis of the factors, which affect the physical demand for gold (such as jewelry and dental) using data from 1992 to 2003. The authors argue that these 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 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. While this paper does not discuss unit root or co-integration issues despite some of the variables used being commonly seen as non-stationary. Caution should be exercised in interpreting this paper's findings however with some econometric issues around treatment of unit roots remaining in the paper

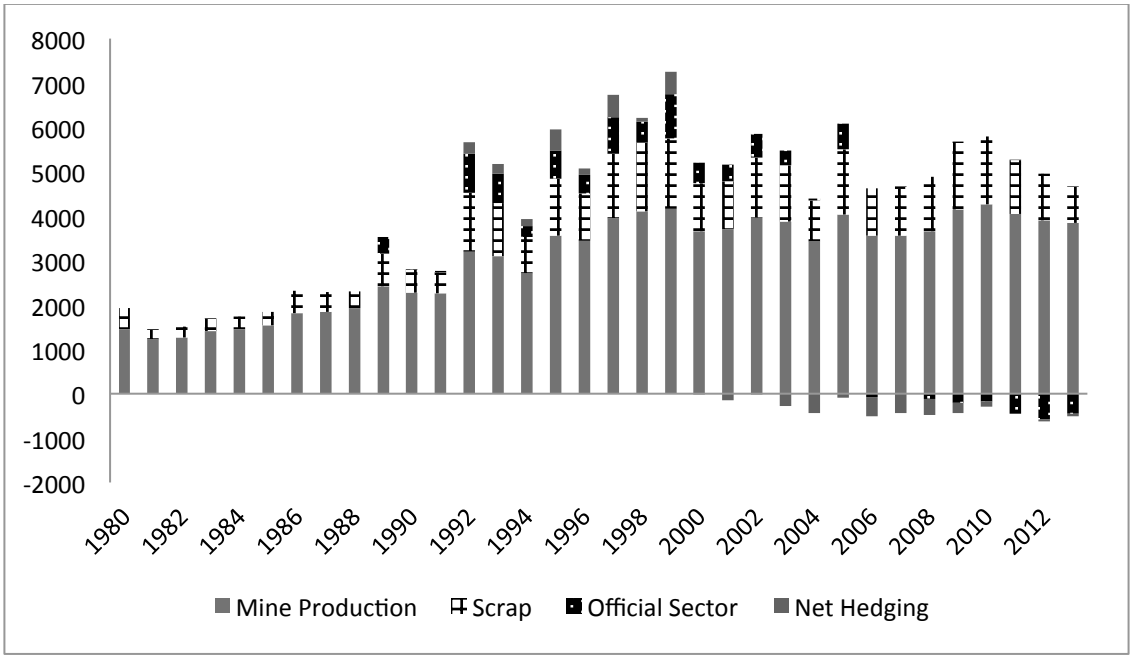
Mozes and Cooks (2013) suggest that the drivers of physical gold demand and gold prices are different on an annual and quarterly perspective from 1992 to 2012. They conclude that physical demand will not support gold prices.. The data on demand used here is however of a significantly different frequency to that and may not be able to capture the effect of physical demand on price changes.

Physical Gold Supply Research

Most of the gold ever mined is still in existence and would form a cube with sides of less than 20 meters. A key feature of gold is its difference to 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.

Total supply plateaued in 1999 and has remained 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. In this section we examine the various sources of supply, the life cycle of gold and discuss empirical evidence 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 released to the market through official sector (central bank) bank sales and producer hedging.

Figure 9- Total World Gold Supply, Tonnes



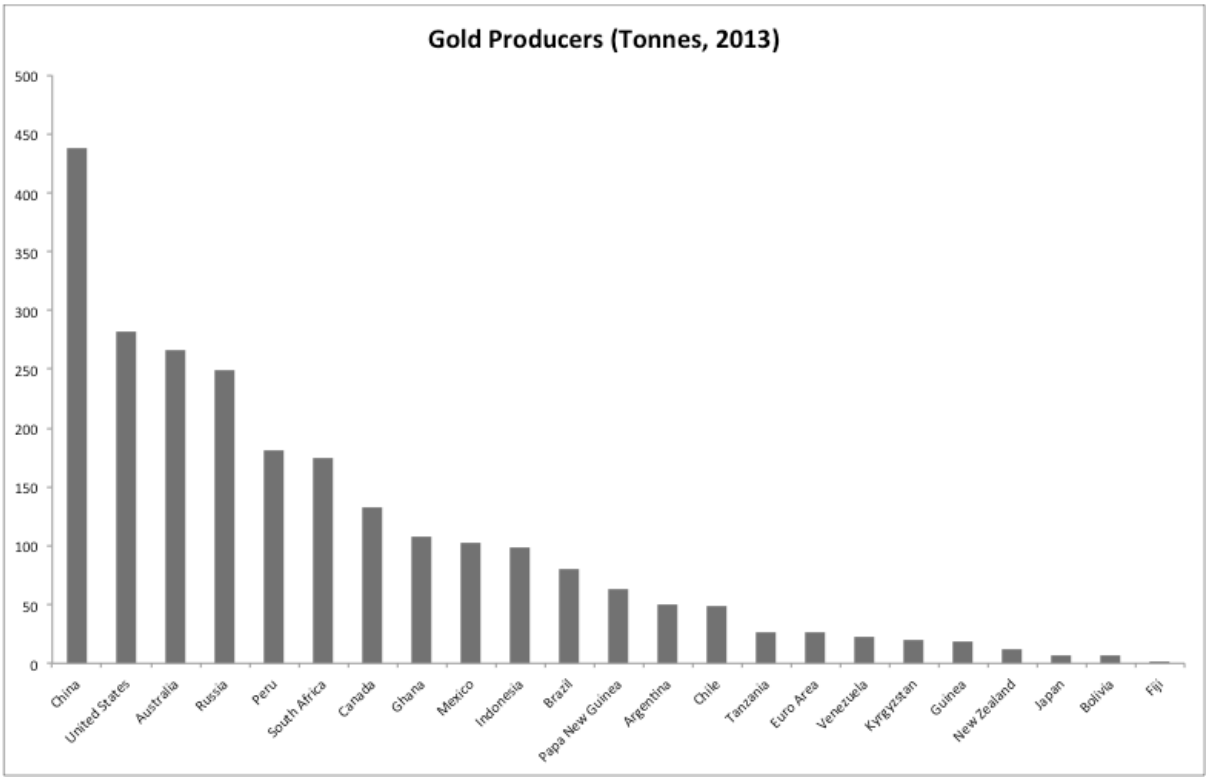
Source: GFMS Gold Surveys, 1989 - 2013

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 cash flows or assets, gold represents what can be referred to as a real asset. Thus unlike most assets, it is not also simultaneously a liability for another market participant. 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 infinite unless destroyed at an atomic level.

Mine supply

Though gold supply as depicted above peaked in 2010, barely above 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 2013 distribution of producing countries is as below.

Figure 10 - Gold Production 2013, Tonnes



Source: GFMS Gold Survey 2014

The volume of gold produced from mining a given quantity of ore depends 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 that is environmentally damaging. The product is then smelted to remove impurities and turned into bullion for further processing into electronics, jewellery etc., or for storage in bar form as an investment.

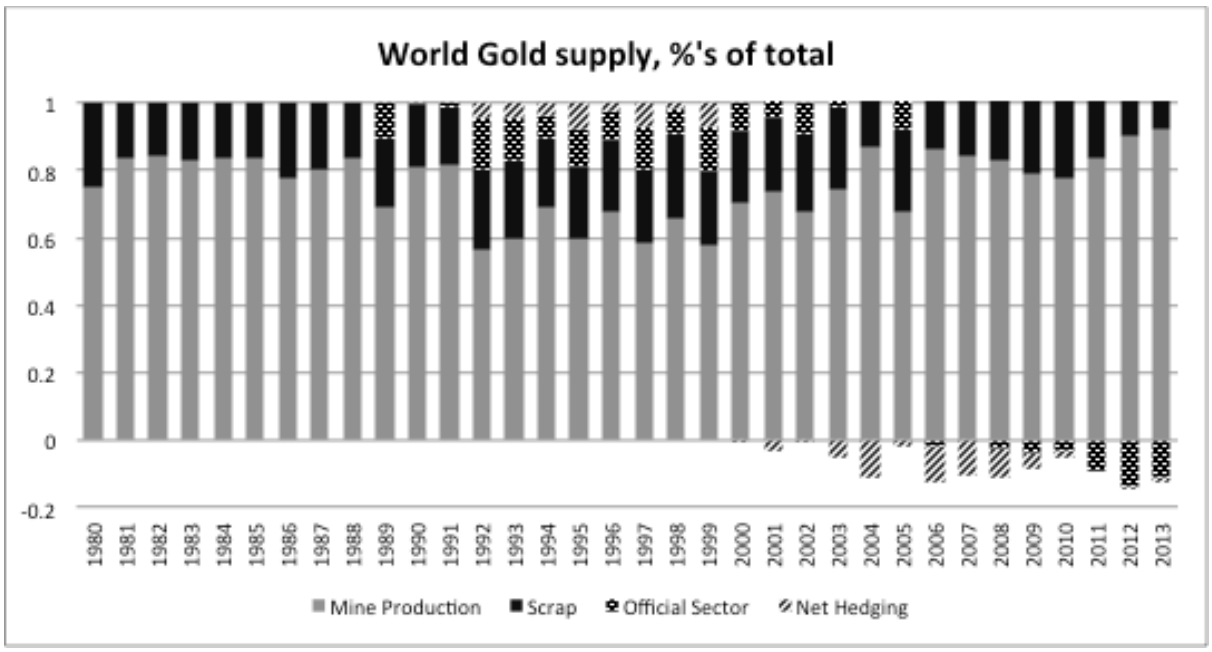
In order to be held in many official vaults as an investment, gold bars must be certified as coming from a refinery on the Good Delivery List maintained and monitored by the LBMA. The majority of these bars will then be melted down to create jewellery or smaller bars and coins for investment, as discussed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

Figure 11 - Total Scrap Supply, Tonnes



Source: GFMS Gold Surveys 2005 - 2014

Based on a visual inspection of Figure 13 above, there appears to bee correlation between high prices around the financial crisis and jumps in scrap supply. As prices declined after 2011 so too did scrap supply. There has, however, been no significant academic economic research to date in relation to the supply of gold from scrap. A study on recycling by Graedel et al. (2011) outlines some detail on the metallurgical aspects of gold (and other metal) recycling. 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 that they find to be based on current prices and the fact that scrap can be processed at a fraction of the cost of ore. A similar study on nickel (Eckelman, Reck, and Graedel (2012)) outlines its price sensitivities across its supply chain.

However, as gold trades as a primarily financial asset while steel and nickel are simple commodities there are differences in the markets that warrant further investigation. The Gold Fields Minerals Surveys carried out annually (and providing the bases for this and the previous section) provide a similar but more detailed analysis of individual countries scrap supply. GFMS 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 above saw central bank (official sector) sales of gold holdings. Feldstein (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. 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 seemed to have become a trend. Coupled with the rise in production volumes, this was a major driver of the gold bear market at the time.

The Global Financial Crisis (GFC) saw 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 long-term 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, more especially the announcement of sales, would push down prices. Their analysis was based on the Hotelling 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.

There are a number of points worthy of mention concerning these papers. Firstly, according to Livernois (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 have seen it is possible to lease gold. Third, the applicability of a Hotelling rule to a renewable resource, as we can consider gold to be in the short run, is unclear.

Producer Hedging

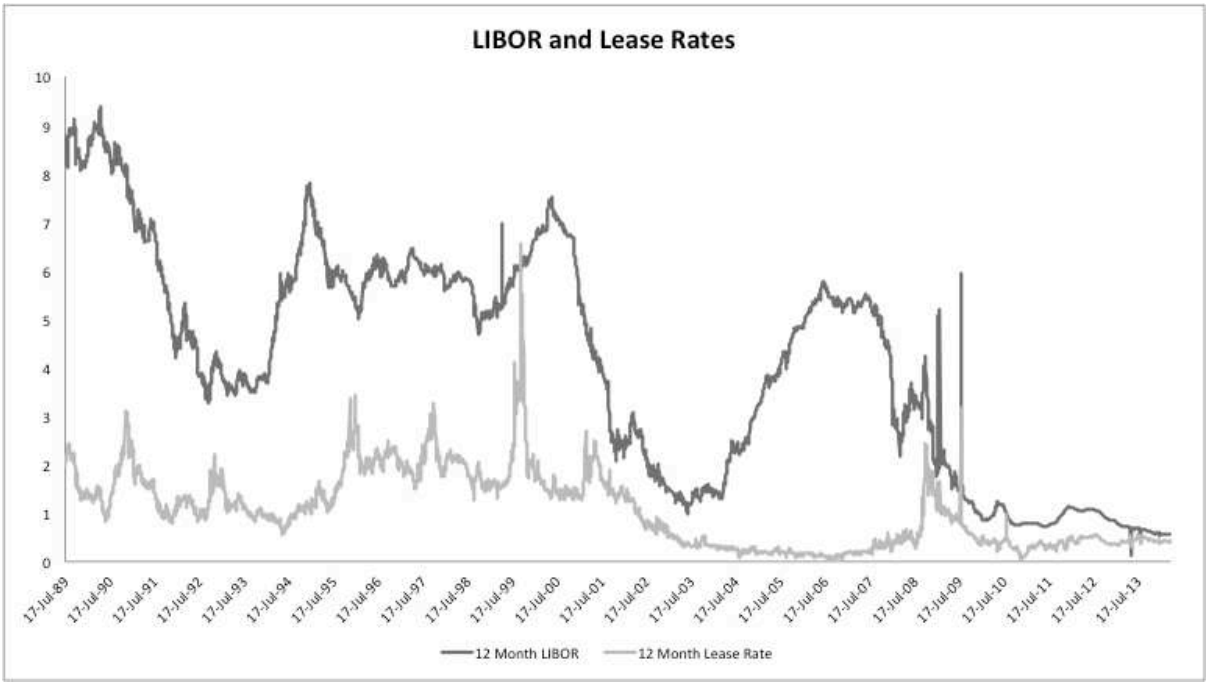
There are a number of papers that utilize the hedging practices of gold mining companies to provide evidence on the selective use of hedging by corporations. An early paper is Tufano (1996), who finds little evidence for selective hedging ability. More recently Jin and Jorion (2007), and Adam, Fernando, and Salas (2015) both cast doubt on the hedging ability or value. Jin and Jorion find that hedging is related mainly to corporate distress while Adam et al note that the market may recognize the value of hedging in gold mining and refining firms but this

is outweighed by asset substitution effects. Overall, Central to understanding this issue is the ideas that hedging by miners (gold producers) can be a source of supply to the market in two ways, through forward sales and leasing. Hedging, as a significant tool of miners was first applied by Barrick Gold and thereafter spread through the industry. It was a source of supply in the 1990's as firms tried to remove their gold price risk. A useful description of corporate hedging in practice, via two case studies, is contained in Chung (2003).

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.

In contrast gold leasing does provide spot market liquidity and immediate financing to the miners. It involves borrowing gold for a fixed period that 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 below. Leasing only provides a net supply when more loans are made than repaid in a particular year.

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



Source: LBMA.org

The relationship between Gold Prices and Gold Mines

In the end, like any other asset, gold is affected by its supply and demand characteristics. Thus studies, such as Bertus & 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. Rockoff (1984) shows that the long run supply of gold is relatively elastic with respect to gold's price

Selvanathan & 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, which is not unreasonable considering the large-scale capital investment involved. This is one of the few papers where production costs are considered, but they were found to be an insignificant factor in explaining production volume changes. Erb and Harvey (2013), however, suggest that gold mine production is not significantly affected by the rise of prices since 2000, from a visual inspection of data.

Many other studies argue that gold miners are price takers rather than price setters Blose and Shieh (1995). Borenstein & 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 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 (back) 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 & Schwartz (1985) and empirically in Krautkraemer (1989) and Moel & Tufano (2002). For example, Krautkraemer (1989) finds that as prices rise, miners tend to mine lower quality ore. O'Connor, Baur, and Lucey (2014) examine this in some detail. They find strong evidence for causality running from gold prices to gold production costs both at a firm and a national level. There is also some industry-based discussion that gold prices drive production costs and not the other way around. GFMS Gold Survey 2013 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).

Gold as an investment

Amongst financial assets gold is quite unique. It virtually sits as its own asset class different even from the other precious metals: silver, platinum and palladium (Batten, Ciner, and Lucey (2010), Batten, Ciner, and Lucey (2014). One reason is that its usefulness as an industrial metal is small 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 production of solar panels.

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 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 Busschau (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 in which recent literature has focused), were not addressed in any detail

Early work on with 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 paper 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 gold versus other assets. He concludes that the 1969 gold price of $35 would not hold without government intervention and would fall significantly if governments moved out of the market. History has proved this 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 depress the price of 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.

Hedging and Portfolio Diversification

How useful is gold as part of an investment portfolio? Is it a hedge, and if so over what period of time? A hedge is defined as "an asset that is uncorrelated or negatively correlated with another asset or portfolio on average" (Baur & Lucey 2010:220). Sumner et al. (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. If there is no spillover, if gold is isolated from stock and bond movements that would be a prima facia signal of its potential to be added to a stock-bond portfolio. There is a very large literature on gold as an investment asset in portfolios.

Gold is a volatile asset when held alone. Jaffe (1989) recommended holding approximately 10% of a (stock) portfolio in gold in order to achieve an optimal. This however works only with the actual asset. 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 et al. (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 & Chan (1998).

Hillier et al. (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 portfolios efficiency: a buy-and-hold strategy and a switching strategy with ortfolio efficiency 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 & Chincarini's (2010) estimates. The switching strategy for gold, silver and platinum does not provide significant efficiency gains.

Bruno & 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. These vary considerably, with weights from 0.1% to 12%[1].

Another characteristic that contributes to gold's diversification abilities is the skewness of its returns distribution. Lucey, Tully, and Poti (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 when the positive skew of gold is taken into consideration in a multimoment asset allocation 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. Surprisingly little research has been undertaken on multi moment optimisation on precious metals.

One recent work is Emmrich and McGroarty (2013) who update Jaffe (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 et al. (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 et al. (2006) who found no benefits from switching, even with hindsight.

Gold as a possible hedge asset has also been examined in relation to currency portfolios. Capie et al. (2005) examine whether gold can act as a hedge against currency risk, specifically as a hedge against 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

[1] 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 Korean gets a 0.1% weighting while India, who have strong cultural links to gold, have a 12% weighting, with the remaining countries between 4% and 7%.

pairs to 16 currencies from 1986 – 2008. Using dynamic conditional correlation models he finds that gold was 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. Similar findings, of gold as a potentially useful hedge for currencies are reported in Reboredo and Rivera-Castro (2014), Yang and Hamori (2013) who also examines the safe haven properties of gold for currencies, and Apergis (2014) who shows gold as a useful predictor and hedge for the Australian dollar. Both Ozturk & Acikalin (2008) and Soytas et al. (2009) examined the role of gold as a hedge against the Turkish both finding that there is hedge potential.

A Safe Haven?

An asset may be a hedge, providing protection on average, but fail in times of extreme stress. 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 and how gold interacts with these stresses has changed.

Ariovich (1983) includes the impact of political tensions on the gold price, dividing them up into those that affect international financial markets, inflation expectations, and the value of the US Dollar. Analysing monthly data from 1972-1981 they find that using a measure of political tension in an explanatory model of the gold price does not increase the power of the model but 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 Abken (1980). The risk premium underlying gold prices is examined by Melvin & 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.

Baur & Lucey (2010) develop 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 or 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 & 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." On an empirical level Baur & 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. In contrast, Bredin, Conlon, and Potì (2015) apply wavelet analysis and suggests that contrary to the 15 day finding of Baur and Lucey gold is be a safe haven for up to a year. Baur & 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.

Cohen and Qadan (2010) link gold to markets constructed measures of risk 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 & McDermott (2010). However Hood & Malik (2013) is based on a much shorter data than Baur & 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. Intriguingly, Ghazali, Lean, and Bahari (2014) finds that Sharia compliant (Islamic law compliant) gold accounts in Malaysia may not provide safe havens. However, this is in some conflict with Gürgün and Ünalmış (2014) which finds safe haven status across a wide range of emerging markets, many with strong Islamic financial characteristics. Returns from the Malaysian stock market haven been shown to have a low correlation with domestically priced gold returns, in 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.

Nelson (1966) 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. This possible reduction in safe haven status between the time periods studied by these recent papers links to Baur & Glover's (2012) 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. The safe haven nature of gold is probably time varying. Lucey and Li (2014) demonstrates instability in the safe haven nature, showing significant periods when gold did not act as either a safe haven or a hedge for US stocks and bonds. Using daily data they examine on a rolling quarterly basis, finding some quarters where gold was and others where it is not a safe haven. Interestingly this is one of the few papers to examine the safe haven status of other precious metals, finding evidence of silver in particular as being a safe haven.

A similar finding is in Choudhry, Hassan, and Shabi (2015), this issue, who finds a breakdown in the safe haven in the financial crisis (see comment above on Lucey and Li (2014) XX. Sumner et al. (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 weaklier to bonds. This finding fits well with the safe haven literature discussed above.

Reboredo (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 finds that it does not. He conclude that as gold's correlations with most dollar pairs is less negative in the lower quintiles; gold does not act as a safe haven for extreme dollar depreciations. This 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 et al. (2013) also 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 & Roll (2011) and O'Connor and Lucey (2012) but at extreme points this is an accurate use of this term. This paper also finds gold as a safe haven against extreme oil price movements, also found in Reboredo (2013).

Soytas et al. (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. Baur and Glover (2012) examine this theoretically.

Gold and other Precious metals

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. .

Silver and gold are closely associated throughout history. 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. But silver 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 a wide range of variables would affect their prices 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 spillovers between the four precious metals, not just gold and silver. Garbade & Silber (1983) investigate spot-futures market linkages and show that gold and silver prices are well integrated, over even short periods, in contract to 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 they are considered to be close substitutes. Historically the ratio of gold to silver prices has varied from 1:1 in ancient Egypt, 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. Wahab et al. (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 that is used to forecast the spread one week ahead. The authors then test whether it is possible to use this knowledge to beat the market but after transaction costs a loss is made.

Koutsoyiannis (1983), by contrast, 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 ones 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 & Mountain (1988) develop an arbitrage model of gold and silver prices from 1980-83 with weekly data. The authors find a granger causal relationship between gold and silver prices running from silver to gold in contrast to Koutsoyiannis (1983). 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. This 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 & 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 however seems to be a mischaracterization of the type of trading necessary to achieve these profits.

Escribano and Granger (1998) find a strong simultaneous relationship between the returns of gold and silver but also find that out of sample predictions about the relationship are increasingly inaccurate 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 Escribano and Granger (1998) 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 & Tully (2006) find that the parity did indeed weaken over the 1990's and Batten et al. (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 that beats a buy and hold strategy.

Using high frequency data over two years on the gold-silver spread Adrangi et al. (2000) examine how spillovers between these markets lead to price discovery. Silver is shown to be the asset that is forced to adjust to allow for convergence back to equilibrium, with gold being the dominant partner in the relationship. Chatrath et al. (2001) develop this by showing that there is evidence of non-linear dependences that can be explained by ARCH type processes. Liu & 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 & 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 activity of platinum producers is 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 practise adopted in one was not adopted in anyway by the other.

Chng & 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 palladiums convenience yields seem to not be affected by any of the precious metals, indicating 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 et al. (2010) addresses this. Between 1986 and 2006 volatility in the 4 precious metals is found to be influenced by each other's volatility. Financial variables such as stock market returns and dividend yields are found to effect 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. Batten et al. (2014b) 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. This is reinforced by Antonakakis and Kizys (2015) in a paper which also looks at oil and currency spillovers. A key feature here is that the Global Financial Crisis appears to mark a breakpoint in the nature of gold spillovers, weakening it considerably while that of platinum increased. This may be down to the greater industrial linkage with platinum.

Gold and Currencies

It has been frequently argued that the US Dollar is one of, 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 dollars 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 & 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 et al. (2010) confirm their finding. By contrast, Sjaastad & Scacciavillani (1996) found that Europe dominated the gold market by analysing the impact of exchange rate changes on the gold price. Sjaastad (2008) finds, when looking at longer and more recent data from 1991 – 2004 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 & 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 casual 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 & Lucey (2012) show that the trade weighted value of 6 currencies have negative relationships with the price gold when expressed in that currency. Intuitively when a currency, such as the dollar, is losing value on average against all major currencies, it is also losing value against gold. Viewing gold as a currency-like asset, it 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.

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. Micronumerosity may be an issue as the number of listed gold companies is small. In addition, gold is not just mined as a solo product but can be associated with other mineral deposits. McDonald & 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 again that their exposure to changes in the gold price is greater for high costs Based on monthly 1981-1990 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 firm's market capitalisation and debt is more volatile than the price of gold.

Faff & 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 Australian dollar not adding to the explanatory power of the regressions. The stocks have a beta of greater than 1 in many of the periods with 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. Borenstein & Farrell (2007) examine 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 valuations of companies change more than proportionately with the gold price. The findings of O'Connor, Baur, and Lucey (2014) on the relationship between gold mining cost and gold prices, finding that world prices lead production costs suggests that examination of gold mining companies as alternatives is not a useful path. This finding is in line with the results of Areal, Oliveira, and Sampaio (2013) who find little benefit from a safe haven perspective of investing in gold mining companies. Again however there is no unanimity with Conover et al. (2009) finding superior (hedging) performance from precious metal equities as opposed to the underlying assets. The pricing dynamics of precious metal miners are examined in this issue by Ciner (2015), who finds an important but sporadic role for trading volume in a large sample of gold mining stocks.

Gold or precious metal mutual funds have been examined recently by Moreno, Rodríguez, and Wang (2013), Pullen, Benson, and Faff (2014), Tsolas (2014). They find that these funds do not outperform benchmarks on a risk-adjusted basis. Pullen et al (2014) in particular critiques the performance marketing of these funds suggesting that benchmark selection is often poor.

Emmrich and McGroarty (2013) also examine gold mutual funds, as diversifiers, finding they act as such but are inefficient compared to actual gold holding.

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. Baur (2013) demonstrates the structural shift in demand which their introduction facilitated. Their development and existence is discussed in detail by O'Connell (2007) and in an Asian context by Wang & Ahmed (2010). Ivanov (2011) examines the influence of Gold and Silver ETFs on price discovery in their respective futures markets. They argue 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 et al. (2014) expand the analysis to 4 gold funds with data starting for some in 2004 and others in 2011. Unsurprisingly gold ETF's track gold prices very closely, as in Ivanov (2013) 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. Emmrich and McGroarty (2013) examine the diversification benefits of gold ETF's. They find that ETFs decrease portfolio volatility by more than bullion, but note however that the sample period for ETF's is much shorter.

'Black Gold' and Gold

Oil is a driver of inflation and inflation in turn is a driver of gold, as seen above. Silver and gold are both affected by oil shocks with shocks increasing their volatility. This volatility is however susceptible to calming by monetary policy actions. Baffes (2007) shows that a rise in in the price of oil by $1 would result in a $0.34 increase in the gold price.

Narayan et al. (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 & Wei (2010). Using neural network approaches Malliaris and Malliaris (2011) finds similar as does Ewing and Malik (2013) .

Sensoy, Hacihasanoglu, and Nguyen (2015) and Khalfaoui, Boutahar, and Boubaker (2015) examine spillovers between (among other assets) oil and gold futures. They both note a convergence of spillovers, with each market increasingly spilling over onto the other. Both

Reboredo (2013) and Ciner, Gurdgiev, and Lucey (2013) suggest limited hedging but some safe haven characteristics for gold against crude oil.

What drives the volatility of Gold?

Byers & Peel (2001) investigate the driver of volatility in gold, and use a data set covering 2.5 years. Their main concern is whether gold, here measured as daily high/low ratios, has a long memory. A long memory would imply that shocks to the variance are long lived. They show that this is the case for gold, along with the other assets they examine.

Cai et al. (2001) examine US news announcements on gold volatility using intraday COMEX data between 1994 and 1997. They find a U shape, where volatility is higher at the opening and closing of sessions and that there are significant long run autocorrelations present as in Byers & Peel (2001). They also show that news announcements do have significant effects on gold's volatility; 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.

Batten, Ciner, and Lucey (2010) examine the volatility of all the precious metals. Financial variables such as stock market returns and dividend yields are found to effect 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 contrast to silver that seems to be the only precious metal not affected by monetary or financial variables. Hammoudeh et al. (2010) find that monetary shocks have long run effects on both gold and silver volatility but with a much shorter dataset (1999-2007).

Gold Market Efficiency

One might think that the Gold market would be one of the most efficiently priced assets available to investors. Firstly it is a homogenous commodity that is traded in many 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 cash flows 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 London fixing. He 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 & Swanson (1981) and Koutsoyiannis (1983) also find autocorrelation but there are sample issues with the Hunt corner. A 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 Fixing prices follow a random walk and confirms Tschoegl's (1980) result of autocorrelation. Cheung and Lai (1993) found that gold returns showed 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. Both Ivanova and Ausloos (1999) and Byers and Peel (2001) also show, using alternative approaches, that gold does display long memory characteristics. Charles, Darné, and Kim (2015) and Ntim et al. (2015) both in this issue examine gold market efficiency. Charles, Darné, and Kim (2015) find an increasing degree of weak form efficiency in gold (and silver and platinum) returns over time. Ntim et al. (2015) suggest that some predictability may be possible, in emerging market gold series but that this is time varying, weakening, and can be in some part explained by local macroeconomic fundamentals.

More recent approaches to forecasting rely on increasingly sophisticated methods. Thus Baur, Beckmann, and Czudaj (2014) and Aye et al. (2015) apply Bayesian methods of dynamic model averaging to assess the forecast ability. Both find that there is significant instability in the underlying determinants, rendering a forecast more problematic. This point is reinforced further by analysis of the forecasting ability of gold market analysts, in Mihaylov, Cheong, and Zurbruegg (2015).

Others find some elements of predictability. Monroe & Cohn (1986) 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 & Silber (1983) investigate spot-futures market linkages and show that gold and silver are well integrated over even short periods, in contract to other commodities examined. More evidence comes from Basu & Clouse (1993) who eamine the ratio of put to call options, but find little predictive power.

Some studies suggest that there was a generally increasing efficiency in the global gold market since the 1970's. Muradoglu et al. (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 et al. (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. Followill & 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.

McQueen & Thorely (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. And 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 (2014) 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 favor of the idea that speculative positioning on futures exchanges has the ability to predict future returns.

Caminschi and Heaney (2014) provide new 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 (2014) 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.

In common with other markets there is a growing literature on anomalies in gold, with a particularly well developed literature on seasonal anomalies. Thus Ball et al. (1982) 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 (1985) again finds significant and positive Wednesday returns but which weaken after 1981. Using data from 1982 - 2002, Lucey & Tully (2006) find small daily effects in the returns but larger effecs in the variance. These appear to be economically insignficant. This paper also finds asymmetric volatility, which was further evaluated and demonstrated in Baur (2012). Yu & Shih (2011) and Blose & Gondhalekar (2013) find weak daily effects and no weekend effect.

The possibility of seasonality at a monthly basis in returns is higher for gold than for most financial assets as there are periods where the demand for physical gold are higher, such as around festivals in India and China. Tschoegl (1987) looks for cyclicality and seasonality in gold returns from 1975-1984 finding some limited seasonality. Seasonal and monthly anomalies have also been shown to exist by Baur (2013) using the London Fixings spot price between 1981 and 2010. He finds an autumn effect akin to that found in equities by Bouman and Jacobsen (2002), Lucey and Zhao (2008) and Andrade (2012). Qi & Wang (2013) find similar. The volatility of gold is also higher at these times. Naylor et al. (2014) confirm that there are monthly effects on gold bullion prices but show higher returns in November and lower in September, January and February albeit using a much shorter data set. They have similar findings for gold ETF's. scopus In relation to gold mining stocks Coutts & 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 to in other asset classes. He finds that while there is some evidence of this for silver prices, no significant relationship is shown to exist

Gold Price Bubbles

Is gold always a bubble as Buiter (2014) suggests? Or just expensive, as suggested by Erb and Harvey (2013). 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 & 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 cash flows from the bond coupons. Using traditional unit root tests they find that the market price of gold corresponds to this 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.

The Diba & Grossman (1984) method of testing for bubbles was criticised by Pindyck (1993). 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 markets view about its future supply of the commodity. He finds a rational price bubble to have occurred somewhere within the sample he examines (1975 – 1990), but his method 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. Possibly for gold the CY may also reflect the value it brings or is believed to bring as a safe haven asset. The convenience yield approach has been implemented in a number of recent studies trying to assess whether gold's price is fundamentally justified by a measurable benefit. Went et al. (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 et al. (2011) find the deviations of gold price from its fundamental value based on a CY approach using a Markov switching model but they see no evidence of a bubble in the period between 1978 and 2010. However Casassus & Collin-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.

Another approach is to model gold's value based on a number of measures, dictated by economic theory and previous empirical findings. Bertus & 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. Białkowski & Bohl (2015) build an approximation of gold's true value in a similar manner to Bertus & 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 & Patterson (2012) to 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 (2015) 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. This reinforces Baur and Glover (2014) modelling of the gold market as best being one involving trend following.

Baur & Glover (2012a) attempt to circumvent the problem of over specification and trying to find an appropriate fundamental determinant of gold's value. They apply Phillips et al.'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 a necessary but not sufficient condition for a price bubble. If gold's fundamental determinant 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 bubbles in gold prices.

An alternative approach is to accept that there may be regimes, and that some fundamentals may differ across these. Application then of a regime switching ADF model may shed light on explosive behaviour. This approach is taken in Lucey and O'Connor (2013) and Bialkowski et al. (2015). Both conclude that when properly specified, the first using lease rates and the second accounting for both ETF flows and sovereign debt dynamics, there is weak evidence for explosive, bubble like, behaviour.

Gold and Inflation

A major theme within gold research relates to its ability to hedge inflation, with most of the studies focusing on 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 thus seen as a hard currency, holding its value as other currencies purchasing powers decrease in the face of a generally positive inflation rate.

US Broad 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

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.

Feldstein 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 rendering this issue less problematic.

Fortune (1987) develops this by explicitly suggesting a channel through which inflation directly affects gold prices: a substitution effect. This channel works in the following way – 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, Montagnoli, and Wright (2006) offer an alternative inflation-gold price channel, based on an arbitrage model developed by Levin, E., Abhyankar, A. and Ghosh (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 (e.g. Blose and Shieh (1995), Borenstein and Farrell (2007)) who assume that gold miners are price takers rather than price setters. This second hypothesised channel is briefly mentioned by Rockoff (1984) as having its roots in classical 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 holds true.

A number of authors have addressed the question of whether gold and inflation have a long run relationship, often assumed in models of the gold price to be true.

Silva (2014) 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. He uses use estimators that are robust to the non-normality of the data used. For the long run analysis they use Johansen (1991) cointegrating 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.

Levin, Abhyankar and Ghosh (1994) address the division between long and the short run equilibrium relationships. They use monthly data from 1976 to 1999 and find a 1:1 cointegrating relationship between the two. This would make gold a strong long run inflation hedge. The Error Correction Model (ECM) developed from the long run model is 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. No formal forecasting was undertaken.

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 (Articulated (1996))

Worthington and Pahlavani (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 cointegrating 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 that we which 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.

Batten, Ciner, and Lucey (2014) find that between 1985 and 2012 no cointegrating relationship existed between gold and US CPI using a range of cointegrating 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 (2000) and Stock and Watson (2007). This seems to point to the finding of cointegration in Worthington and Pahlavani (2007) as stemming from that year.

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) investigate 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.

Beckmann 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 Consumer Price Index (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, The authors highlight the fact that gold is an effective inflation hedge only over the long term. The long-term relationship nature of the relationship, and its significant time variation, is also a feature of Bampinas and Panagiotidis (2015), this issue, who show gold, but not silver, as a long-run inflation hedge, stronger in the USA than the UK.

The theoretical interrelationship between gold, inflation and interest rates espoused by Feldstein (1980) and Fortune (1987) is given strong empirical backing by Batten et al. (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 1980's and 1990'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. 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.

Gold and inflation as predictors of each other

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 Colombia University Business School. Based on this model the investor would buy gold when the index pointed to a rise in inflation, simultaneously selling holdings of either bonds or equities. When a decline in inflation was expected, based on analysis of 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 (1997) 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) consider 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 link to inflation implicitly assumes that gold is a money-like commodity. Dubey, Geanakoplos, and Shubik (2003) are 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 ascetic 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 London Interbank Offer Rate (LIBOR). This would allow utility to be gained from holding gold purely as an investment.

The central issue here remains 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. In addition the channel through which the relationship might occur is also unresolved empirically

Gold and Interest rates

Many commentators view interest rates, regardless of 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 (1987) 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 cash flow, 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. 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, and a positive relationship is predicted. This fits with the Hotelling but which has proven to be a poor predictor of commodity price movements.

The empirical model applied by Abakan (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. As a non-interest bearing asset, short-term investors will only hold it if its price appreciates sufficiently to compensate them for the missed interest from holding risk free T-bills. Using daily data, Koutsoyiannis (1983) found a very weak link between gold in US Dollars and the nominal interest rate on US$ denominated 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%. Again 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.

But not all studies find that a link exists. Silva (2014) find no relationship between gold prices and interest rates on using 10 years of annual data, though concerns remain over the presence of unit root issues 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 recently Tully and Lucey (2007) apply 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.

Baur (2011) argues that there is a different relationship between gold and long versus 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 (1987) 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 & 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.

Erb and Harvey (2013) note the long-term negative relationship between the real price of gold and real interest rates. This holds for both the UK (albeit weaker) and the USA. For the USA they find, over a 15y period, a negative correlation of -.82, while for the UK it is, over a 30-year period around -0.31. They are at pains to stress the danger of "correlation as causation" but suggest the relationship is compelling. They discount a number of possible causal factors; the lack of transparency on gold leases from the central banks makes it hard to assess impact, the opportunity cost argument is an argument which remains to be seen as being effective or

otherwise, while the Gibson's Paradox as elaborated by Barsky and Summers (1988) is unlikely to hold in fiat money regimes and perhaps did not even hold in gold standard times.

Behavioural aspects of Gold Investment

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 that is commonly linked with investor psychology in the financial press.

Psychological barriers have been shown to exist in gold prices by Aggarwal & Lucey (2007) indicating behaviorally 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 & 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 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 (2014) evidence of initial overreactions to news is found. When news is broken in good and bad 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. Aggarwal, Lucey, and O'Connor (2014) also find evidence of gold behavioral influences, showing that gold displays a variety of over reaction and over optimisim indicators, based on revisions to futures premia. The dispersion, as opposed to the level, of beliefs about the future path of gold, as measured by analysts forecast dispersion, is found by Smales and Yang (2015) to be important. Positive economic news and greater dispersion are more influential than negative and concensus.

Conclusion

There is a large, and growing, literature on gold. This review endeavours to collate this literature, in particular as it applies to gold as an investment asset, and to contextualise the papers in this special issue. Gold has been a subject of renewed investment attention over the last two decades ad the fortunes of the gold price and of the volume of gold related research have had a tendency to mirror each other. The authors here hope that this might be a relationship, which breaks down, and that regardless of the future evolution of the price gold research will continue to flourish.

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