Quantitative Finance and Economics

http://www.aimspress.com/journal/QFE

QFE, 1(3): 253–271
DOI:10.3934/QFE.2017.3.253
Received date: 24 July 2017
Accepted date: 16 September 2017
Published date: 12 October 2017

Research article

Hedging Market Volatility with Gold

Mehmet F. Dicle * and John D. Levendis

Loyola University New Orleans, College of Business, 6363 St. Charles Avenue, Box 15, New Orleans, LA 70118, USA

* **Correspondence:** Eamil: mfdicle@gmail.com; Tel: +1-504-864-7078; Fax: +1-504-864-7970.

Abstract: The 2008 financial crisis refocused investors' attention to several safe-haven assets, most notably gold and US Treasuries. We compare the role of these two assets as potential hedge instruments for thirteen major indexes' returns and their volatilities. Our study extends the literature by using gold returns purged from the effects of being denominated in US dollars. We also utilize seventeen different volatility indexes to include US and international equities as well as currencies instead of the common S&P-500 index. While gold and Treasuries are comparable in their correlation with contemporaneous market returns, Treasuries seem to be safe haven asset of choice. Gold is more correlated than Treasuries in terms of lead-lag relationships with market returns as well as market volatility indexes.

Keywords: gold; US treasuries; safety asset; safe haven; volatility

1. Introduction

Along with the financial crisis in 2008 and gold prices surging to all time high in 2011, academic research into gold has also surged. There are three main qualities about the use of gold as an investment security: to diversify, to hedge and to be a safe haven. Baur (2010) define a diversification instrument "as an asset that is positively (but not perfectly correlated) with another asset or portfolio on average;" a hedge instrument "as an asset that is uncorrelated or negatively correlated with another asset or portfolio on average;" and a safe haven instrument "as an asset that is uncorrelated or negatively correlated with another asset or portfolio in times of market stress or turmoil."

The earlier literature seems to be indiscriminate about these three completely different uses of gold within investment portfolios. Therefore the earlier focus is more about the diversification value of gold within investment portfolios and lack thereof Mcdonald (1977); Sherman (1982); Jaffe (1989); Chua (1990); Hillier (2006). However, after the 2008 crisis, the need to find a safe haven investment as well as to hedge market risk defined the boundaries of gold's use for particular investment purposes.

The recent financial literature has focused on testing the hedging and safe-haven functions of gold Baur (2010a, 2010b); Joy (2011); Coudert (2011); Anand (2012); Ghazali (2013); Dee (2013); Ciner (2013); Reboredo (2013a, 2013b); Hood (2013); Gurgun (2014); Bredin (2015); Beckmann (2015). **This thorough analysis of gold combines two sources of volatility resulting in biased results.**

Almost all of the studies cited above use the value of gold as denominated in US dollars. Therefore, as the US dollar value increases gold prices (denominated in US dollars) would naturally decrease. This change in the gold price is not necessarily because of the actual value of gold. Any negative or positive correlations with dollar-denominated gold can be the result of changes in the US dollar's value as much as from changes in gold's value. In other words, if gold value is kept constant, the changes in the US dollar value would change the gold's value in US dollar. Results that are based on this simultaneous price variation in gold would purely be based on the US dollar. Thus, using gold's US dollar value in a study that evaluate gold for its hedging and safe haven qualities is akin to using gold value along with the value of the US dollar. International studies of gold denominated in other currencies such as the euro or British pound would be biased for the same reasons. This argument is similar to the arguments made by Scott (2002).

In this study, we suggest a simple method to purge US dollar value and report results based on gold's own value only. Gold is traditionally traded on the gold bullion floor in London. The gold bullion exchange provides daily gold fixings in US dollars, euros and British pounds. We calculate the return in gold in each of the three currencies and average these returns for each trading day. Using daily gold price averages in three currencies[*] purges any specific currency value effect on gold's actual value. By purging US dollar value, we believe that this study provides the first true evidence of gold's value as a hedging, diversifying and/or safe haven security.

The second deficiency in the gold study literature as we see it is the method by which the safe haven quality of gold is evaluated. Baur (2010a) conclude that "investors buy gold on days of extreme negative returns and sell it when market participants regain confidence and volatility is lower" (p. 228). Baur (2010a) define safe haven assets for "times of market stress or turmoil" (p. 219). In a similar study, Baur (2010b) define a safe haven asset as one: "that holds its value in 'stormy weather' or adverse market conditions" (p. 1886). Even though Baur (2010a) definition for safe haven asset refers to higher volatility, their conclusion is based on the "days of extreme negative returns" (p. 228). Similarly, although Baur and McDermott's definition of a safe haven asset refers to "adverse market conditions" they conclude "gold can be seen as a panic buy in the immediate aftermath of an extreme negative market shock" (p. 1897). We argue that this asymmetric view of negative returns for market stress is overly restrictive. Based on the Baur (2010a) definition of safe haven assets, market stress and turmoil would be defined as market volatility and not only times of extreme negative returns. We are not suggesting that investors need a safe haven from positive returns. We are suggesting that investors need a safe haven from high volatility (with the possibility of extreme negative returns) and not just realized extreme negative return days. **We extend the previous literature to evaluate gold as a safe haven asset from volatility and not just from realized extreme negative returns**.

US financial markets have experienced significant volatility in the past. The implied volatility index (VIX) has reached to 59.89 on October 1^{st}, 2008 which is down to 10.59 on August 1^{st}, 2017. Volatility, especially high levels of volatility, has many repercussions. Investors require higher returns for higher volatility (Lundblad, 2007). Thus, return is a function of volatility. Also, high volatility may deter

[*]Since the actual gold fixing in London is based on three currencies only, we do not extend the analysis to other currencies.

investors from financial securities that have traditionally higher volatility. Investors may prefer bonds to stocks, value stocks to growth stocks and larger companies to smaller companies. Finally, volatility may lead to financial crisis or collapse. It is primarily why most equity markets have implemented volatility based circuit breakers. Unfortunately, these circuit breakers, however, do not usually extend more than a trading day. It is these reasons, volatility needs to be addressed. It is these reasons that researchers need to evaluate alternative investment choices for investors to seek shelter from extreme volatility. Our study evaluates gold as one of such securities.

The study proceeds as follows. In the next section we briefly discuss the literature on gold in terms of the macroeconomy, exchange rates, and equities. The data section includes the variable definitions, notations and data sources. Econometric models are defined in the following section along with the empirical results. Concluding remarks summarize the conclusions and implications of the study. Tables to provide empirical results are included at the end of the study.

2. Literature Review

Gold is widely regarded as a safety asset, offering safe haven from instability in the real macroeconomy, foreign exchange markets, or the equity markets.

2.1. Macroeconomy

A long stream of research has investigated the relationship between gold prices and macroeconomic/geopolitical news. Research indicates a strong tendency for the market to realize higher returns on gold in light of negative macroeconomic and/or geopolitical news releases Koutsoyiannis (1983); Baker (1985); Christie (2000); Cai (2001); Roache (2010). Mccown (2006) finds that gold prices are highly correlated with expected levels of inflation. Evaluating US and Japan, Wang (2011) report that ability of gold to hedge inflation is dependent on the time horizon. While gold performance as an inflation hedge is poor in the short-run, it's performance is much stronger in the long-run. Beckmann (2013), for instance find that gold can be used to hedge expected inflation for US, UK, Japan and for the EU. They show, similar to Wang (2011), that hedging inflation with gold is stronger for US and the UK especially in the long-run. Having established that the gold is a potential hedging instrument against inflation, especially in the long-run, Batten (2014) evaluate this potential across multiple time periods. They report that the gold and inflation has a dynamic relationship that is stronger during certain time periods, especially during the past decade. Furthermore and more importantly, the gold and inflation relationship is reported to depend on changes in interest rates.

2.2. Exchange rates

Gold's relationship to currency exchange rates has been repeatedly identified by researchers. For example, Baker (1985); Sjaastad (1996) and Ghosh (2004) conclude that fluctuations in the price of gold are often influenced by changes in the value of the dollar. Sherman (1983) finds a negative correlation between gold prices and the US exchange rate. Ciner (2013) suggests that gold acts as a safe haven specifically against currency depreciations of the US dollar and the British pound.

While the evidence identifies a strong relationship between gold prices and the levels of exchange rates, another strand of research argues that changes in gold values are due to the volatility (rather than the level) of currency values. For example, Kaufmann (1989) and Sjaastad (2008), find some evidence that the price of gold is significantly related to volatility in the US dollar exchange rate. Capie (2005) also finds that gold serves as a hedge against volatility in the foreign exchange value of the dollar, however, this relationship seems to depend strongly on unpredictable political events.

On the other hand, Scott (2002) argues that since gold is a real asset quoted in a variety of currencies, the fluctuations in gold prices by currency simply reflects the relative strength of the currency in which it is quoted.

More recently, Joy (2011) finds that gold is not a safe-haven, but is a hedge against currency risk. Our paper can be considered a complement to Joy's as we focus on equity risk (Joy focuses on currency risk), while also taking Scott-Ram's critique seriously. Joy (2011) also provides one of the major changes in the literature in terms of the economic model that is used to test volatility and its transference. By using dynamic conditional correlation multivariate GARCH model, Joy (2011) estimates a system of a VAR model for multiple currencies.

With a similar econometric analysis to Joy (2011), Papadamou (2014) evaluates US dollar, euro, British pound and Japanese yen. While both studies use multivariate GARCH and estimate the currencies against gold as a system thus capturing variance transference across currencies, the main difference between the two studies is the use of dynamic conditional correlations. Papadamou (2014) employs a constant conditional correlation VAR GARCH model instead of the DCC-GARCH model. Their results are very similar to Joy (2011). The dynamic nature of the conditional correlations does not seem to make much of a difference for the results.

2.3. Equities

A more recent stream of research has investigated the role of gold as a safe haven from equity volatility, rather than in macro or monetary fluctuations. Whaley (1993) introduced the concept of a volatility index, eventually bringing about the Chicago Board Options Exchange's trademark Volatility Index (VIX). The VIX is calculated using monthly and weekly SPX options listed on CBOE with expirations that are between 23 and 37 days.

Cohen (2010) finds significant bi-directional causality between the VIX and gold returns during the low-volatility period of November 2004 through August 2007. During the higher volatility period from August 2007 to July 2009, they find that gold returns Granger-cause the VIX. On the other hand, Qadan (2012) find that the VIX Granger-causes gold futures, implying that gold is a safe haven asset from volatility.

Gold seems to be uncorrelated with equities on average (making it a good hedge) and uncorrelated with equities during downturns, making it a safe-haven asset Baur (2010a). Coudert (2011) also finds that gold and equity returns are generally uncorrelated in the developed markets, implying that gold is viewed as a safe-haven asset by investors.

The evidence is somewhat weaker in Baur (2010b), who find that gold offered safe-haven for only some of the developed equity markets, with much of the correlation due only to the most recent financial crisis.

A good safety asset should have lower volatility during times of instability.Baur (2012) does not find this to be the case for gold; he finds that increases in gold prices presage increased volatility in equity markets. However, Baur argues that equity-market volatility feeds back upon gold markets, which paradoxically become less stable. Paradoxically, Baur argues that its safe-haven attributes render gold an ineffective safe haven.

While majority of the existing literature on gold-equity relationship as a hedge and as a safe-haven, Gurgun (2014) evaluate gold for emerging and developing countries. As most of the US, UK, EU and Japanese markets are international and there is significant international cointegration between these markets and all other equity markets around the world, the study by Gurgun (2014) is important as they pay special attention to domestic investors. They show that gold can be considered a hedge as well as a safe haven security. This result is extended to most of the twenty eight countries they analyzed.

More recently, Bredin (2015) analyze gold as a hedge and as a safe haven against volatility of equities in US, UK and German markets. They show that gold, up to one year, can be used as a hedge and as a safe haven. It is important to note that Bredin (2015) consider financial crises such as "Black Monday" (1987) and report that gold's performance as a safe haven extend to these periods.

Our contribution to the literature is in two major points. Initially, we argue that the literature ignored the fact that gold is a a dollar-denominated security. It is true that the US dollar is the main currency for many of the gold exchanges around the world. However, in studying gold's safe-haven properties, dollar-denomination mixes variations in the dollar with variations in gold prices. We therefore propose a new denomination-free version of gold value by averaging daily percentage returns of gold for the US dollar, the euro and the British pound.

Our second contribution is in terms of the safe haven definition for gold studies. While the prospect of realizing extreme negative returns is the reason investors seek safe haven, we argue that extreme volatility is the impetus for seeking safe haven. In other words: what is important is the risk, not just the realization, of negative returns. Thus, instead of evaluating extreme negative returns, we evaluate gold as a safe haven asset evaluating volatility.

3. The Data

The data for this study include security indexes and corresponding volatility indexes with daily frequency. The Chicago Board Options Exchange (CBOE) provide several volatility indexes for public use.[†] Out of the twenty-nine volatility indexes we utilize seventeen by excluding indexes that are based on interest rates, commodities and individual stocks. Our focus is on the major US equity markets (S&P-500, S&P-100, Dow 30, NASDAQ 100 and Russell 2000), international equity markets (through ETFs such as EFA, EEM, FXI, EWZ), currencies (through an ETF FXE and actual foreign exchange rates) and volatility itself (through the actual VIX index itself). Volatility indexes are calculated following the option pricing model by Black (1973).[‡] The ETF EFA includes companies from Europe, Australia, Asia, and the Far East.[§] The ETF EEM includes companies from emerging markets.[¶] And the ETFs FXI and EWZ include companies from China and Brazil, respectively.

The data for the corresponding security indexes and ETFs are obtained from NASDAQ.[‖] The exchange rate and 10-year Treasury constant maturity rates are from the Federal Reserve Bank of St. Louis (Fred).[**] Finally, the data for daily gold fixings in US dollar, euro and British pound are obtained from London Bullion Market Association.[††]

[†] Available via http://www.cboe.com/products/vix-index-volatility/volatility-indexes
[‡] More information about how volatility indexes are calculated can be found at http://www.cboe.com/products/vix-index-volatility
[§] More detail available via https://www.ishares.com/us/products/239623/EFA
[¶] Mode detail available via https://www.ishares.com/us/products/239637/EEM
[‖] Available via http://nasdaq.com
[**] Available via https://fred.stlouisfed.org/categories/15 and https://fred.stlouisfed.org/series/DGS10, respectively.
[††] Available via http://www.lbma.org.uk/

Table 1. Descriptive statistics for volatility indexes, security indexes, ETFs and currencies included in the study. Δ refers to daily log difference change and *t* refers to the trading day. *Avg* for gold refers to daily average return for gold in US dollar, euro and British pound. DF refers to the augmented Dickey-Fuller unit root test. *, ** and * refer to statistical significance at the 10%, 5% and 1% respectively.**

Indexes and securities	Notation	First	Mean	Min.	Max.	Stdev.	DF-z	
S&P 500	$\Delta GSPC_t$	01/03/2000	0.0001	-0.0947	0.1096	0.0123	-71.6886	***
NASDAQ 100	ΔNDX_t	01/25/2001	0.0002	-0.1111	0.1185	0.0162	-67.3051	***
S&P 100	ΔOEX_t	01/03/2000	0.0001	-0.0919	0.1066	0.0122	-72.1711	***
Dow 30	ΔDJI_t	01/03/2000	0.0001	-0.0820	0.1051	0.0115	-71.4699	***
Russell 2000	ΔRUT_t	01/05/2004	0.0003	-0.1261	0.0886	0.0153	-63.4079	***
iShares MSCI EAFE ETF	ΔEFA_t	01/03/2008	0.0000	-0.1184	0.1475	0.0159	-54.8648	***
iShares MSCI Emerging Markets ETF	ΔEEM_t	03/17/2011	0.0001	-0.0871	0.0605	0.0136	-41.5116	***
iShares China Large-Cap ETF	ΔFXI_t	03/17/2011	0.0001	-0.0744	0.0682	0.0156	-40.7328	***
iShares MSCI Brazil Capped ETF	ΔEWZ_t	03/17/2011	-0.0003	-0.1782	0.0848	0.0201	-39.8716	***
U.S. / Euro Foreign Exchange Rate	$\Delta DEXUSEU_t$	01/03/2007	-0.0000	-0.0300	0.0462	0.0064	-49.8627	***
Japan / U.S. Foreign Exchange Rate	$\Delta DEXJPUS_t$	01/03/2007	-0.0000	-0.0522	0.0334	0.0069	-51.2129	***
U.S. / U.K. Foreign Exchange Rate	$\Delta DEXUSUK_t$	01/03/2007	-0.0001	-0.0817	0.0443	0.0063	-47.8114	***
CurrencyShares Euro ETF	ΔFXE_t	03/15/2010	-0.0001	-0.0273	0.0312	0.0060	-42.6582	***
London Gold Fixing (USD, EUR, GBP)	$\Delta Gold_{Avg,t}$	01/04/2000	0.0003	-0.0949	0.0757	0.0104	-67.2360	***
10-Year Treasury Constant Maturity Rate	$\Delta Treasury_t$	01/04/2000	-0.0003	-0.1850	0.0963	0.0192	-65.0828	***
Volatility indexes (VI)	Notation	First	Mean	Min.	Max.	Stdev.	DF-z	
CBOE VI	ΔVIX_t	01/03/2000	-0.0002	-0.3506	0.4960	0.0665	-72.3218	***
CBOE NASDAQ VI	ΔVXN_t	01/25/2001	-0.0003	-0.3130	0.3622	0.0567	-66.5832	***
CBOE S&P 100 VI	ΔVXO_t	01/03/2000	-0.0002	-0.3815	0.5323	0.0743	-75.9089	***
CBOE DJIA VI	ΔVXD_t	01/03/2000	-0.0002	-0.4081	0.5281	0.0641	-74.4737	***
CBOE Russell 2000 VI	ΔRVX_t	01/05/2004	-0.0001	-0.2515	0.3613	0.0544	-61.6919	***
CBOE Short-Term VI	$\Delta VXST_t$	01/04/2011	-0.0004	-0.5399	0.8114	0.1207	-44.7343	***
CBOE 3-Month VI	ΔVXV_t	12/05/2007	-0.0003	-0.2340	0.3284	0.0460	-53.7712	***
CBOE Mid-Term VI	$\Delta VXMT_t$	01/08/2008	-0.0002	-0.1779	0.2032	0.0333	-51.9707	***
CBOE EFA ETF VI	$\Delta VXEFA_t$	01/03/2008	-0.0003	-0.6867	0.4548	0.0738	-54.9421	***
CBOE Emerging Markets ETF VI	$\Delta VXEEM_t$	03/17/2011	-0.0005	-0.2981	0.5049	0.0615	-41.0036	***
CBOE China ETF VI	$\Delta VXFXI_t$	03/17/2011	-0.0004	-0.1851	0.3658	0.0499	-39.9588	***
CBOE Brazil ETF VI	$\Delta VXEWZ_t$	03/17/2011	-0.0001	-0.6196	0.3240	0.0501	-39.8790	***
CBOE/CME FX Euro VI	$\Delta EUVIX_t$	01/03/2007	-0.0009	-0.7397	0.4572	0.0501	-53.8616	***
CBOE/CME FX Yen VI	$\Delta JYVIX_t$	01/03/2007	-0.0002	-0.2801	0.4123	0.0498	-50.4963	***
CBOE/CME FX British Pound VI	$\Delta BPVIX_t$	01/03/2007	-0.0005	-0.4387	0.3713	0.0430	-46.0753	***
CBOE EuroCurrency ETF VI	ΔEVZ_t	03/15/2010	-0.0002	-0.3981	0.2891	0.0441	-42.3998	***
CBOE VIX of VIX Index	$\Delta VVIX_t$	01/04/2007	-0.0000	-0.2023	0.4511	0.0507	-55.6217	***

The descriptives for all securities included in the study are provided in Table 1. In the table Δ refers to daily log difference change and *t* refers to trading day. *Avg* for gold refers to daily average return for gold in US dollar, euro and British pound. The upper part of the table provides the statistics for individual security indexes, ETFs, currencies, as well as for gold and 10-year Treasury constant maturity rate. The lower part of the table provides the same statistics for the corresponding volatility indexes (VI). Each variable's sample beginning date is provided as part of the descriptive statistics and range from year 2000 to year 2011. All variables are stationary based on the augmented Dickey-Fuller stationarity tests.

4. Models and Empirical Results

The empirical evaluation of gold as a hedging instrument as well as a safe haven asset is done with two separate but complementary econometric analyses. Initially, we test the lead and lag relationships for gold vs. individual security returns and gold vs. volatility indexes. These tests are also performed for Treasury rates to compare the two assets and to evaluate the gold's performance against a well known safety asset. For the gold vs. security returns: a lead by gold over security returns, within this context, would indicate that investors would follow gold returns to make decisions in investments of assets. A lead by securities over gold would indicate that investors move to gold following returns in assets. For the gold vs. volatility indexes: a lead by gold over volatility indexes would indicate that gold could be an indicator of future volatility. A lead by volatility index over gold would indicate flight to gold following volatility.

The lead and lag relationships are tested using Granger (1969) causality model as follows:

$$\Delta y_{it} = \alpha_{1i} + \sum_{j=1}^{2} \beta_{1ij} \Delta y_{i,t-j} + \sum_{k=1}^{2} \gamma_{1ik} \Delta x_{i,t-k} + \epsilon_{it} \quad (1)$$

$$\Delta x_{it} = \alpha_{2i} + \sum_{j=1}^{2} \beta_{2ij} \Delta x_{i,t-j} + \sum_{k=1}^{2} \gamma_{2ik} \Delta y_{i,t-k} + e_{it} \quad (2)$$

The Wald test for non-causality tests the following restrictions:

$$\Delta x_{it} \rightarrow \Delta y_{it} : \gamma_{1i1} = \gamma_{1i2} = 0 \quad (3)$$

$$\Delta y_{it} \rightarrow \Delta x_{it} : \gamma_{2i1} = \gamma_{2i2} = 0 \quad (4)$$

Within the equations above, y variable is either gold or Treasury rates and the x variable is one of the evaluated indexes, volatility indexes, ETFs, or currencies.

Since our study is similar in methodology to Joy (2011), we replicate his DCC-MGARCH methodology and extend it to our analysis. Our DCC-MGARCH model and estimation results are provided in the supplementary section of this study. Dynamic conditional correlation type multivariate GARCH is estimated as a system where the error covariances and conditional correlations evolve according to autoregressive processes (the details of the method are spelled out in Appendix B). It also depends on the very high number of parameters estimated and many related assumptions. Our methodology depends on fewer assumptions and require fewer parameters to be estimated. Our results are strikingly similar to the results of the DCC-MGARCH model.

Table 2 provides the estimation results for gold and index returns while Table 3 provides the results for gold and volatility indexes. We find that gold returns lead RUT, EFA, EEM and US dollar British pound exchange rates at 5% statistical significance or better. There is however no lead by gold over major US indexes such as S&P-500, S&P-100, NASDAQ 100 and Dow 30. For the lead over gold, S&P-500, EEM (developing mkts), and EWZ (Brazil) are significant. Although, S&P-500 is significant, the lack of evidence for other major US equity index subdues this result. Overall, the lead-lag between gold and index returns could be described as weak at best.

Compared to gold, Treasury rates do not perform any better. The only lead Treasury rates have over returns is for the US dollar and Japanese yen.

Table 2. Granger causality results for index returns vs. Gold and vs. 10-Year Treasury Constant Maturity Rate. Δ refers to daily log difference change and t refers to the trading day. Avg for gold refers to daily average return for gold in US dollar, euro and British pound. *, ** and * refer to statistical significance at the 10%, 5% and 1% respectively.**

(y)	Index (x)	$F_{y\to x}$		$F_{x\to y}$	
$\Delta Gold_{Avg,t}$	$\Delta GSPC_t$	4.7831	*	6.0327	**
	ΔNDX_t	1.6692		4.0493	
	ΔOEX_t	4.2406		3.5607	
	ΔDJI_t	4.6973	*	2.9024	
	ΔRUT_t	13.6058	***	2.7519	
	ΔEFA_t	9.7182	***	4.6010	
	ΔEEM_t	6.3377	**	8.5638	**
	ΔFXI_t	4.4468		5.2435	*
	ΔEWZ_t	5.9886	*	14.6628	***
	$\Delta DEXUSEU_t$	2.9670		0.5260	
	$\Delta DEXJPUS_t$	2.0194		4.3104	
	$\Delta DEXUSUK_t$	7.2210	**	1.5380	
	ΔFXE_t	0.2532		0.7204	
$\Delta Treasury_t$	$\Delta GSPC_t$	0.8286		2.9438	
	ΔNDX_t	2.6544		0.5934	
	ΔOEX_t	1.4370		3.4482	
	ΔDJI_t	1.5316		3.4515	
	ΔRUT_t	1.3880		1.0946	
	ΔEFA_t	0.5737		1.3131	
	ΔEEM_t	2.8405		0.6586	
	ΔFXI_t	2.1950		3.2119	
	ΔEWZ_t	0.2640		0.8301	
	$\Delta DEXUSEU_t$	3.8920		0.4882	
	$\Delta DEXJPUS_t$	64.4994	***	0.7178	
	$\Delta DEXUSUK_t$	1.5812		0.5689	
	ΔFXE_t	2.1633		3.1163	

For the lead and lag relationship between gold and volatility indexes however the results are significantly different. We find that **all major US equity volatility indexes and developed market ETF EFA (developed markets) volatility lead gold returns: a clear and strong evidence of flight to gold phenomenon**. Treasury rates do not have such a lead. Instead, **we find that Treasury rates lead currency volatilities**. Interestingly, the volatility index for volatility index itself, VVIX, leads gold as well as Treasuries.

The second set of tests evaluates the contemporaneous relations for gold vs. individual security returns, and gold vs. volatility indexes. Similar to the lead-lag tests, Treasury rates are also evaluated to compare the performance of gold vs. a well known security for hedging. Estimations for contemporaneous relationships provide evidence of gold's hedging potential and safe-haven qualities. The results for gold are compared to those of Treasuries, which are well-known as hedges and safe haven securities. In this context, a negative contemporaneous relationship between gold and index returns implies a hedging quality for gold (Baur, 2010a) while a positive relationship would implies a diversification quality for gold. Treasuries requires a further interpretation. As we analyze the daily changes in the 10 year Treasury rates, a positive relationship between Treasury rate and index returns would mean a hedging quality for Treasuries as bond prices decrease since interest rates increase.

Table 3. Granger causality results for volatility indexes vs. Gold and vs. 10-Year Treasury Constant Maturity Rate. Δ refers to daily log difference change and *t* refers to the trading day. *Avg* for gold refers to daily average return for gold in US dollar, euro and British pound. *, ** and * refer to statistical significance at the 10%, 5% and 1% respectively.**

(y)	VIX (x)	$F_{y\to x}$		$F_{x\to y}$	
$\Delta Gold_{Avg,t}$	ΔVIX_t	1.4944		21.3515	***
	ΔVXN_t	1.4606		14.2577	***
	ΔVXO_t	3.1946		19.9518	***
	ΔVXD_t	0.8862		18.8243	***
	ΔRVX_t	7.4843	**	23.5169	***
	$\Delta VXST_t$	1.7546		1.9814	
	ΔVXV_t	3.1133		3.9230	
	$\Delta VXMT_t$	1.9674		4.1000	
	$\Delta VXEFA_t$	0.8779		9.9007	***
	$\Delta VXEEM_t$	4.5914		1.4013	
	$\Delta VXFXI_t$	6.9811	**	0.7013	
	$\Delta VXEWZ_t$	9.2742	***	5.9522	*
	$\Delta EUVIX_t$	2.5932		2.0354	
	$\Delta JYVIX_t$	0.3256		1.7725	
	$\Delta BPVIX_t$	1.0087		2.6306	
	ΔEVZ_t	1.6753		3.4109	
	$\Delta VVIX_t$	3.1193		7.9859	**
$\Delta Treasury_t$	ΔVIX_t	4.5685		1.7019	
	ΔVXN_t	5.2928	*	3.6698	
	ΔVXO_t	1.4935		3.5417	
	ΔVXD_t	6.1271	**	1.9826	
	ΔRVX_t	3.8767		1.7863	
	$\Delta VXST_t$	4.1921		0.9201	
	ΔVXV_t	1.9423		3.4563	
	$\Delta VXMT_t$	4.6692	*	3.2958	
	$\Delta VXEFA_t$	6.2733	**	1.8868	
	$\Delta VXEEM_t$	2.2029		0.6462	
	$\Delta VXFXI_t$	2.6211		2.3506	
	$\Delta VXEWZ_t$	3.0170		0.0450	
	$\Delta EUVIX_t$	17.1424	***	0.6144	
	$\Delta JYVIX_t$	7.5397	**	4.6280	*
	$\Delta BPVIX_t$	10.6203	***	3.9090	
	ΔEVZ_t	9.7183	***	1.2067	
	$\Delta VVIX_t$	6.1986	**	7.6153	**

Contemporaneous relationships are evaluated with a GARCH (1,1) model Bollerslev (1986) as follows:

$$x_t = \beta_0 + \sum_{i=1}^{n} \beta_i y_{t-i} + \epsilon_t \tag{5}$$

$$\sigma_t^2 = \alpha_0 + \sum_{i=1}^{q} \alpha_i \epsilon_{t-i}^2 + \sum_{i=1}^{p} \gamma_i \sigma_{t-i}^2 \text{ where } \epsilon_t | \delta_{t-1} \sim N(0, \sigma_t^2)$$

Table 4 provides the GARCH(1,1) estimation results for gold vs. index returns while Table 5 provides the results for gold vs. volatility indexes. **We find significant evidence of negative correlation between gold returns and index returns for major US equity indexes and ETF EFA**

(developed markets). **These results provide strong evidence for the hedging quality of gold for major US and developed market equities**. Currencies also have significant negative correlations with gold returns. There is no significant correlation for FXE which is the tradable US dollar euro ETF. However, the correlation is significant for the actual US dollar and euro exchange rate.

As a comparison, Treasury rates have positive statistically significant correlations with all of the index returns except for the FXE (the dollar-euro ETF). Notice also that the test statistics for US dollar and euro exchange rate are also quite low albeit still statistically significant. As such, **these results also provide strong evidence for Treasuries to have hedge qualities**.

Table 5 provides the evidence needed to deem gold as a safe haven. The volatility indexes for US equities are positively and statistically correlated with gold. Likewise, the volatility index for developed market equities (EFA) are also positively correlated with gold. Short-term and medium term volatility indexes also have positive correlations with gold.

While the safe haven evidence is quite strong for gold in terms of volatilities for US equities and developed market equities, the evidence for Treasury rates is overwhelming. **Treasuries are a safe haven to all volatilities included in our study**.

Table 4. GARCH(1,1) estimation results for index returns vs. Gold and vs. 10-Year Treasury Constant Maturity Rate. Δ refers to daily log difference change and t refers to the trading day. Avg for gold refers to daily average return for gold in US dollar, euro and British pound. *, ** and * refer to statistical significance at the 10%, 5% and 1% respectively.**

Index	$\Delta Gold_{Avg,t}$		Constant		χ^2	N
$\Delta GSPC_t$	-0.0334	***	0.0005	***	13.39	4,261
ΔNDX_t	-0.0545	***	0.0007	***	20.81	4,002
ΔOEX_t	-0.0374	***	0.0004	***	17.74	4,261
ΔDJI_t	-0.0364	***	0.0005	***	18.20	4,261
ΔRUT_t	-0.0075		0.0005	**	0.28	3,289
ΔEFA_t	-0.0343	**	0.0003		4.65	2,317
ΔEEM_t	0.0583	**	0.0002		6.36	1,535
ΔFXI_t	0.0163		0.0003		0.40	1,535
ΔEWZ_t	0.1090	***	-0.0003		9.29	1,535
$\Delta DEXUSEU_t$	0.1003	***	0.0000		154.04	2,462
$\Delta DEXJPUS_t$	-0.1437	***	0.0001		269.18	2,458
$\Delta DEXUSUK_t$	0.0459	***	-0.0000		26.88	2,352
ΔFXE_t	0.0158		-0.0001		2.47	1,780
Index	$\Delta Treasury_t$		Constant		χ^2	N
$\Delta GSPC_t$	0.1598	***	0.0004	***	815.41	4,191
ΔNDX_t	0.1723	***	0.0006	***	580.77	3,936
ΔOEX_t	0.1559	***	0.0004	***	792.39	4,191
ΔDJI_t	0.1532	***	0.0005	***	794.15	4,191
ΔRUT_t	0.1996	***	0.0004	**	539.35	3,237
ΔEFA_t	0.1739	***	0.0003		473.21	2,279
ΔEEM_t	0.1595	***	0.0003		236.27	1,511
ΔFXI_t	0.1887	***	0.0003		252.66	1,511
ΔEWZ_t	0.1794	***	-0.0003		100.50	1,511
$\Delta DEXUSEU_t$	0.0102	**	0.0000		5.35	2,514
$\Delta DEXJPUS_t$	0.1086	***	0.0001		582.46	2,510
$\Delta DEXUSUK_t$	0.0223	***	0.0000		22.94	2,405
ΔFXE_t	0.0028		-0.0001		0.38	1,754

Table 5. GARCH(1,1) estimation results for volatility indexes vs. Gold and vs. 10-Year Treasury Constant Maturity Rate. Δ refers to daily log difference change and t refers to the trading day. Avg for gold refers to daily average return for gold in US dollar, euro and British pound. *, ** and * refer to statistical significance at the 10%, 5% and 1% respectively.**

Index	$\Delta Gold_{Avg,t}$		Constant		χ^2	N
ΔVIX_t	0.1988	***	-0.0012		11.26	4,261
ΔVXN_t	0.1114	**	-0.0013	*	3.86	4,002
ΔVXO_t	0.1987	***	-0.0010		6.97	4,261
ΔVXD_t	0.1506	***	-0.0012		7.52	4,261
ΔRVX_t	0.0109		-0.0010		0.04	3,289
$\Delta VXST_t$	0.1471		0.0000		0.77	1,584
ΔVXV_t	0.0720		-0.0007		2.55	2,331
$\Delta VXMT_t$	0.0674	**	-0.0007		4.06	2,314
$\Delta VXEFA_t$	0.2180	**	-0.0009		4.99	2,317
$\Delta VXEEM_t$	-0.1470		-0.0014		2.51	1,535
$\Delta VXFXI_t$	-0.1221	*	-0.0009		3.21	1,535
$\Delta VXEWZ_t$	-0.1605	**	-0.0009		5.43	1,535
$\Delta EUVIX_t$	0.0850		-0.0021	***	1.59	2,462
$\Delta JYVIX_t$	0.1625	**	-0.0019	**	5.68	2,458
$\Delta BPVIX_t$	0.0511		-0.0026	***	0.84	2,352
ΔEVZ_t	0.0743		-0.0013		0.74	1,780
$\Delta VVIX_t$	0.0550		0.0003		0.96	2,558
Index	$\Delta Treasury_d$		Constant		χ^2	N
ΔVIX_t	-0.9462	***	-0.0020	**	624.49	4,191
ΔVXN_t	-0.7416	***	-0.0019	**	519.51	3,936
ΔVXO_t	-1.0382	***	-0.0020	**	631.82	4,191
ΔVXD_t	-0.8874	***	-0.0018	**	615.91	4,191
ΔRVX_t	-0.7607	***	-0.0019	**	496.48	3,237
$\Delta VXST_t$	-1.6591	***	-0.0036		240.60	1,559
ΔVXV_t	-0.6665	***	-0.0011		635.67	2,296
$\Delta VXMT_t$	-0.4743	***	-0.0010	*	628.77	2,276
$\Delta VXEFA_t$	-0.8274	***	-0.0022	*	326.80	2,279
$\Delta VXEEM_t$	-0.7551	***	-0.0023		188.22	1,511
$\Delta VXFXI_t$	-0.5155	***	-0.0013		142.95	1,511
$\Delta VXEWZ_t$	-0.3999	***	-0.0009		81.98	1,511
$\Delta EUVIX_t$	-0.3444	***	-0.0019	**	116.06	2,514
$\Delta JYVIX_t$	-0.2838	***	-0.0014	*	69.36	2,510
$\Delta BPVIX_t$	-0.2542	***	-0.0023	***	68.28	2,405
ΔEVZ_t	-0.3281	***	-0.0011		70.12	1,754
$\Delta VVIX_t$	-0.5325	***	0.0000		239.48	2,518

5. Concluding remarks

The diversification, hedging, and safe haven qualities of gold have received considerable attention in the literature especially after the 2008 crisis. The evidence have been mixed with various methodologies. In this study, we emphasize two shortcomings of the existing literature. First, we argue that as long as gold is denominated in US dollar, its true value cannot be evaluated. As a remedy, we propose daily average return of gold in US dollar, euro and British pound fixings. Second, the interpretation of safe haven in the literature have been limited to realized excessive negative returns. However, we argue that the investors are enticed to seek a safe haven from the *possibility* of excessive negative returns as indicated by high volatility. Thus, as a remedy, tested gold against the volatility indexes provided by CBOE. Our results provide strong evidence that gold is both a hedge instrument and a safe haven. Based on the results provided in Tables 4 and 5, we posit that Treasuries may be a better safe haven asset than gold.

Conflict of Interest

All authors declare no conflicts of interest in this paper.

References

Anand R, Madhogaria S (2012) Is gold a safe-haven?-An econometric analysis. *Procedia Econ Financ* 1: 24-33.

Arouri MEH, Lahiani A, Nguyen DK (2015) World gold prices and stock returns in China: Insights for hedging and diversification strategies. *Econ Model* 44: 273-282.

Baker SA, Tassel RCV (1985) Forecasting the price of gold: A fundamentalist approach. *Atl Econ J* 13: 43-51.

Batten JA, Ciner C, Lucey BM (2014) On the economic determinants of the goldinflation relation. *Resour Policy* 41: 101-108.

Baur DG, Lucey BM (2010a) Is gold a hedge or a safe haven? An analysis of stocks, bonds and gold. *Financ Rev* 45: 217-229.

Baur DG, McDermott TK (2010b) Is gold a safe haven? International evidence. *J Bank Financ* 34: 1886-1898.

Baur DG (2012) Asymmetric volatility in the gold market. *J Altern Invest* 14: 26-38.

Beckmann J, Czudaj R (2013) Gold as an inflation hedge in a time-varying coefficient framework. *North Am J Econ Financ* 24: 208-222.

Beckmann J, Berger T, Czuda R (2015) Does gold act as a hedge or a safe haven for stocks? A smooth transition approach. *Econ Model* 48: 16-24.

Black F, Scholes M (1973) The pricing of options and corporate liabilities. *J Political Econ* 637-654.

Black KH (2006) Improving hedge fund risk exposures by hedging equity market volatility, or how the VIX ate my kurtosis. *J Trading* 1: 6-15.

Bollerslev T (1986) Generalized autoregressive conditional heteroskedasticity. *J Econ* 31: 307-327.

Bredin D, Conlon T, Potì V (2015) Does gold glitter in the long-run? Gold as a hedge and safe haven across time and investment horizon. *Int Rev Financ Anal* 41: 320-328.

Cai J, Cheung YL, Wong MSC (2001) What moves the gold market? *J Futur Mark* 21: 257-278.

Capie F, Mills TC, Wood G (2005) Gold as a hedge against the dollar. *J Int Financ Mark, Inst Money* 15: 343-352.

Christie-David R, Chaudhry M, Koch TW (2000) Do macroeconomics news releases affect gold and silver prices? *J Econ Bus* 52: 405-421.

Chua JH, Sick G, Woodward RS (1990) Diversifying with gold stocks. *Financ Anal J* 46: 76-79.

Ciner C, Gurdgie C, Lucey BM (2013) Hedges and safe havens: An examination of stocks, bonds, gold, oil and exchange rates. *Int Rev Financ Anal* 29: 202-211.

Cohen G, Qadan M (2010) Is gold still a shelter to fear? *Am J Soc Manag Sci* 1: 39-43.

Coudert V, Raymond H (2011) Gold and financial assets: Are there any safe havens in bear markets. *Econ Bull* 31: 1613-1622.

Dee J, Li L, Zheng Z (2013) Is gold a hedge or a safe haven? Evidence from inflation and stock market. *Int J Dev Sustain* 2: 12-27.

Engle RF (1982) Autoregressive conditional heteroscedasticity with estimates of the variance of United Kingdom inflation. *Econ: J Econ Soc* 987-1007.

Engle R (2002) Dynamic conditional correlation: A simple class of multivariate generalized autoregressive conditional heteroskedasticity models. *J Bus Econ Stat* 20: 339-350.

Ghazali MF, Lean HH, Bahari Z (2013) Is gold a hedge or a safe haven? An empirical evidence of gold and stocks in Malaysia. *Int J Bus Soc* 14: 428.

Ghosh D, Levin EJ, Macmillan (2004) Gold as an inflation hedge? *Stud Econ Financ* 22: 1-25.

Granger CWJ (1969) Investigating causal relations by econometric models and cross-spectral methods. *Econ: Je Econ Soc* 424-438.

Gürgün G, Ünalmış İ (2014) Is gold a safe haven against equity market investment in emerging and developing countries? *Financ Res Lett* 11: 341-348.

Hillier D, Draper P and Faff R (2006) Do precious metals shine? An investment perspective. *Financ Anal J* 62: 98-106.

Hood M, Malik F (2013) Is gold the best hedge and a safe haven under changing stock market volatility? *Rev Financ Econ* 22: 47-52.

Jaffe JF (1989) Gold and gold stocks as investments for institutional portfolios. *Financ Anal J* 45: 53-59.

Joy M (2011) Gold and the US dollar: Hedge or haven? *Financ Res Lett* 8: 120-131.

Kaufmann TD, Winters RA (1989) The price of gold: A simple model. *Resour Policy* 15: 309-313.

Koutsoyiannis A (1983) A short-run pricing model for a speculative asset, tested with data from the gold bullion market. *Appl Econ* 15: 563-581.

Lundblad C (2007) The risk return tradeoff in the long run: 1836-2003. *J Financ Econ* 85: 123-150.

McCown JR, Zimmerman JR. Is Gold a Zero-Beta Asset? Analysis of the Investment Potential of Precious Metals, SSRN eLibrary (English), 2006. Available at SSRN: http://ssrn.com/paper=920496.

McDonald JG, Solnick BH (1977) Valuation and strategy for gold stocks. *J Portf Manag* 3: 29-33.

Mishra PK, Das JR, Mishra SK (2010) Gold price volatility and stock market returns in India. *Am J Sci Res* 9: 47-55.

Papadamou S, Markopoulos T (2014) Investigating intraday interdependence between gold, silver and three major currencies: The Euro, British Pound and Japanese Yen. *Int Adv Econ Res* 20: 399-410.

Qadan M, Yagil J (2012) Fear sentiments and gold price: Testing causality in-mean and in-variance. *Appl Econ Lett* 19: 363-366.

Ranaldo A, Soderlind P (2010) Safe haven currencies. *Rev Financ* 14: 385-407.

Reboredo JC (2013a) Is gold a safe haven or a hedge for the US dollar? Implications for risk management. *J Bank Financ* 37: 2665-2676.

Reboredo JC (2013b) Is gold a hedge or safe haven against oil price movements? *Res Policy* 38: 130-137.

Roache SK, Rossi M (2010) The effects of economic news on commodity prices. *Q Rev Econ Financ* 50: 377-385.

Scott-Ram R (2002) Managing portfolio risk with gold. World Gold Council, London.

Sherman EJ (1982) Gold: A conservative, prudent diversifier. *J Portf Manage* 8: 21-27.

Sherman EJ (1983) A gold pricing model. *J Portf Manag* 9: 68-70.

Sjaastad LA, Scacciavillani F (1996) The price of gold and the exchange rate. *J Int Money Financ* 15: 879-897.

Sjaastad LA (2008) The price of gold and the exchange rates: Once again. *Res Policy* 33: 118-124.

Wang KM, Lee YM, Thi TBN (2011) Time and place where gold acts as an inflation hedge: An application of long-run and short-run threshold model. *Econ Model* 28: 806-819.

Whaley RE (1993) Derivatives on market volatility: Hedging tools long overdue. *J Deriv* 1: 71-84.

A. Supplementary: DCC-MGARCH

Any VAR can be written in companion form:

$$Y_t = \beta Y_{t-1} + \epsilon_t \tag{A.1}$$

Expressed in this way Y_{t-1} can contain various lags of Y (not just one) and may also contain exogenous X variables of arbitrary lags. The error term is modeled as

$$\epsilon_t \sim N\left(\mu, \sigma^2\right) = N\left(0, H_t\right) \tag{A.2}$$

where H_t is a matrix of conditional covariances. The subscript on H_t indicates that the matrix is time-varying. Rather than estimating each of the components of a completely unique H_t matrix each time period, Engle (2002) suggests that the components of the matrix evolve according to particular constraints employing the familiar GARCH(p,q) process. Specifically, Engle suggested that the variance/covariance matrix H_t be decomposed as:

$$H_t = D_t^{1/2} R_t D_t^{1/2}. \tag{A.3}$$

Here, D_t is a diagonal matrix of conditional variances with each entry (σ_{it}^2) evolving according to a GARCH(p,q) process:

$$\sigma_{it}^2 = \alpha_{i0} + \sum_{j=1}^{q} \alpha_{ij} \epsilon_{i,t-j}^2 + \sum_{j=1}^{p} \phi_{ij} \sigma_{t-j}^2 \tag{A.4}$$

The off-diagonal elements of D_t are zero. The matrix D_t is decomposed into its factors ($D_t^{1/2}$) so the entries in $D_t^{1/2}$ are conditional standard deviations. Even though the entries of D_t are all on the diagonal so that there are no non-zero covariances, Engle allows for covariance between the GARCH error terms via the matrix R_t. The matrix R_t is a matrix of time-varying "conditional quasicorrelations." Here again, we wish to avoid estimating each of the components of a matrix separately for each time period. We would quickly run out of degrees of freedom. Therefore, Engle supposes that R_t also evolves in a constrained fashion. Specifically,

$$R_t = diag\left(Q_t\right)^{-1/2} Q_t diag\left(Q_t\right)^{-1/2} \tag{A.5}$$

and

$$Q_t = \left(1 - \lambda_1 - \lambda_2\right) R + \lambda_1 \left(D_t^{-1/2} \epsilon_t\right) \left(D_t^{-1/2} \epsilon_t\right)' + \lambda_2 Q_{t-1}. \tag{A.6}$$

The matrix Q_t is a matrix of conditional correlations. It is modeled as a weighted average of three terms: the constant conditional correlation R, last period's time-varying conditional correlation, Q_{t-1}, such that Q_t is partially autoregressive, and standardized squared residuals. The λ_1 and λ_2 terms are weights for averaging. The λ_2 term also functions like the adjustment parameters in a VECM model, nudging the Q_{t-1} matrix of conditional correlations toward is value in Q_t. In the case where function like the adjustment parameters in a VECM $\lambda_1 = \lambda_2 = 0$, then there is no adjustment, and Q_t does not vary; it is equal to a constant correlation matrix R.

Table A.1. DCC-MGARCH estimation results for index returns vs. Gold and vs. 10-Year Treasury Constant Maturity Rate. Δ refers to daily log difference change and t refers to the trading day. Avg for gold refers to daily average return for gold in US dollar, euro and British pound. *, ** and * refer to statistical significance at the 10%, 5% and 1% respectively.**

y	x			y						x					
(y)	Index (x)	Constant		Arch(1)		Garch(1)		Constant		Arch(1)		Garch(1)		chi^2	N
$\Delta Gold_{Avg,t}$	$\Delta GSPC_d$	0.0000	***	0.0942	***	0.8893	***	0.0000	***	0.0988	***	0.8867	***	23.02	4,259
	ΔNDX_d	0.0000	***	0.0838	***	0.9011	***	0.0000	***	0.0787	***	0.9125	***	13.22	4,000
	ΔOEX_d	0.0000	***	0.0942	***	0.8894	***	0.0000	***	0.1028	***	0.8832	***	26.96	4,259
	ΔDJI_d	0.0000	***	0.0941	***	0.8896	***	0.0000	***	0.1037	***	0.8806	***	19.17	4,259
	ΔRUT_d	0.0000	***	0.0731	***	0.9175	***	0.0000	***	0.0781	***	0.9027	***	25.80	3,287
	ΔEFA_d	0.0000	***	0.0775	***	0.9035	***	0.0000	***	0.1142	***	0.8812	***	23.06	2,315
	ΔEEM_d	0.0000	***	0.0955	***	0.8640	***	0.0000	**	0.1133	***	0.8688	***	29.98	1,533
	ΔFXI_d	0.0000	***	0.0912	***	0.8693	***	0.0000	**	0.0824	***	0.8979	***	18.52	1,533
	$\Delta DEXUSEU_d$	0.0000	***	0.0777	***	0.9026	***	0.0000	***	0.0407	***	0.9563	***	3.12	2,460
	$\Delta DEXJPUS_d$	0.0000	***	0.0852	***	0.8959	***	0.0000	***	0.0524	***	0.9375	***	7.53	2,456
	$\Delta DEXUSUK_d$	0.0000	***	0.0723	***	0.9073	***	0.0000	**	0.0696	***	0.9262	***	3.45	2,350
	ΔFXE_d	0.0000	***	0.0871	***	0.8707	***	0.0000	**	0.0307	***	0.9660	***	5.08	1,778
$\Delta Treasury_d$	$\Delta GSPC_d$	0.0000	***	0.0495	***	0.9496	***	0.0000	***	0.1024	***	0.8809	***	24.11	4,189
	ΔNDX_d	0.0000	***	0.0443	***	0.9548	***	0.0000	***	0.0768	***	0.9134	***	15.47	3,934
	ΔOEX_d	0.0000	***	0.0497	***	0.9495	***	0.0000	***	0.1079	***	0.8765	***	29.10	4,189
	ΔDJI_d	0.0000	***	0.0494	***	0.9496	***	0.0000	***	0.1096	***	0.8731	***	20.64	4,189
	ΔRUT_d	0.0000	**	0.0418	***	0.9577	***	0.0000	***	0.0823	***	0.8941	***	19.71	3,235
	ΔEFA_d	0.0000	***	0.0504	***	0.9427	***	0.0000	***	0.1169	***	0.8740	***	16.92	2,277
	ΔEEM_d	0.0000	**	0.0448	***	0.9424	***	0.0000	***	0.1103	***	0.8619	***	13.23	1,509
	ΔFXI_d	0.0000	**	0.0430	***	0.9453	***	0.0000	**	0.0747	***	0.8986	***	12.85	1,509
	ΔEWZ_d	0.0000	**	0.0455	***	0.9423	***	0.0000	***	0.1208	***	0.8625	***	5.66	1,509
	$\Delta DEXUSEU_d$	0.0000	**	0.0549	***	0.9421	***	0.0000	***	0.0404	***	0.9565	***	13.50	2,512
	$\Delta DEXJPUS_d$	0.0000	**	0.0586	***	0.9408	***	0.0000	***	0.0549	***	0.9340	***	82.66	2,508
	$\Delta DEXUSUK_d$	0.0000	**	0.0578	***	0.9394	***	0.0000	**	0.0701	***	0.9262	***	3.13	2,403
	ΔFXE_d	0.0000	**	0.0531	***	0.9326	***	0.0000	**	0.0294	***	0.9674	***	8.58	1,752

Table A.2. Causality test results based on DCC-MGARCH estimation for index returns vs. Gold and vs. 10-Year Treasury Constant Maturity Rate. Δ refers to daily log difference change and *t* refers to the trading day. *Avg* for gold refers to daily average return for gold in US dollar, euro and British pound. *, ** and * refer to statistical significance at the 10%, 5% and 1% respectively.**

(y)	Index (x)	$F_{y \to x}$		$F_{x \to y}$		Corr(x,y)	
$\Delta Gold_{Avg,t}$	$\Delta GSPC_d$	6.28	**	3.66		-0.0467	***
	ΔNDX_d	5.25	*	2.75		-0.0431	
	ΔOEX_d	6.53	**	2.09		-0.0511	*
	ΔDJI_d	9.94	***	0.67		-0.0578	*
	ΔRUT_d	6.70	**	7.64	**	-0.0074	
	ΔEFA_d	4.78	*	3.65		-0.0216	
	ΔEEM_d	6.39	**	19.96	***	0.0442	
	ΔFXI_d	4.92	*	9.65	***	0.0307	
	$\Delta DEXUSEU_d$	0.70		1.36		0.1897	***
	$\Delta DEXJPUS_d$	0.23		2.85		-0.2685	***
	$\Delta DEXUSUK_d$	1.48		1.14		0.0648	
	ΔFXE_d	0.21		2.07		0.0427	
$\Delta Treasury_d$	$\Delta GSPC_d$	2.65		2.18		0.3148	***
	ΔNDX_d	3.01		0.06		0.3154	***
	ΔOEX_d	2.54		2.66		0.3146	***
	ΔDJI_d	2.81		2.14		0.3270	***
	ΔRUT_d	3.81		0.01		0.3100	***
	ΔEFA_d	1.45		0.35		0.3184	***
	ΔEEM_d	9.19	**	1.64		0.1934	**
	ΔFXI_d	6.04	**	3.77		0.2437	***
	ΔEWZ_d	1.48		1.17		0.0571	
	$\Delta DEXUSEU_d$	9.66	***	1.03		0.0488	
	$\Delta DEXJPUS_d$	61.57	***	0.85		0.4154	***
	$\Delta DEXUSUK_d$	0.83		0.65		0.0926	
	ΔFXE_d	1.56		1.95		0.0496	

Table A.3. DCC-MGARCH estimation results for volatility indexes vs. Gold and vs. 10-Year Treasury Constant Maturity Rate. Δ refers to daily log difference change and *t* refers to the trading day. *Avg* for gold refers to daily average return for gold in US dollar, euro and British pound. *, ** and * refer to statistical significance at the 10%, 5% and 1% respectively.**

y	x	y						x							
(y)	VIX (x)	Constant		Arch(1)		Garch(1)		Constant		Arch(1)		Garch(1)		chi^2	N
$\Delta Gold_{Avg,t}$	ΔVIX_d	0.0000	***	0.0934	***	0.8902	***	0.0003	***	0.1044	***	0.8316	***	55.56	4,259
	ΔVXN_d	0.0000	***	0.0835	***	0.9017	***	0.0001	***	0.0924	***	0.8748	***	28.47	4,000
	ΔVXO_d	0.0000	***	0.0938	***	0.8903	***	0.0003	***	0.1077	***	0.8448	***	79.25	4,259
	ΔVXD_d	0.0000	***	0.0940	***	0.8898	***	0.0003	***	0.1057	***	0.8284	***	53.61	4,259
	ΔRVX_d	0.0000	***	0.0724	***	0.9185	***	0.0002	***	0.0823	***	0.8447	***	49.48	3,287
	$\Delta VXMT_d$	0.0000	***	0.0776	***	0.9031	***	0.0001	***	0.1644	***	0.7394	***	11.57	2,312
	$\Delta VXEEM_d$	0.0000	***	0.0906	***	0.8716	***	0.0004	**	0.0856	***	0.8157	***	11.52	1,533
	$\Delta VXFXI_d$	0.0000	***	0.0854	***	0.8761	***	0.0001	***	0.0997	***	0.8382	***	7.63	1,533
	$\Delta EUVIX_d$	0.0000	***	0.0800	***	0.8996	***	0.0003	***	0.1371	***	0.7476	***	10.73	2,460
	$\Delta JYVIX_d$	0.0000	***	0.0794	***	0.9013	***	0.0002	***	0.1421	***	0.7839	***	11.49	2,456
	$\Delta BPVIX_d$	0.0000	***	0.0782	***	0.9018	***	0.0002	***	0.1263	***	0.7874	***	11.22	2,350
	ΔEVZ_d	0.0000	***	0.0903	***	0.8690	***	0.0000	*	0.0246	***	0.9637	***	19.16	1,778
$\Delta Treasury_t$	ΔVIX_d	0.0000	***	0.0483	***	0.9505	***	0.0003	***	0.1132	***	0.8087	***	41.09	4,189
	ΔVXN_d	0.0000	***	0.0444	***	0.9544	***	0.0001	***	0.1014	***	0.8530	***	25.97	3,934
	ΔVXO_d	0.0000	***	0.0482	***	0.9507	***	0.0003	***	0.1149	***	0.8274	***	55.68	4,189
	ΔVXD_d	0.0000	***	0.0479	***	0.9510	***	0.0003	***	0.1222	***	0.7912	***	35.41	4,189
	ΔRVX_d	0.0000	**	0.0423	***	0.9571	***	0.0002	***	0.0911	***	0.8275	***	21.58	3,235
	$\Delta VXST_d$	0.0000	**	0.0456	***	0.9461	***	0.0034	***	0.1053	***	0.6495	***	23.35	1,557
	ΔVXV_d	0.0000	***	0.0481	***	0.9437	***	0.0002	***	0.1572	***	0.7320	***	20.11	2,294
	$\Delta VXMT_d$	0.0000	***	0.0474	***	0.9444	***	0.0001	***	0.1639	***	0.7287	***	16.73	2,274
	$\Delta VXEFA_d$	0.0000	***	0.0496	***	0.9421	***	0.0009	***	0.1524	***	0.6695	***	22.62	2,277
	$\Delta VXEEM_d$	0.0000	**	0.0483	***	0.9413	***	0.0004	**	0.0797	***	0.8213	***	8.19	1,509
	$\Delta VXFXI_d$	0.0000	**	0.0443	***	0.9428	***	0.0002	***	0.1058	***	0.8137	***	7.66	1,509
	$\Delta VXEWZ_d$	0.0000	**	0.0452	***	0.9419	***	0.0003	***	0.1484	***	0.7463	***	6.81	1,509
	$\Delta EUVIX_d$	0.0000	**	0.0538	***	0.9443	***	0.0001	***	0.0655	***	0.8960	***	24.70	2,512
	$\Delta JYVIX_d$	0.0000	**	0.0576	***	0.9411	***	0.0002	***	0.1330	***	0.7847	***	15.63	2,508
	$\Delta BPVIX_d$	0.0000	**	0.0557	***	0.9421	***	0.0001	***	0.1145	***	0.8122	***	30.35	2,403
	ΔEVZ_d	0.0000	**	0.0486	***	0.9406	***	0.0000	*	0.0219	***	0.9673	***	29.43	1,752
	$\Delta VVIX_d$	0.0000	**	0.0584	***	0.9404	***	0.0005	***	0.1341	***	0.6576	***	26.91	2,516

Table A.4. Causality test results based on DCC-MGARCH estimation for volatility indexes vs. Gold and vs. 10-Year Treasury Constant Maturity Rate. Δ refers to daily log difference change and t refers to the trading day. Avg for gold refers to daily average return for gold in US dollar, euro and British pound. *, ** and * refer to statistical significance at the 10%, 5% and 1% respectively.**

(y)	VIX (x)	$F_{y \to x}$		$F_{x \to y}$		Corr(x,y)	
$\Delta Gold_{Avg,t}$	ΔVIX_d	1.34		15.48	***	0.0304	
	ΔVXN_d	0.34		14.52	***	0.0179	
	ΔVXO_d	2.11		14.80	***	0.0308	
	ΔVXD_d	0.42		13.00	***	0.0208	
	ΔRVX_d	6.59	**	22.49	***	-0.0025	
	$\Delta VXMT_d$	2.52		3.60		0.0061	
	$\Delta VXEEM_d$	3.31		2.91		-0.0001	
	$\Delta VXFXI_d$	4.32		0.32		0.0632	
	$\Delta EUVIX_d$	3.51		2.58		0.0090	
	$\Delta JYVIX_d$	0.97		7.36	**	0.0328	
	$\Delta BPVIX_d$	0.64		2.73		0.0032	
	ΔEVZ_d	2.98		2.05		0.0299	
$\Delta Treasury_t$	ΔVIX_d	6.34	**	3.55		-0.2647	***
	ΔVXN_d	6.93	**	2.82		-0.2667	***
	ΔVXO_d	1.60		5.14	*	-0.2770	***
	ΔVXD_d	5.73	*	6.37	**	-0.2641	***
	ΔRVX_d	7.68	**	0.31		-0.2652	***
	$\Delta VXST_d$	5.82	*	2.87		-0.3060	***
	ΔVXV_d	4.98	*	3.05		-0.3622	***
	$\Delta VXMT_d$	6.10	**	2.06		-0.3722	***
	$\Delta VXEFA_d$	2.53		3.02		-0.2676	***
	$\Delta VXEEM_d$	2.95		4.00		-0.2516	***
	$\Delta VXFXI_d$	0.63		3.95		-0.2322	***
	$\Delta VXEWZ_d$	3.53		0.05		-0.1259	*
	$\Delta EUVIX_d$	16.70	***	0.25		-0.1680	
	$\Delta JYVIX_d$	5.89	*	2.58		-0.1582	***
	$\Delta BPVIX_d$	16.64	***	1.90		-0.1330	
	ΔEVZ_d	9.07	**	3.21		-0.1428	**
	$\Delta VVIX_d$	8.81	**	10.85	***	-0.2767	***

AIMS Press