International Review of Financial Analysis 80 (2022) 102027

Contents lists available at ScienceDirect

International Review of Financial Analysis

journal homepage: www.elsevier.com/locate/irfa

Exploring the transmission mechanism of speculative and inventory arbitrage activity to commodity price volatility. Novel evidence for the US economy

Wei Yao[a,*], Constantinos Alexiou[b]

[a] School of Economics and Business, Tilburg University, 5037, AB, Tilburg, the Netherlands
[b] Cranfield School of Management, Cranfield University, Cranfield MK43 0AL, UK

ARTICLE INFO

JEL classification:
C50
E31
E4
F4
Q43

Keywords:
Monetary policy
Commodity price volatility
Speculative activity
Inventory arbitrage activity
Transmission mechanism

ABSTRACT

In the realm of monetary policy, we explore the transmission mechanism that relates speculative activity, inventory arbitrage activity, and commodity price volatility. In this direction, an ARMA-GARCH model is adopted to test this transmission effect on seven commodities using weekly U.S. data for the period 2008:12 to 2018:6. The results suggest that inventory arbitrage activities transmit monetary policy's effect onto commodities by strengthening the effect of the real interest rate on commodities' prices; in the case of palladium and crude oil's price conditional variances however the opposite effect is established. Speculative activities transmit monetary policy's effect mainly on commodities by increasing the positive effect of the real interest rate on metals and crude oil's prices, and on palladium and crude oil's price conditional variances. Our results show that inventory arbitrage activities are negatively related with commodities' prices, whilst speculative activities are positively related with commodities' prices. The two activities appear to exert mixed effects on commodities' price conditional volatilities. Additional evidence indicates that the relationship between the real interest rate and commodities' prices is positive and significant when unconventional monetary policy is considered, whilst we find that the real interest rate does not have any significant impact on most commodities' price conditional volatilities.

1. Introduction

Soon after the onset of the Subprime Mortgage Crisis in the USA, the Federal Reserve reacted by implementing unconventional monetary policy in an attempt to stabilize the financial market through the large-scale asset purchasing (LSAP) program as well as boost economic activity. During this period,[1] commodity futures' prices, which appear to be following the same pattern as inventory arbitrage activity and speculative activity, exhibited high variation from the equilibrium level (see for instance crude oil's price fluctuation in Figs. 1, 2 and 3 in the appendix). As such, the impact of US quantitative easing (QE) policy on commodities' prices and volatilities in conjunction with the scant evidence in the literature has provided the motivation to explore the transmission mechanisms of speculative and inventory arbitrage activity to commodity price volatility. The contribution of this study is therefore of great importance for academics and policy makers alike as the generated evidence helps us to gain further insights into the relationship between real interest rates and commodities' real price variations under unconventional monetary policy whilst at the same time consider the impact of inventory arbitrage activities and speculative activities on the conditional variances of commodities prices.

According to Frankel (2006), monetary policy (real interest rates) may exert its impact on commodities' real prices through inventory arbitrage activities and speculative activities. Frankel (2006, 2014) however, does not explore the underlying transmission mechanism of speculative activities vis-à-vis commodities' prices and volatilities. Gospodinov and Jamali (2013, 2017) examine the relationship between monetary policy's surprise/uncertainty, the inventory, speculative activities, and commodities' prices, by looking into the relationships in pairs, rather than including all variables in one equation as suggested by Frankel (2006); nor do they study the relationship between monetary policy, inventory, speculative activities, and commodities' volatilities. In a similar study, Apergis, Chatziantoniou, and Cooray (2020) compare the effects of the conventional monetary policy and unconventional monetary policy on commodities' prices and volatilities by EGARCH-X model, but they fail to account for the mechanism of the inventory

* Corresponding author.
E-mail addresses: w.yao@tilburguniversity.edu (W. Yao), constantinos.alexiou@cranfield.ac.uk (C. Alexiou).

[1] A short time-map presenting the FED's QE policy is provided in Table 5A in the appendix.

https://doi.org/10.1016/j.irfa.2022.102027
Received 8 July 2021; Received in revised form 1 November 2021; Accepted 7 January 2022
Available online 14 January 2022

and speculative activities in their model. Some others by building on the existing framework, tried to explore the relationship between unconventional monetary policy and commodity prices (see, Saghaian & Reed, 2015 and Sharon, Eric, & Lena, 2015). But very few empirical studies look at whether the two transmission channels of inventory and speculative activities still work under unconventional monetary policy.

In view of the existing insufficient evidence this empirical effort attempts to provide further insights into the transmission path of unconventional monetary policy on commodity prices and most crucially gauge the impact of unconventional monetary policy on commodity futures market.

In this direction, following Frankel's (2006) framework, and using weekly data spanning the period 2008:12 to 2018:06 for the U.S. economy, we generate evidence that points to a significant and positive relationship between real interest rates and commodities' real prices. The relationship however between real interest rates and some commodities' price conditional volatilities turns out to be insignificant. The evidence obtained also suggests that inventory arbitrage activities transmit the impact of the real interest rate onto commodities by strengthening the relationship between the real interest rate and commodities' real prices but weakening the relationship between the real interest rate and palladium and crude oil's price conditional variances.

Moreover, inventory arbitrage activities are significant and negative with most commodities' prices (the only exceptions are cotton, soybean and coffee's prices which are found to be positive and significant). However, the evidence on the relationship between inventory arbitrage activities and commodities' price conditional variances is mixed. In particular, the relationship between inventory arbitrage activities and the price conditional variances of cotton, soybean and coffee are significant and positive whilst the ones relating to palladium, copper and crude oil's price conditional variances are found to be significant and negative.

Further evidence suggests that speculative activities mainly transmit the effect of the real interest rate onto metals and crude oil by strengthening the rate's effect on their prices. It seems that speculative activities do not exert a significant impact on the relationship between the real interest rate and most commodities' price conditional variances. They only boost the effect of the real interest rate on palladium and crude oil's price conditional variances significantly. The relationship of speculative activities with commodities prices is positive and significant. However, the relationship of speculative activities with commodities' price conditional variances is mixed, e.g., speculative activities are positive and significant with palladium, crude oil, and coffee's price conditional variances, but negative and significant with gold, copper, and cotton's price conditional variances.

An additional innovation on the paper is the inclusion of four variables and two interaction terms (i.e., the real interest rate, the inventory arbitrage activities, the speculative activities, commodities' real prices and conditional variances, the interaction terms of the real interest rate and the inventory arbitrage activities, the interaction terms of the real interest rate and the speculative activities) in the ARMA-GARCH model to test the transmission mechanism of the inventory and speculative activities for the unconventional monetary policy's effect on commodities' real prices and volatilities.[2]

[2] Volatility can be divided into three categories: historical, conditional and implied volatility. Historical volatility is calculated with a time-series model as the standard deviation of the observed prices. Conditional volatility is calculated with an ARCH/GARCH model as the ARCH/GARCH volatility of the known information from the historical data (see Bollerslev, 1986; Engle, 1982). Implied volatility is the market's forecast of the volatility which is inferred from the prices of call options using the Black-Scholes model. In this paper, we use the ARMA-GARCH model to test the relationship between inventory arbitrage activity, speculative activity and commodity price conditional volatility. This is different to Frankel and Rose (2010), whose commodity price volatility is calculated as the historical volatility.

The contribution of our study vis-à-vis Frankel (2006) is fourfold: (a) By taking into consideration the heterogeneity of commodity prices, we provide a more in-depth analysis of the effect of the real interest rate, inventory arbitrage activities, and speculative activities on commodity prices and their volatilities. Thus, this is the first study on the transmission process of inventory and speculative activities for monetary policy to commodities' prices and volatilities. Our novel evidence shows that inventory arbitrage activities may boost the real interest rate's effect on commodities' real prices but dampen the rate's effect on palladium and crude oil's price conditional variances. Speculative activities may strengthen the real interest rate effect on metals and crude oil's prices and some commodities' price conditional variances, such as palladium and crude oil. (b) We provide evidence of a significant and positive relationship between the real interest rate and commodities' prices during the unconventional monetary policy period, which is in contrast with Frankel's (2006) theoretical negative hypothesis. (c) We further supplement the existing evidence by establishing no significant relationship between the real interest rate and some commodities' price conditional variances. (d) We finally demonstrate that the effect of the inventory arbitrage activities and the speculative activities on commodities' price conditional variances are mixed. The inventory arbitrage activities have a significant and negative relationship with palladium, copper, and crude oil's price conditional variances, but a significant and positive relationship with cotton, soybean, and coffee's price conditional variances; whilst speculative activities exert a significant and positive impact on palladium, crude oil, and coffee's price conditional variances, but they have a significant and negative effect on gold, copper, and cotton's price conditional variances.

The rest of the paper is organized as follows: Section 2 reviews the existing literature whilst Section 3 elaborates on the hypotheses and theoretical framework used in the study. Section 4 presents the data and the model utilized in the empirical investigation and Section 5 reports and discusses the results. Section 6 provides additional evidence on the robustness of the emerging evidence whilst Section 7 wraps up the study by offering some concluding remarks.

2. Literature review

2.1. The relationship between monetary policy and commodity prices

The existing literature on the relationship between monetary policy and commodity prices can be split into three strands. The first strand looks at the negative impact monetary policy exerting on commodity prices (see Akram, 2009; Basistha & Kurov, 2015; Frankel, 2006; Glick & Leduc, 2012; Gospodinov & Jamali, 2017; Kuttner, 2001; Rosa, 2014). In this context, Tomson and Summers (2012), by replicating Frankel's (2006) model with a structural break in 1985, provide evidence that points to a positive relationship between the U.S. 3-month T-bill rate and 26 individual commodities' prices over the period 1950 to 2005, but this relationship turns out to be insignificant. Frankel and Rose (2010) suggest that inventory arbitrage activity and speculative activity have negative effects on some individual commodities' prices. The effect of the real interest rate on the commodity price disappears when the data are adjusted for stability by means of first differences.

Recently, new studies in this area suggest that the substantial change in commodity prices in the last two decades is more complex than initially thought, and that this fluctuation is not merely due to changes in monetary policy, but primarily other factors such as inflation, the exchange rate, supply and demand pressure, and inventory adjustment (see Hegerty, 2016; Tan & Liu, 2015).

The second strand relates monetary policy to commodity price volatility. Gruber and Vigfusson's (2013) empirical study indicate that a lower interest rate may lead to a decreased commodity price volatility, especially that of storable commodities, because lower inventory costs may increase the incentive to smooth the price in response to transitory shocks. They also point out that a lower interest rate may not cause the price volatility to decrease, due to persistent shocks. Karali and Power (2013), by removing the price volatility term caused by macroeconomic factors from the total commodity price volatility, and focusing on the remaining volatility, suggest that, for most commodities, the low-frequency volatility is affected by inflation, industrial output, inventory, and the long-term to short-term interest rate spread, especially during the period of high volatility. Most commodities' price volatilities are increased by a positive or negative change in inflation, the industrial output index, or the long-term to short-term interest rate spread. Hayo, Kutan, and Neuenkirch (2012) adopt a GARCH (1,1) model to test the effect of monetary policy's event announcement on commodity price volatility over the period from 1998 to 2009. The results point to a positive and significant relationship between U.S. monetary policy and commodity prices. In this context, the expected variation in the target rate reduces the price volatility, whilst the unexpected variation in the target rate increases the price volatility. Furthermore, Siami-Namini, Hudson, and Trindade (2019) test commodity price indices from February 1992 to March 2017 using an autoregressive moving average–exponential generalized autoregressive conditional heteroscedasticity (ARMA-EGARCH) (1,1) process and a vector error correction model (VECM) to find the conditional volatilities of commodity price indices overshoot the monetary policy's changes.

The third strand focuses on the transmission mechanism between monetary policy and commodity prices. Mishkin (1995) and Cecchetti and Kohler (2014) summarize the four primary mechanisms: the interest rate, the exchange rate, the asset price, and the credit channel. Mishkin (1978) points out that a contractionary monetary policy causes the interest rate to increase, limiting a company's liquidity, hence stifling both investment activity and aggregate demand. Using the same line of argument, Taylor (1995) suggests that contractionary monetary policy causes the nominal interest rate to rise, whilst the goods price is affected by both the nominal interest rate and the inflation rate. In addition, Frankel (1986), referring to manufacturing commodity prices' low-speed adjustment to monetary policy changes, suggests that in the short term there exists an overshooting effect between the interest rate and agricultural commodity prices. Frankel (2006) also identifies three mechanisms through which monetary policy can affect commodity prices: the supply and demand channel, the inventory channel, and the financial channel. More recently, Frankel (2014) establishes an arbitrage model for storable commodities, providing estimates on the negative effect of the interest rate on crude oil's price. He suggests that the negative effect is transmitted from the interest rate to crude oil's price through inventory demand adjustment. Gospodinov and Jamali (2013), based on a non-arbitrage model, suggest that the unexpected part of the interest rate exerts an impact on the commodity price indirectly, and the effect is transmitted through the inventory convenience and the risk premium.

2.2. The relationship between speculative activity and commodity prices

According to the traditional speculative theory (see Working, 1960), speculation stabilizes the financial markets. It is explained that, when speculators buy/sell commodities, they increase/decrease depressed/inflated prices. Besides this, speculators take the opposing position to hedgers, and provide liquidity to the market. By taking opposing positions, they add to the overall trading volume as well. However, the non-traditional theory points out that increased participation by speculators could drive prices away from fundamental values, and so cause "bubbles" or even manipulate the market (see Hamilton, 2009; Masters, 2008, 2009). Kaldor (1976) specifies that speculative activity could sometimes stabilize and at other times destabilize the financial market because short-period expectations are most flexible, and there is a certain range of price fluctuation within which speculation is much more likely to work in a destabilizing direction, that is, when the price fluctuates within a small range and over a short period.

As far as speculative activity's effect on the commodity price is concerned, the existing empirical literature focuses on two aspects. The first is speculative activity's effect in terms of changing commodity prices (see Kaufmann & Ullman, 2009; Morana, 2013; Singleton, 2011; Tang & Xiong, 2012; Vansteenkiste, 2011). This literature supports the non-traditional theory that speculative activity boosts commodity price movements. The second aspect focuses on speculative activity's effect on commodity price volatility. Based on empirical results, some of the literature points out that speculative activity has a positive and significant effect on commodity price volatility and so destabilizes price fluctuation (see Algieri, 2012; Du, Yu, & Hayes, 2011; Hart & Kreps, 1986; Luu & Martens, 2003; Stein, 1987; Streeter & Tomek, 1992). Simultaneously, there is research indicating that speculative activity's destabilization only lasts for a short period (see Baldi, Peri, & Vandone, 2011; Lombardi & Robays, 2011). Manera, Nicolini, and Vignati (2016), using weekly data from 1986 to 2010 in a GARCH (1, 1) model, suggest that short-term speculative activity has a positive and significant impact on volatility, while long-term speculative activity has a negative effect on volatility for four energy commodities and seven non-energy commodities. Their results are in accordance with Peck (1981), Roswell and Purcell (1992), Streeter and Tomek (1992), and Brunetti and Buyuksahin (2009).

It should be noted that, in both cases, there are studies suggesting that speculative activity does not play a key role in the fluctuation of commodity prices (see Alquist & Gervais, 2012; Beidas-Strom & Pescatori, 2014; Hamilton, 2009; Kilian & Murphy, 2012; Knittel & Pindyck, 2016; Korniotis, 2009; Sanders & Irwin, 2011).

2.3. The relationship between inventory arbitrage activity and commodity prices

The theory of the effect of storage on commodity prices goes as far back as the Keynesian revolution. More specifically, Keynes (1930) argued that, under normal conditions, the commodity futures price is lower than its spot price because producers are willing to hedge themselves against the price volatility during the production period, hence the term "normal backwardation[3]". According to that theory, the commodity futures price goes up when it approaches its maturity. Kaldor (1976), by taking speculative activity into consideration, suggests there are two factors which affect a commodity futures price's basis – i.e., the interest rate and the convenience yield. He therefore suggests that the convenience yield should be deducted from the carrying cost. Only the net carrying cost, which can be positive or negative, reflects the physical stocks' effect on the commodity price basis.[4] Working (1948) takes the inventory scarcity (the inverse of inventory) into consideration to explain the inverse carrying charge in the futures market[5] (that is when the commodity futures price is higher than its spot price, which is contrary to the normal backwardation). He suggests inventory's effect on the carrying charge should be divided into two conditions. When the stock is large, the commodity futures price goes up as it approaches maturity. That is in line with Keynes' (1930) normal backwardation theory. When the stock is small, however, the normal backwardation

[3] More formally, "if the price of a futures contract that expires in the near terms is higher than the price of a contract with the same terms that expires at a later date, the relationship between the two is called backwardation. When however, the contract with the longer-term expiration commands a higher price, then this relationship is called contango" (see Financial Dictionary, The Free Dictionary by Farlex).

[4] The commodity price basis is the spread between the commodity spot price and its futures price.

[5] "'Carrying charge', like most other economic terms, is used in varying senses. The Federal Trade Commission in its valuable *Report on the Grain Trade*, uses 'carrying charge' only in the sense of carrying costs, treated usually as comprising commercial charges for interest, insurance, and storage in public elevators. (Op. cit., VI [1924], 147, 192 ff.) What are here called carrying charges it refers to always as spreads" (see Working, 1948, p.1).

theory becomes impractical. Brennan (1958) explains the inverse carrying charge from the point of view of hedging activity, and production and storage activity. Telser (1958) analyzes cotton and wheat's price basis with data from 1927 to 1953 and suggests there is no evidence of the futures price going up or down as it approaches maturity.

On the empirical front, most such studies on the theory of storage are developed by looking at different effects, i.e., inventory's effect on the commodity price basis, the effect of inventory arbitrage activity on the commodity price, monetary policy's effect on inventory and the commodity price, and the non-linear relationship between inventory and the commodity price.

As far as inventory's effect on the commodity price basis is concerned, Fama and French (1988) suggest that, when the inventory is low, the basis for the interest adjustment fluctuates more, and metal's spot price becomes more volatile than its futures price. Rougledge, Seppi, and Spatt (2000) establish an equilibrium model to show that both inventory scarcity, and supply and demand shocks, can promote the formation of the backwardation structure, with inventory scarcity being positively related to commodity price volatility. Geman and Nguyen (2005) suggest that the bean price is positively related to inventory scarcity, based on a U.S. and a global bean inventory sample. Lien and Yang (2008) suggest that both inventory scarcity and abundance can lead daily commodity prices to become more volatile. Symeonidis, Prokopczuk, Brooks, and Lazar (2012) suggest that low inventory relates to backwardation, and high inventory relates to contango.[6] The inventory is negatively related to most commodity price volatility (i.e., inventory scarcity is positively related to most commodity price volatility), especially when the market is in the structure of backwardation. Others also argue that the theory of storage is not supported by some commodities' prices (see Fama & French, 1987).

As Ng and Pirrong (1994) state, "The theory of storage posits that the marginal value of convenience declines as inventory increases" (p.206), those who focus on the effect of inventory arbitrage activity on commodity prices suggest that the convenience yield is positively related to the commodity price. Pindyck (2001) shows evidence of a positive relationship between the convenience yield and the commodity spot price. However, he also highlights that the two are not perfectly correlated. It is possible that, when the spot price is very high, the convenience yield will be very low. Benoit (2015) confirms that the convenience yield is related to inventory, conditional variance, and intra-day price change.

When it comes to inventory arbitrage activity's transmission, Frankel (2014) explores monetary policy's effect on inventory and commodity prices and suggests that the interest rate has a negative effect on the latter. He also states that a low real interest rate is one of the essential reasons for a rise in commodity price, and that the transmission mechanism works through increased demand for inventory. Further, Tan and Liu (2015)suggest that a positive shock from the interest rate leads to an increase, but not a decrease, in inventory. Other studies show that the commodity price can provide important information about the nature of monetary policy (see Bhar & Hamori, 2007).

Touching on the non-linear relationship between inventory and commodity prices, Deaton and Laroque (1992) establish a competitive storage model and indicate that a non-linear relationship is more suitable for commodity price prediction because there will not be negative inventory in the market. They also suggest that inventory speculation can cause the asymmetry in the commodity price change. Kogan, Livdan, and Yaron (2009) suggest a V-shaped non-linear relationship between commodity price volatility and its price basis. It should be stressed that their model is based on the price of non-storable consumption goods. Carbonez, Nguyen, and Sercu (2010), however, point out that there is no evidence of a V-shaped relationship between commodity price volatility and its spread for storable agricultural commodities. Gorton, Hayashi, and Rouwenhorst (2012) suggest a non-linear relationship between inventory and commodity price but find no evidence of a relationship between inventory and commodity price volatility. Geman and Smith (2013) suggest that, when the excess volatility is considered, the relationship between inventory and metal's spot price volatility is strengthened.

On the whole, the very few studies that examine the relationship between monetary policy's surprise/uncertainty, inventory, speculative activities, and commodities' prices, appear to be examining the relationships in pairs, rather than including all variables in one equation (see, Gospodinov & Jamali, 2013, 2017); moreover, these studies fail to take into account the relationship between monetary policy, inventory, speculative activities, and commodities' volatilities (see, Apergis et al., 2020); whilst most importantly they provide little information on the relationship between unconventional monetary policy and commodity prices (see, Saghaian & Reed, 2015 and Sharon et al., 2015). As such, it becomes apparent that there is a clear need for further research to provide insights into the transmission path of unconventional monetary policy on commodity prices and most crucially gauge the impact of unconventional monetary policy on commodity futures market.

3. Framework of analysis and development of hypotheses

Despite the existing evidence on the relationships between monetary policy and commodity prices, inventory arbitrage activity and commodity prices, and speculative activity and commodity prices, there is only scant evidence on the mechanisms by which inventory activity and speculative activity transmit the effect of the monetary policy on commodity prices and their volatilities (See Frankel, 2006; Frankel, 2014; Gospodinov & Jamali, 2013; Gospodinov & Jamali, 2017).

In particular, Frankel's (1986) commodity price overshooting model can be couched in the following terms:

$$\Delta p_c = \frac{1+\theta\lambda}{1-\alpha+\theta\lambda}\Delta m + \lambda\frac{1+\theta\lambda}{1-\alpha+\theta\lambda}\Delta\mu \tag{1}$$

Eq. (1) relates the commodity's price change (Δp_c) to the proportion of the change of money supply (Δm) at the rate of $\left(\frac{1+\theta\lambda}{1-\alpha+\theta\lambda}\right)$ ($\alpha > 0$). As θ goes to infinity, the coefficient goes to unity and the overshooting disappears. A change in the growth rate μ changes the long-run equilibrium price by $\lambda\Delta\mu$.

Frankel (2006) recommends adding an inventory arbitrage equation into the overshooting model; this is expressed in the following terms:

$$\mathrm{q} - \overline{q} = -\frac{1}{\theta}(i - E(\Delta p) - cy + sc + rp) \tag{2}$$

where "p" is the global economic index; "q" is the commodity's real price; "$\overline{q}$" is the commodity's real price at its equilibrium level; "i" is the nominal interest rate; "cy" is the convenience yield; "sc" is the storage costs; "rp" is the risk premium.

Eq. (2) can be re-written as follows:

$$\mathrm{q} - \overline{q} = -\frac{1}{\theta}\left(i - i_p\right) + \frac{1}{\theta}cy - \frac{1}{\theta}\mathrm{rp} + c \tag{3}$$

where "i_p" is the inflation rate; "($i - i_p$)" is the real interest; "($\mathrm{q} - \overline{q}$)" stands for the variance of the commodity's real price from the equilibrium level. Storage cost "sc" is hypothesized to be constant because commodity storage is usually kept as a fixed value and amended in a stair-like fashion.

We follow Fama and French (1988) "the Interest-Adjusted Basis" as the inventory convenience yield "cy" for arbitrage activities in our model. As the inventory arbitrage activities are carried out when the physical goods are in scarcity, rather than in abundance, the interest-adjusted basis is inverse to the inventory convenience yield (see Fama & French, 1988, p.4).

[6] See footnote 3 for definition.

To capture the risk premium "rp" for speculative activities, the ratio of the net long position of non-commercial traders to the total position of non-commercial traders is used as proposed by Ederington and Lee (2002) and Schwarz's (2012). Given that the risk premium can be regarded as the return for taking the risk in the market, and because the net long position is long (buying) position minus short (selling) position, the ratio of the net long position of non-commercial traders to the total position of non-commercial traders is inverse to the risk premium.

Eq. (3) therefore indicates that commodity's real price variance is negatively related to the real interest rate, negatively related to inventory arbitrage activity, and positively related to speculative activity.

As to the transmission of the inventory, Frankel (2014) suggests that a low real interest rate is one of the essential reasons for commodity price rise. The transmission mechanism works through the increased demand for inventory. When the demand for inventory rises, the inventory arbitrage activities become active, and may in turn magnify the effect of the low real interest rate on commodity price and variance.

Out of the very few studies that explore the transmission of speculative activities, Vansteenkiste (2011) finds that hedging activities are the key driving force behind the oil price movements from 1992 to 2004, while the speculative activities are the most prominent force behind the oil price movements after 2004; hence arguing that speculative activities may magnify the effect of the low real interest rate on commodity price and variance.

In view of the above we propose the following hypotheses:

Hypothesis 1. The U.S. real interest rate is negatively related to commodity price variance.

Hypothesis 2. Inventory arbitrage activity is negatively related to commodity price variance and may work as a transmission mechanism which boosts the effect of real interest rates on the real prices of commodities and their variances.

Hypothesis 3. Speculative activity is positively related to commodity price variance and may act as a transmission mechanism which boosts the effect of real interest rates on the real prices and variances of commodities.

4. Data and model specification

We use weekly data[7] spanning the period from 2008:12:19 to 2018:6:8[8] to assess the effect of an easy monetary policy on commodity prices and volatilities. For palladium, the sample covers the period from 2010:2:26 to 2018:6:8. (See Tables 1A and 2A in the appendix for data sources and descriptive statistics of the variables).[9]

The continuous first month (the nearest) futures price of seven individual commodities and the continuous second month (next to the nearest) futures price are used for the commodity spot price and futures price respectively.[10] The seven commodities are classified as follows: precious metals (gold and palladium), industrial metal (copper), energy (crude oil), textiles (cotton), and food stuffs (soybean and coffee). Due to data availability, we use one commodity for each category. Palladium has also been used to supplement the results pertaining to gold due to its value preservation feature against monetary depreciation. Furthermore, coffee is thought to represent those commodities whose prices are mostly affected by the export-oriented policies.

The real price of commodity j is calculated as $q_{jt} = \frac{nominal\ S_{jt}}{(1+\text{inflation rate})}$ where "t" is the time, i.e., weeks. "S_{jt}" stands for the continuous first month futures price of commodity j at time t. The inflation rate is $IR_t = \frac{CPI-100}{100}$, where the index is calculated using 2010 = 100. It should be stressed that, in view of the nature of the data for the inflation rate, i.e., it is monthly, we use the monthly value for all weeks in that month.

We take the interest-adjusted basis as the proxy for the inventory arbitrage activity. The interest-adjusted basis for commodity j is calculated as $cy_{jt}^{(n)} = (1 + i_t^{(n)})S_{jt} - F_{jt}^{(n)}$[11], where "n" equals one week; "i_t" is the risk-free interest rate proxied by the real U.S. 3-month T-bill rate; "S_{jt}" stands for the spot price which is calculated by the continuous first month futures price of commodity j at time t; "F_{jt}" stands for the futures price which is calculated by the continuous second month futures price of commodity j at time t.

Following Ederington and Lee (2002) and Schwarz (2012) we take the ratio of the net long position of non-commercial traders to the total position of non-commercial traders ("rp") of commodity j at time t as the risk premium for speculative activities' proxy:

$$rp_{jt} = \frac{long\ non-commercial\ position - short\ non-commercial\ position}{total\ non-commercial\ position}$$

The real short-term interest rate $= \frac{nominal\ short-term\ interest\ rate - inflation\ rate}{1+inflation\ rate}$. We use the U.S. 6-month T-bill rate as the real U.S. short-term interest rate, a proxy for U.S. monetary policy. The interest rate data are daily data at the end of each week.

The TED[12] spread is used as a control variable.

For robustness check, we use commodities' nominal prices in lieu of commodities' real prices and the 1-year Treasury bill rate instead of 6-month Treasury bill rate. Given that hedging activities go against the physical buy and sell activities when the commodities are bought/sold in physical market, the buyer will sell/buy in the futures market to hedge the price variance. As such we establish a new proxy for inventory level by calculating the difference between the short and long position of

[7] In practice, the inventory arbitrage activity, which is based on the physical cargo trading, may be carried out with back-to-back contracts or with trans-week/month/year contracts. The back-to-back contract means the physical cargo is bought and sold simultaneously, when the purchase contract and the sales contract are signed at the same time. Meanwhile, the speculative activity, which is based on the futures and papers trading, may be carried out at a frequency of days, weeks, months or even years, by rolling the pricing period over and over again. Therefore, weekly data can be used for both physical cargo trading activity and futures and papers trading activity.

[8] Although the QE policy ended in 2013, the Federal target rate was kept below 2% until 13th June 2018 (see appendix – QE Policy and Federal Target Rate Time Schedule). The low Federal target rate (below 2%) is also a representative of the easy monetary policy. We therefore extend our sample period to June 2018 to see the ten-year easy monetary policy's effect on commodity real prices.

[9] We test monthly data, but find the ARCH and GARCH are not significant, which means the heterogeneity is not significant in monthly data. Our results in the mean equation of GARCH model with weekly data have been confirmed by means of a SVAR model using monthly data but reported for economy of space.

[10] Geman and Smith (2013, p.13) proposition states that, "In many commodity markets, liquidity exists mainly in the futures market while spot markets are thinly traded, if at all. In these cases, it is common to use the first nearby future price as a proxy for the spot price."

[11] The theory of storage suggests that the return from purchasing commodities at time t and selling them at time T F(t, T)-S(t) equals to the interest foregone during storage S(*t*)R(t, T) plus the marginal warehouse cost W(t, T) and minus the marginal convenience yield C(t, T), which can be stated in the equation: F(t, T)-S(t) = S(*t*)R(t, T) + W(t, T)-C(t, T). For most commodities, the warehouse cost can be seen as constant. So, we can have C (t, T) = S(t) R (t, T) + S(t) - F (t, T). If we set the time span from purchasing time t to selling time T is n, we can have $cy_{jt}^{(n)} = (1 + i_t^{(n)})S_{jt} - F_{jt}^{(n)}$ for commodity j.

[12] TED is an acronym that encompasses T-Bill and ED, the Eurodollar futures contract.

commercial activities[13]. As to speculative activities, we use Working's T[14] in lieu of the ratio of the net long position of non-commercial activities to the total non-commercial positions. However, because Working's T stands for the speculative activities' filling the gap of the hedging activities, the sign of the coefficients of Working's T with commodities' prices is inverse with that of the coefficients of the ratio of the net long position of non-commercial activities to the total non-commercial positions.

Finally, the ADF unit root test shows that the commodities' real prices, the real interest rate, the inventory arbitrage activities, the speculative activities are not stationary, so we take the first-order difference to ensure stationarity. The ADF unit root test for the first-order difference time series shows they are stationary and can be included in the regression without generating spurious results. (See ADF unit root tests in Table 3A in the appendix). The Ljung-box test shows the existence of the heteroscedasticity of commodities' real prices and nominal prices[15] (See Ljung-box tests in Table 4A in the appendix).

In view of the existing heteroscedasticity, we use ARMA-GARCH[16] approach to test the relationship between monetary policy, commodity price, speculative activity, and inventory arbitrage activity. Engle (1982) recommends an ARCH model for considering the heteroscedasticity in the linear regression: $y_i = \beta_0 + \beta_1 x_{i1} + \ldots + \beta_k x_{ik} + \varepsilon_t$, $\sigma_t^2 = E(\varepsilon_t^2) = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \ldots + \alpha_p \varepsilon_{t-q}^2$, $0 < \alpha < 1$. The higher α_q is, the greater is the shock from the previous period p on the conditional variance[17] σ^2. Bollerslev (1986) adds the auto-regression of the conditional variance σ^2 to the ARCH model. Thus, the GARCH model is expressed as $\sigma_t^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \ldots + \alpha_q \varepsilon_{t-q}^2 + \beta_1 \sigma_{t-1}^2 + \ldots + \beta_p \sigma_{t-p}^2$, where p is the auto-regression order of σ_t^2, q is the lag order of ε_t^2, σ_t^2 is the conditional variance, called the GARCH variance, and ε_t^2 is the disturbance variance, called the ARCH variance.

We add exogenous variables to the conditional variance equation: $\sigma_t^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \ldots + \alpha_q \varepsilon_{t-q}^2 + \beta_1 \sigma_{t-1}^2 + \ldots + \beta_p \sigma_{t-p}^2 + \delta_1 x_{i1} + \ldots + \delta_k x_{ik}$. With this equation, we can test the impacts of the real interest rate, inventory arbitrage activity, and speculative activity on the commodity price's conditional volatility.[18]

The ARMA-GARCH model is expressed in the following terms:

The commodity price regression is given as:

$$q_{jt} - \overline{q_j} = c_j + b_{j1} i_t + b_{j2} cy_{jt} + b_{j3} rp_{jt} + \varepsilon_{jt} \tag{4}$$

Where "$q_{jt} - \overline{q_j}$" denotes the deviation of commodity j's real price from the long-run equilibrium price (here is the sample's mean), "i_t" is the real interest rate, "cy_{jt}" denotes the inventory convenience yield standing for commodity j's inventory arbitrage activity, and "rp_{jt}" is proxied for the risk premium standing for commodity j's speculative activity.

The ARCH and GARCH variance regression:

$$\sigma_{jt}^2 = \alpha_0 + \alpha_1 \varepsilon_{jt-1}^2 + \alpha_2 \varepsilon_{jt-2}^2 + \ldots + \alpha_m \varepsilon_{jt-q}^2 + \beta_1 \sigma_{jt-1}^2 + \beta_2 \sigma_{jt-2}^2 + \ldots + \beta_n \sigma_{jt-p}^2 + \delta_1 i_t + \delta_2 cy_{jt} + \delta_3 rp_{jt} \tag{5}$$

where σ_{jt}^2 stands for the GARCH variance of commodity j's price deviation from the long-run equilibrium level and ε_{jt}^2 stands for the ARCH variance of commodity j's price deviation from the long-run equilibrium level.

We use the interaction of the real interest rate and the inventory arbitrage activities and the interaction of the real interest rate and the speculative activities to gauge the effect of the inventory arbitrage activities and the speculative activities on the relationship between the real interest rate and commodities' prices and conditional variances.

5. Empirical evidence and discussion

5.1. Results

In Table 1, we report the results on the relationship between the real 6-month Treasury bill rate, the interest-adjusted basis inventory arbitrage activities, the net long position of non-commercial activities and commodities' real prices and conditional variances.

As it can be observed, the mean equation estimates suggest that the correlation between the real commodities' prices and the real interest rates are positive and significant whilst the coefficients of gold, palladium, and crude oil are notably more than one. All seven commodities' real prices are significantly correlated with the arbitrage activities. Gold, palladium, copper, and crude oil's real prices are negatively related to the arbitrage activities. The interaction term of the real interest rate and the arbitrage activities shows that the arbitrage activities may strengthen the relationship between the real interest rate and commodities' real prices. Furthermore, all seven real commodities' prices are positively and significantly associated with speculative activities. The interaction term of the real interest rate and the speculative activities shows that speculative activities strengthen the positive relationship between the real interest rate and metals' and crude oil's real prices.

Turning to the arch equation estimates, we dwell upon three main points. First, four commodities' real price conditional variances are significantly related with the real interest rate (gold, copper, crude oil, and soybean). All commodities' real price conditional variances are positively related with the real interest rate. The positive relationship between commodities' real price conditional variances and real interest rate are in line with Apergis et al. (2020).

Second, six out of seven commodities' price conditional variances are significantly related with the arbitrage activities (except for gold). Three

[13] Taušer and Čajka (2016) introduce the way of wheat farmers to lock the profit by hedging in futures market in detail (See Taušer & Čajka, 2016, pp. 176–178). When the inventory level is increased, the commodity holders' position may be seen as in long position, and they may sell futures to hedge against the price going down. And when the inventory level is decreased, the commodity holders' position may be seen as in short position, and they may buy futures to hedge against the price going up.

[14] Working (1960) suggests increased speculative positions will arise with increased hedging pressures in the futures market, therefore, he suggests an index to assess the adequacy of speculative activities in the futures market, comparing to hedging activities as follows: $T = 1 + \frac{NCS}{HL+HS}$ $(HS \geq HL)$; $T = 1 + \frac{NCL}{HL+HS}$ $(HS \leq HL)$; where NCL is the abbreviation for non-commercial long positions, NCS is non-commercial short positions; HL is the abbreviation for long hedge positions and HS is short hedge positions.

[15] Our ARMA-GARCH model also shows the coefficients of the heteroscedasticity are at 1% level of significance.

[16] We test ARMA-GARCH model with the indication of the autoregression and partial regression of the price and the residual's square and present the most significant relationship between the variables.

[17] "If a random variable y_t is drawn from the conditional density function $f = (y_t|y_{t-1})$, the forecast of today's value based upon the past information, under standard assumptions, is simply $E(y_t|y_{t-1})$, which depends upon the value of the conditioning variable y_{t-1}. The variance of this one-period forecast is given by $V(y_t|y_{t-1})$. Such an expression recognizes that the conditional forecast variance depends upon past information and may therefore be a random variable. For conventional econometric models, however, the conditional variance does not depend upon y_{t-1}. This paper will propose a class of models where the variance does depend upon the past and will argue for their usefulness in economics." (See Engle, 1982, page 987).

[18] We follow Manera et al.'s (2016) method of taking the real interest rate, inventory arbitrage activity, and speculative activity as exogenous variables in the GARCH conditional variance model to test the impacts of the three variables on the commodity's real price volatility.

commodities' real price conditional variances are negatively related with the arbitrage activities (palladium, copper, and crude oil), while four commodities' price conditional variances are positively related with the arbitrage activities (gold, cotton, soybean, and coffee). The positive relationship between commodities' price conditional variances is in line with Rougledge et al. (2000), Symeonidis et al. (2012). However, the negative relationship between palladium, copper and crude oil's price conditional variances and the arbitrage activities may be explained by Lien and Yang's (2008) results that both inventory scarcity and abundance can lead daily commodity prices to become more volatile.

The interaction term of the real interest rate and the arbitrage activities shows that the arbitrage activities weaken the relationship between the real interest rate and palladium and crude oil's price conditional variances significantly but strengthens the relationship between the real interest rate and gold, soybean, and coffee's price conditional variances significantly.

Third, six out of seven commodities' price conditional variances are significantly related with the speculative activities (except for soybean). Palladium, crude oil, and coffee's price conditional variances are positively related with the speculative activities, while gold, copper cotton and soybean's price conditional variances are negatively related with the speculative activities.

The interaction term of the real interest rate and the speculative activities shows that the speculative activities strengthen the relationship between the real interest rate and palladium and crude oil's price conditional variances significantly.

On the whole, for the prices' means (a) the relationship between commodities' real prices and the real interest rate is significantly positive, i.e., does not support hypothesis 1; (b) the arbitrage activities may increase the absolute value of the coefficients of the real interest rate and commodities' real prices; i.e. in line with hypothesis 2; (c) the relationships between the arbitrage activities and commodities' real prices are negative for most commodities i.e., in keeping with hypothesis 2; (d) the relationships between the speculative activities and commodities' real prices are positive for all seven commodities, i.e., in support of hypothesis 3; (e) the fact that we find that speculative activities exert a positive and significant impact on the relationship between the real interest rate and metals, crude oil and coffee's prices merits attention provides additional evidence in support of hypothesis 3.

As far as the conditional variances are concerned, (a) the real interest rate affects gold, copper, crude oil, and soybean's price conditional variances significantly, but not the other commodities' price conditional variances. This piece of new evidence complements hypothesis 1; (b) the arbitrage activities exert a negative impact on palladium, copper and crude oil's price conditional variances significantly, i.e., this is a piece of new evidence, i.e., in line with hypothesis 2; but exerts significantly positive impact on some commodities' price conditional variances, such as cotton, soybean and coffee, that is counter to our hypothesis 2; (c) arbitrage activities weakens the effect of the real interest rate on some commodities' real price conditional variances significantly, such as palladium and crude oil. This finding does not support hypothesis 2; (d) the speculative activities may exert significant and negative impact on such commodities' price conditional variances as gold, copper, cotton, and soybean; but are positively and significantly related with some other commodities' price conditional variances (palladium, crude oil, and coffee). This is a piece of new evidence that complements our hypothesis 3; (e) the speculative activities significantly strengthen the real interest rate's effect on some commodities' price conditional variances such as palladium and crude oil, i.e., this is in line with hypothesis 3, but significantly weaken the real interest rate's effect on gold and copper's price conditional variances, which is in counter to our hypothesis 3. The fact that the speculative activities do not affect the relationship between the real interest rate and some other commodities' price conditional variances significantly (such as cotton, soybean, and coffee) provides new evidence that complements hypothesis 3.

5.2. Discussion

The main studies in the extant literature on the relationship between monetary policy and commodities' prices have attempted to address the following hypotheses: (1) is the relationship between the two variables positive or negative; (2) do long-term interest rates have stronger effect on commodities' prices than short-term interest rates; (3) does unconventional monetary policy have stronger effect on commodities' prices than the conventional monetary policy; (4) does the transmission mechanism from monetary policy to commodities' prices work and if so, how?

This study, focusing on the first, the third and the fourth, points to explore the transmission mechanisms of the inventory arbitrage activities and the speculative activities of the unconventional monetary policy's effect on commodities' prices and conditional variances.

Other studies have focused on the positive/negative relationship between monetary policy and commodities' prices and volatilities, such as Frankel (2006), Tomson and Summers (2012), Hammoudeh, Nguyen, and Sousa (2015), Akram (2009), Basistha and Kurov (2015), Baffes and Savescu (2014), Siami-Namini et al. (2019), Frankel and Rose (2010), Hayo et al. (2012). Their results indicate that some commodities' prices and volatilities are positive with the interest rates (see Appendix B, where we summarize previous studies in the area); for example, Frankel's (2006) result indicates that metals and crude oil's real returns are positively related with the real interest rate whilst Hammoudeh et al. (2015) demonstrate that crude oil and heating oil's prices respond positively to the effective Federal Funds rate in the first two quarters. Hayo et al. (2012) show that energy's conditional variances have positive coefficient with target rate surprise. When the unconventional monetary policy is considered, Apergis et al. (2020) argue that the coefficients of metals and crude oil's prices with Federal funds rate are negative and significant, while the coefficients of metals and crude oil's conditional variances with Federal funds rate are positive and significant.

From the standpoint of monetary policy, the preceding analysis suggests that under the unconventional monetary policy, the coefficients of the real interest rate and commodities' real prices are positive and significant; whilst the coefficients of the real interest rate and commodities' conditional variances are mixed (only gold, copper, crude oil, and soybean's conditional variances are positive and significant with the real interest rate, other commodities' conditional variances are not significant). The significant and positive relationships show that under the quantitative easing monetary policy, the relationship between the real interest rate and some commodities' prices and volatilities (such as metals and crude oil) are no longer negatively related in theory. Our results indicate that such positive relationships may be boosted by the speculative activities. For example, crude oil's prices rose sharply since the beginning of quantitative easing monetary policy at the end of 2008 and remained high for a long time and did not decline until the second half of 2014 (See Figs. 1, 2, and 3 in the appendix).

As to the focus of the research, our novel evidence indicates that the inventory arbitrage activities may boost the real interest rate's effect on commodities' real prices, whilst the speculative activities may strengthen the real interest rate's effect on metals and crude oil's real prices. The inventory arbitrage activities may dampen the real interest rate's effect on metals and crude oil's conditional variances, whilst the speculative activities may boost some commodities' conditional variances such as palladium and crude oil. This significant transmission implies that under the quantitative easing monetary policy, both inventory arbitrage activities and speculative activities focus on the trading of metals and crude oil in the futures market, leading to the huge fluctuation of palladium and crude oil's prices. Our results indicate that inventory arbitrage may stabilize commodities' price fluctuations, but speculative activities may destabilize commodities' price fluctuations; further, the effect of speculative activities is greater than inventory arbitrage activities. This conclusion supplements Frankel (2014) and

Table 1
The relationship of the real 6-month T-bill rate, the interest-adjusted basis inventory arbitrage activities, the net long position of non-commercial activities and commodities' real prices and conditional variances.

	mean equation										arch equation									
commodities' real price/the specific model	real 6-month T-bill rate		arbitrage activities		real 6-month T-bill rate × arbitrage activities		speculative activities		real 6-month T-bill rate × speculative activities		real 6-month T-bill rate		arbitrage activities		real 6-month T-bill rate × arbitrage activities		speculative activities		real 6-month T-bill rate × speculative activities	
goldrp	**79.668**	***	**−6.071**	***	−0.016	**	**48.118**	**	**5.000**	***	**3.542**	***	0.011		0.007	***	**−20.822**	***	**−1.131**	**
ar (1) ma (1) arch (1 2 3 4 5)	0.000		0.000		0.041		0.022		0.007		0.005		0.881		0.003		0.000		0.070	
palladiumrp	**45.135**	***	**−5.916**	***	0.020	*	**167.225**	***	**12.943**	***	0.993		−0.763	***	−0.010	***	**26.511**	*	**3.227**	**
ar (1) ma (1) arch (1) garch (1)	0.000		0.000		0.095		0.000		0.000		0.071		0.000		0.001		0.067		0.012	
copperrp	0.189	***	**−3.599**	***	0.133	***	0.396	***	0.034	***	**1.977**	***	**−68.047**	***	−0.656		**−35.683**	***	**−2.443**	***
ar (1) ma (1) arch (3 4 5)	0.000		0.000		0.000		0.000		0.000		0.010		0.002		0.476		0.000		0.000	
crudeoilrp	**2.833**	***	−0.482	***	0.226	***	**21.398**	***	**1.226**	***	**1.071**	**	**−3.874**	***	−0.058	**	**51.493**	***	**4.000**	***
ar (8) arch (1) garch (1)	0.000		0.001		0.000		0.000		0.000		0.009		0.000		0.023		0.000		0.003	
cottonrp	0.011	***	0.080	**	0.005	*	0.064	**	−0.002		0.187		**11.659**	***	0.154		**−5.154**	**	−0.202	
ar (1/3) ma (1/3) arch (1) garch (1)	0.000		0.035		0.096		0.038		0.591		0.524		0.000		0.283		0.023		0.382	
soybeanrp	0.171	***	0.801	***	0.070	***	0.627	**	−0.012		**1.024**	*	**5.681**	***	0.552	*	**−2.439**		−0.504	
ar (1) ma (1) arch (1) garch (1)	0.000		0.000		0.000		0.045		0.686		0.061		0.000		0.079		0.685		0.540	
coffeerp	0.039	***	0.416	*	0.135	***	0.189	***	0.013	***	0.151		**31.220**	**	**2.912**	**	**7.058**	***	0.036	
ar (1) ma (1) arch (2 4 5 7)	0.000		0.066		0.000		0.000		0.005		0.736		0.026		0.016		0.001		0.918	

Note: ***, ** and * denote significance at the 1%, 5% and 10% levels. "ar ()" is the abbreviation for the autoregression lags; "ma ()" is the abbreviation for the moving average lags; "arch ()" is the abbreviation for the disturbance variance lags; "garch ()" is the abbreviation for the conditional variance lags.

Gospodinov and Jamali (2013) which do not show the transmission mechanism of the inventory and the speculative activities for monetary policy's effect on commodities' prices and volatilities. (See Appendix 1, where we summarize and compare the extant studies on the relationship between monetary policy and commodities' prices and volatilities and our results).

6. Robustness check

To consolidate our results, we conduct robustness checks by using commodities' nominal prices in lieu of commodities' real prices, the 1-year Treasury bill rate in lieu of the 6-month Treasury bill rate, the net short position of commercial activities (hedging inventory) for the interest-adjusted basis convenience yield, Working's T for the ratio of the net long position to the total position of non-commercial activities.

Table 2 reports the result on the relationship between commodities' nominal price, the real interest rate and the interest-adjusted basis inventory arbitrage activities, the ratio of the net long position to the total position of non-commercial activities. The result is the same as that in the commodities' real price model. Only the coefficient of gold's price conditional variance with the speculative activities turns to positive and insignificant.

Table 3 exhibits the relationship between commodities' real price and the real 1-year Treasury bill rate, the interest-adjusted basis inventory arbitrage activities, the ratio of the net long position to the total position of non-commercial activities. The result is the same as that in the real 6-month Treasury bill rate's model. However, the coefficient of copper's real price conditional variance with the arbitrage activities becomes positive and insignificant.

Table 4 shows the relationship between commodities' real price and the real 6-month Treasury bill rate, the hedging inventory, the ratio of the net long position to the total position of non-commercial activities. The result is much different from that in the interest-adjusted basis inventory arbitrage activities' model. The absolute value of the coefficients between hedging inventory proxy and commodities' real price conditional variances (such as copper, crude oil, cotton, soybean, and coffee) become smaller than those in the "Interest-adjusted Basis" arbitrage activities model.

Finally, Table 5 shows the results of the relationship between commodities' real price and the real 6-month Treasury bill rate, the interest-adjusted basis inventory arbitrage activities, the Working's T. The results support the findings in the model using the ratio of the net long position to the total position of non-commercial activities as the speculative activity proxy, especially the relationship of metals and crude oil's real prices and their price conditional variances with the Working's T proxy.

7. Conclusions and limitation

By considering the heterogeneity of a commodity's real price with an ARMA-GARCH model and based on weekly data spanning the period from 2008:12 to 2018:06, our results, in contrast to Frankel's (2006), suggest that the U.S. real interest rate is significantly and positively related to the commodities' prices under unconventional monetary policy. Furthermore, our new evidence also indicates that the real interest rate exerts a significant impact on some commodities' price conditional variances, such as gold, copper, crude oil, and soybean.

The nascent evidence generated in this study suggests that the inventory arbitrage activities may strengthen the relationship between the real interest rate and commodities' prices but weaken the effect of the real interest rate on some commodities' price conditional variances significantly (palladium and crude oil). The inventory arbitrage activities are negatively related to most commodities' prices. However, the impact of the inventory arbitrage activities on commodities' price conditional variances is rather mixed i.e., the relationships of the inventory arbitrage activities with palladium, copper and crude oil's price conditional variances are negative and significant, while those with cotton, soybean and coffee's price conditional variances are positive and significant.

Furthermore, our novel evidence also indicates that speculative activities may strengthen the relationship between the real interest rate and metals and crude oil's prices; but do not affect the relationship between the real interest rate and most commodities' price conditional variances significantly. They only boost the real interest rate effect on palladium and crude oil's price conditional variances significantly. Moreover, the speculative activities exert a significant and positive impact on all commodities' prices but exert a significant impact on most commodities' price conditional variances except for soybean. The evidence on the relationship between speculative activities and commodities' price conditional variances is again mixed, i.e., the speculative activities are positively related with palladium, crude oil, and coffee's price conditional variances, but negatively related with gold, copper, cotton, and soybean's price conditional variances.

The key aspects of our empirical analysis, compared to other studies in the existing literature, can be summarized as follows:

(a) We take into consideration the heterogeneity of commodity prices. This provides us with a more detailed analysis of the effect of the real interest rate, inventory arbitrage activities, and speculative activities on commodities' price volatilities. In this context, we find that the transmission of inventory arbitrage activities may be milder, compared to that of speculative activities. It may boost slightly the relationship between the real interest rate and commodities' prices but dampen slightly the relationship between the real interest rate and some commodities' price conditional variances such as palladium and crude oil.

(b) We supplement Frankel (2006) empirical evidence of a speculative activities' mechanism on the real interest rate's effect by suggesting that speculative activities may strengthen the relationship between the real interest rate and metals, crude oil and coffee's prices and the relationship between the real interest rate and some commodities' price conditional variances such as palladium and crude oil. However, speculative activities do not exert a significant impact on the relationship between the real interest rate and other commodities' prices and conditional variances.

(c) In contrast to Frankel's (2006) theoretical negative relationship, we establish a significant and positive relationship between the real interest rate and commodities' prices during the unconventional monetary policy's period. Our evidence supplements Frankel's (2006) in that the relationship between the real interest rate and some commodities' price conditional variances are not significant.

The implication of this study is of great significance to policy makers as it provides further insights into the implementation of unconventional monetary policy and its impact on the commodities market. When quantitative easing is implemented, it appears that the real interest rate is positively and significantly related to the commodities' real prices, but not significantly related to commodity price conditional variances. Such relationships can be transmitted through frequent inventory arbitrage activities and financial speculative activities. The inventory arbitrage activity may transmit the effect of unconventional monetary policy onto commodities by boosting the relationship between the real interest rate and commodities' real prices but dampening the real interest rate's effect on metals and crude oil's conditional variances. Our empirical results indicate that speculative activities may strengthen the real interest rate's effect on metals and crude oil's prices and the real interest rate's effect on some commodities' conditional variances such as palladium, crude oil, and coffee.

De Gregorio (2012) and Gomez-Pineda (2016) suggest that the transmission mechanism from commodity price fluctuation to monetary

Table 2

The relationship of the real 6-month T-bill rate, the interest-adjusted basis inventory arbitrage activities, the net long position of non- commercial activities and commodities' nominal prices and conditional variances.

	mean equation					arch equation				
commodities' nominal price/ the model	real 6-month T-bill rate	arbitrage activities	real 6-month T-bill rate × arbitrage activities	speculative activities	real 6-month T-bill rate × speculative activities	real 6-month T-bill rate	arbitrage activities	real 6-month T-bill rate × arbitrage activities	speculative activities	real 6-month T-bill rate × speculative activities
goldnp	**91.225** ***	**−6.249** ***	0.059 ***	**58.440** ***	**4.979** ***	**1.206**	0.009	0.003	**12.400**	**1.375**
ar (1 2 3 6) arch (1 2 3 5)	0.000	0.000	0.000	0.000	0.000	0.429	0.932	0.340	0.378	0.269
palladiumnp	**45.879** ***	**−6.991** ***	0.020 *	**175.570** ***	**13.818** ***	**1.176** *	−0.767 ***	−0.011 ***	**28.647** **	**3.195** ***
ar (1) ma (1) arch (1) garch (1)	0.000	0.000	0.066	0.000	0.000	0.056	0.000	0.000	0.011	0.006
coppernp	0.192 ***	**−4.348** ***	0.143 ***	0.421 ***	0.035 ***	**1.895** ***	**−65.585** ***	**−1.477** *	**−34.475** ***	**−2.193** ***
ar (1 4 7 10) ma (110) arch (3 4 5)	0.000	0.000	0.000	0.000	0.000	0.006	0.001	0.064	0.000	0.001
crudeoilnp	**2.369** ***	−1.051 ***	0.212 ***	**21.541** ***	**1.149** ***	**−2.005**	0.663 *	−0.156 ***	**52.261** ***	**4.487** ***
ar (8) arch (1) garch (1)	0.000	0.000	0.000	0.000	0.013	0.146	0.064	0.001	0.002	0.105
cottonnp	0.006 ***	0.072 *	0.005	0.018	−0.005	0.244	**10.021** ***	0.254 *	**−4.925** **	−0.245
ar (1) ma (1) arch (1) garch (1)	0.008	0.068	0.161	0.533	0.148	0.417	0.000	0.072	0.022	0.278
soybeannp	0.048 *	0.824 ***	0.058 ***	0.616 *	−0.025	0.749	**4.951** ***	0.538 *	**−1.429**	−0.388
ar (1) ma (1) arch (1) garch (1)	0.091	0.000	0.000	0.053	0.436	0.158	0.000	0.084	0.809	0.619
coffeenp	0.020 ***	0.486 *	0.128 ***	0.269 ***	0.014 **	0.077	**29.062** ***	**2.146** ***	**2.364** *	−0.101
ar (1/8) ma (1/8) arch (2 5)	0.003	0.082	0.000	0.000	0.016	0.796	0.003	0.009	0.100	0.665

Note: ***, ** and * denote significance at the 1%, 5% and 10% levels. "ar ()" is the abbreviation for the autoregression lags; "ma ()" is the abbreviation for the moving average lags; "arch ()" is the abbreviation for the disturbance variance lags; "garch ()" is the abbreviation for the conditional variance lags.

Table 3
The relationship of the real 1-year T-bill rate, the interest-adjusted basis inventory arbitrage activities, the net long position of non-commercial activities and commodities' real prices and conditional variances.

	mean equation					arch equation				
commodities' real price/the model	real 1-yearT-bill rate	arbitrage activities	real 1-year T-bill rate × arbitrage activities	speculative activities	real 1-year T-bill rate × speculative activities	real 1-year T-bill rate	arbitrage activities	real 1-year T-bill rate × arbitrage activities	speculative activities	real 1-year T-bill rate × speculative activities
goldrp	**82.090** ***	**−5.696** ***	0.003	**47.707**	**4.074**	**1.211**	0.287 *	0.003	**−25.604** ***	**−2.979** *
ar (1) ma (1) arch (1) garch (1)	0.000	0.000	0.738	0.102	0.123	0.545	0.089	0.215	0.002	0.067
palladiumrp	**46.228** ***	**−6.117** ***	0.013	**187.657** ***	**14.220** ***	1.322 *	−0.831 ***	−0.014 ***	**31.882** ***	**3.775** ***
ar (1) ma (1) arch (1) garch (1)	0.000	0.000	0.170	0.000	0.000	0.085	0.000	0.000	0.006	0.003
copperrp	0.184 ***	**−3.960** ***	0.111 ***	0.656 ***	0.048 ***	**1.647** *	0.721	1.866	**−28.930** ***	**−2.152** **
ar (1 2 8) ma (8) arch (3 4 5 7)	0.000	0.000	0.000	0.000	0.000	0.073	0.975	0.128	0.001	0.015
crudeoilrp	**2.850** ***	−0.525 ***	0.227 ***	**21.532** ***	**1.264** ***	**1.038** **	**−3.828** ***	−0.062 **	**50.490** ***	**3.928** ***
ar (8) arch (1) garch (1)	0.000	0.002	0.000	0.000	0.003	0.012	0.000	0.014	0.000	0.005
cottonrp	0.013 ***	0.074 ***	0.005	0.021	−0.004	0.162	**11.464** ***	0.121	**−4.595** **	−0.196
ar (1) ma (1) arch (1) garch (1)	0.000	0.064	0.151	0.474	0.220	0.578	0.000	0.388	0.026	0.377
soybeanrp	0.163 ***	0.809 ***	0.068 ***	0.628 **	−0.012	**1.016** *	**5.637** ***	0.535 *	**−2.347**	−0.505
ar (1) ma (1) arch (1) garch (1)	0.000	0.000	0.000	0.042	0.684	0.067	0.000	0.088	0.690	0.541
coffeerp	0.032 ***	0.426 *	0.124 ***	0.129 ***	0.009 *	0.052	**29.335** ***	**2.635** **	**5.055** ***	0.002
ar (3) arch (2 3 4 5 7)	0.000	0.079	0.000	0.003	0.069	0.898	0.010	0.022	0.006	0.996

Note: ***, ** and * denote significance at the 1%, 5% and 10% levels. "ar ()" is the abbreviation for the autoregression lags; "ma ()" is the abbreviation for the moving average lags; "arch ()" is the abbreviation for the disturbance variance lags; "garch ()" is the abbreviation for the conditional variance lags.

Table 4
The relationship of the real 6-month T-bill rate, the hedging inventory, the net long position of non-commercial activities and commodities' real prices and conditional variances.

	mean equation					arch equation				
commodities' real price/the model	real 6-month T-bill rate	hedge inventory	real 6-month T-bill rate × hedge inventory	speculative activities	real 6-month T-bill rate × speculative activities	real 6-month T-bill rate	hedge inventory	real 6-month T-bill rate × hedge inventory	speculative activities	real 6-month T-bill rate × speculative activities
goldrp	**14.454** ***	0.395 ***	0.025	**−63.453**	**−7.565**	0.573 **	−0.007	0.000	**−6.627** *	−0.871
arch (1)	0.000	0.003	0.178	0.166	0.300	0.014	0.474	0.849	0.067	0.148
palladiumrp	**12.871** ***	**1.466**	0.025	**105.574** **	**−3.543**	−0.004	−0.036	−0.012 *	**1.570**	0.373
ar (3 4 5) arch (2)	0.000	0.270	0.831	0.000	0.289	0.984	0.606	0.102	0.504	0.139
copperrp	0.036 ***	−0.002	0.000	0.401 *	0.028	−0.457	−0.543 ***	−0.017 **	**61.983** ***	**2.196** *
arch (1) garch (1)	0.000	0.381	0.155	0.100	0.317	0.540	0.000	0.012	0.000	0.072
crudeoilrp	0.493 ***	−0.019	−0.001	**30.960** ***	**1.404**	−0.680 ***	0.031 ***	0.004 ***	**−19.216** ***	**−1.950** **
ar (2) arch (2 5)	0.049	0.112	0.310	0.000	0.108	0.002	0.004	0.007	0.001	0.020
cottonrp	0.010 ***	0.000	0.000	0.045 **	0.000	0.627	0.013 **	0.001 ***	**−8.594** **	**−1.055** ***
ar (2 7) ma (3 5) arch (2 4 9)	0.000	0.472	0.708	0.011	0.729	0.147	0.018	0.001	0.012	0.001
soybeanrp	0.128 ***	0.007 ***	0.000 *	**−1.245** ***	−0.090	−0.072	0.016	0.000	**−12.018** *	−0.671
ar (3) ma (3) arch (1 4 5)	0.000	0.000	0.090	0.009	0.213	0.866	0.432	0.910	0.078	0.512
coffeerp	0.008	0.003 ***	0.000	−0.094	−0.008	−0.271	−0.053	−0.016 *	**11.189** ***	**1.407** **
ar (5) arch (4 5 7)	0.179	0.007	0.245	0.233	0.588	0.317	0.293	0.055	0.003	0.047

Note: ***, ** and * denote significance at the 1%, 5% and 10% levels. "ar ()" is the abbreviation for the autoregression lags; "ma ()" is the abbreviation for the moving average lags; "arch ()" is the abbreviation for the disturbance variance lags; "garch ()" is the abbreviation for the conditional variance lags.

Table 5
The relationship of the real 6-month T-bill rate, the interest-adjusted basis inventory arbitrage activities, the Working's T and commodities' real prices and conditional variances.

	mean equation										arch equation									
commodities' real price/the model	real 6-month T-bill rate		arbitrage activities		real 6-month T-bill rate × arbitrage activities		Working's T		real 6-month T-bill rate × Working's T		real 6-month T-bill rate		arbitrage activities		real 6-month T-bill rate × arbitrage activities		Working's T		real 6-month T-bill rate × Working's T	
goldrp	**97.543**	***	**−5.840**	***	0.012		**−98.139**	**	**−9.079**	**	**−2.274**		0.139		0.006		**27.811**		**2.941**	
ar (2 4) arch (1 3 5 8 10)	0.000		0.000		0.115		0.046		0.019		0.497		0.126		0.116		0.475		0.324	
palladiumrp	**78.725**	***	**−6.354**	***	0.022	**	**−214.670**	***	**−18.205**	***	**7.819**	***	−0.555	***	−0.025	***	**−28.266**	***	**−2.874**	***
ar (1 6 7) arch (2 4)	0.000		0.000		0.014		0.000		0.000		0.000		0.000		0.000		0.002		0.000	
copperrp	0.238	***	**−3.453**	***	0.147	***	−0.468	***	−0.033	***	**−11.285**	***	**138.860**	**	3.334	**	**83.759**	***	**6.800**	***
ar (1 7) ma (13) arch (1 3 4 5)	0.000		0.000		0.000		0.000		0.003		0.003		0.018		0.046		0.000		0.001	
crudeoilrp	**6.989**	***	−0.418	**	0.218	***	**−61.662**	***	**−3.321**	**	**−7.508**		**−2.405**	***	−0.102	***	**96.928**	**	**7.109**	
ar (1) ma (1) arch (1) garch (1)	0.000		0.011		0.000		0.001		0.035		0.211		0.000		0.000		0.012		0.180	
cottonrp	0.016	*	−0.051		−0.003		−0.154	*	−0.005		−0.328		**11.856**	***	0.208		**1.952**		0.335	
ar (1/4) ma (1/4) arch (2 9)	0.096		0.145		0.366		0.061		0.573		0.650		0.000		0.195		0.720		0.573	
soybeanrp	−0.017		0.764	***	0.067	***	0.279	*	0.143	**	0.790		**4.739**	***	0.323		**−5.686**	***	−0.738	
arch (1 2 4 5)	0.839		0.000		0.000		0.066		0.039		0.589		0.000		0.134		0.008		0.556	
coffeerp	0.068	***	0.135		0.123	***	−0.104		−0.024		1.621		**26.034**	*	**2.533**	**	**−33.054**	***	−1.260	
ar (1) ma (1 7) arch (2 3 5 7)	0.003		0.574		0.000		0.524		0.191		0.303		0.077		0.018		0.000		0.323	

Note: ***, ** and * denote significance at the 1%, 5% and 10% levels. "ar ()" is the abbreviation for the autoregression lags; "ma ()" is the abbreviation for the moving average lags; "arch ()" is the abbreviation for the disturbance variance lags; "garch ()" is the abbreviation for the conditional variance lags.

policy's response begins with the transmission from commodity price to noncore inflation, such as energy and food's inflation, then further to core inflation by Phillips curve effect, and finally tackles the monetary policy's response and the real interest rate. So, when policy makers intend to carry out the unconventional monetary policy, it would be advisable that they take into consideration the relationship between the real interest rate and commodities' prices and volatilities and try to balance the transmission mechanism of the inventory arbitrage activities and the speculative activities.

According to Liao, He and Chen (2013) "the purpose of QE is to stimulate the real estate market directly in USA… the mortgage rates have been lowered to remove the obstacles to economic recovery. Since the Federal Reserve implemented QE in 2008, it has not only rescued commercial banks, investment banks and other financial institutions but also mortgage companies, mutual funds, enterprises and other non-financial institutions." (p.60–61). Therefore, the implication for policy makers may lie in the system by which the large amount of funds that the Federal Reserve injects in the market may flow to the real economies instead of the financial speculative markets. As such, the Federal Reserve may increase the market interest rate market but maintain the low interest rate to the real economies whilst at the same time individual families can be provided with consumer coupons to stimulate consumption.

Potential limitations of this study could exist in the nature of the data used. More specifically, the frequency of the data, i.e., weekly, prevents us from exploring the daily responses of commodity prices and volatilities, and inventory arbitrage and speculative activity, to monetary policy changes. According to Basistha and Kurov (2015), the response of the energy commodity price to an FOMC announcement is significant when daily data are used but lasts for only 5 to 20 trading days. In this context, future research could be conducted to investigate the channels through which speculative activity transmits monetary policy's effect onto commodity prices and volatilities using high-frequency data. In addition, given the inherent limitations emanating from the GARCH methodological framework of analysis - i.e. the fact that we have only been able to test the relationships between the real interest rate, inventory arbitrage activity, speculative activity and the commodities' real prices by considering their conditional volatilities - we feel that future research should also consider the disturbance volatility, so as to provide a more comprehensive empirical exploration of the underlying relationships.

Appendix A. Appendix

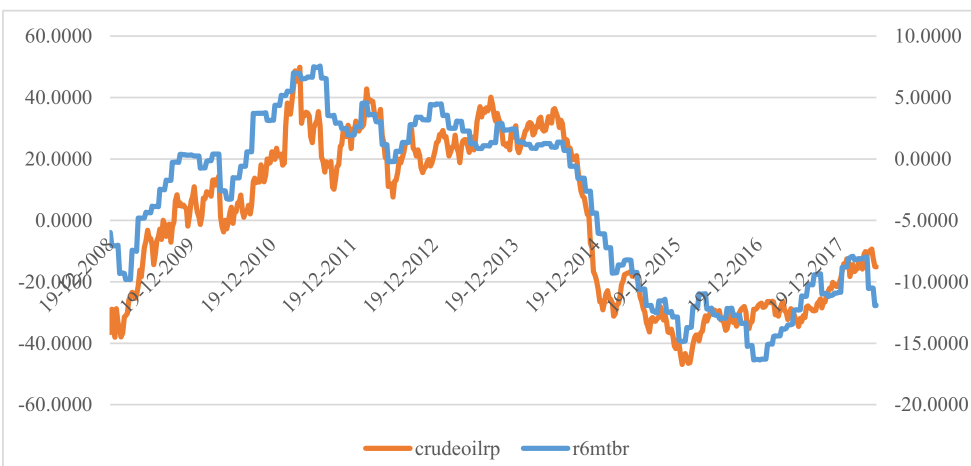

Fig. 1. The Real 6-Month Treasury Bill Rate and Crude oil's Real Prices Variance from Its Average Level.
Note: "crudeoilrp" is the abbreviation for crude oil's real price variance from its average level; "r6mtbr" is the abbreviation for the real 6-month treasury bill rate.

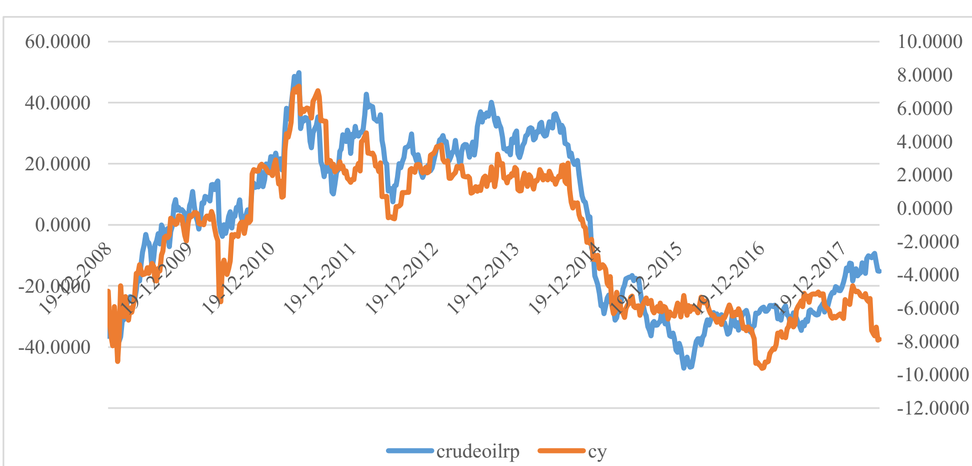

Fig. 2. The Inventory Arbitrage Activity and Crude oil's Real Prices Variance from Its Average Level.
Note: "crudeoilrp" is the abbreviation for crude oil's real price variance from its average level; "cy" is the abbreviation for the inventory convenience yield proxy for the inventory arbitrage activity.

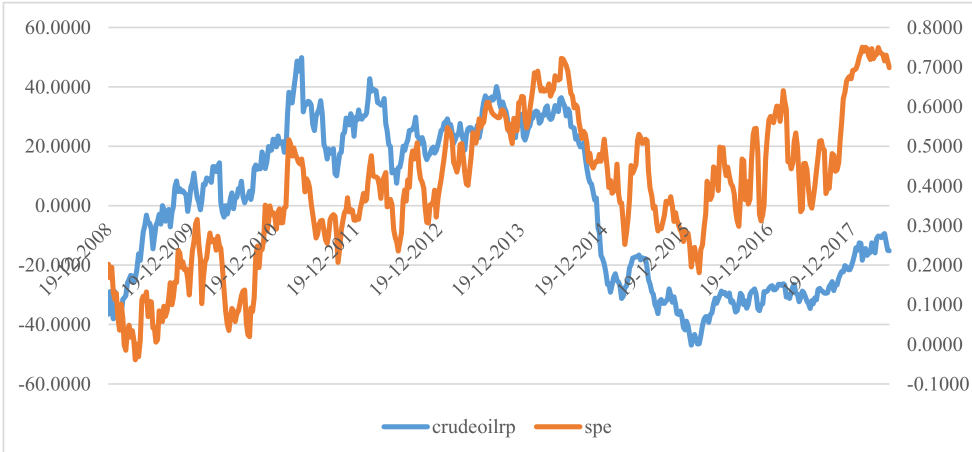

Fig. 3. The Speculative Activity and Crude oil's Real Prices Variance from Its Average Level.
Note: "crudeoilrp" is the abbreviation for crude oil's real price variance from its average level; "spe" is the abbreviation for the percentage of the net long position of non-commercial to the total position of non-commercial proxy for the speculative activity.
Data source: CBOT, FRED.

Table 1A
Data sources.

Variables			Data sources
Dependent variables	7 individual commodity prices	gold, copper	COMEX from Reuters
		palladium, light sweet crude oil	NYMEX from Reuters
		cotton, coffee	ICE U.S. from Reuters
		soybean	CHICAGO BOARD OF TRADE from Reuters
Independent variables	non-commercial positions of 7 individual commodities	palladium, light sweet crude oil	NEW YORK MERCANTILE EXCHANGE from Reuters
		gold, copper	COMMODITY EXCHANGE INC. from Reuters
		cotton	NEW YORK COTTON EXCHANGE from Reuters
		soybean	CHICAGO BOARD OF TRADE from Reuters
		coffee	COFFEE/ SUGAR EXCHANGE, ICE FUTURES U.S. from Reuters
	interest rates	U.S. 6-month treasury bill rate (second market)	FRED
		U.S. 1-year treasury bill rate (second market)	FRED
		U.S. 3-month treasury bill rate	FRED
	control variable	TED spread	FRED
Others	inflation rate	U.S. CPI	OECD

Table 2A
Descriptive statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
threemtbr	495	0.27	0.419	0	1.9
sixmtbr	495	0.35	0.451	0.02	2.07
oneytbr	495	0.453	0.475	0.082	2.232
goldnc1	495	1307.657	216.164	836.4	1873.7
goldnc2	495	1308.049	216.238	836.6	1874.4
goldnspe	495	0.525	0.197	0.032	0.843
goldwkt	495	1.159	0.093	1.048	1.475
goldhinv	495	173.796	78.519	2.911	340.207
palladiumnc1	432	723.624	135.755	426.9	1108
palladiumnc2	432	723.648	135.32	426.9	1109.3
palladiumnspe	432	0.597	0.2	0.067	0.849
palladiumwkt	432	1.207	0.161	1.058	1.831
palladiumhinv	432	14.729	7.098	1.818	32.356
coppernc1	495	3.039	0.65	1.275	4.571
coppernc2	495	3.039	0.65	1.288	4.58
coppernspe	495	−0.003	0.211	−0.66	0.419
copperwkt	495	1.304	0.115	1.074	1.655
copperhinv	495	−0.329	26.79	−53.991	66.222
crudeoilnc1	495	73.313	22.477	29.42	113.93
crudeoilnc2	495	73.882	22.075	30.39	114.43
crudeoilnspe	495	0.393	0.182	−0.039	0.75

(continued on next page)

Table 2A (*continued*)

Variable	Obs	Mean	Std. Dev.	Min	Max
crudeoilwkt	495	1.118	0.038	1.05	1.248
crudeoilhinv	495	270.586	163.241	−7.089	764.797
cottonnc1	495	0.81	0.275	0.403	2.151
cottonnc2	495	0.802	0.25	0.414	2.127
cottonnspe	495	0.355	0.249	−0.199	0.818
cottonwkt	495	1.159	0.093	1.037	1.437
cottonhinv	495	43.124	37.458	−33.039	139.107
soybeannc1	495	11.506	2.189	8.55	17.645
soybeannc2	495	11.41	2.097	8.552	17.565
soybeannspe	495	0.347	0.268	−0.256	0.804
soybeanwkt	495	1.147	0.078	1.036	1.378
soybeanhinv	495	56.814	91.132	−134.427	260.845
coffeenc1	495	1.559	0.431	1.041	2.993
coffeenc2	495	1.582	0.43	1.064	2.999
coffeenspe	495	0.185	0.328	−0.333	0.755
coffeewkt	495	1.166	0.088	1.037	1.353
coffeehinv	495	10.677	25.126	−44.332	69.632

Note: “threemtbr” is the abbreviation for 3-month Treasury bill rate; “sixmtbr” is the abbreviation for 6-month Treasury bill rate; “oneytbr” is the abbreviation for 1-year Treasury bill rate; “commoditync1” is the abbreviation for the continuous first month futures price of the commodity; “commoditync2” is the abbreviation for the continuous second month futures price of the commodity; “commodityspe” is the ratio of the net long position of non-commercial of the commodity to its total non-commercial positions; “commoditywkt” is the Working’s T of the commodity; “commodityhinv” is the net short position of commercial of the commodity.

Table 3A
ADF unit root tests.

	Z value	*p*-value	Z value - first difference	p-value
teds	−6.595			
r6mtbr	−0.545	0.883	−22.384	0.000
r1ytbr	−0.534	0.885	−22.236	0.000
goldnp	−2.343	0.158	−21.497	0.000
goldrp	−1.823	0.369	−21.080	0.000
goldcy	−0.471	0.898	−22.283	0.000
goldr6mtbrcy	−1.070	0.727	−23.047	0.000
goldr1ytbrcy	−1.079	0.723	−22.896	0.000
goldspe	−2.963	0.039	−17.606	0.000
goldr6mtbrspe	−1.614	0.476	−18.565	0.000
goldr1ytbrspe	−1.589	0.489	−18.541	0.000
goldwkt	−2.967	0.038	−16.830	0.000
goldr6mtbrwkt	−0.622	0.866	−21.058	0.000
goldhinv	−2.741	0.067	−17.193	0.000
goldr6mtbrhinv	−1.585	0.491	−18.015	0.000
palladiumnp	−2.029	0.274	−20.738	0.000
palladiumrp	−2.334	0.161	−20.739	0.000
palladiumcy	−0.164	0.943	−21.833	0.000
palladiumr6mtbrcy	−0.947	0.772	−22.121	0.000
palladiumr1ytbrcy	−0.953	0.770	−22.095	0.000
palladiumspe	−2.663	0.081	−15.076	0.000
palladiumr6mtbrspe	−0.914	0.783	−16.293	0.000
palladiumr1ytbrspe	−0.915	0.783	−16.291	0.000
palladiumwkt	−2.773	0.062	−14.551	0.000
palladiumr6mtbrwkt	−0.777	0.826	−18.098	0.000
palladiumhinv	−2.297	0.173	−15.400	0.000
palladiumr6mtbrhinv	−1.031	0.742	−17.489	0.000
coppernp	−2.759	0.064	−23.165	0.000
copperrp	−2.239	0.192	−22.568	0.000
coppercy	−0.434	0.904	−22.172	0.000
copperr6mtbrcy	−0.985	0.759	−21.897	0.000
copperr1ytbrcy	−1.003	0.752	−21.814	0.000
copperspe	−2.904	0.045	−18.110	0.000
copperr6mtbrspe	−2.377	0.148	−17.397	0.000
copperr1ytbrspe	−2.332	0.162	−17.379	0.000
copperwkt	−2.706	0.073	−21.853	0.000
copperr6mtbrwkt	−0.571	0.878	−22.596	0.000
copperhinv	−2.210	0.203	−16.231	0.000
copperr6mtbrhinv	−1.963	0.303	−15.531	0.000
crudeoilnp	−1.989	0.292	−21.710	0.000
crudeoilrp	−1.688	0.438	−21.327	0.000
crudeoilcy	−1.932	0.317	−25.315	0.000
crudeoilr6mtbrcy	−1.531	0.518	−24.684	0.000
crudeoilr1ytbrcy	−1.492	0.537	−24.342	0.000
crudeoilspe	−2.062	0.260	−18.921	0.000
crudeoilr6mtbrspe	−0.519	0.888	−20.300	0.000

(*continued on next page*)

Table 3A (*continued*)

	Z value	*p*-value	Z value - first difference	p-value
crudeoilr1ytbrspe	−0.520	0.888	−20.250	0.000
crudeoilwkt	−3.022	0.033		
crudeoilr6mtbrwkt	−0.632	0.864	−21.656	0.000
crudeoilhinv	−0.829	0.811	−16.428	0.000
crudeoilr6mtbrhinv	0.189	0.972	−20.205	0.000
cottonnp	−2.060	0.261	−20.686	0.000
cottonrp	−1.885	0.339	−20.435	0.000
cottoncy	−3.758	0.003		
cottonr6mtbrcy	−3.805	0.003		
cottonr1ytbrcy	−3.845	0.003		
cottonspe	−2.554	0.103	−17.258	0.000
cottonr6mtbrspe	−0.862	0.800	−17.961	0.000
cottonr1ytbrspe	−0.861	0.801	−17.938	0.000
cottonwkt	−2.486	0.119	−18.759	0.000
cottonr6mtbrwkt	−0.711	0.854	−22.200	0.000
cottonhinv	−1.957	0.306	−16.031	0.000
cottonr6mtbrhinv	−0.689	0.850	−16.860	0.000
soybeannp	−2.170	0.217	−23.277	0.000
soybeanrp	−1.641	0.462	−23.092	0.000
soybeancy	−2.190	0.210	−31.697	0.000
soybeanr6mtbrcy	−1.306	0.626	−24.268	0.000
soybeanr1ytbrcy	−1.315	0.622	−24.186	0.000
soybeanspe	−2.570	0.099	−16.709	0.000
soybeanr6mtbrspe	−1.922	0.322	−17.282	0.000
soybeanr1ytbrspe	−1.915	0.325	−17.259	0.000
soybeanwkt	−3.288	0.015		
soybeanr6mtbrwkt	−0.640	0.862	−22.268	0.000
soybeanhinv	−2.348	0.157	−15.915	0.000
soybeanr6mtbrhinv	−2.556	0.102	−17.356	0.000
coffeenp	−1.807	0.377	−19.986	0.000
coffeerp	−1.472	0.547	−19.492	0.000
coffeecy	−1.279	0.639	−23.505	0.000
coffeer6mtbrcy	−1.376	0.594	−23.687	0.000
coffeer1ytbrcy	−1.382	0.591	−23.541	0.000
coffeespe	−2.266	0.183	−16.831	0.000
coffeer6mtbrspe	−2.579	0.097	−18.610	0.000
coffeer1ytbrspe	−2.561	0.101	−18.567	0.000
coffeewkt	−2.101	0.244	−18.051	0.000
coffeer6mtbrwkt	−0.493	0.893	−22.202	0.000
coffeehinv	−2.255	0.187	−17.583	0.000
coffeer6mtbrhinv	−2.407	0.140	−18.318	0.000

5% Critical Value: −2.876.

Note: "r6mtbr" is the abbreviation for real 6-month T-bill rate; "r1ytbr" is the abbreviation for real 1-year T-bill rate; "commoditynp" is the abbreviation for the nominal price of the commodity; "commodityrp" is the abbreviation for the real price of the commodity; "commoditycy" is the abbreviation for the interest-adjusted basis inventory convenience yield for arbitrage activities; "commodityspe" is the abbreviation for the ratio of the net long position of non-commercial to the total non-commercial positions for speculative activities; "commodity6mtbrcy" is the abbreviation for the interactive term of the real 6-month T-bill rate and the interest-adjusted basis inventory convenience yield; "commodity6mtbrspe" is the abbreviation for the interactive term of the real 6-month T-bill rate and the ratio of the net long position of non-commercial to the total non-commercial positions for speculative activities; "commodityhinv" is the abbreviation for the net short position of commercial for inventory; "commodity6mtbrhinv" is the abbreviation for the interactive term of the real 6-month T-bill rate and the net short position of commercial for inventory; "commoditywkt" is the abbreviation for Working's T of the commodity; "commodity6mtbrwkt" is the abbreviation for the interactive term of the real 6-month T-bill rate and Working's T of the commodity; "commodity1ytbrcy" is the abbreviation for the interactive term of the real 1-year T-bill rate and the interest-adjusted basis inventory convenience yield; "commodity1ytbrspe" is the abbreviation for the interactive term of the real 1-year T-bill rate and the net long position of non-commercial.

Table 4A
Ljung-box tests.

commodity price	Q test for mean equation	*p* value	Q test for ARCH equation	p value
goldrp	59.670	0.023	208.254	0.000
palladiumrp	42.583	0.361	82.090	0.000
copperrp	54.189	0.067	242.437	0.000
crudeoilrp	30.761	0.853	63.177	0.011
cottonrp	109.699	0.000	217.538	0.000
soybeanrp	28.501	0.913	127.894	0.000
coffeerp	95.877	0.000	220.634	0.000

Table 5A
QE policy and federal target rate time map.

QE policy		Federal target rate	
		18th September 2007	to lower the target rate from 5.25% to 4.75%
QE1: 25th November 2008 - 28th April 2010	to purchase institutional bonds and mortgage-backed securities (MBS)		
		16th December 2008	to lower the target rate to 0–0.25%
QE2: 4th November 2010–June 2011	to further purchase $600 billion worth of longer-term US Treasury bonds		
QE3: 14th September 2012	to purchase $40 billion worth of mortgage-backed securities (MBS) each month and to leave the distortion operation unchanged		
QE4: 13th December 2012	to purchase 45 billion US dollars of government bonds each month to replace the distortion operation		
		15th December 2016	to raise the target rate to 0.5%–0.75%
		16th March 2017	to raise the target rate to 0.75%–1%
		15th June 2017	to raise the target rate to 1%–1.25%
		13th June 2018	to raise the target rate to 1.75%–2%

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.irfa.2022.102027.

References

Akram, F. (2009). Commodity prices, interest rates and the dollar. *Energy Economics, 31*, 838–851.

Algieri, B. (2012). *Price volatility, speculation and excessive speculation in commodity markets: Sheep or shepherd behavior?*. ZEF Discussion Papers on Development Policy, No. 166.

Alquist, R., & Gervais, O. (2012). The role of financial speculation in driving the price of crude oil. *The Energy Journal, 34*(3), 35–54.

Apergis, N., Chatziantoniou, I., & Cooray, A. (2020). Monetary policy and commodity markets: Unconventional versus conventional impact and the role of economic uncertainty. *International Review of Financial Analysis, 71*(2020), 101536.

Baffes, J., & Savescu, C. (2014). Monetary conditions and metal prices. *Applied Economics Letters, 21*(7), 447–452.

Baldi, L., Peri, M., & Vandone, D. (2011). *Spot and futures prices of agricultural commodities: Fundamentals and speculation* (Working paper).

Basistha, A., & Kurov, A. (2015). The impact of monetary policy surprises on energy prices. *The Journal of Futures Markets, 35*(1, Jan), 87–103.

Beidas-Strom, S., & Pescatori, A. (2014). *Oil price volatility and the role of speculation. IMF working paper 14/2018*.

Benoit, S. (2015). Explaining the convenience yield in the WTI crude oil market using realized volatility and jumps. *Economic Modelling, 44*, 243–251.

Bhar, R., & Hamori, S. (2007). Information content of commodity futures prices for monetary price. *Economic Modelling, 25*, 274–283.

Bollerslev, T. (1986). Generalized autoregressive conditional heteroskedasticity. *Journal of Econometrics, 31*, 307–327.

Brennan, M. (1958). The supply of storage. *The American Economic Review, 48*(1, Mar), 50–72.

Brunetti, C., & Buyuksahin, B. (2009). *Is speculation destabilizing?* (SSRN working paper).

Carbonez, K., Nguyen, T., & Sercu, P. (2010). *The asymmetric effects of scarcity and abundance on storable commodity price dynamics and hedge ratios*. Working paper. Katholieke Universiteit Leuven.

Cecchetti, S., & Kohler, M. (2014). When capital adequacy and interest rate policy are substitutes (and when they are not). *International Journal of Central Banking, 10*(3, Sep), 1–28.

De Gregorio, J. (2012). Policy corner: Commodity prices, monetary policy, and inflation. *IMF Economic Review, 60*(4), 600–633.

Deaton, A., & Laroque, G. (1992). On the behavior of commodity prices. *Review of Economic Studies, 59*(1), 1–23.

Du, X., Yu, C., & Hayes, D. (2011). Speculation and volatility spillover in the crude oil and agricultural commodity markets: A Bayesian analysis. *Energy Economics, 33*, 497–503.

Ederington, L., & Lee, J. (2002). Who trades futures and how: Evidence from the heating oil futures market. *The Journal of Business, 75*(2, Apr), 353–373.

Engle, R. (1982). Autoregressive conditional heteroscedasticity with estimates of the variance of United Kingdom inflation. *Econometrica, 50*(4, Jul), 987–1007.

Fama, E., & French, K. (1987). Commodity futures prices: Some evidence on forecast power, premiums, and the theory of storage. *Journal of Business, 60*(1), 55–73.

Fama, E., & French, K. (1988). Business cycles and the behavior of metals prices. *The Journal of Finance, 43*(5), 1075–1093.

Frankel, J. (1986). Expectations and commodity price dynamics: The overshooting model. *American Journal of Agricultural Economics, 68*(2, May), 344–348.

Frankel, J. (2006). *The effect of monetary policy on real commodity prices*. NBER working paper, no. 12713.

Frankel, J. (2014). Effects of speculation and interest rates in a "carry trade" model of commodity prices. *Journal of International Money and Finance, 42*, 88–112.

Frankel, J., & Rose, A. (2010). *Determinants of agricultural and mineral commodity prices. HKS faculty research Working paper series RWP10–038*. John F. Kennedy School of Government, Harvard University.

Geman, H., & Nguyen, V. (2005). Soybean inventory and forward curve dynamics. *Management Science, 51*(7), 1076–1091.

Geman, H., & Smith, W. O. (2013). Theory of storage, inventory and volatility in the LME base metals. *Resources Policy, 38*(1), 18–28.

Glick, R., & Leduc, S. (2012). Central bank announcements of asset purchases and the impact on global financial and commodity markets. *Journal of International Money and Finance, 31*, 2078–2101.

Gomez-Pineda, J. G. (2016). *Commodity price fluctuations, core inflation and policy interest rates*. Banco de la Republica de Colombia, No. 967.

Gorton, G., Hayashi, F., & Rouwenhorst, K. (2012). The fundamentals of commodity futures returns. *Review of Finance, 17*, 35–105.

Gospodinov, N., & Jamali, I. (2013). Monetary policy surprises, positions of traders, and changes in commodity futures prices. In *Federal Reserve Bank of Atlanta working paper, 2013-12*.

Gospodinov, N., & Jamali, I. (2017). Monetary policy uncertainty, positions of traders and changes in commodity futures prices. *European Financial Management, 2018*(24), 239–260.

Gruber, J., & Vigfusson, R. (2013). *Interest rates and the volatility and correlation of commodity prices* (SSRN working paper).

Hamilton, J. (2009). *Causes and consequences of the oil shock of 2007–2008*. NBER working paper, no. 15002.

Hammoudeh, S., Nguyen, D. K., & Sousa, R. M. (2015). US monetary policy and sectoral commodity prices. *Journal of International Money and Finance, 57*, 61–85.

Hart, D., & Kreps, M. (1986). Price destabilizing speculation. *Journal of Political Economy, 94*(5), 927–952.

Hayo, B., Kutan, A. M., & Neuenkirch, M. (2012). Communication matters: US monetary policy and commodity price volatility. *Economics Letters, 117*, 247–249.

Hegerty, S. (2016). Commodity-price volatility and macroeconomic spillovers: Evidence from nine emerging markets. *North American Journal of Economics and Finance, 35*, 23–37.

Kaldor, N. (1976). Speculation and economic stability. In *The economics of futures trading* (pp. 111–123). London: Palgrave Macmillan.

Karali, B., & Power, G. (2013). Short- and long-run determinants of commodity price volatility. *American Journal of Agricultural Economics, 95*(3), 724–773.

Kaufmann, R., & Ullman, B. (2009). Oil prices, speculation, and fundamentals: Interpreting causal relations among spot and futures prices. *Energy Economics, 31*, 550–558.

Keynes, J. (1930). *A treatise on money* (vol. II, pp. 142–144). London: Macmillan.

Kilian, L., & Murphy, D. (2012). Why agnostic sign restrictions are not enough: Understanding the dynamics of oil market VAR models. *Journal of the European Economic Association, 10*(5, Oct), 1166–1188.
Knittel, C., & Pindyck, R. (2016). The simple economics of commodity price speculation. *American Economic Journal: Macroeconomics, 8*(2), 85–110.
Kogan, L., Livdan, D., & Yaron, A. (2009). Oil futures prices in a production economy with investment constraints. The. *Journal of Finance, 64*(3, Jun), 1345–1375.
Korniotis, G. (2009). *Does speculation affect spot price levels? The case of metals with and without futures markets* (pp. 2009–2029). Washington, D.C: Finance and Economics Discussion Series, Divisions of Research & Statistics and Monetary Affairs, Federal Reserve Board.
Kuttner, K. (2001). Monetary policy surprises, positions of traders, and changes in commodity futures prices. *Journal of Monetary Economics, 47*, 523–544.
Liao, G. M., He, C. T., & Chen, W. L. (2013). The shift of USA monetary policy and the logic behind it. *Shanghai Finance, 3*, 57–62.
Lien, D., & Yang, L. (2008). Asymmetric effect of basis on dynamic futures hedging: Empirical evidence from commodity markets. *Journal of Banking & Finance, 32*, 187–198.
Lombardi, M., & Robays, I. (2011). *Do financial investors destabilize the oil price?*. ECB working paper, no. 1346.
Luu, C., & Martens, M. (2003). Testing the mixture-of-distributions hypothesis using "realized" volatility. *Journal of Futures Markets: Futures, Options, and Other Derivative Products, 23*(7), 661–679.
Manera, M., Nicolini, M., & Vignati, I. (2016). Modelling futures price volatility in energy markets: Is there a role for financial speculation? *Energy Economics, 53*, 220–229.
Masters, W. (2008). *Testimony before the committee on homeland security and governmental affairs*. United States Senate. May 20.
Masters, W. (2009). *Testimony before the commodity futures trading commission*. United States Senate. August 5.
Mishkin, F. (1978). Efficient-markets theory: Implications for monetary policy. *Brookings Papers on Economic Activity, 9*(3, Jan), 707–752.
Mishkin, F. (1995). Symposium on the monetary transmission mechanism. *Journal of Economic Perspectives, 9*(4, Fall), 3–10.
Morana, C. (2013). Oil price dynamics, macro-finance interactions and the role of financial speculation. *Journal of Banking & Finance, 37*, 206–226.
Ng, V., & Pirrong, S. (1994). Fundamentals and volatility: Storage, spreads, and the dynamics of metals prices. *The Journal of Business, 67*(2, Apr), 203–230.
Peck, A. (1981). The adequacy of speculation on the wheat, corn, and soybean futures markets. *Research in Domestic and International Agribusiness Management, 2*, 17–29.
Pindyck, R. (2001). The dynamics of commodity spot and futures markets: A primer. *The Energy Journal, 22*(3), 1–29.
Rosa, C. (2014). The high-frequency response of energy prices to U.S. monetary policy: Understanding the empirical evidence. *Energy Economics, 45*, 295–303.
Roswell, J., & Purcell, W. (1992). Speculative activity and price volatility in the live cattle futures market. In *Proceedings of the NCR-134 conference on applied commodity Price analysis, forecasting, and market risk management. Chicago, IL*.
Rougledge, B., Seppi, D., & Spatt, C. (2000). Equilibrium forward curves for commodities. *The Journal of Finance, 55*(3), 1297–1338.
Saghaian, S., & Reed, M. (2015). Spillover effects of U.S. Federal Reserve's recent quantitative easing on Canadian commodity prices. *International Journal of Food and Agricultural Economics, 3*(1), 33–43.
Sanders, S., & Irwin, D. (2011). The impact of index funds in commodity futures markets: A systems approach. *The Journal of Alternative Investments, Summer*, 40–49.
Schwarz, K. (2012). Are speculators informed? *Journal of Futures Markets, 32*(1), 1–23.
Sharon, K., Eric, S., & Lena, S. (2015). *Large-scale asset purchases: Impact on commodity prices and international spillover effects*. Bank of Canada Working paper, no. 2015-21.
Siami-Namini, S., Hudson, D., & Trindade, A. (2019). Commodity price volatility and U. S. monetary policy: Commodity price overshooting revisited. *Agribusiness, 35*, 200–218.
Singleton, K. (2011). *Investor flows and the 2008 boom/bust in oil prices* (SSRN working paper).
Stein, C. (1987). Informational externalities and welfare-reducing speculation. *Journal of Political Economy, 95*(6), 1123–1145.
Streeter, H., & Tomek, G. (1992). Variability in soybean futures prices: An integrated framework. *The Journal of Futures Markets, 12*(6), 705–728.
Symeonidis, L., Prokopczuk, M., Brooks, C., & Lazar, E. (2012). Futures basis, inventory and commodity price volatility: An empirical analysis. *Economic Modelling, 29*, 2651–2663.
Tan, F., & Liu, J. (2015). *The effects of real interest rate and inventory on int2*.
Tang, K., & Xiong, W. (2012). Index investment and the financialization of commodities. *Financial Analysts Journal, 68*(6), 54–74.
Taušer, J., & Čajka, R. (2016). Hedging techniques in commodity risk management. *Agricultural Economics, 60*(4), 174–182.
Taylor, J. (1995). The monetary transmission mechanism: An empirical framework. *Journal of Economic Perspectives, 9*(4, Fall), 11–26.
Telser, L. (1958). Futures trading and the storage of cotton and wheat. *Journal of Political Economy, 66*(3, Jun), 233–255.
Tomson, A., & Summers, P. (2012). The effect of monetary policy on real commodity prices: A re-examination. *The Journal of Economics (MVEA), 38*(1), 1–21.
Vansteenkiste, L. (2011). *What is driving oil futures prices? Fundamentals versus speculation*. ECB working paper, no. 1371/August 2011.
Working, H. (1948). Theory of the inverse carrying charge in futures markets. *Journal of Farm Economics, 30*(1, Feb), 1–28.
Working, H. (1960). Speculation on hedging markets. *Food Research Institute Studies, I, 2*.

Exploring the transmission mechanism of speculative and inventory arbitrage activity to commodity price volatility. Novel evidence for the US economy

Wei, Yao

Yao W, Alexiou C. (2022) Exploring the transmission mechanism of speculative and inventory arbitrage activity to commodity price volatility. Novel evidence for the US economy, International Review of Financial Analysis, Volume 80, March 2022, Article number 102027

https://doi.org/10.1016/j.irfa.2022.102027