On the efficiency of the global gold markets

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Abstract

This paper examines the weak-form efficiency of the global gold markets with specific focus on the random walks (RWS) and martingale difference sequence (MDS) hypotheses, and consequently, investigates the extent to which predictability or non-predictability of global daily spot gold price return series behaviour can be explained by volatilities in macroeconomic fundamentals. We apply traditional parametric variance-ratio tests and their recent non-parametric modifications based on ranks and signs to one of the largest datasets on world gold markets to-date, consisting of daily spot price series of 28 emerging and developed gold markets from January 1968 to August 2014. First, our results show that gold markets in Egypt, Indonesia, Mexico, Nepal, Pakistan, Russia, Saudi Arabia, UAE and Vietnam are not weak-form efficient neither from the perspective of the strict RWS nor in the relaxed MDS sense. By contrast, RWS and MDS hypotheses cannot be rejected for gold markets in Hong Kong, Japan, Switzerland, UK and US at the conventional rejection levels. Results for gold markets in Australia, Bahrain, Brazil, Canada, China, Germany, India, Malaysia, Singapore, South Africa, South Korea, Taiwan, Thailand and Turkey are, however, mixed. Second, our findings show that greater changes in economic fundamentals are associated with lower levels of rejecting the RWS and MDS hypotheses. Third, our evidence shows that the probability of rejecting the weak-form efficiency is higher in emerging gold markets than developed ones. Fourth, our results show that the RWS hypothesis is rejected more frequently than its MDS alternative, and thereby justifying our decision to conduct an explicit test of the RWS and MDS hypotheses. Our results are robust to estimating subsamples, overlapping rolling windows and endogeneity corrected models, as well as controlling for a number of country-specific institutional and trading factors. Our findings have crucial implications for global portfolio managers, investors, poly-makers and regulatory authorities.

Keywords: Global gold markets; Macroeconomic variables; Random walks and martingales; Weak-form efficiency; Variance-ratios; Ranks and signs

JEL Classification: G1 Financial markets; G14 Information and market efficiency; G15 International financial markets; G17 Financial forecasting

1. Introduction

In this paper, we seek to contribute to the extant international finance and financial markets literature in two main ways – by examining the: (i) weak-form efficiency of daily gold spot price return series of a large number of global gold markets with particular focus on testing the random walks (RWS) and martingales difference sequence (MDS) hypotheses; and (ii) extent to which gold price returns predictability or non-predictability can be explained by volatilities in macroeconomic fundamentals. Specifically, and to the best of our knowledge, we provide evidence for the first time in 17 gold markets (i.e., Bahrain, Brazil, Egypt, Indonesia, Malaysia, Mexico, Nepal, Pakistan, Russia, Saudi Arabia, Singapore, South Africa, South Korea, Taiwan, Thailand, UAE and Vietnam) and extend prior findings in 11 gold markets (i.e., Australia, Canada, China, Germany, Hong Kong, India, Japan, Switzerland, Turkey, UK and US) relating to the efficiency and determinants of gold price return series behaviour.

Gold has been widely acknowledged as one of the most ancient and important precious metals (Blose & Shieh, 1995; Blose, 1996; Dubey et al., 2003; Bialkowski et al., 2014). Its uses vary widely, including being utilised as a: (i) medium of exchange and currency (e.g., gold bars and coins) (Sjaastad, 2008; Chang et al., 2013); (ii) standard underlying the international monetary and/or exchange rate system (Govett & Govett, 1982; Capie et al., 2005); (iii) 'safe haven' and 'store of value' for central bankers and investors (Baur & Lucey, 2010; Baur & McDermott, 2010), especially in periods of financial and political turmoil; (iv) hedging and derivative instrument (Narayan et al., 2010; Wang et al., 2011); (v) risk and portfolio diversification security (Davidson et al, 2005; Wang & Lee, 2011); (vi) priceless decorative ornaments (e.g., Jewellery) and socio-cultural status symbol (e.g., authority, power, social standing, and wealth) (Batchelor & Gulley, 1995; Baur & McDermott, 2010); and (vii) raw material for producing electronic/technological goods (Solt & Swanson, 1981; Rockerbie, 1999; WGC, 2011, 2014a, b), amongst others.

Understanding the behaviour of gold prices and markets, therefore, has been one of the intriguing and challenging topics in international finance (Tschoegl, 1978, 1980; Smith, 2002; Ewing & Malik, 2013; Pierdzioch et al., 2014). Specifically, and given its varied uses (i.e., central banking, electronic or industrial, investment, Jewelry, monetary, and technology), examining gold price return behaviour in the context of a weak-form efficient market may not only be of interest to researchers, but also investors, policy-makers and regulators. In particular, Belaire-Franch and Opong (2005a, b, 2010) suggest that whilst researchers are generally interested in understanding the behaviour of security prices over-time, investors and practitioners (i.e., arbitrageurs, hedgers, and speculators) are normally keen on detecting patterns of market inefficiencies that can be exploited. In contrast, the main aim of policy-makers and regulators is to enhance pricing efficiency of financial assets by improving the speed of information flow in the financial markets in which gold is traded. Thus, knowledge of the return behaviour of gold prices, particularly in the contest of the RWS and MDS, is understandably of a major interest to a large number of key actors and participants in the global financial markets.

Not surprisingly, therefore, a large number of studies have focused on understanding the behaviour of gold prices and markets (Booth & Kaen, 1979; Solt & Swanson, 1981; Ball et al., 1982; Ball et al., 1985; Ho, 1985; Beckers, 1984; Shafiee & Topal, 2010; Lucey et al., 2013, 2014), albeit in different strands. One strand of the literature has examined the determinants of gold prices with specific focus on the interplay of gold demand and supply forces (Feldstein, 1980; Govett & Govett, 1982; Kaufmann & Winters, 1989; Rockerbie, 1999; Selvanathan & Selvanathan, 1999; Apergis, 2014), whilst another strand has investigated the capacity of gold to act as a ‘safe haven’, ‘store of value’, hedging and derivative instrument, and risk and portfolio diversification security (Blose, 1996; Davidson et al., 2003; Capie et al., 2005; Conover et al., 2009; Baur & McDermott, 2010; Baur & Lucey, 2010; Wang et al., 2010, 2011; Bialkowski et al., 2014). A third strand of the literature has assessed the interdependencies, linkages, spillovers, information flow and efficiency among gold markets (e.g., Japan, UK, and US), and also between gold and other markets (e.g., stock, bond, and other precious metals markets) (Laulajainen, 1990; Xu & Fung, 2005; Chang et al., 2013; Ewing & Malik, 2013; Caminschi & Heaney, 2014; Lucey et al., 2013, 2014), whilst a fourth strand of the literature has sought to ascertain whether there exists a causality and/or co-integration relationship between gold prices/markets and macroeconomic variables often by employing different versions of autoregressive conditional hetereoskedasticity (ARCH) models (Sjaastad & Scacciavillani, 1996; Mahdavi & Zhou, 1997; Kutan & Aksoy, 2004; Tully & Lucey, 2007; Sjaastad, 2008; Blose, 2010; Zhang & Wei, 2010; Pukthuanthong & Roll, 2011). Of direct relevance to our study, the final strand of the literature has focused on examining the predictability of gold price returns (Tschoegl, 1980;

Monroe & Cohn, 1986; Basu & Clouse, 1993; Muradoglu et al., 1998; Christie-David et al., 2000; Smith, 2002; Mani & Vuyyuri, 2003; Mills, 2004; Parisi et al., 2008; Wang et al., 2011; Yu & Shih, 2011; Baur, 2013; Blose & Gondhalekar, 2013; Pierdzioch et al., 2014).

There are, however, a number of observable weaknesses within the current literature, especially with respect to studies that focus on the efficiency of gold prices. First, the findings of previous studies that explicitly examine the weak-form efficiency of gold returns are widely mixed, even within the same study. For example, evidence by Tschoegl (1978, 1980), Ball et al. (1985), Beckers (1985), Ho (1985) and Pierdzioch et al. (2014) suggests that gold price returns are weak-form efficient. By contrast, the findings of Solt and Swanson (1981), Ball et al. (1982), Basu and Clouse (1993), Narayan et al. (2010), Shafiee and Topal (2010), Baur (2013), and Blose and Gondhalekar (2013) suggest that gold prices are predictable, whilst those of Monroe and Cohn (1986), Smith (2002), Parisi et al. (2008), and Wang et al. (2011) are mixed. Second, despite the conflicting findings, existing studies have mostly simply focused on testing rather than explaining efficiency, and in particular, the extent to which predictability or non-predictability of gold price returns can be explained by observable changes in the underlying macroeconomic variables.

Third, the existing weak-form efficiency studies on gold prices have tested mostly the RWS hypothesis with virtually no study providing explicit test of its MDS alternative. However, unlike the RWS, the MDS has the unique capacity to relax the strict gaussian-random variable assumption underlying the RWS hypothesis to permit for the possible existence of time-varying volatilities in an asset's return series like conditional-hetereoscedasticity, which though expecting successive residual increments to be independent, does not necessarily require it to be identically distributed (*iid*), and thereby permitting a more powerful test of gold price return efficiency. Finally, despite the rapid growth and expansion in the size and number of global gold markets with gold being currently traded in organised futures, exchange traded funds (ETFs) and other derivatives markets in about 40 countries (O'Callaghan, 1991; WGC, 2011, 2014a, b), existing studies have focused mostly on the Western European, Japanese, UK and US markets to the neglect of a relatively small, but rapidly growing emerging gold markets in Africa and Middle East, Asia-Pacific, Eastern-Europe and South America. This limits opportunities for comparative analysis of the findings between developed markets (matured and large) and emerging markets (new and small) gold markets, and thereby arguably impairing a more complete international understanding of the gold price return behaviour.

Consequently, the current study seeks to address the limitations of prior studies on the weak-form efficiency of gold price returns, and thereby extending, as well as making a number of new contributions to the extant international finance literature. First, we contribute to the literature by testing the weak-form efficiency in the price series of the global gold markets. However, rather than simply testing for weak-form efficiency of gold price returns, we take a different approach from prior studies by simultaneously examining the extent to which volatilities in the underlying macroeconomic fundamentals (e.g., exchange, inflation, and interbank rates) can explain observable efficiencies and inefficiencies in the gold returns series. As prior studies suggest that macroeconomic variables drive gold prices (Feldstein, 1980; Tully & Lucey, 2007; Christie-David et al., 2000; Narayan et al., 2010; Shafiee & Topal, 2010; Lili & Chengmei, 2013; Apergis, 2014), we conjecture that increased volatilities in such fundamentals may equally be associated with rapid changes in the efficiency of gold price returns series and vice-versa. Second, we contribute to the literature by explicitly offering evidence on the RWS and MDS hypotheses, and thereby allowing us to provide a more robust test of the weak-form efficiency for gold prices and markets. Third, to the best of our knowledge, we employ for the first time the Wright's (2000) non-parametric variance-ratio tests based on ranks and signs alongside its Lo and MacKinlay (1988, 1989) parametric alternative. In several Monte Carlo tests, Wright shows that his non-parametric alternative is better specified, and thereby permitting us to provide a more robust tests of the RWS and MDS. Finally, we employ daily gold spot price return series between 1968 and 2014 from organised markets in 28 countries with developed and emerging gold markets spanning over every continent. This is by far one of the most extensive and up-to-date gold price returns datasets to be used to-date. This allows us not only to shed new insights on gold price return behaviour around the world, but also conduct a comparative analysis between developed and emerging gold markets over a relatively long period of time (i.e., 46 year-period).

Our results contribute to the literature in several ways. First, our findings show that gold markets in Egypt, Indonesia, Mexico, Nepal, Pakistan, Russia, Saudi Arabia, UAE and Vietnam are not weak-form efficient neither from the perspective of the strict RWS nor in the relaxed MDS sense, but both hypotheses cannot be rejected for gold markets in Hong Kong, Japan, Switzerland, UK and US. We, however, find mixed results for gold markets in Australia, Bahrain, Brazil, Canada, China, Germany, India, Malaysia, Singapore, South Africa, South Korea, Taiwan, Thailand and Turkey. Second, our findings show that higher volatilities in macroeconomic variables (i.e., crude oil price, inflation rate, interbank rate, multilateral exchange rate and share price) are associated with lower levels of rejecting the RWS and MDS hypotheses. Third, our results show that the RWS hypothesis is rejected more frequently than its MDS alternative with the non-parametric variance-ratio tests producing more consistent findings compared with the parametric tests. Fourth, our evidence shows that the probability of rejecting the weak-form efficiency is higher in emerging gold markets than developed ones. Our results are robust to estimating subsamples, overlapping rolling windows and endogeneity consistent models, as well as controlling for a number of country-specific institutional and trading factors. Our findings have crucial implications for global portfolio managers, investors, poly-makers and regulatory authorities.

The remainder of the paper is organised as follows. Section 2 reviews the prior empirical literature on the efficiency of gold markets. Section 3 provides an overview of the global gold market. Section 4 describes data and research methodology. Section 5 presents empirical results and discussion, whilst section 6 concludes.

2. Prior empirical literature on the efficiency of gold markets

The past decades have witnessed the emergence of a vast theoretical and empirical literature on the behaviour of gold prices and markets. Although generally closely related, and as previously summarised, a closer examination of this literature, however, reveals distinctive strands, namely those analysing: (i) factors influencing gold prices (e.g., Batchelor & Gulley, 1995; Blose & Shieh, 1995; Rockerbie, 1999; Selvanathan & Selvanathan, 1999; Apergis, 2014); (ii) interdependencies among and between global gold markets and other security markets (e.g., Ewing & Malik, 2013; Caminschi & Heaney, 2014; Lucey et al., 2013, 2014); (iii) investment and risk reduction properties of gold (e.g., Baur & McDermott, 2010; Baur & Lucey, 2010; Wang et al., 2010, 2011; Wang & Lee, 2011; Bialkowski et al., 2014); (iv) causality and co-integration relationship between gold returns/markets and macroeconomic variables (e.g., Kutan & Aksoy, 2004; Tully & Lucey, 2007; Sjaastad, 2008; Blose, 2010; Zhang & Wei, 2010; Pukthuanthong & Roll, 2011); and (v) efficiency of gold price returns series (e.g., Tschoegl, 1978, 1980; Smith, 2002; Wang et al., 2011; Yu & Shih, 2011; Baur, 2013) .

Of the five identified strands of the literature, those analysing gold price return efficiency, the main focus of this study, are observably the largest. Indeed, since Fama's (1965, 1970) simple, but powerful testable specification of relative market efficiencies depending on a taxonomy of information set available to market participants (i.e., weak-form, semi strong-form and strong-form), a large amount of literature has emerged on the weak-form efficiency of financial assets, primarily relating to whether stock prices are randomly generated (Lo & MacKinlay, 1988, 1989; Campbell et al., 1997; Ayadi & Pyun, 1994; Urrutia, 1995; Smith et al., 2002; Belaire-Franch & Opong, 2005a; Ntim et al., 2007, 2011; Ntim, 2012), but also other securities, such as exchange rates, bonds and precious metals (Hsieh, 1991; Liu & He, 1991; Belaire-Franch & Opong, 2005b, 2010; Chuluun et al., 2011).

With specific reference to the behaviour of gold prices, Tschoegl (1978, 1980), Booth and Kaen (1979), and Solt and Swanson (1981) are among the pioneers to explicitly investigate the weak-form efficiency of the gold market, although they report mixed findings. Whereas the findings of Tschoegl (1978, 1980) suggest that the null hypothesis that information contained in the sequences of successive price changes cannot be forecasted is not rejected in daily and monthly return series of London morning (AM) and afternoon (PM) 'fixing' gold prices from January 1975 to June 1977, those of Solt and Swanson (1981) reject the notion of random walks in monthly, quarterly and yearly return series of London Friday closing (PM) gold prices from 1971 to 1979. The results of Booth and Kaen (1979) based on daily changes in US spot gold prices from January 1972 to June 1977 also rejected the RWS hypothesis, implying that US gold prices were predictable. Similarly, Ball et al. (1982) report evidence of a weekend effect in daily AM and PM London 'fixing' gold price series using data from 1975 to 1979, suggesting that gold price returns are significantly different during weekends than weekdays. Additionally, Beckers (1984) and Ho (1985) have independently examined the weak-form efficiency in the daily gold price return series of the Dutch (i.e., daily gold options prices on the European Options Exchange from January to December 1981) and UK (i.e., daily closing/'fixing' prices on the London gold market from 1979 to 1980) gold markets, respectively. The results of both studies fail to reject the notion of weak-form efficiency in both gold markets. The findings of Beckers (1984) have been supported by those of Ball et al. (1985), which also failed to reject the RWS hypothesis in daily gold option prices of the same Dutch-based European Options Exchange from April 1981 to June 1982. However, the results of Monroe and Cohn (1986) using monthly price series of gold futures traded on the Chicago Mercantile Exchange from 1976 to 1982 are mixed. Specifically, their findings suggest that the RWS hypothesis is rejected for the Chicago gold futures market in some periods, but not for other periods, implying that gold futures price series' weak-form efficiency changes over-time.

It is worth noting that mixed evidence relating to the random walk behaviour in gold price series reported by these studies are largely consistent with those of similar earlier indirect tests that sought to detect random gold price movements by Lipschitz and Otani (1977), McDonald and Solnik (1977) and Abken (1980). Equally important, however, is that most of the studies conducted in this era are discernibly based on the application of simple traditional statistical techniques (e.g., autocorrelation, runs, and unit root tests) (Tschoegl, 1978, 1980; Booth & Kaen, 1979; Solt & Swanson, 1981; Beckers, 1984, Ho, 1985; Monroe & Cohn, 1986). A major weakness of all these simple techniques is that they assume linearity in financial asset price return series (Savit, 1988; Ntim, *et al*., 2007, 2011; Ntim, 2012), often leading to spurious rejection or acceptance of the RWS hypothesis (Hsieh, 1991; Chow & Denning, 1993; Wright, 2000; Luger, 2003).

Consequently, and with the availability of more powerful computers coupled with advances in econometric and mathematical modelling (Belaire-Franch & Opong, 2005a, b, 2010), recent studies examining whether gold prices follow random walk behaviour mainly employ powerful and sophisticated statistical techniques (e.g., chaos, fractals, neural networks, variance-ratios, and ARCH-GARCH models) (Parisi et al., 2008; Shafiee & Topal, 2010; Wang et al., 2011; Pierdzioch et al., 2014). These advanced mathematical techniques are generally capable of dealing with security return series with non-linear distributions, and thereby providing a more precise test of the RWS hypothesis. However, the findings of recent studies employing more sophisticated statistical techniques are still generally mixed (Basu & Clouse, 1993; Christie-David et al., 2000; Mills, 2004; Narayan et al., 2008; Yu & Shih, 2011; Baur, 2013; Blose & Gondhalekar, 2013). For example, using real-time forecasting approach and London monthly PM 'fixing' gold prices between 2000 and 2010, the findings of Pierdzioch et al. (2014) suggest that the London gold market is weak-form efficient. By contrast, utilising long-term trend reverting jump and dip diffusion model to monthly spot gold prices from 1968 to 2008, the results of Shafiee and Topal (2010) reject the RWS hypothesis in the UK gold markets. Similarly, Baur (2013) and Blose and Gondhalekar (2013) document evidence of an existence of significant autumn and weekend effects in UK and US gold returns, respectively, suggesting that UK and US gold markets are weak-form inefficient. The findings of Smith (2002) for the UK gold market, Parisi et al. (2008) for the US gold market, and Wang et al. (2011) for the US gold market, who employed variance-ratio, neural networks, and multifractals statistical techniques, respectively, are rather mixed. For example, Smith (2002) examines the RWS hypothesis for daily London AM, PM and over-the-counter (OTC) or 'closing' gold prices from January 1990 to September 2001 by employing Chow and Denning's (1993) multiple variance-ratio tests, with his findings suggesting that London AM and PM return series are not weak-form efficient, whilst that of the OTC market appears to be randomly generated.

Thus, it is evident from above that the current literature seems to suffer from a number of weaknesses. First, despite the apparent conflicting findings, existing studies simply test rather than seek to identify factors that may explain consistencies or deviations from the RWS hypothesis. However, past studies suggest that gold prices are determined by a number of macroeconomic factors (Davidson et al., 2003; Tully & Lucey, 2007; Wang & Lee, 2011; Wang et al., 2011). For example, and briefly, high levels of inflationary pressures can render local currencies less attractive and increase the demand for gold, and thus increased gold price volatility (e.g., Wang et al., 2011), and vice-versa. Similar theoretical arguments can be made for other macroeconomic variables, such as exchanges rates, interest rates, crude oil price, money supply and property prices (e.g., Blose, 1996; Capie et al., Baur & McDermott, 2010). Hence, we depart from most prior studies to not just simply test the weak-form efficiency, but also attempt to ascertain whether the degree of efficiency may be influenced by the extent of volatilities in the underlying macroeconomic fundamentals. Second, despite the development and expansion in formally organised gold markets worldwide primarily through gold futures, ETFs and other gold derivatives (O'Callaghan, 1991; Tully & Lucey, 2007; FuangKasem et al., 2012; WGC, 2014a, b), existing studies on the behaviour of gold price series are concentrated in a few developed gold markets, especially UK and US, with emerging gold markets studies by Rockerbie (1999) on South Africa, Muradoglu et al. (1998), and Kutan and Aksoy (2004) on Turkey, Mani and Vuyyuri (2003) and Fuangkasem et al. (2012) on India, Baur et al. (2010) and Lucey et al. (2014) that include a number of emerging gold markets, such as Brazil, China, and India, and Apergis (2014) on Australia being rare exceptions. Even among these limited studies on emerging gold markets, only Muradoglu et al. (1998), and Kutan and Aksoy (2004) directly examine the efficiency of gold price return series. Arguably, this limits opportunities for comparative analysis relating to the predictability of gold prices in developed and emerging gold markets. We, therefore, address this weakness by conducting our tests in both developed and emerging gold markets. Third, existing studies examining whether gold prices are predictable have focused mostly on testing the RWS hypothesis compared with its MDS alternative. However, as the MDS is able to relax the strict independent and identically distributed (*iid*) returns assumption implies that it is better able to provide a more conclusive weak-form efficiency test. Hence, we explicitly develop and test both the RWS and MDS hypotheses. Finally, to the best of our knowledge, we employ for the first time Wright's (2000) non-parametric tests based on ranks and signs to the weak-form efficiency in gold price return series, which are known to be robust even in the presence of conditional heteroskedasticity.

3. An overview of the global gold market

Unlike markets for other modern financial assets, the gold market has ancient origins. However, a truly 'free' market for gold did not emerge until the dissolution of the Bretton Woods gold standard monetary system between 1968 and 1973 (i.e., a system in which the standard unit of exchange was determined by a specified quantity of gold, originally pegged at US$35 or GBP£12.50 to a quantity of 1 ounce of gold). Thus, the introduction of a 'free' gold market transformed gold trading in that it allowed gold to be officially traded widely around the globe. Nevertheless, the current global gold market can narrowly be classified into two, namely in: (i) London's OTC (24 hours) cash (spot) centred bullion market; and (ii) gold futures, ETFs and other gold derivatives markets worldwide (Lucey et al., 2013, 2014). A closer examination, however, reveals a slightly more broad and complex picture than this simple two-tier or 'bipolar' classification of the global gold market. In particular, O'Callaghan (1991) offers a detailed historical overview of the structure, operation and market microstructure of the global gold market. Thus, we draw from the prior literature, especially O'Callaghan (1991) in classifying the global gold market as follows:

(i). UK – the oldest, largest, most liquid and influential organised market.

(ii). A group of matured and large organised markets, consisting of Hong Kong, Singapore and Switzerland that have become global trading, storage and distribution centres ('transit markets') of physical gold bullion bars.

(iii). A group of matured and large organised markets, consisting of Brazil, Canada, Japan, Netherlands and US who are pioneers of high frequency exchange-based trading of financial gold products (i.e., ETFs, futures, and other gold derivatives).

(iv). A group of medium-sized markets, including Australia, the mainland European market (e.g., Belgium, France, Germany, Italy, and Luxembourg), South Africa, and Turkey.

(v). A group of small, but rapidly growing markets in Asia-Pacific (e.g., China, India, Indonesia, Malaysia, Philippines, South Korea, Taiwan, Thailand and Vietnam), Eastern Europe (e.g., Russia), and Middle East (e.g., Bahrain, Jordan, Kuwait, Saudi Arabia and UAE).

(vi). Finally, a group of very small (frontier) markets that are struggling to take-off in Africa and Middle East (e.g., Egypt, Kenya and Israel), Asia-Pacific (e.g., Nepal and Pakistan), and the Americas (e.g., Mexico).

Table 1 summarises some of the trading arrangements (i.e., formal trading date, days, hours, system, cash/physical settlement, contract specifications, clearing and settlement days, markets and cities) of the sampled gold markets, whilst Table 2 reports some descriptive statistics, primarily relating to gold and other financial market development indicators (i.e., number of commodity futures/options, gold in tonnes, gold in US$m, total foreign exchange reserves excluding gold in US$m, total reserves in US$m, gold as a % of total reserves, equity market capitalisation as a % of GDP, and total number of equity listed) as at the end of the sampled period. As Table 1 shows, the UK (London) is the oldest known organised gold market, having started around 1800, but has observably experienced a chequered history (closed and re-opened several times, for example, in 1840, 1919, 1939, 1954 and 1968) (see O'Callaghan, 1991, p.19). The London market started with its five original brokers, who informally traded in gold bullions with mining companies and refineries until 1919, where the market was officially established. It gained further prominence in 1987 when its membership was expanded through the formation of the London Bullion Market Association (LBMA), which currently has 53 full members (dealers), including the five London gold price 'fix' members and 33 associate members (see Table 1) and loosely supervised by the Bank of England. London is by far the biggest gold market in the world both in size and volume. For example, on average, 18.3m ounces of gold worth US$13.9bn were reportedly cleared daily by the LBMA in 2008. Similarly, London as a gold trading centre accounted for about 86% of the total global volume traded in 2011 (Lucey et al., 2013, p.813). As Table 1 shows, the London gold market is essentially an OTC cash centred spot pricing of gold bullion (i.e., gold bars) market, and thereby guaranteeing continuous (24 hours) trading of gold bullions worldwide. Usually the gold bars must be 99.5% purity or fineness in gold content of 400 ounces (400oz) in size per contract, although other contract specifications, such as 99.95% or 99.99% with 100oz are available. The London market opens formally for trading between 8am and 5pm from Monday to Friday and similar to most markets around the world, trades are normally quoted in US$ (this is explained by the fact that gold was valued mainly in US dollars during the international gold standard monetary system period), which are settled in cash over 2 trading days.

Although primarily a spot market, in April 1982, the London gold futures market was opened and the London Stock Exchange (LSE) also trades in gold futures, options, ETFs and other derivatives with minimum price movement of US$0.10 per gram (within a 5% initial margin trading) and no maximum price movement limit with opportunities for both cash and physical settlement. However, what makes London the most liquid and influential market in the world is arguably its twice-daily (morning/AM – 10.30am and afternoon/PM – 3pm) spot price 'fixings' (O'Callaghan, 1991). The price is famously 'fixed' by the influential five ('quintupoly') LBMA gold 'fix' members, currently consisting of Barclays Capital, HSBC, Societe Generale, Bank of Nova Scotia (current chair), and Rothschild & Sons. The 'fix' typically begins with the chairman suggesting a starting price with each participant linked to its trading room via a telephone in which each firm is regularly updated by the chairman as to whether it is a net seller or buyer at a particular price. The price is altered until equilibrium price is reached and subsequently the 'fix' is declared and announced immediately. The 'fix' price then becomes the reference point or benchmark for all gold markets around the world and thus, almost every other gold market in the world quotes the London (loco-London) AM and PM 'fix' prices, as well as its own local market price. In fact, the importance of the London 'fix' has been summed up by Smith (1981, p.77) as follows: "*Because of its format and the expertise of its members, and the communication from London, I believe that the fixings are truly–the truly–genuine open outcry market, where real volume can be moved at one price–a price at which anyone in the world can participate in directly, or through some else, and it is a price that is published for all people to see* (cited in O'Callaghan, 1991, p.20)". The 'fix' used to be conducted once daily (10.30am), but the 3pm 'fix' was introduced in the 1960s to allow US investors to participate in the trading. A notable downside of the London spot gold ‘fix’ pricing system is that because each participant in the market communicates its net position, it is difficult to determine the actual volume of gold transacted at any ‘fix’.

Insert Table 1 about here

Insert Table 2 about here

Apart from London, trading in Hong Kong, Singapore and Switzerland together constitutes the next biggest physical gold bullion market in the world. A common characteristic of these three markets is that they are large centres for the trading, storage and distribution (‘transit markets’) of gold bullion bars with Hong Kong and Singapore serving the Asia-Pacific market (e.g., China and India), whilst Switzerland serving the European market. These markets are also relatively old, large and matured. For example, and as Table 1 shows, the Hong Kong market (Chinese Gold and Silver Exchange Society – CGSE) has informally existed since 1910, officially growing rapidly from 1974. Daily trading takes place from Monday to Saturday with trading typically settled over 2 days with both cash and physical settlements possible. Unlike London, but similar to New York, a small number of trading is still conducted in the open outcry market with a daily price ‘fixing’ at 11.30am, but trading is mainly electronic-based with prices quoted in both London prices (loco-London) and Hong Kong dollars (loco-Hong Kong) in traditional 100 Chinese tael per contract of 99% fineness. Any transaction of 35kg attracts no initial trading margins, but any trading above 35kg attracts an initial margin of HKD140,000 for each 5kg of additional trading with a minimum price movement of HKD0.50 per tael and no maximum price movement limit.

The Singapore gold market was officially set up in 1969 – primarily a cash-based market with 5 days trading between 8.3am and 11.25am of 25kg per contract of 99.99% purity. There is a 10% initial margin requirement with a minimum price movement of SGD0.005 per gram and no maximum price movement limit with settlement over 2 trading days. Unlike the Hong Kong and Singapore markets, the Switzerland gold market (Zurich) was established in 1961 following the closure of the London market in 1939 for trading, storage and distribution of physical gold bullion bars. In fact, it is the largest physical gold bullion market after London. Popularly known as the Zurich ‘Gold Pool’, the market is distinctively informal and unregulated, remaining a loose co-operation among the three Swiss major banks – Credit Suisse, Union Bank, and Swiss Bank. Unlike London and Hong Kong, however, there is no price fixing system in the Zurich market. Instead, at any given time of each trading day (i.e., Monday to Friday between 8am and 5pm of 100oz per contract with 99.95%

fineness and settled within 2 trading days), the price is set based on the interplay of demand and supply forces. Hence, the market encourages direct competition among its participants, which has a minimum price movement of CHF0.10 per ounce and no maximum price limits or restrictions within an electronic trading platform.

In contrast to the large physical gold bullion markets in Hong Kong, Singapore, Switzerland and UK, Brazil, Canada, Japan, Netherlands and US were among the pioneers who helped in developing the financial gold products market (i.e., futures, options, ETFs and other derivatives) in organised exchanges often set-up in a high frequency electronic trading environment. According to O'Callaghan (1991), the first gold futures contract was launched in the Canadian Winnipeg Commodity Exchange (WCE) in 1972. This was followed by the launching of gold futures contracts on a number of commodity exchanges, including the New York Mercantile Exchange (NYMEX), especially its commodity division (COMEX) and Chicago Mercantile Exchange (CME) in 1974, the European Options Exchange (EOE) in Amsterdam in 1978, Tokyo Commodity Exchange (TOCOM) in 1982 and Brazilian Mercantile and Futures Exchange (BM&F) in Sao Paulo in 1986. This development sparked rapid development of, and expansion in, the trading of financial gold products and markets around the globe.[1] In fact, most of the remaining gold markets[2] in Table 1 are gold futures market offering varying choice in terms of products, contract specifications and other trading arrangements.

Additionally, and as Table 2 shows, the past decades have witnessed rapid development of relatively large financial markets outside those of traditional countries with advanced financial markets, such as Japan, UK and US. For example, equity market capitalisation as a percentage of GDP, one measure of financial development for India in 2013 was 130%, comparing favourably with that of the US of about 111%. Similarly, the number of commodity futures and options contracts traded in 2013 in China was the highest in the world at about 142m. India has the highest number of listed firms, and although US is a dominant player in terms of total global gold reserves market (i.e., in terms of tonnes, US$m, FX reserves in US$m, total reserves in US$m and gold as a % of total reserves), Table 2 shows that a clear majority is held outside the traditional markets of Japan, UK and US. However, and notwithstanding the existence of a large and diverse global gold market, prior studies on the

[1]It should be noted there is some limited trading in physical gold bullion bars in all these countries as well, but they are relatively small compared either to the volume and value of trading in their gold derivative markets or the bullion markets of Hong Kong, London, Singapore and Zurich. For example, a small number of gold bullion is still traded on the NYMEX through the traditional open outcry market system. This is also applicable to most of the other gold markets in Africa and Middle East, Asia-Pacific, Europe and the Americas.

[2]These are Australia, Bahrain, China, Germany, India, Indonesia, Malaysia, Mexico, Nepal, Pakistan, Russia, South Africa, South Korea, Taiwan, Thailand, Turkey, and UAE, which for brevity, we do not discuss these gold markets in detail, but their characteristics are evident in the Table 1.

efficiency of the gold markets are concentrated mainly in a few matured gold markets, especially UK and UK, and thereby arguably limiting the current understanding of the price behaviour of the global gold markets. The current study, therefore, seeks to extend, as well as provide new insights on the efficiency of both emerging and developed gold markets.

4. Data and research methodology

4.1 Data

We employ two main types of datasets in testing our hypotheses. First, we use daily spot gold price return series of gold markets in 28 countries from four major continents (i.e., Africa and Middle East, Americas, Asia-Pacific, and Europe) form January 1968 to August 2014. All the daily spot gold prices are quoted in the relevant local currencies. Thus, our returns series span over 46 years, ranging from the longest period of 3 January 1968 to 13 August 2014 for the UK (12,162 daily observations) to the shortest period of 24 June 2010 to 13 August 2014 for Taiwan (1,080 daily observations). The data was collected from two main sources, namely the: (i) World Gold Council (WGC) website; and (ii) *DataStream* database. The data begins from January 1968 because it was the first year in which the gold price was ‘freely’ set by market forces around the world, and ends in August 2014 because it was the latest year for which data was available in the WGC and *DataStream* databases at the time of data collection. Second, we collect data on macroeconomic fundamentals, including broad money (M2+) supply, crude oil price, inflation (consumer price index - CPI) rate, interbank (overnight) borrowing rate, interest (3-month treasury-bill rate – t-bill), multilateral exchange rate, residential property price and share price. Macroeconomic data on multilateral (effective) exchange rate and residential property prices were collected from the *Bank for International Settlement* (BIS) website, whilst the data on broad money supply, inflation (CPI) rate, interbank rate, interest (t-bill) rate, and share price were collected from *DataStream*. Twenty-eight gold markets were included in the sample because they were the countries for which data was available on them in the BIS, WGC and/or *DataStream* databases. For brevity, Table 3 and 7 provide additional detailed descriptions of the dataset used.

4.2 The RWS and MDS hypotheses

The strict RWS and the relaxed MDS hypotheses of the weak-form market efficiency are explicitly tested. The RWS hypothesis indicates that in an efficient market, successive price changes follow that of a gaussian-random variable (*iid*). This means that future price changes cannot be predicted based on past price history. In line with Campbell et al. (1997), a financial asset's price series (P_t) is said to follow a random walk, if: $P_t = \mu + P_{t-1} + \varepsilon_t$, $\varepsilon_t \sim IDD\ N(0, \partial^2)$, where (P_t) refers to the log of the asset's return series under consideration, (i.e., the daily gold spot price return series) at time (day) *t*; μ is an arbitrary drift parameter; and the error term $\varepsilon_t \sim IDD\ N(0, \partial^2)$ is independently and identically distributed (*iid*) with zero mean and unit variance (∂^2). Thus, the strict RWS hypothesis to be tested is as follows:

H_1 : The global daily spot gold price return series follow a random walk.

On the other hand, an asset's price series (P_t) is said to follow a martingale difference sequence (MDS) if it meets the following condition: $E[P_{t+1} - P_t \mid P_t, P_{t-1}, \ldots] = 0$, where (P_t) is the log of the asset's price series under consideration (i.e., the global gold price return series) at time (day) *t*. This implies that the gold's price is equally likely to increase, as it is to decrease, and thus renders it difficult to forecast. However, a major distinction between the RWS and the MDS hypotheses is that the latter relaxes the strict *iid* assumption to allow for the possible existence of time-varying volatilities in the gold's price return series, such as conditional-hetereoscedasticity, which though expecting successive residual changes to be independent, does not necessarily need it to be identically distributed. Hence, the relaxed MDS hypothesis to be tested is as follows:

H_2 :The global daily spot gold price return series follow a martingale difference sequence.

4.3 Research methodology

The weak-form efficiency is tested by first applying the Lo and MacKinlay (1988, 1989) parametric variance-ratios tests, then, followed by the implementation of its recent non-parametric modification suggested by Wright (2000) based in ranks and signs. The Lo and MacKinlay (1988) (hereafter LM) variance-ratio test assumes that if a natural logarithm of a time series (p_t) follows a pure random walk, then the variance of its *k*-differences in a finite sample increases proportionally with the difference, *k*, where *k* refers to the number days interval, such as 15, 20, 25 and 30 days. Following LM (1988), let (p_t) denote a time series consisting of T observations $p_1, p_2, \ldots, p_T$ of asset returns. Then, the variance-ratio of the k-th difference, VR(k), is defined as:

$$VR(k) = \frac{\partial^2(k)}{\partial^2(1)}, \tag{1}$$

where, $VR(k)$ is the variance-ratio of a gold's price return series k-th difference; $\partial^2(k)$ is the unbiased estimator of $1/k$ of the variance of an index k difference, under the null hypothesis; $\partial^2(1)$ is the variance of the first-difference of a gold price returns series, and k is the number of days of base observations intervals or lags[3], where k = 15, 20, 25 and 30 days with regard to this study. The estimated variance, $VR(k)$, values for all k-th lags, under the null hypothesis, are expected to be equal to unity if the observed series truly follow a random walk. Following LM (1988), the estimator of the k-period difference, $\partial^2(k)$, is calculated as:

$\partial^2(k) = \frac{1}{Tk}\sum_{t=k}^{T}(p_t + \ldots + p_{t-k+1} - k\hat{\mu})^2$, where $\hat{\mu}$ is the estimated arbitrary drift parameter defined as: $\hat{\mu} = \frac{1}{T}\sum_{t=1}^{T} p_t$, and the unbiased estimator of the variance of the first difference, $\partial^2(1)$, is computed as: $\partial^2(1) = \frac{1}{T}\sum_{t=1}^{T}(p_t - \hat{\mu})^2$. The LM (1988) test statistic is implemented in two specifications. The first test statistic, which is considered as a test for the strict RWS hypothesis with reference to this study, $M_1(k)$ is given by:

$$M_1(k) = \frac{VR(k) - 1}{\phi(k)^{1/2}}, \tag{2}$$

which, under the assumption of homoscedasticity, is normally distributed with zero mean, and unit variance, i.e., $N(0,1)$. The homoscedastic-consistent asymptotic variance of the variance ratio, $\phi(k)$, is given by:

$$\phi(k) = \frac{2(2k-1)(k-1)}{3kT}. \tag{3}$$

[3]According to Lo and MacKinlay (1988, p.46), the arbitrary base lag (k) selected, must be any equally spaced integer, which is greater than one. Similarly, the daily base intervals, where k = 15, 20, 25 and 30 days have been chosen on that basis. Additionally, we employ different testing intervals, such as where k = 2, 4, 8 and 16 days or 5, 10, 15 and 20 days, as part of our robustness checks.

The hetereoscedasticity-consistent test statistic, which is understood as a test for the relaxed MDS hypothesis with respect to this study, $M_2(k)$, is given by:

$$M_2(k) = \frac{VR(k)-1}{\phi^*(k)^{1/2}}, \tag{4}$$

LM (1988) show that, unlike the M_1, the M_2 test statistic under the null hypothesis is robust to many forms of hetereoscedasticities. A corresponding hetereoscedasticity-consistent asymptotic variance for the M_2 test statistic is defined as:

$$\phi^*(k) = \sum_{j=1}^{k-1}\left[\frac{2(k-j)}{k}\right]^2 \delta(j) \text{ and } \delta(j) = \frac{\sum_{t=j+1}^{T}(p_t-\hat{\mu})^2(p_{t-j}-\hat{\mu})^2}{\left[\sum_{t=1}^{T}(p_t-\hat{\mu})^2\right]^2}.$$

Non-parametric tests are widely regarded to be robust even in the presence of non-normalities (e.g., Luger, 2003). Informed by this idea, Wright (2000) modifies LM's (1988) parametric variance-ratio test to a non-parametric variance-ratio test. A major distinction is that Wright's (2000) non-parametric variance-ratio test statistics substitute the return differences used in LM (1988) with return ranks and signs. Following Wright (2000), let $r(p_t)$ be the rank of p_t among $p_1, p_2, \ldots, p_T$. Then, r_{1t} and r_{2t} are the ranks of the returns p_1 and p_2 respectively, defined as:

$$r_{1t} = \left(r\left(p_t - \frac{T+1}{2}\right)\right) \bigg/ \sqrt{\frac{(T-1)(T+1)}{12}}, \quad \text{and,}$$

$$r_{2t} = \Phi^{-1}(r(p_t)/(T+1)).$$

According to Wright (2000), the rank series r_{1t} is a simple linear transformation of the ranks, standardised to have zero sample mean and a unit variance. Similarly, the rank series r_{2t}, where Φ^{-1} is the inverse of the standard normal cumulative distribution function, also has zero sample mean and variance approximately equal to one. The rank series r_{1t} and r_{2t} are put in place of p_t in the definition of LM (1988) test statistics, which is written as R_1 and R_2, where:

$$R_1 = \left(\frac{\frac{1}{Tk}\sum_{t=k}^{T}(r_{1t} + ... + r_{1t-k+1})^2}{\frac{1}{T}\sum_{t=1}^{T} r_{1t}{}^2} - 1 \right) \times \phi(k)^{-1/2}, \text{ and} \tag{5}$$

$$R_2 = \left(\frac{\frac{1}{Tk}\sum_{t=k}^{T}(r_{2t} + ... + r_{2t-k+1})^2}{\frac{1}{T}\sum_{t=1}^{T} r_{2t}{}^2} - 1 \right) \times \phi(k)^{-1/2}, \tag{6}$$

where $\phi(k)$ is defined in equation (3).

Wright (2000) demonstrates that the distribution of the test statistics is generated under the assumption that the rank $r(p_t)$ is a random permutation of the numbers $1,2,...,T$, with each having equal probability. Therefore, the exact sampling distribution of R_1 and R_2 can be simulated to an arbitrary degree of accuracy, for given choices of *T* and *k*. Due to this, the distribution does not suffer from disturbance parameters; hence, it can be used to construct a test with exact power. By contrast, the test statistic based on the signs of returns rather than ranks, S_1 and S_2, is given by:

$$s_1 = \left(\frac{\frac{1}{Tk}\sum_{t=k}^{T}(s_t + ... + s_{t-k+1})^2}{\frac{1}{T}\sum_{t=1}^{T} s_t{}^2} - 1 \right) \times \phi(k)^{-1/2}, \text{ and} \tag{7}$$

$$s_2 = \left(\frac{\frac{1}{Tk}\sum_{t=k}^{T}(s_t(\overline{\mu}) + ... + s_{t-k+1}(\overline{\mu}))^2}{\frac{1}{T}\sum_{t=1}^{T} s_t(\overline{\mu})^2} - 1 \right) \times \phi(k)^{-1/2}, \tag{8}$$

where, $\phi(k)$ is defined in (4), $s_t = 2u(p_t, 0), s_t(\overline{\mu}) = 2u(p_t, \overline{\mu}),$ and

$$u(x_t, q) = \begin{cases} 0.5 & if \quad x_t > q, \\ -0.5 & otherwise. \end{cases}$$

In several Monte-Carlo tests, Wright (2000) shows that the ranks (R_1 and R_2) are well-specified under the assumption of homoscedasticity (*RWS* hypothesis), whereas the signs (S_1 and S_2) are exact under hetereoscedastic conditions (*MDS* hypothesis). We, therefore, employ them in conducting an explicit test of the RWS and MDS hypotheses.

5. Empirical results and discussion

5.1 Data properties

Table 3 reports summary descriptive statistics and diagnostics of naturally logged computed daily spot gold price return series for all 28 gold markets examined. Panels *A, B, C,* and *D* report descriptive statistics and diagnostics of gold returns for gold markets in Africa and Middle East, Americas, Asia-Pacific and Europe, respectively. In line with the findings of past studies (Tschoegl, 1978, 1980; Beckers, 1984; Muradoglu et al., 1998; Smith, 2002; Wang et al., 2011), the table indicates that daily average returns for all the 28 gold return series examined are small, ranging from a minimum of -0.0487% for Taiwan to a maximum of 0.235% for Brazil. Noticeably, all the sampled gold markets depict positive mean returns behaviour apart from Pakistan and Taiwan in Panel *C*. The volatility or standard deviation (*SD*) suggests that daily gold price volatilities are fairly large, ranging from a maximum of 3.189% for Taiwan to a minimum of 1.561% for the UK. For symmetry, the standard normal distribution should have zero skewness, whilst the kurtosis test statistic should not exceed the absolute figure of 3. The findings contained in Table indicate that symmetry and mesokurtic distribution are consistently rejected by the skewness and kurtosis tests statistics at the 1% significance level for the return series for all 28 gold markets examined.

Insert Table 3 about here

As a robustness check, Kolmogorov-Smirnov (*K-S*) parametric and Anderson-Darling (*A-D*) non-parametric goodness-of-fit tests are further employed, with both tests statistic discernibly rejecting the log-normality assumption for the return series of all 28 gold markets investigated at the 1% significance level. Overall, the findings from our summary statistics and diagnostics are generally in line with those reported by past studies that indicate that gold returns are not normally distributed (e.g., Muradoglu et al., 1998; Tully & Lucey, 2007; Baur & McDermott, 2010; Baur, 2013; Blose & Gondhalekar, 2013). More importantly, it offers empirical support for our decision to apply non-normal and especially, Wright's (2000) ranks and signs-based (non-parametric) variance-ratio tests, which are known to be robust to different types of non-linearities and serial correlations, including auto-regressive moving average and its fractionally integrated alternatives.

5.2 Empirical results and discussion: The efficiency of global gold markets

Table 4 reports the findings of the variance-ratio tests for the naturally logged calculated daily gold return series for gold markets in Africa and Middle East, and the Americas. Column 1 indicates the specific time period, *k*, which is the number of interval days, where *k*=15, 20, 25 and 30 days for each of the eight gold return series. Columns 2 to 7 present the test statistics for M_1, M_2, R_1, R_2, S_1 and S_2 for each gold market's return series investigated. M_1 reports the Lo and MacKinlay (LM) (1988) tests statistics under the null hypothesis of homoscedasticity (RWS), whereas M_2 presents similar test statistics under the assumption of hetereoscedasticity (MDS hypothesis). The ranks (R_1 and R_2) and signs (S_1 and S_2) refer to Wright (2000) non-parametric alternative variance-ratio tests. A number of interesting findings emerge from Table 4. First, the findings indicate that both the RWS (M_1, R_1 and R_2) and MDS (M_2, S_1 and S_2) hypotheses are consistently rejected at the 1% significance level for the gold return series for all intervals of *k* for the gold markets in Egypt, Saudi Arabia, and UAE in Africa and Middle East, and Mexico in the Americas, implying that these gold markets are not efficient in the weak-from, neither from the perspective of the strict RWS nor in the relaxed MDS sense. Noticeably, all rejections with respect to LM's test statistics for the gold markets in Mexico, Saudi Arabia and UAE are in the lower tail (have negative signs) of the distribution, suggesting that any serial dependence is negative, whereas the opposite evidence is observed for the Egyptian market.

Second, applying the M_1 test statistic, the RWS hypothesis cannot be rejected for the US except when *k*=15 at the unconventional 10% significance level. Similarly, the M_2 test statistic indicates that the MDS hypothesis cannot be rejected for the US gold market at any reasonable significance level. The implication is that the RWS and MDS are supported for the US gold market based on LM's test statistics. However, Wright (2000) demonstrates that LM's variance-ratio tests statistics are not robust to hetereoscedasticity, and thus, we investigate the RWS and MDS for the US gold market by applying his robust ranks (R_1 and R_2) and signs (M_2, S_1 and S_2) alternative, respectively. Discernibly, Table 4 shows that the RWS cannot be rejected for the US market except when *k*=25 and 30 at the unconventional 10% significance level when R_1 and R_2 are implemented, respectively. Similarly, employing the S_1 and S_2 test statistics indicate that MDS hypothesis cannot be rejected for the US gold market at any reasonable significance level, suggesting the acceptance of the RWS and MDS hypotheses by LM's M_1 and M_2 test statistics are robust to hetereoscedasticity.

Third, the findings relating to the weak-from efficiency for Bahrain, South Africa and Turkey (Africa and Middle East) and Brazil and Canada (the Americas), as contained in Table 4 are, however, mixed. For Brazil, Canada and Turkey, the RWS and MDS cannot be rejected when the M_1 and M_2 are applied (except when k=15 and 20 for Brazil and Turkey, and when k=15 for Canada for the M_1 test statistic). However, when the robust R_1 and R_2 are implemented, the RWS is rejected for all three gold markets (except when k=15 for R_1 for Canada), implying that the acceptance of the RWS hypothesis by the M_1 appears to be spurious. In contrast, the MDS hypothesis cannot be rejected for all three gold markets when the S_1 and S_2 test statistics are employed (except when k=15 and 20 for S_1 for Brazil and when k=30 for S_2 for Canada), meaning that the acceptance of the MDS hypothesis by the M_2 test statistic is insensitive to the presence of hetereoscedasticity. For the South African gold market, the RWS and MDS hypotheses cannot be rejected when M_1 and M_2 are applied (except when k=15 for the M_1 and when k=15 and 20 for the M_2), but when the robust ranks and signs alternative are employed, the RWS and MDS hypotheses are consistently rejected at the 1% significance level, suggesting that the acceptance of the RWS and MDS hypotheses by the M_1 and M_2 are not robust to hetereoscedasticity. A similar evidence is observed for the gold market in Bahrain in which the MDS hypothesis cannot be rejected when the M_2 test statistic is implemented (except when k=25 and 30), but its hetereoscedasticity consistent S_1 and S_2 consistently reject the MDS hypothesis at the 1% significance level. Observably, both the LM's M_1 and Wright's robust ranks (R_1 and R_2) consistently reject the RWS hypothesis for the Bahrain gold market.

Overall, the evidence from Table 4 is that the daily gold price return series of the US gold market are weak-form efficient both from the RWS and MDS perspectives, whilst the opposite evidence holds for the gold markets in Egypt, Mexico, Saudi Arabia and UAE. The Brazilian, Canadian and Turkish gold markets are efficient in the relaxed MDS sense, but not from the perspective of the strict RWS. For the gold markets in Bahrain and South Africa, whilst the results obtained by implementing LM's test statistics are mixed, that of Wright's signs and ranks consistently reject the RWS and MDS hypotheses for both gold markets, implying that both gold markets are not efficient in the weak-form.

Insert Table 4 about here

Table 5 presents the findings relating to the gold markets in the Asia-Pacific region. First, the results indicate the RWS and MDS hypotheses are rejected for gold markets in Indonesia, Nepal and Pakistan irrespective of the test statistic used, implying that these gold markets are conclusively not efficient in the weak-form. Second, the RWS and MDS cannot be rejected for gold markets in Hong Kong and Japan (except when k=15 for M_1, when k=30 for R_1, and when k=15 and 30 for S_1 in the case of Hong Kong; and when k=15 for M_1 and R_1, and when k=15 and 20 for R_2 in the case of Japan, mainly at the unconventional 10% significance level), implying that their gold return series are largely weak-form efficient. Third, the results relating to the gold markets in Australia, China, India, Malaysia and Singapore are mixed. Specifically, whereas the MDS hypothesis cannot be rejected for the 4 gold markets irrespective of the test statistic that is applied (except when k=15 and 20 for M_2, when k=25 and 30 for S_1, and when k=30 for S_2 in the case of China; when k=15 and 20 for S_1 in the case of India; when k=15 for M_2, when k=25 and 30 for S_1, and when k=30 for S_2 in the case of Malaysia; and when k=15 for S_1 in the case of Singapore, primarily at the unconventional 10% significance level), the RWS hypothesis is consistently rejected for all 4 gold markets irrespective of the test statistic that is implemented, although the LM's M_1 test statistic appears to lack power (i.e., rejections are visibly weak – mostly at the 10% significance level). In sum, the main evidence that emerges from examining Table 5 is that gold markets in Indonesia, Nepal and Pakistan are not weak-form efficient both in the RWS and MDS sense, but the exact opposite evidence holds for gold markets in Hong Kong and Japan. Gold markets in Australia, China, Malaysia and Singapore are weak-form efficient in the sense of the relaxed MDS hypothesis, but not in the perspective of the strict RWS hypothesis.

Insert Table 5 about here

Table 6 reports the variance-ratio tests results relating to gold markets in the Asia-Pacific and Europe. First, the findings indicate that the RWS and MDS hypotheses are conclusively rejected for the gold markets in Russia and Vietnam irrespective of the test statistic used, implying that daily spot gold return series from the two markets are not efficient in the work-form. Second, the RWS and MDS hypotheses cannot be rejected for the Swiss and UK gold markets irrespective of the test statistic used (except when k=30 for M_1, R_1, R_2, S_1 and S_2 in the case of Switzerland; and when k=30 for M_1 and R_1, and when k=25 and 30 for R_2 in the case of the UK, notably at the unconventional 10% significance level), suggesting that the Swiss and UK gold markets are fairly efficient in the weak-form. Third, mixed results are observed for the gold markets in Germany, South Korea, Taiwan and Thailand – the MDS hypothesis cannot generally be rejected for these markets (except when k=15 for M_2 and when k=25 and 30 for S_2 in the case of South Korea), but the RWS hypothesis is rejected for the four gold markets. When k=25 and 30 for M_1 in the case of Germany and when k=30 for M_1 in the case of South Korea, are discernible exceptions. Fourth, the findings show that the RWS hypothesis is rejected more frequently than its MDS alternative, implying that most of the rejections of the weak-form efficiency in the global gold markets are due to hetereoscedascity problems instead of simple autocorrelation ones. Finally, consistent with the findings of past studies (Belaire-Franch & Opong, 2005a, b, 2010; Ntim et al., 2007, 2011; Ntim, 2012), LM's (1988, 1989) variance-ratio tests (M_1 and M_2) generally produce mixed results, whereas those of Wright's (2000) ranks (R_1 and R_2) and signs (S_1 and S_2) based alternatives are fairly consistent.

Insert Table 6 about here

To sum up, our analysis of the daily spot gold price return behaviour so far suggests that gold markets in Hong Kong, Japan, Switzerland, UK and US are fairly efficient in the weak-form with respect to the RWS and MDS hypotheses. By contrast, it demonstrates that daily returns of gold markets in Egypt, Indonesia, Mexico, Nepal, Pakistan, Russia, Saudi Arabia, UAE, and Vietnam do not follow RWS or MDS. Gold markets in Australia, Brazil, Canada, China, India, Malaysia, Singapore, South Korea, Taiwan, Thailand and Turkey are efficient with respect to MDS hypothesis, but not with regard to RWS hypothesis. For the return series of the Bahraini and South African gold markets, however, whilst the LM's (1988, 1989) parametric (M_1 and M_2) test statistics are unable to conclusively reject the RWS and MDS hypotheses, Wright's (2000) robust ranks (R_1 and R_2) and signs (S_1 and S_2) based alternatives consistently reject the RWS and MDS hypotheses for both gold markets, implying that the failure of the parametric variance-ratio tests to reject the weak-form efficiency for both gold markets may be due to hetereoscedasticity problems rather than autocorrelation ones. Overall, our results are generally in line with the findings of past studies on the efficiency of gold markets (Ball et al., 1982, 1985; Muradoglu et al., 1998; Parisi et al., 2008; Narayan et al., 2010; Shafiee & Topal, 2010; Yu & Shih, 2011; Baur, 2013; Blose & Gondhalekar, 2013; Pierdzioch et al., 2014). For example, our findings that suggest that the return series of the UK and US gold markets are weak-form efficient offer support for the similar findings of Tschoegl (1978, 1980), Monroe and Cohn (1986), Smith (2002) and Pierdzioch et al. (2014), but contradict those of Ball et al. (1982), Booth and Kaen (1979), Solt and Swanson (1981), Shafiee and Topal (2010), Baur (2013), and Blose and Gondhalekar (2013) that rejected the weak-form in both gold markets. Similarly, the findings of

Muradoglu et al. (1998) rejected the notion of random walk in the Turkish gold market, and thus our evidence that the return series of the Turkish gold market do not follow random walk offers further support for their findings.

5.3 Empirical results and discussion: Global gold market efficiency and macroeconomic variables

In line with past studies that have examined the efficiency of gold markets (Ho, 1985; Beckers, 1984; Basu & Clouse, 1993; Christie-David et al., 2000; Mani & Vuyyuri, 2003; Mills, 2004; Parisi et al., 2008; Narayan et al., 2010; Yu & Shih, 2011; Baur, 2013; Blose & Gondhalekar, 2013; Pierdzioch et al., 2014), our findings are observably generally mixed. It is, however, not easily conceivable why some gold markets are efficient, whilst others are not. For example, whereas some developed global gold markets, such as Hong Kong, Japan, Switzerland, UK and US are weak-form efficient, the behaviour of daily gold price return series of other matured gold markets, such as Australia, Brazil, Canada, Germany, Singapore and Turkey do not follow random walk. However, the findings of past studies suggest that gold prices can be influenced by a number of macroeconomic fundamentals (Christie-David et al., 2000; Sjaastad, 2008; Blose, 2010; Zhang & Wei, 2010; Pukthuanthong & Roll, 2011). For example, increased crude oil prices can lead to greater inflationary pressures, and thus, increased demand for gold as an alternative 'safe haven' investment (Baur & McDermott, 2010; Baur & Lucey, 2010; Ewing & Malik, 2013; Lili & Chengmei, 2013). Similarly, greater increases in broad money supply (M2+) (i.e., 'quantitative easing') without a corresponding increase in the production of goods and services can create inflationary pressures through rising prices, and thereby leading to greater demand for gold (Mahdavi & Zhou, 1997). Similar theoretical and empirical links have been made between gold prices and: (i) exchange rates (Sjaastad & Scacciavillani, 1996; Wang et al., 2011); equity returns (Baur, 2013); and interest rates (Mani & Vuyyuri, 2003), amongst other macroeconomic variables. Consequently, we argue that one way of explaining the extent to which a gold market's return series are efficient or inefficient is to examine volatilities in the underlying macroeconomic fundamentals. Specifically, we conjecture that increased volatilities in the underlying macroeconomic variables are more likely to be associated with rapid changes in the efficiency of the gold market and vice-versa. Thus, we depart from previous studies from simply testing the efficiency of gold returns to examining the extent to which changes in the underlying macroeconomic fundamentals can explain predictability or non-predictability of such returns.

Table 7 contains a logit regression results of the effect of changes in macroeconomic variables [(i.e., Δbroad money [M2+] supply, Δcrude oil price, Δinflation [CPI] rate, Δinterbank borrowing rate, Δinterest [3-month t-bill] rate, Δmultilateral exchange, Δresidential property prices and Δshare prices)] on the probability of rejecting the RWS (M_1, R_1 and R_2) and MDS (M_1, S_1 and S_2) hypotheses. The dependent variables (M_1, M_1, R_1, R_2, S_1 and S_2) are binary variables, which take the value of 1 if the RWS or MDS hypothesis is rejected at the 1%, 5% or 10% significance level. To ascertain whether the maturity of a gold market impacts on its efficiency, we include an emerging gold market dummy[4], which takes a value of 1 if a country is classified as a developing/emerging country by the World Bank and five other reputable global rating agencies (Dow Jones, FTSE, MSCI, Russell and S&P), 0 otherwise.

Insert Table 7 about here

A number of interesting findings are observable in Table 7. First, and consistent with our intuition, the findings generally indicate that changes in the underlying macroeconomic fundamentals are fairly capable of explaining the probability of rejecting the RWS and MDS hypotheses. Specifically, changes in crude oil price, inflation rate, interbank borrowing rate, multilateral exchange rate and share price are statistically significant and negatively related to the probability of rejecting the RWS (M_1, R_1 and R_2) and MDS (M_1, S_1 and S_2) hypotheses. This provides new evidence to suggest that the probability of rejecting the RWS and MDS hypotheses is significantly lower when there are greater changes (volatilities) in these five underlying macroeconomic variables. Second, and by contrast, we do not find any evidence to suggest that changes in broad money (M2+) supply, interest (t-bill) rate and residential property prices are associated with the probability of rejecting the RWS and MDS hypotheses, implying that not every underlying macroeconomic variable has the capacity to explain the probability of predicting gold returns. Third, the coefficient on the emerging gold markets dummy is discernibly significant and positively related to the probability of rejecting the RWS and MDS hypotheses. This also provides new evidence to suggest that the probability of rejecting the RWS and MDS hypotheses is higher

[4]It should be noted that our classification is based on the 2008 list of developing/emerging countries classified jointly by the World Bank and five other reputable global rating agencies (i.e., Dow Jones, FTSE, MSCI, Russell and S&P), whereby countries are classified based on six broad development factors: (i) per capital income; (i) maturity and effectiveness of market and regulatory environment; (iii) the speed of custody and settlement; (iv) development, maturity and sophistication of the derivatives markets; (v) the sophistication of the landscape for trading and market dealing; and (vi) the size and depth of the market.

in emerging gold markets than their developed counterparts. Overall, our findings have implications for international portfolio managers, investors, policy-makers and regulatory authorities.

5.4 Robustness analyses

We conduct a number of additional analyses as a way of ascertaining the robustness of our results. First, to address the potential endogenous association that may result from estimating contemporaneous link between probability of rejecting the RWS/MDS hypotheses and macroeconomic variables, we use one-year lagged explanatory variables as alternative to contemporaneous ones. Table 8 contains a logit regression of the effect of lagged changes in macroeconomic variables on the probability of rejecting the weak-form (RWS and MDS) hypotheses. Apart from minor sensitivities in terms of the magnitude of the coefficients, our previous evidence that increased changes in crude oil price, inflation rate, interbank borrowing rate, multilateral exchange rate and share price are associated with significantly lower probability of rejecting the RWS and MDS hypotheses remains fairly unchanged.

Insert Table 8 about here

Second, it can be argued that gold price return predictability may not only be driven be macroeconomic variables, but also country-specific institutional (e.g., exchange rate regime, international accounting standards legal system, national gold regulations, and national governance quality) and trading (e.g., availability of gold ETFs, market liquidity and daily price movement restrictions) characteristics.[5] For example, the use of a de facto independent free floating exchange rate regime may lead to an increase in the volatility of exchanges rates and gold prices, and thereby a potential reduction in the predictability of gold prices. By contrast, reliance on a fixed or managed exchange rate regime may lead to exchange rates and gold prices not changing to reflect the underlying macroeconomic conditions, and thus a potential increase in the ability to accurately predict gold price returns. National duties, regulations and restrictions relating to the importation and taxation of purchases (demand) and sales (supply) of specific quantities of gold may not only have significant effect on the price of gold in that country, but also the price of gold in neighbouring countries and the global gold market in general. Gold regulations in India, for example, limit the weight of all imported gold to 10kgs; as well as impose an

[5]We are grateful to an anonymous reviewer for this suggestion.

import duty of 15% and additional special tax of 3% on all imported gold. In fact, a clear majority (20 out of 28) of the countries in our sample have some form of national regulations (e.g., quality, quantity and taxation) relating to the importation, sale and purchase of gold and its ornaments.

Similarly, strong legal system, good national governance, and increased commitment towards accountability, transparency and disclosure through the full adoption of international accounting standards can improve pricing efficiency of financial assets, including gold through the attraction of foreign direct investments and international investors. In addition to the institutional factors, national trading conditions and environment can have an effect on the efficiency of gold price returns. For example, the availability of gold ETFs, greater stock market liquidity and removal of maximum daily gold price movements can improve the efficiency of gold prices. Thus, to ascertain the extent to which country-specific institutional factors and trading characteristics drive our findings, we re-run our findings in Table 7 by including a number of institutional (exchange rate regime, international accounting standards legal system, national gold regulations, and national governance quality) and trading (gold ETFs, market liquidity and price movement restrictions). Observably, the findings reported in Table 9 are generally consistent with those reported in Table 7, suggesting that our previous results are fairly robust to the inclusion of the country-specific institutional factors and trading charateristics. Specifically, the findings contained in Table 9 indicate that changes in crude oil price, inflation rate, interbank borrowing rate, multilateral exchange rate and share price are statistically significant and negatively related to the probability of rejecting the RWS (M_1, R_1 and R_2) and MDS (M_1, S_1 and S_2) hypotheses. With specific reference to the institutional factors and trading characteristics, the findings suggest that the quality of national governance, the use of independent floating exchange rate regime, and greater stock market liquidity are associated with lower levels of predicting gold price returns. By contrast, we do not find any evidence to suggest that the adoption of international accounting standards, legal system, national gold regulations, price movement restrictions and the availability of gold ETFs have a significant impact on the efficiency of gold price returns.

Third, to ascertain whether efficiency changes over-time, we re-implement our test by conducting four separate ten-year sub-sample periods (1968 to 1977; 1978 to 1987; 1988 to 1997; and 1998 to 2014) and our results our reported in Table 10. As R_1 and S_1 are better specified and more powerful under the assumption of RWS and MDS hypotheses, respectively, we limit our analysis to them although the findings are essentially similar irrespective of the test statistic that is applied. Similarly, and for brevity, we report results for 10 of the gold markets (with at least one representation from each major continent) we examined, but the findings generally follow similar trend. The results contained in Table 10 suggest generally that gold return predictability reduces over-time. For example, daily spot gold price returns for Australia are reasonably predictable in the first two decades (Windows I and II), but follow RWS and MDS in the last two decades (Windows III and IV). Similar patterns can be observed for Canada, China, Germany and South Africa, and even for India and Saudi Arabia, where gold returns remain highly predictable, there are observable reductions in the levels of rejection of the RWS and MDS hypotheses over-time. Our mixed results for South Africa have been particularly surprising because as a major gold producer, one will expect gold price returns to be fairly efficient. Our additional analyses, thus, offer further insights on clarifying the mixed findings for South Africa in particular.

Fourth, we conduct a number of additional analyses, which for brevity are not reported, but available upon request. For example, to account for country-level effects over-time, we-run our logit model by including country and year dummies with the central tenor of our findings remaining essentially the same. Fifth, since rejections are usually at the conventional 1% and 5% significance levels, we re-estimate our logit model by excluding all rejections at the 10% significance level. We observe some improvements in the statistical significance and magnitude of the coefficients, as well as in the diagnostics and explanatory power of the model, but our main conclusions remain unaffected. Sixth, to further ascertain whether efficiency changes over-time, we carry additional analysis by estimating a five-year overlapping rolling window. Similar to the four separate ten-year subsamples, we do observe evidence of decreasing return predictability over-time irrespective of the variance-ratio test statistic that is applied, especially over the last decade and particularly for the matured gold markets. Finally, to determine whether our findings are sensitive to the testing interval (i.e., the lag of ‘*k*’) used, we repeat our analysis by employing two different intervals of k: (i) when k=2, 4, 8, and 16 days; and (ii) when k=5, 10, 15, and 20 days, with our findings suggesting that our central evidence is insensitive to the testing interval or the lag of k used. Overall, our robustness analyses make us fairly confident that our findings are not spuriously driven by any endogenous or unidentified hetereogeneities.

6. Summary and conclusion

Although the number of formal gold markets in the world has increased rapidly, especially over the last decade, existing studies on the efficiency of gold markets are limited to a few developed markets, especially those in the UK and US, and thereby limiting current understanding of the return behaviour of global gold markets. Additionally, the few existing studies have also mainly merely tested the efficiency of gold markets with limited attempts at identifying the factors that may explain the degree of a gold market's efficiency. This paper has, therefore, examined the weak-form efficiency of global gold markets with specific focus on the random walks (RWS) and martingale difference sequence (MDS) hypotheses, and consequently, investigated the extent to which predictability or non-predictability of global daily spot gold price return series behaviour can be explained by volatilities in macroeconomic fundamentals.

Our findings contribute to the literature in a number of ways. First, our results indicate that gold markets in Egypt, Indonesia, Mexico, Nepal, Pakistan, Russia, Saudi Arabia, UAE and Vietnam are not weak-form efficient neither from the perspective of the strict RWS nor in the relaxed MDS sense, but both hypotheses cannot be rejected for gold markets in Hong Kong, Japan, Switzerland, UK and US. We, however, find conflicting findings for gold markets in Australia, Bahrain, Brazil, Canada, China, Germany, India, Malaysia, Singapore, South Africa, South Korea, Taiwan, Thailand and Turkey. Generally, our study contributes to the literature by providing new evidence on the gold return behaviour and efficiency in Bahrain, Brazil, Egypt, Indonesia, Malaysia, Mexico, Nepal, Pakistan, Russia, Saudi Arabia, Singapore, South Africa, South Korea, Taiwan, Thailand, UAE and Vietnam) and extending prior findings in gold markets in Australia, Canada, China, Germany, Hong Kong, India, Japan, Switzerland, Turkey, UK and US.

Second, our results suggest that the higher the volatilities in macroeconomic variables (i.e., crude oil price, inflation rate, interbank rate, multilateral exchange rate and share price), the less likely it is to reject the RWS and MDS hypotheses. Third, our results show that the RWS hypothesis is rejected more frequently than its MDS alternative, and thereby justifying our decision to conduct an explicit test of the RWS and MDS hypotheses. Fourth, in line with the findings of prior studies, the results obtained by applying Wright's (2000) non-parametric variance-ratio tests are more consistent, whilst those of the Lo and MacKinlay's (1988, 1989) parametric alternatives are generally mixed. Finally, our evidence shows that the probability of rejecting the weak-form efficiency is higher in emerging gold markets than developed ones. Our findings are fairly robust to estimating subsamples, overlapping rolling windows and endogeneity consistent models, as well as controlling for a number of country-specific institutional factors and trading characteristics.

Our findings have crucial implications for global portfolio managers, investors, poly-makers and regulatory authorities. For international portfolio managers and investors, our evidence of gold return predictability in some gold markets does not only offer opportunities for immediate exploitation, but also risk reduction through the formation of portfolio strategies that strike a fair balance between investments in efficient and inefficient gold markets. For policy-makers and regulatory authorities, our evidence offers a stronger impetus to strengthen market regulations, infrastructure, and microstructure. In particular, and as smaller and less matured markets are generally less efficient, policies that can encourage greater integration and co-operation, for example, through mergers and acquisitions both within and across continents may be a step in the right direction.

Finally, whilst the findings of our study are important and robust, its limitations need to be explicitly acknowledged. First, due to data limitations, we do not fully examine (we only investigate liquidity, price limits and availability of gold ETFs) how market trading and market microstructure (e.g., trading volume, system, frequency, margin requirements, settlement, contract size, and tick size, amongst others) impact of on the efficiency of gold market return series. Thus, future studies may enhance their findings by examining how these factors affect the efficiency of gold market returns. Second, we examine a limited number of macroeconomic variables and institutional factors that can potentially explain the predictability or non-predictability of global gold market returns, and thus future studies may improve their findings by exploring the effect of other factors, such as political instability and financial crisis, on gold market efficiency. Third, due to data limitations, our test is limited to 28 gold markets, and thus future studies may improve the insights that they may be able to offer by expanding their sample, especially to include gold markets with limited evidence, such as those in Belgium, France, Luxembourg, Israel, Kenya, Kuwait, Nigeria, and Philippines. Finally, although we find evidence of return predictability in some gold markets, it is not easily clear whether it will be economically profitable to be exploited taking into consideration inherent costs, such as transaction costs. Future studies may enhance their results by assessing economic feasibility of an investment strategy that may seek to exploit such predictability opportunities.

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Table 1: Some of the trading arrangements of the sampled global gold markets at the end of the sampled period

Country	*First gold trading date*	*Trading days*	*Trading hours/(min-max daily price movement limits in national currency/g/oz)*	*Trading system*	*Cash/Phy settlement*	*Contract size/Purity/in. margin*	*Clear/ settle*	*Main gold market(s)*	*Main trading city(ies)*
Australia	1978	Mon-Fri.	10am-4pm/(aud.05g/no limit)	Electronic	Both	100oz/.9995/aud6600	T+1	ASX/SFE	Sydney
Bahrain	2010	Mon-Fri.	9.3am-9.30pm/(bhd.10g/none)	Electronic	Cash	1kg/.995/bhd4%	T+1	BFX	Manama
Brazil	1986	Mon-Fri.	10am-5pm; 5.45-7pm/(brl.001g/none)	Electronic	Both	250g/.999/R$average	T+2	BM&FBovespa	Rio/Sao Paulo
Canada	1972	Sun-Fri.	6pm-5pm/(cad.10oz/none)	Electronic	Both	100oz/.995/cad5%	T+1	CMC/WCE	Toronto/Winn.
China	2002	Mon-Fri.	9am-11.30am; 1.30pm-3pm; 9pm-2.30am/(cny.10g/none)	Electronic	Both	100g/.9999/cny10500	T+2	SHFE/SGE	Shanghai/ Shenzhen
Egypt	-	-	-	-	-	-	-	-	-
Germany	1959	Mon-Sun.	8am-10.30am(euro.01oz/none)	Electronic	Cash	100oz/.9995/euro5%	T+1	EUREX/SOFFEX	Frankfurt
Hong Kong	1910 (Grew 1974)	Mon-Sat.	9am-12pm; 2pm-5pm 7am-5am/(hkd.5tael/none)	Open outcry Electronic	Both	100tael/.99/free - 35kg, HKD140k -5kg	T+2	CGSE/HKEX /HKMEX	Hong Kong
India	1990	Mon-Fri.	10am-11.30am/(inr.125/market)	Electronic	Both	1000g/.995/inr75000	T+3	NCDEX/MCX/NMCE	Calcutt/Mumbai
Indonesia	1999	Mon-Fri.	8am-5.30pm/(idr.05g/market)	Electronic	Both	1kg/.9995/idr15%	T+2	JFX/ICDX	Jakarta
Japan	1982	Mon-Fri.	9am-3.15pm; 4.30pm-4am(jny1g/non)	Electronic	Both	1kg/.9999/jpy45000	T+2	TOCOM	Tokyo
Malaysia	1980	Mon-Fri.	9am-12.30; 2.30-7pm/(rm.05g/100%)	Electronic	Cash	100g/.995/rm4004	T+2	KLSE/MDEX/KLCE/	Kua. Lumpur
Mexico	1998	Mon-Fri.	8am-3pm/(mxn1/market)	Electronic	Cash	100oz//.995/mxn10%	T+3	MEXDER/MSE	Mexico City
Nepal	2009	Mon-Sat.	10.30am-11pm(npr0.10g/market)	Electronic	Cash	1000g/.995/npr60000	T+0	MEX/NSE	Kathmandu
Pakistan	2007	Mon-Fri.	5am-2am/(pkr10oz/25%)	Electronic	Both	10z/.995/pkr-formula	T+0	PMEX/NCEL	Karachi
Russia	2013	Mon-Fri.	10am-11.50pm/(rub1g/none)	Electronic	Cash	100g/.9999/rub800	T+0	MOEX/RTS	Moscow
Saudi Arabia	-	-	-	-	-	-	-	-	-
Singapore	1969	Mon-Fri.	8.30am-11.25am/(sgd.005g/none)	Electronic	Cash	25kg/.9999/sgd10%	T+2	SICOM/SGX/SMX	Singapore
South Africa	1987	Mon-Fri.	9am-3.45pm/(zar.1g/market)	Electronic	Cash	100g/.995/Zar7800	T+3	JSE-CDM/SAFEX	Johannesburg
South Korea	1999	Mon-Fri.	9am-3.15pm/(krw10g/none)	Electronic	Cash	1kg/.9999/krw10000	T+1	KRX	Busan/Seoul
Switzerland	1961	Mon-Fri.	8am-5pm(chf.10oz/none)	Electronic	Cash	100oz/.9995/chf5%)	T+2	EUREX/SOFFEX	Zurich
Taiwan	2006	Mon-Fri.	8.45am-1.45pm/(twd.10oz/15%)	Electronic	Cash	10oz/.995/twd-mkt.	T+1	TAIFEX	Taipei
Thailand	2009	Mon-Fri.	9.45am-12.30; 2.30-4.55pm/(thb10/10%)	Electronic	Both	152.44g/.965/thb-mkt	T+1	TFEX/SET	Bangkok
Turkey	1989	Mon-Sun.	4pm-4pm/(try1g/none)	Electronic	Both	400oz/.995/try15%	T+0	IGE/ISE	Istanbul
UAE	2005	Mon- Fri.	7am-23.30pm/(aed0.10g/100%)	Electronic	Both	320z/.995/aed10%	T+2	DGCX/DMCC/DCCC	Dubai
UK (Around 1800)	1840 (Re-opened 1919)	Mon- Fri.	London: Morning Fix 10.30am; Afternoon Fix 3pm; LBMA 8am-5pm/ ($.10oz/none)	Telephone Electronic	Both	400oz/.995/gbp5%	T+2	LBM/TLGMFL/LSE	London
US	1974	Mon- Fri. Sun- Fri.	COMEX/NYMEX: 8.20am-1.30pm. CME/GLOBEX: 6pm-5.15pm/(usd0.10/none)	Open outcry Electronic	Both	100oz/.995/usd1350	T+2 T+1	COMEX/ CME/ GLOBEX/NYMEX	New York/ Chicago
Vietnam	-	-	-	-	-	-	-	-	-

Notes/sources: O'Callaghan (1991), Australian Securities Exchange (ASX) and Sydney Futures Exchange (SFE) merged in 2006; Shanghai Futures Exchange (SHFE)/Shanghai Gold Exchange (SGE). Brazilian Mercantile and Futures Exchange (BM&F) and Sao Paulo Stock Exchange (Bovespa) merged in 2008. Chinese Gold and Silver Exchange Society (CGSE) of Hong Kong; Deutche Borse (DTB), and Swiss Options and Financial Futures Exchange (SOFFEX) merged in 1998 to form EUREX. National Commodity and Derivative Exchange (NCDEX)/Multi Commodity Exchange of India (MCX)/National Multi Commodity Exchange of India (NMCE). Indonesia Commodities and Derivatives Exchange (ICDX)/Jakarta Futures Exchange (JFX). Tokyo Commodity Exchange (TOCOM) via a merger of Tokyo Textile Exchange (1951), Tokyo Rubber Exchange (1952), and Tokyo Gold Exchange (1982) in 1984. Kuala Lumpur Stock Exchange (KLSE)/Malaysian Derivatives Exchange (MDEX) merged with the Kuala Lumpur Options and Financial Futures Exchange (KLOFFEE), and the Commodity and Monetary Exchange of Malaysia (COMMEX) in 2001 to form Bursa Malaysia in 2004. Mexican Derivative Exchange (MEXDER)/Mexican Stock Exchange (MSE). Mercantile Exchange of Nepal (MEX)/Nepal Spot Exchange (NSE). National Commodity Exchange (NCEL), now called Pakistan Mercantile Exchange (PMEX). Russian Trading System (RTS), restructured in 1995 as Moscow Exchange (MOEX). Bahrain Financial Exchange (BFX). Singapore Stock Exchange (SGX)/Singapore Commodity Exchange (SICOM)/Singapore Mercantile Exchange (SMX). JSE Commodity Derivatives Market (JSE-CDM) merged with the South African Futures Exchange (SAFEX) in 2001. Korean Exchange (KRX). Taiwan Futures Exchange (TAIFEX). Thailand Futures Exchange (TFEX)/Stock Exchange of Thailand (SET). Istanbul Gold Exchange (IGE) merged with the Istanbul Stock Exchange (ISE) to form Borsa Istanbul in 2013. Dubai Multi Commodities Centre (DMCC)/Dubai Gold and Commodities Exchange (DGCX)/Dubai Commodities Clearing Corporation (DCCC). Refers to the London morning (AM) and afternoon (PM) gold price fixing by the powerful five members ('quintupoly') of the London Bullion Market Association (LBMA) via The London Gold Market Fixing Ltd (TLGMFL). The current five London Gold Fix Members (LBMA members currently consists of 53 full members and 33 associate members) are: The Bank of Nova Scotia-ScotiaMocatta (current chair), Barclays Capital, HSBC Bank USA London Branch; N M Rothschild & Sons LTD; and Societe Generale. COMEX is the Commodity Exchange division of the New York Mercantile Exchange (NYMEX)/ Chicago Mercantile Exchange (CME Group). Egypt, Saudi Arabia and Vietnam to do not have formal gold markets, but do significant trading through the over-the-counter market (i.e., they are among the top ten major gold consumer countries in the world), as reported by the World Gold Council (WGC) in March 2014, and thus are included in the sampled countries. All reported trading arrangements are based on information as of March 2014. 'Oz' means troy ounce and 'g' or 'kg' is a gram or kilogram.

Table 2: Some descriptive statistics on the sampled global gold markets

Country	*Number of commodity futures/options traded on exchanges (Jan. 2013)*	*Gold (tonnes) Q1 (2014) in troy ounces**	*Gold (US$m) Q1 (2014)***	*FX reserves****	*Total reserves***** (US$m) Q1 (2014)*	*Gold as % of total reserves Q1 (2014)*	*Equity market cap as a % of GDP (Dec. 2013)*	*Number of equity listed (Dec. 2013)*
Australia	53683	79.85	3,316.42	54,052.09	57,368.51	5.80	100.42	2,050
Bahrain	-	4.67	193.76	5,347.04	5,540.81	3.50	73.68	50
Brazil	123 211	67.20	2,790.77	361,129.70	363,920.48	0.80	56.77	362
Canada	427271	2.99	124.01	76,324.86	76,448.86	0.20	118.78	3,973
China	141723667	1,054.09	43,777.41	3,966,050.57	4,009,827.98	1.10	42.72	2,454
Egypt	-	75.61	3,140.24	13,831.79	16,972.03	18.50	20.63	234
Germany	27858922	3,386.36	140,639.28	66,791.61	207,430.89	67.80	43.32	7743
Hong Kong	-	2.08	86.55	316,781.28	316,867.83	0.90	1013.96	1,551
India	-	557.75	23,163.79	285,031.68	308,195.46	7.50	130.76	6,859
Indonesia	-	78.07	3,242.29	99,340.02	102,582.31	3.20	50.21	463
Japan	-	765.22	31,780.20	1,247,526.29	1,279,306.49	2.50	71.16	3,478
Malaysia	786191	35.46	1,472.60	128,721.75	130,194.35	1.10	142.45	919
Mexico	-	122.75	5,097.98	180,368.60	185,466.58	2.70	42.78	136
Nepal (Q4 2013)	-	36.33	1,407.02	5,293.48	6,700.50	21.00	41.45	370
Pakistan	-	64.43	2,676.02	6,689.95	9,365.97	28.60	65.35	1511
Russia	1577229	1,040.71	43,221.96	442,773.46	485,995.42	8.90	41.60	291
Saudi Arabia	-	322.90	13,410.56	741,252.17	754,662.73	1.80	51.52	158
Singapore	-	127.40	5,291.01	272,700.84	277,991.85	1.90	269.37	776
South Africa	197625	125.13	5,196.71	44,347.26	49,543.97	10.50	255.42	385
South Korea	1236	104.44	4,337.38	346,926.86	351,264.25	1.20	93.63	1779
Switzerland	-	1,040.06	43,194.87	502,745.91	545,940.79	7.90	204.99	279
Taiwan	8833	423.63	17,593.64	419,199.00	430,677.93	4.20	151.27	841
Thailand	305436	152.41	6,329.58	161,153.92	167,483.49	3.80	109.76	559
Turkey	-	483.54	20,081.96	105,989.01	126,070.98	15.90	32.64	243
UAE (Q4 2013)	-	-	-	68,202.65	-	-	18.68	65
UK	14013600	310.25	12,885.21	97,272.43	110,157.64	11.70	270.96	2,469
US	70177895	8,133.46	337,791.24	133,243.32	471,034.56	71.70	111.42	4914
Vietnam	-	-	-	-	-	-	21.69	307
Total	257131588	18596.79	772242.46	10149087.54	10847012.66	-	-	45219
London PM Fix	-	1291.75	1291.75	1291.75	1291.75	1291.75	-	-
SDR: USD	-	1.54563	1.54563	1.54563	1.54563	1.54563	-	-
Ex Japan, UK & US	172940093	9387.86	389785.81	8671045.50	8986513.97	-	-	34358
All countries	-	28,700.18	1,191,948.64	12,301,055.09	13,493,003.73	9.00	-	-

Notes/Sources: Number of commodity futures/options traded, number of listed firms and market capitalisation data were collected from the World Federation of Stock Exchanges 2013 annual market reports. 2013 Gross Domestic Product (GDP) collected from the International Monetary Fund website. Gold data collected from the World Gold Council (WGC) website in August 2014. The US number of listed firms is made up of NASDAQ (2579) and NYSE (2335). Canadian number of listed firms consists of TMX GROUP including the Toronto Stock Exchange's (TSX) venture capital listed firms. The number of Indian listed firms is made of Bombay Stock Exchange (BSE) (5195) and National Stock Exchange (NSE) (1664). The number of Chinese listed firms consists of Shanghai (914) and Shenzhen (1540) Stock Exchanges. Japanese listed firms is made up of Osaka (1174) and Tokyo (2304) Stock Exchanges. UK listings include the Alternative Investment Market (AIM) listed firms. Pakistani listed firms are made up of Karachi (579), + Islamabad (261), and Lahore (671) Stock Exchanges. The number of commodity futures/options traded for the US is made up of the CME GROUP, Intercontinental Exchange (ICE) futures in the US and New York Stock Exchange LIFFE Commodity market. The number of commodity futures/options traded includes the Dalian Commodity, Shanghai Futures and Zhengzhou Commodity Exchanges. UK commodity futures/options traded includes London Metal Exchange only (excludes LBA/OTC markets), whilst the number of commodity futures/options reported for Germany is made up of Euronext and ICE Futures in Europe (Euro area). *****The WGC notes that gold is reported in millions of troy ounces converted into metric tonnes at 32,151 ounces per tonne. ******The US dollar value of gold reserves is calculated by the WGC. The value of gold holdings is calculated using the end-of-quarter London PM fix gold price (there are 32,151 troy ounces in a metric tonne). *******Foreign exchange and total reserves minus Gold. ******** Total reserves are calculated by the WGC by adding the US dollar value of gold and foreign exchange reserves.

Table 3: Descriptive statistics and diagnostics of daily spot gold price return series of global gold markets

Gold market	Mean	Volatility	Skewness	Kurtosis	K-S	A-D	N
Panel A: Africa and Middle Eastern gold markets							
Bahrain	0.000126	0.02931	-13.39***	440.30***	0.34**	243.76***	3284
Egypt	0.000248	0.01659	-32.53***	1972.75***	0.93***	628.52***	6700
Saudi Arabia	0.000186	0.01691	-22.15***	1320.58***	0.82***	486.20***	9289
South Africa	0.000452	0.01751	-19.96***	1152.67***	0.65***	457.62***	9289
Turkey	0.001254	0.01867	-16.41***	1055.60***	0.60***	413.48***	8246
UAE	0.000169	0.01698	-21.94***	1298.40***	0.78***	475.95***	9289
Panel B: The Americas gold markets							
Brazil	0.002350	0.03145	-21.92***	694.74***	0.41**	265.74***	7423
Canada	0.000154	0.01633	-24.57***	1517.72***	0.84***	498.16***	9289
Mexico	0.000393	0.01934	-24.56***	1348.04***	0.72***	490.42***	5378
US	0.000158	0.01613	-25.53***	1594.97***	0.85***	523.39***	9291
Panel C: Asia-Pacific gold markets							
Australia	0.000210	0.01588	-23.76***	1529.11***	0.84***	523.94***	10335
China	0.000248	0.01753	-20.41***	1468.50***	0.82***	518.35***	7720
Hong Kong	0.000159	0.01602	-25.20***	1566.30***	0.85***	539.12***	9293
India	0.000393	0.01704	-21.60***	1282.86***	0.76***	470.31***	9289
Indonesia	0.000560	0.02904	-9.45***	604.39***	0.44**	256.53***	9289
Japan	0.000103	0.01693	-22.13***	1315.73***	0.82***	520.47***	9289
Malaysia	0.000177	0.02568	-24.25***	944.02***	0.54***	352.06***	2440
Nepal	0.000428	0.02920	3.75***	767.71***	0.47**	339.28***	4882
Pakistan	-0.000225	0.02728	-28.47***	1043.98***	0.67***	428.72***	1731
Singapore	0.000020	0.02265	-33.22***	1464.70***	0.81***	517.46***	2599
South Korea	0.000277	0.01819	-17.69***	990.96***	0.52***	348.10***	9289
Taiwan	-0.000487	0.03189	-28.59***	896.13***	0.49**	340.69***	1080
Thailand	0.000231	0.01740	-20.15***	1181.90***	0.70***	438.57***	9289
Vietnam	0.000337	0.01726	-30.00***	1755.07***	0.88***	585.33***	6440
Panel D: European gold markets							
Germany	0.000178	0.01602	-26.07***	1640.09***	0.87***	567.72***	9291
Russia	0.001043	0.02352	-9.36***	694.71***	0.45**	281.40***	5630
Switzerland	0.000102	0.01642	-24.22***	1486.29***	0.83***	532.03***	9289
UK	0.000326	0.01561	-21.27***	1397.84***	0.85***	543.67***	12162

Notes: A-D and *K-S* represent Anderson-Darling and Kolmogorov-Smirnov goodness-of-fit absolute values with ******* and ****** means that the log-normality assumption is rejected at the 1% and 5% levels, respectively. Panels *A*, *B*, *C*, and *D* present descriptive statistics and diagnostics of the daily spot gold price return series of African and Middle Eastern, the Americas, Asian-Pacific, and European gold markets, respectively. Volatility is the standard deviation (SD) of the spot gold price return series, whilst *N* refers to the number of time series observations. The daily gold spot prices were collected from two main sources: (i) *DataStream*; and (ii) WGC website. The WGC website contains continuous data on daily spot price series for the top 20 consumer and producer countries in the world from December 1978 to August 2014, whilst *DataStream* has similar data on some countries from January 1968 to August 2014. Where data is available on a particular country in both databases (e.g., Australia, Brazil, China, Germany, Russia, Switzerland UK, and US, amongst others), we source from the database with the longest series. For example, the series for the UK in the WGC database begins from 29 December 1978, whilst it starts from 3 January 1968 in *DataStream* and thus, we use the series from *DataStream* for the UK instead of that of the WGC. Thus, our returns series span over 46 years, ranging from the longest period of 3 January 1968 to 13 August 2014 for the UK (12,162 daily observations) to the shortest period of 24 June 2010 to 13 August 2014 for Taiwan (1,080 daily observations). All daily spot prices used were quoted in the applicable local currencies. Countries with long series in WGC database that were used are: Canada (02/01/179-08/08/2014); China (07/01/1985-08/08/2014); Egypt (05/12/1988-08/08/2014); Germany (29/12/1978-08/08/2014); India (02/01/1979-08/08/2014); Indonesia (02/01/1979-08/08/2014); Japan (02/01/1979-08/08/2014); Russia India (11/01/1993-08/08/2014); Saudi Arabia (02/01/1979-08/08/2014); South Africa (02/01/1979-08/08/2014); South Korea (02/01/1979-08/08/2014); Switzerland (02/01/1979-08/08/2014); Thailand (02/01/1979-08/08/2014); Turkey (31/12/1982-08/08/2014); UAE (02/01/1979-08/08/2014); US (29/12/1978-08/08/2014); and Vietnam (04/12/1989-08/08/2014). By contrast, countries with long series in *DataStream* that were used are: Australia (02/01/1975-13/08/2014); Bahrain (11/01/2002-13/08/2014); Brazil (31/01/1986-13/08/2014); Hong Kong (02/01/1979-13/08/2014); Malaysia (04/04/2005-13/08/2014); Mexico (04/04/1994-13/08/2014); Nepal (29/11/1995-13/08/2014); Pakistan (27/12/2007-13/08/2014); Singapore (30/08/2004-13/08/2014); Taiwan (24/06/2010-13/08/2014); and UK (03/01/1968-13/08/2014).

Tables 4: Variance-ratio tests results for the daily spot gold price return series of gold markets in Africa and Middle East

Period:	M_1	M_2	R_1	R_2	S_1	S_2
Bahrain						
k=15	-2.90***	-1.40	2.25**	-2.52***	-2.97***	3.52***
k=20	-2.57***	-1.63	2.47***	-2.64***	-2.85***	3.74***
k=25	-2.20**	-1.76*	3.16***	-2.78***	-2.71***	3.86***
k=30	-2.04**	-1.89*	3.30***	-2.90***	-2.53**	3.92***
Egypt						
k=15	6.05***	5.12***	7.27***	7.80***	9.43***	7.56***
k=20	6.27***	5.39***	7.32***	8.24***	9.74***	7.89***
k=25	6.48***	5.68***	7.53***	8.67***	9.86***	8.28***
k=30	6.92***	5.89***	7.75***	8.95***	9.98***	8.60***
Saudi Arabia						
k=15	-7.96***	-5.34***	8.32***	8.59***	10.77***	9.20***
k=20	-7.70***	-5.17***	8.46***	8.97***	10.95***	9.42***
k=25	-7.42***	-4.86***	8.70***	9.15***	11.32***	9.64***
k=30	-7.26***	-4.65***	8.84***	9.38***	11.59***	9.86***
South Africa						
k=15	-1.69*	-1.86*	3.42***	3.58***	5.21***	4.81***
k=20	-1.45	-1.72*	3.50***	3.75***	5.45***	4.96***
k=25	-1.28	-1.59	3.78***	3.81***	5.76***	5.12***
k=30	-1.00	-1.37	3.86***	3.96***	5.80***	5.30***
Turkey						
k=15	-1.98**	-1.59	3.54***	1.67*	-1.64	-0.96
k=20	-1.75*	-1.43	3.86***	1.76*	-1.47	-0.74
k=25	-1.58	-1.27	4.09***	1.92**	-1.32	-0.53
k=30	-1.49	-1.03	4.21***	2.36**	-1.05	-0.39
UAE						
k=15	-6.33***	-6.58***	-7.36***	-8.93***	6.38***	7.32***
k=20	-6.52***	-5.75***	-7.49***	-8.71***	6.55***	7.51***
k=25	-6.75***	-4.87***	-7.52***	-8.56***	6.70***	7.73***
k=30	-6.90***	-3.98***	-7.68***	-8.49***	6.81***	7.92***
Variance-ratio tests results for the daily spot gold price return series of gold markets in the Americas						
Brazil						
k=15	-2.10**	-1.55	3.32***	3.73***	2.08**	1.58
k=20	-1.86*	-1.36	3.47***	3.89***	1.83**	1.37
k=25	-1.63	-1.27	3.60***	4.10***	1.54	1.25
k=30	-1.32	-1.10	3.75***	4.34***	1.21	1.04
Canada						
k=15	-2.13**	-1.50	-2.86***	1.33	1.08	1.35
k=20	-1.64	-1.37	-2.50**	1.92**	1.36	1.43
k=25	-0.98	-0.21	-1.86*	2.49**	1.59	1.60
k=30	-0.32	-0.15	-1.65*	2.78***	1.64	1.75*
Mexico						
k=15	-5.86***	-7.65***	8.76***	7.45***	8.17***	9.30***
k=20	-5.65***	-7.40***	8.94***	7.67***	8.30***	9.56***
k=25	-6.43***	-7.31***	9.28***	7.80***	9.52***	9.72***
k=30	-6.20***	-7.12***	9.42***	7.93***	9.73***	9.89***
US						
k=15	-1.78*	-0.86	1.34	1.49	1.06	1.27
k=20	-1.53	-0.65	1.51	1.56	1.28	1.33
k=25	-1.39	-0.52	1.72*	1.68*	1.36	1.48
k=30	-1.22	-0.40	1.88*	1.75*	1.45	1.59

Note: A test statistic with *****, ****, and *** indicates significance at 1%, 5%, and 10% levels respectively. Figures in columns 2-7 give the values of the test statistics for M_1, M_2, R_1, R_2, S_1 and S_2 for each daily spot gold price return series. M_1 and M_2 are based on the conventional Lo and MacKinlay's (1988) parametric variance-ratio tests, while R_1, R_2, S_1 and S_2 are based on the recent non-parametric (ranks and signs) modification proposed by Wright (2000). The M_1 is robust under the assumption of homoscedasticity (*RWS*), whilst the M_2 is more precise under heteroscedasticity (*MDS*) conditions. Similarly, the ranks (R_1, R_2) are more powerful under homoscedasticity (*RWS*) conditions, whereas the signs (S_1 and S_2) are robust under the assumption of hetereoscedasticity. Thus, the M_1, R_1, and R_2 explicitly test the *RWS* hypothesis, whilst the M_2, S_1 and S_2 test the *MDS* hypothesis.

Table 5: Variance-ratio tests results for the daily spot gold price return series of gold markets in the Asia-Pacific region

Period:	M_1	M_2	R_1	R_2	S_1	S_2
Australia						
k=15	2.20**	1.28	-2.93***	3.42***	-1.64	-1.59
k=20	2.42**	1.40	-2.58***	3.54***	-1.48	-1.36
k=25	2.58***	1.57	-2.32**	3.75***	-1.32	-1.21
k=30	2.75**	1.62	-2.15**	3.91***	-1.17	-1.05
China						
k=15	-3.03***	-1.79**	2.32**	-3.76***	1.54	1.42
k=20	-2.62***	-1.68*	2.45**	-3.54***	1.63	1.51
k=25	-1.99**	-1.53	2.76***	-3.32***	1.82*	1.60
k=30	-1.67*	-1.42	2.93***	-3.20***	1.97**	1.75*
Hong Kong						
k=15	-1.65*	-1.50	1.46	1.55	-1.67*	-1.58
k=20	-1.60	-1.40	1.54	1.63	-1.60	-1.46
k=25	-1.45	-1.34	1.62	1.85*	-1.53	-1.37
k=30	-1.32	-1.27	1.85*	1.94*	-1.42	-1.25
India						
k=15	-3.45***	-1.50	5.21***	-4.87***	1.78*	1.43
k=20	-3.43***	-1.37	5.34***	-4.63***	1.67*	1.56
k=25	-3.67***	-1.29	5.47***	-4.41***	1.52	1.71
k=30	-3.10***	-1.13	5.61***	-4.23***	1.46	1.84
Indonesia						
k=15	-5.43***	-4.06***	6.20***	-5.43***	7.53***	8.31***
k=20	-5.28***	-4.47***	6.51***	-5.62***	7.66***	8.52***
k=25	-4.76***	-4.86***	6.76***	-5.75***	7.78***	8.73***
k=30	-4.54***	-4.98***	6.80***	-5.82***	7.93***	8.87***
Japan						
k=15	-1.67*	-1.46	-1.80*	-2.04**	-1.64	-1.50
k=20	-1.54	-1.32	-1.63	-1.83*	-1.53	-1.41
k=25	-1.32	-1.18	-1.47	-1.62	-1.45	-1.33
k=30	-1.21	-1.05	-1.25	-1.41	-1.32	-1.24
Malaysia						
k=15	-2.03**	-1.67*	-4.76***	-5.82***	1.43	1.24
k=20	-1.89*	-1.45	-4.48***	-5.64***	1.57	1.41
k=25	-1.77*	-1.28	-4.27***	-5.45***	1.68*	1.63
k=30	-1.65*	-1.06	-4.16***	-5.27***	1.79*	1.75*
Nepal						
k=15	-3.42***	-3.02***	3.05***	-3.43***	4.32***	3.20***
k=20	-3.23***	-2.56**	3.28***	-3.21***	4.53***	3.44***
k=25	-2.84***	-1.98**	3.42***	-2.54**	4.71***	3.65***
k=30	-2.32**	-1.75*	3.61***	-2.06**	4.90***	3.87***
Pakistan						
k=15	-3.60***	-4.93***	5.32***	-6.75***	7.76***	9.24***
k=20	-3.43***	-4.75***	5.48***	-6.92***	7.95***	9.45***
k=25	-3.21***	-4.52***	5.56***	-7.10***	8.32***	9.60***
k=30	-3.05***	-4.36***	5.80***	-7.48***	9.54***	9.82***
Singapore						
k=15	1.67*	1.33	-2.97***	-3.68***	-1.78*	-1.64
k=20	1.73*	1.42	-2.75***	-3.43***	-1.63	-1.48
k=25	1.84*	1.56	-2.64***	-3.25***	-1.52	-1.25
k=30	1.92*	1.63	-2.52**	-3.10***	-1.41	-1.09

Note: A test statistic with *******, ****, and ***** indicates significance at 1%, 5%, and 10% levels respectively. Figures in columns 2-7 give the values of the test statistics for M_1, M_2, R_1, R_2, S_1 and S_2 for each daily spot gold price return series. M_1 and M_2 are based on the conventional Lo and MacKinlay's (1988) parametric variance-ratio tests, while R_1, R_2, S_1 and S_2 are based on the recent non-parametric (ranks and signs) modification proposed by Wright (2000). The M_1 is robust under the assumption of homoscedasticity (*RWS*), whilst the M_2 is more precise under heteroscedasticity (*MDS*) conditions. Similarly, the ranks (R_1, R_2) are more powerful under homoscedasticity (*RWS*) conditions, whereas the signs (S_1 and S_2) are robust under the assumption of hetereoscedasticity. Thus, the M_1, R_1, and R_2 explicitly test the *RWS* hypothesis, whilst the M_2, S_1 and S_2 test the *MDS* hypothesis.

Table 6: Variance-ratio tests results for the daily spot gold price return series of gold markets in the Asia-Pacific region

Period:	M_1	M_2	R_1	R_2	S_1	S_2
South Korea						
k=15	-1.98**	-1.66*	2.31**	2.65***	1.30	1.44
k=20	-1.80*	-1.54	2.54**	2.84***	1.46	1.62
k=25	-1.67*	-1.32	2.67***	3.17***	1.59	1.78*
k=30	-1.53	-1.11	2.78***	3.35***	1.64	1.86*
Taiwan						
k=15	1.72*	1.27	2.54**	3.67***	1.46	1.32
k=20	1.97**	1.43	2.82***	3.95***	1.58	1.45
k=25	2.28**	1.56	3.20***	4.38***	1.67*	1.57
k=30	2.69***	1.61	3.55***	4.72***	1.79*	1.63
Thailand						
k=15	2.43**	1.18	3.65***	4.57***	1.33	1.22
k=20	2.56**	1.32	3.98***	4.91***	1.45	1.36
k=25	2.74***	1.46	4.31***	5.30***	1.52	1.47
k=30	2.89***	1.53	4.76***	5.62***	1.64	1.58
Vietnam						
k=15	-5.75***	-6.90***	7.32***	8.25***	8.63***	9.35***
k=20	-5.63***	-6.77***	7.45***	8.36***	8.85***	9.49***
k=25	-5.51***	-6.64***	7.67***	8.47***	9.27***	9.68***
k=30	-5.44***	6.58***	7.80***	8.58***	9.43***	9.76***
Variance-ratio tests results for the daily spot gold price return series of gold markets in the European region						
Germany						
k=15	-1.97**	-1.69*	1.96**	3.35***	1.24	1.04
k=20	-1.75*	-1.45	2.31**	3.52***	1.37	1.23
k=25	-1.54	-1.28	2.75***	3.76***	1.51	1.38
k=30	-1.32	-1.06	3.18***	3.94***	1.62	1.50
Russia						
k=15	-3.68***	-2.78***	4.44***	5.52***	7.24***	8.75***
k=20	-3.05***	-2.19**	4.44***	5.86***	7.65***	8.98***
k=25	-2.43**	-1.85*	5.59***	6.35***	7.89***	9.42***
k=30	-2.17**	-1.67*	5.30***	6.67***	7.96***	9.73***
Switzerland						
k=15	1.46	1.27	1.43	1.47	1.32	1.45
k=20	1.55	1.39	1.50	1.52	1.47	1.59
k=25	1.64	1.45	1.61	1.63	1.58	1.64
k=30	1.75*	1.58	1.72*	1.78*	1.63	1.72*
UK						
k=15	1.21	0.97	1.36	1.57	1.07	1.24
k=20	1.42	1.08	1.43	1.63	1.23	1.46
k=25	1.63	1.36	1.58	1.72*	1.41	1.59
k=30	1.76*	1.54	1.67*	1.99**	1.54	1.63

Note: A test statistic with *****, ****, and *** indicates significance at 1%, 5%, and 10% levels respectively. Figures in columns 2-7 give the values of the test statistics for M_1, M_2, R_1, R_2, S_1 and S_2 for each daily spot gold price return series. M_1 and M_2 are based on the conventional Lo and MacKinlay's (1988) parametric variance-ratio tests, while R_1, R_2, S_1 and S_2 are based on the recent non-parametric (ranks and signs) modification proposed by Wright (2000). The M_1 is robust under the assumption of homoscedasticity (*RWS*), whilst the M_2 is more precise under heteroscedasticity (*MDS*) conditions. Similarly, the ranks (R_1, R_2) are more powerful under homoscedasticity (*RWS*) conditions, whereas the signs (S_1 and S_2) are robust under the assumption of hetereoscedasticity. Thus, the M_1, R_1, and R_2 explicitly test the *RWS* hypothesis, whilst the M_2, S_1 and S_2 test the *MDS* hypothesis.

Table 7: Effect of changes in macroeconomic variables on the probability of rejecting the RWS and MDS hypotheses

Dependent variable (Model)	*M1 (RWS) (1)*	*M2 (MDS) (2)*	*R1 (RWS) (3)*	*R2 (RWS) (4)*	*S1 (MDS) (5)*	*S2 (MDS) (6)*
Macroeconomic variables:						
ΔBroad money (M2+) supply	0.051	0.065	0.083	0.090	0.076	0.072
	(0.624)	(0.608)	(0.501)	(0.486)	(0.573)	(0.587)
ΔCrude oil price	-0.172*	-0.179*	-0.336***	-0.350***	-0.225**	-0.218**
	(0.060)	(0.054)	(0.000)	(0.000)	(0.020)	(0.027)
ΔInflation (CPI) rate	-0.230***	-0.239***	-0.320***	-0.332***	-0.279***	-0.265***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
ΔInterbank borrowing rate	-0.155*	-0.160*	-0.192**	-0.205**	-0.174*	-0.167*
	(0.078)	(0.075)	(0.040)	(0.039)	(0.063)	(0.066)
ΔInterest (t-bill) rate	-0.069	-0.073	-0.103	-0.108	-0.089	-0.085
	(0.510)	(0.497)	(0.379)	(0.373)	(0.400)	(0.410)
ΔMultilateral exchange rate	-0.219***	-0.226***	-0.298***	-0.309***	-0.270***	-0.263***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
ΔResidential property price	0.045	0.052	0.069	0.078	0.068	0.063
	(0.627)	(0.619)	(0.500)	(0.489)	(0.537)	(0.548)
ΔShare price	-0.249**	-0.267***	-0.305***	-0.324***	-0.286***	-0.277**
	(0.020)	(0.010)	(0.000)	(0.000)	(0.005)	(0.008)
Emerging gold markets dummy	0.218***	0.225***	0.368***	0.360***	0.295***	0.283***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	-0.380***	-0.402***	-0.765***	-0.796***	-0.546***	-0.520***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Pseudo R^2	0.375	0.400	0.481	0.485	0.469	0.466
Durbin-Watson	1.957	2.037	2.219	2.270	2.197	2.189
LR Chi (X^2)	5.793***	5.986***	7.478***	7.653***	6.785***	6.686***
Sample Size (*N*)	789	847	1058	1105	972	954

Notes: This table reports the findings of a logit regression of the changes in macroeconomic variables on the probability of rejecting the weak-form efficiency in the daily spot gold price return series in 28 global gold markets. Specifically, it seeks to test the effect of changes in the underlying macroeconomic fundamentals on the probability of rejecting the random walk (*RWS*) and martingale difference sequence (*MDS*) hypotheses in the daily spot gold price returns series of the 28 global gold markets investigated. Macroeconomic data on multilateral (effective) exchange rate and residential property prices were collected from the Bank for International Settlement (BIS) website, whilst the data on broad money supply (M2+), inflation (consumer price index – CPI) rate, interbank (overnight/short-term) borrowing rate, interest (3-month government treasury-bill – t-bill) rate, and share price were collected from *DataStream*. ΔBroad money (i.e., notes, coins, and demand deposits) supply is measured as month-on-month naturally logged changes in reported broad money supply. ΔCrude oil price is operationalised as month-on-month naturally logged changes in Brent crude oil price. ΔInflation rate refers to the month-on-month naturally logged changes in the consumer price index. ΔInterbank borrowing rate is measured as month-on-month naturally logged changes in the short-term (overnight) interbank borrowing rate. Δinterest (t-bill) rate is operationalised as a quarter-on-quarter naturally logged changes in the interest (3-month government t-bill) rate. ΔMultilateral (effective) exchange rate is measured as month-on-month naturally logged changes in the monthly trade weighted BIS multilateral exchange rate index series of a country's currency against a basket of currencies based on the relative strength or value of trade (exports and imports). ΔResidential property price refers to the quarter-on-quarter naturally logged changes in the quarterly residential BIS property price index series. ΔShare price is measured as the month-on-month naturally logged changes in the broad all share (equity) index series for each country. For example, the FTSE all share index is used for the UK, whilst the S&P 500 index is used for the US. Emerging gold market dummy is a binary variable that takes the value of 1 if a rejection is from a developing gold market [(i.e., based on the 2008 list of developing/emerging countries classified jointly by the World Bank and five other reputable global rating agencies (i.e., Dow Jones, FTSE, MSCI, Russell and S&P), whereby countries are classified based on six broad development factors: (i) per capital income; (i) maturity and effectiveness of market and regulatory environment; (iii) the speed of custody and settlement; (iv) development, maturity and sophistication of the derivatives markets; (v) the sophistication of the landscape for trading and market dealing; and (vi) the size and depth of the market)] (Bahrain, Brazil, China, Egypt, India, Indonesia, Malaysia, Mexico, Nepal, Pakistan, Russia, Saudi Arabia, South Africa, Taiwan, Thailand, Turkey, UAE and Vietnam), 0 otherwise (i.e., Australia, Canada, Germany, Hong Kong, Japan, Singapore, South Korea, Switzerland, UK, and US). Note that similar to the daily spot gold prices, all macroeconomic variables are in their respective local currencies and that the data is not always balanced for all countries and variables due to access limitations. For example, Bahrain, Nepal, Pakistan and Vietnam are not covered by the BIS multilateral exchange rates. Similarly, Bahrain, Nepal, Pakistan, Taiwan and Vietnam are not included in the BIS residential property index series. Share index return series are also short for some countries, such as Bahrain, China, Nepal, Russia, Saudi Arabia, UAE, and Vietnam with more recent stock market development and activity. The dependent variables (M_1, M_2, R_1, R_2, S_1 and S_2) are binary variables which take the value of 1 if the *RWS* and *MDS* hypotheses are rejected 1%, 5% or 10% level, 0 otherwise. M_1 and M_2 are based on the conventional Lo and MacKinlay's (1988) parametric variance-ratio tests, while R_1, R_2, S_1 and S_2 are based on the recent non-parametric (ranks and signs) modification proposed by Wright (2000). The M_1 is robust under the assumption of homoscedasticity (*RWS*), whilst the M_2 is more precise under heteroscedasticity (*MDS*) conditions. Similarly, the ranks (R_1, R_2) are more powerful under homoscedasticity (*RWS*) conditions, whereas the signs (S_1 and S_2) are robust under the assumption of hetereoscedasticity. Thus, the M_1, R_1, and R_2 explicitly test the *RWS* hypothesis, whilst the M_2, S_1 and S_2 test the *MDS* hypothesis. Following Peterson (2009), the coefficients are estimated by using the robust *Clustered Standard Errors* technique along country and year dimensions. *P*-values are in parentheses. *******, ******, and ***** denote significance at the 1%, 5% and 10% levels, respectively.

Table 8: Effect of lagged changes in macroeconomic variables on the probability of rejecting the weak-form hypotheses

Dependent variable (Model)	*M1 (RWS) (1)*	*M2 (MDS) (2)*	*R1 (RWS) (3)*	*R2 (RWS) (4)*	*S1 (MDS) (5)*	*S2 (MDS) (6)*
Macroeconomic variables:						
ΔBroad money (M2+) supply$_{t-1}$	0.053	0.069	0.085	0.091	0.079	0.074
	(0.620)	(0.597)	(0.510)	(0.496)	(0.562)	(0.581)
ΔCrude oil price$_{t-1}$	-0.164*	-0.176*	-0.329***	-0.340***	-0.219**	-0.214**
	(0.075)	(0.058)	(0.000)	(0.000)	(0.027)	(0.030)
ΔInflation (CPI) rate$_{t-1}$	-0.210***	-0.219***	-0.296***	-0.306***	-0.255***	-0.250***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
ΔInterbank borrowing rate$_{t-1}$	-0.150*	-0.164*	-0.185**	-0.192**	-0.173*	-0.167*
	(0.082)	(0.070)	(0.050)	(0.048)	(0.070)	(0.075)
ΔInterest (t-bill) rate$_{t-1}$	-0.052	-0.054	-0.090	-0.094	-0.075	-0.077
	(0.541)	(0.533)	(0.399)	(0.376)	(0.419)	(0.415)
ΔMultilateral exchange rate$_{t-1}$	-0.215***	-0.221***	-0.296***	-0.302***	-0.265***	-0.257***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
ΔResidential property price$_{t-1}$	0.040	0.043	0.066	0.072	0.060	0.057
	(0.642)	(0.636)	(0.504)	(0.492)	(0.545)	(0.553)
ΔShare price$_{t-1}$	-0.236**	-0.247**	-0.305***	-0.308***	-0.267***	-0.254**
	(0.025)	(0.020)	(0.000)	(0.000)	(0.010)	(0.017)
Emerging gold markets dummy	0.190***	0.195***	0.323***	0.336***	0.275***	0.262***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	-0.369***	-0.392***	-0.740***	-0.769***	-0.520***	-0.512***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Pseudo R^2	0.358	0.379	0.460	0.467	0.450	0.435
Durbin-Watson	1.951	2.022	2.186	2.215	2.116	2.120
LR Chi (X^2)	4.687***	4.899***	6.848***	6.982***	5.897***	5.783***
Sample Size (*N*)	718	785	994	1067	898	879

Notes: This table reports the findings of a logit regression of one-year lagged changes in macroeconomic variables on the probability of rejecting the weak-form efficiency in the daily spot gold price return series in 28 global gold markets. Specifically, it seeks to test the effect of lagged changes in the underlying macroeconomic fundamentals on the probability of rejecting the random walk (*RWS*) and martingale difference sequence (*MDS*) hypotheses in the daily spot gold price returns series of the 28 global gold markets investigated. The variables are the same as defined under Table 7 except that we have introduced a year lag between the macroeconomic variables and the probability of rejection in order to avoid potential endogenous association that may arise to due simultaneity or contemporaneity. M_1 and M_2 are based on the conventional Lo and MacKinlay's (1988) parametric variance-ratio tests, while R_1, R_2, S_1 and S_2 are based on the recent non-parametric (ranks and signs) modification proposed by Wright (2000). The M_1 is robust under the assumption of homoscedasticity (*RWS*), whilst the M_2 is more precise under heteroscedasticity (*MDS*) conditions. Similarly, the ranks (R_1, R_2) are more powerful under homoscedasticity (*RWS*) conditions, whereas the signs (S_1 and S_2) are robust under the assumption of hetereoscedasticity. Thus, the M_1, R_1, and R_2 explicitly test the *RWS* hypothesis, whilst the M_2, S_1 and S_2 test the *MDS* hypothesis. Following Peterson (2009), the coefficients are estimated by using the robust *Clustered Standard Errors* technique along country and year dimensions. *P*-values are in parentheses. *******, ******, and ***** denote significance at the 1%, 5% and 10% levels, respectively.

Table 9: Effect of changes in macroeconomic variables on efficiency: Incorporating institutional and trading factors

Dependent variable (Model)	*M1 (RWS) (1)*	*M2 (MDS) (2)*	*R1 (RWS) (3)*	*R2 (RWS) (4)*	*S1 (MDS) (5)*	*S2 (MDS) (6)*
Macroeconomic variables:						
ΔBroad money (M2+) supply	0.065	0.075	0.092	0.107	0.089	0.086
	(0.604)	(0.592)	(0.480)	(0.465)	(0.531)	(0.542)
ΔCrude oil price	-0.180*	-0.193**	-0.358***	-0.364***	-0.249***	-0.242**
	(0.052)	(0.046)	(0.000)	(0.000)	(0.010)	(0.013)
ΔInflation (CPI) rate	-0.235***	-0.244***	-0.325***	-0.338***	-0.285***	-0.274***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
ΔInterbank borrowing rate	-0.167*	-0.175*	-0.208**	-0.213**	-0.195*	-0.190**
	(0.068)	(0.060)	(0.036)	(0.029)	(0.038)	(0.046)
ΔInterest (t-bill) rate	-0.075	-0.083	-0.107	-0.118	-0.091	-0.087
	(0.496)	(0.485)	(0.372)	(0.363)	(0.389)	(0.394)
ΔMultilateral exchange rate	-0.228***	-0.236***	-0.304***	-0.318***	-0.275***	-0.263***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
ΔResidential property price	0.064	0.075	0.073	0.086	0.070	0.066
	(0.587)	(0.561)	(0.490)	(0.482)	(0.490)	(0.510)
ΔShare price	-0.269***	-0.275***	-0.328***	-0.334***	-0.289***	-0.275***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Emerging gold markets	0.223***	0.230***	0.367***	0.359***	0.290***	0.279***
dummy	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Institutional factors as control variables:						
Exchange rate regime	-0.310***	-0.321***	-0.343***	-0.352***	-0.283***	-0.274***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Inter. accounting standards	0.096	0.104	0.132	0.125	0.120	0.116
	(0.865)	(0.851)	(0.710)	(0.720)	(0.734)	(0.738)
Legal system	-0.015	-0.019	-0.036	-0.030	-0.025	-0.023
	(0.987)	(0.975)	(0.905)	(0.916)	(0.948)	(0.956)
National gold regulations	0.105	0.109	0.116	0.125	0.097	0.094
	(0.798)	(0.787)	(0.780)	(0.764)	(0.876)	(0.885)
National governance quality	-0.342***	-0.350***	-0.369***	-0.372***	-0.298***	-0.290***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Trading factors as control variables:						
Gold exchange traded funds	-0.028	-0.033	-0.056	-0.050	-0.045	-0.043
	(0.976)	(0.960)	(0.913)	(0.924)	(0.947)	(0.950)
Market liquidity	-0.265***	0.270***	0.289***	0.275***	0.253***	0.246***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Price movement restrictions	0.010	0.015	0.027	0.032	0.045	0.040
	(0.996)	(0.990)	(0.895)	(0.884)	(0.867)	(0.872)
Constant	-0.243***	-0.260***	-0.532***	-0.545***	-0.346***	-0.330***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Pseudo R^2	0.518	0.529	0.608	0.614	0.576	0.565
Durbin-Watson	2.042	2.053	2.680	2.705	2.627	2.549
LR Chi (X^2)	7.875***	7.963***	9.365***	9.248***	8.568***	8.479***
Sample Size (*N*)	789	847	1058	1105	972	954

Notes: This table reports the findings of a logit regression of changes in macroeconomic variables on the probability of rejecting the weak-form efficiency in the daily spot gold price return series in 28 global gold markets, whilst controlling for country-specific institutional (i.e., exchange rate regime, international accounting standards, legal system, national gold regulations and national governance quality) and trading (i.e., gold exchange traded funds - ETFs, market liquidity and price movement restrictions). The macroeconomic variables are the same as defined under Table 7. Exchange rate regime is a dummy variable that takes the value of 1 if a country's exchange rate is freely determined by market forces (i.e., independently floating) (i.e., Australia, Brazil, Canada, Germany, Japan, Mexico, South Africa, South Korea, Switzerland, Taiwan, Turkey, UK and US), 0 otherwise (i.e., Bahrain, China, Egypt, India, Indonesia, Hong Kong, Malaysia, Nepal, Pakistan, Russia, Saudi Arabia, Singapore, Thailand, UAE, and Vietnam), based on the IMF's 2008 de facto classification of exchange rate regimes around the world. International accounting standards is a dummy variable if a country has fully adopted international financial reporting standards (IFRs) (i.e., Australia, Brazil, Canada, Germany, Hong Kong, Malaysia, Mexico, Nepal, Russia, South Africa, South Korea, Switzerland, Taiwan, Turkey, UAE, and UK), 0 otherwise (i.e., China, Egypt, India, Indonesia, Japan, Pakistan, Saudi Arabia, Singapore, Thailand, US and Vietnam). Legal system is a dummy variable that takes the value of 1 if a country's legal system has common law origins (i.e., Australia, Canada, India, Malaysia, Pakistan, Singapore, South Africa, UK and US), 0 otherwise (i.e., Bahrain, Brazil, China, Egypt, Germany, Indonesia, Japan, Mexico, Nepal, Russia, Saudi Arabia, South Korea, Switzerland, Taiwan, Thailand, Turkey, UAE and Vietnam). National gold regulations is a dummy variable that takes the value of 1 if a country has specific national or local regulations/restrictions/duties relating to the importation/taxation and/or purchase/sale of specified quantities of gold (i.e., Australia, Brazil, Canada, Egypt, Germany, India, Indonesia, Japan, Malaysia, Mexico, Pakistan, Russia, South Africa, South Korea, Switzerland, Taiwan, Thailand, UK, US and Vietnam), 0 otherwise (i.e., Bahrain, China, Hong Kong, Nepal, Saudi Arabia, Singapore, Turkey and UAE). National governance quality is measured by the Transparency International's corruption perceptions index, which has been published annually since 1995. Gold exchange traded funds (ETFs) is a dummy variable that takes the value of 1 if ETFs are traded on a country's gold market (i.e., Australia, Bahrain, Brazil, Canada, China, Germany, Hong Kong, India, Indonesia, Japan, Malaysia, Russia, Singapore, South Africa, South Korea, Switzerland, Taiwan, Turkey, UAE, UK and US), 0 otherwise (i.e., Egypt, Mexico, Nepal, Pakistan, Saudi Arabia, Thailand, and Vietnam). Market liquidity is measured as the percentage of the annual value of shares traded to the annual market capitalisation in a country. Price movement restrictions is a dummy variable that takes a value of 1 if a gold market sets a maximum permissible daily gold price movement (i.e., India, Indonesia, Malaysia, Mexico, Nepal, Pakistan, South Africa, Taiwan, Thailand, and UAE), 0 otherwise (i.e., Australia, Bahrain, Brazil, Canada, China, Germany, Hong Kong, Japan, Russia, Singapore, South Korea, Switzerland, Turkey, UK and US). M_1 and M_2 are based on the conventional Lo and MacKinlay's (1988) parametric variance-ratio tests, while R_1, R_2, S_1 and S_2 are based on the recent non-parametric (ranks and signs) modification proposed by Wright (2000). The M_1 is robust under the assumption of homoscedasticity (*RWS*), whilst the M_2 is more precise under heteroscedasticity (*MDS*) conditions. Similarly, the ranks (R_1, R_2) are more powerful under homoscedasticity (*RWS*) conditions, whereas the signs (S_1 and S_2) are robust under the assumption of hetereoscedasticity. Thus, the M_1, R_1, and R_2 explicitly test the *RWS* hypothesis, whilst the M_2, S_1 and S_2 test the *MDS* hypothesis. Following Peterson (2009), the coefficients are estimated by using the robust *Clustered Standard Errors* technique along country and year dimensions. *P*-values are in parentheses. *******, ******, and ***** denote significance at the 1%, 5% and 10% levels, respectively.

Table 10: Variance-ratio tests results for the daily spot gold price return series based on four separate ten-year windows

Windows	**I: 1968 – 1977**		**II: 1978 – 1987**		**III: 1988 – 1997**		**IV: 1998 – 2014**	
Period	R_1	S_1	R_1	S_1	R_1	S_1	R_1	S_1
Australia								
k=15	-3.23***	-2.45**	-2.56***	-1.98**	-1.66*	-1.47	-1.62	-1.24
k=20	-3.05***	-2.38**	-2.32**	-1.80*	-1.52	-1.40	-1.50	-1.18
k=25	-2.98***	-2.20**	-2.10**	-1.72*	-1.45	-1.35	-1.43	-1.10
k=30	-2.82***	-2.11**	-1.98**	-1.65*	-1.36	-1.26	-1.38	-1.05
Canada								
k=15	-2.98***	--1.97**	-1.99**	-1.63	-1.60	-1.34	-1.36	-1.20
k=20	-2.83***	- -1.85*	-1.82*	-1.57	-1.55	-1.21	-1.23	-1.11
k=25	-2.71***	-1.73*	-1.70*	-1.42	-1.42	-1.14	-1.17	-1.03
k=30	-2.64***	-1.62	-1.64	-1.30	-1.37	-1.02	-1.00	-0.92
China								
k=15	4.53***	-2.37**	2.70***	-2.00**	1.43	-1.63	1.30	-1.25
k=20	4.58***	-2.30**	2.81***	-1.89*	1.59	-1.51	1.38	-1.10
k=25	4.65***	-2.24**	2.94***	-1.73*	1.66*	-1.40	1.46	-1.03
k=30	4.79***	-2.17**	3.10***	-1.60	1.74*	-1.32	1.52	-0.95
Hong Kong								
k=15	2.10**	-1.62	1.65*	-1.53	1.29	-1.45	1.12	-0.97
k=20	2.23**	-1.51	1.72*	-1.41	1.38	-1.33	1.00	-0.85
k=25	2.34**	-1.40	1.85*	-1.33	1.47	-1.27	0.92	-0.73
k=30	2.46**	-1.32	1.93*	-1.25	1.52	-1.11	0.87	-0.61
India								
k=15	6.30***	4.34***	5.28***	2.20**	4.42***	1.67*	3.62***	1.32
k=20	6.46***	4.45***	5.40***	2.33**	4.57***	1.74*	3.75***	1.46
k=25	6.59***	4.56***	5.52***	2.46**	4.65***	1.86*	3.89***	1.58
k=30	6.68***	4.67***	5.65***	2.51**	4.73***	1.95*	3.94***	1.63
Germany								
k=15	2.31**	1.65*	1.45	1.67*	1.37	1.24	1.28	0.87
k=20	2.40**	1.73*	1.52	1.78*	1.46	1.38	1.34	0.96
k=25	2.46**	1.80*	1.60	1.86*	1.53	1.47	1.46	1.14
k=30	2.52**	1.91*	1.64	1.95*	1.58	1.52	1.54	1.38
Saudi Arabia								
k=15	12.45***	14.33***	10.65***	13.52***	9.42***	11.65***	7.58***	9.58***
k=20	12.56***	14.46***	10.76***	13.68***	9.56***	11.78***	7.67***	9.66***
k=25	12.67***	14.59***	10.87***	13.79***	9.67***	11.89***	7.79***	9.75***
k=30	12.78***	14.65***	10.94***	13.87***	9.75***	11.96***	7.85***	9.80***
South Africa								
k=15	3.14***	4.20***	1.93**	2.20**	1.22	1.36	0.68	1.16
k=20	3.26***	4.34***	2.25**	2.31**	1.35	1.47	0.75	1.27
k=25	3.38***	4.47***	2.34**	2.42**	1.42	1.53	0.89	1.38
k=30	3.42***	4.54***	2.45**	2.53**	1.54	1.64	0.97	1.45
UK								
k=15	1.63	1.32	1.28	1.18	1.10	1.00	0.68	0.39
k=20	1.68*	1.40	1.35	1.23	1.25	1.08	0.74	0.47
k=25	1.72*	1.51	1.44	1.36	1.36	1.17	0.85	0.54
k=30	1.80*	1.62	1.50	1.44	1.47	1.23	0.96	0.62
US								
k=15	1.68*	1.45	1.32	1.26	1.20	1.11	0.89	0.48
k=20	1.73*	1.57	1.46	1.32	1.34	1.25	0.95	0.57
k=25	1.85*	1.63	1.52	1.43	1.42	1.37	1.08	0.69
k=30	1.92*	1.71*	1.64	1.50	1.54	1.43	1.19	0.78

Note: A test statistic with *******, ******, and ***** indicates significance at 1%, 5%, and 10% levels respectively. Figures in windows I to IV give the values of the test statistics for R_1 and S_1 for selected daily spot gold price return series over four ten-year windows, respectively. R_1 and S_1 are based on the recent non-parametric (ranks and signs) modification proposed by Wright (2000). The rank (R_2) is more powerful under homoscedasticity (*RWS*) conditions, whereas the sign (S_1) is robust under the assumption of hetereoscedasticity. Thus, the R_1 explicitly tests the *RWS* hypothesis, whilst the S_1 tests the *MDS* hypothesis.