



On the transmission mechanism between the inventory arbitrage activity, speculative activity and the commodity price under the US QE policy: Evidence from a TVP-VAR model

Wei Yao^{a,*}, Constantinos Alexiou^b

^a School of Economics and Business, Tilburg University, 5037 AB, Tilburg, Netherlands

^b Cranfield School of Management, Cranfield University, Cranfield, MK43 0AL, UK

ARTICLE INFO

JEL classification:

C50
E31
E4
F4
Q43

Keywords:

QE policy
Commodity price
Speculative activity
Transmission mechanism

ABSTRACT

We investigate the transmission that relates the speculative activity, the inventory arbitrage activity, and the commodity price under the US quantitative easing (QE) policy. In this direction, a TVP-VAR model is adopted to test the transmission effect on seven commodities' prices using monthly data over the period 2003:4 to 2018:6. The evidence supports Frankel's (2006) model on the transmission mechanism of the inventory arbitrage activity and the speculative activity on the effect of the real interest rate on commodities' real prices in the short run during the US QE policy period. Moreover, speculative activity appears to increase the effect of the interest rate on commodities' prices in the current period, whilst the evidence between inventory arbitrage activity and the interest rate on commodities' prices is found to be mixed. Further analysis indicates that the transmission of arbitrage activities concerning the effect of the interest rate on commodities' prices is influenced by the arbitrage condition between the commodity and the interest rate markets as well as the changes in commodities' futures basis. More specifically, the inventory arbitrage activities of precious metals and energy commodities play a significant role in transmitting the effect of the interest rate on their prices whilst energy commodities' price is more flexible than other commodities' prices in response to a shock from both inventory arbitrage and speculative activities. Lastly, the influence of the interest rate, the inventory arbitrage activity and the speculative activity is found to be stronger during the de-financialization period.

1. Introduction

Since September 2001, when the Federal Reserve lowered the Federal Funds rate, commodities' prices, especially crude oil's price, have experienced substantial increases and fluctuations. Although commodities' prices decreased during the interest rate hike from June 2004 to June 2006, they demonstrated large increases and fluctuations again over the entire QE policy period. At the same time, the short position of the commercials and the long position of the non-commercials are kept at the high level before the subprime crisis and over the QE policy period. Even though the Federal Reserve started the Taper policy¹ in January 2014 and raised the Federal Funds rate in December 2015, the short position of the commercials and the long position of the non-commercials decreased afterward but

* Corresponding author.

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

¹ Taper policy is the reversal of the quantitative easing policy, implemented by a central bank and intended to stimulate economic growth. Tapering refers specifically to the reduction of central bank assets.

rebounded in the year of 2016–2018.

When the Federal Reserve initiated the quantitative easing policy (QE) responding to the subprime crisis in December 2008, the Federal Funds rate is reduced to the Zero Lower Bound (ZLB), which means any further deduction in the interest rate will not stimulate the economy (Fisher, 1896). In this context, even if there is a significant increase in the money supply, the increased money will only be “held” and will not enter the production field of the economy i.e., the system is in a *liquidity trap* (Keynes, 1936). Notwithstanding, even if the interest rate is at the ZLB, monetary policy can still be effective under specific conditions. For example, the Pigou Effect implies that the actual monetary balance can affect the total demand function when the interest rate is at the ZLB.

In our context, whilst some studies suggest that commodities are endowed with the financial attributes and are part of the asset investment portfolio (Adam & Glück, 2015; Barsky & Kilian, 2004; Wang et al., 2021), others argue that QE provides large amount of liquidity to the market, promoting the speculative activity to drive up commodities’ prices (Adams, et al., 2020; Bianchi et al., 2020; Krishnamurthy & Vissing-Jorgensen, 2011; Manera et al., 2016; Morana, 2013; Singleton, 2014).

The portfolio effect suggests that the central banks’ purchasing bonds increases the money supply while reducing the supply of the financial assets and boosting the demand for the financial assets. As a result, the price of financial assets rises which in turn encourages enterprises to increase the supply of new financial assets. They further invest the funds in the expansion of the production which leads to the rise of the production cost. At the same time, the expansion of the production increases the income level of the whole society through the investment multiplier, generating the increase in the total demand. Through the above process, the asset structure of the economic agents (enterprises and consumers) restores balance, i.e., they increase their holdings of other assets (various financial assets and physical assets) as well as their holdings of money, and the marginal revenue of these assets reach a new equilibrium level. Regarding the portfolio effect, Keynesian theory emphasizes the change of the interest rate in the entire adjustment process, whilst Monetarists highlight the change of the price.

From the perspective of the transmission mechanism for the interest rate impact on commodities’ prices, Frankel (1986) suggests that in the short run, the commodity price falls as the real interest rate rises due to the decrease of the money supply and the excessive rise of the nominal interest rate over the expected inflation rate. Due to the inelastic nature of the manufactured goods’ prices, commodities’ prices overshoot in reaction to the change in the real interest rate. Frankel (2006) further proposes three mechanisms through which the real interest rate may exert the impact on commodities’ prices: the supply and demand channel, the inventory channel and the financial channel. A few studies, based on Frankel’s (1986) commodity price overshooting model and Frankel’s (2006) transmission model, suggest that when the real interest rate is lowered, the risk premium and the inventory convenience yield can transmit the negative effect of the real interest rate on the deviation of the commodity real price from its long-run equilibrium. For example, Frankel (2014) establishes a carry trade model for storable commodities and estimates that the negative effect of the interest rate on crude oil’s price is transferred by the negative effect of the interest rate on crude oil’s inventory demand. Although his sample includes the QE policy period (from 1950 to 2012), Frankel (2014) does not explore the mechanism of the speculative activity relating to the effect of the interest rate on commodities’ prices, even though he includes the speculative activity in his model. Gospodinov and Jamali (2013), using a no-arbitrage model, suggest that the surprise component of the interest rate exerts an impact on the commodity price indirectly, transmitted through the inventory convenience yield and the risk premium. Gospodinov and Jamali (2017) provide evidence of a relationship between the monetary policy uncertainty and the excess of the speculative activity. The fact, however, that Gospodinov and Jamali (2013, 2017) do not incorporate the four variables in one equation model, as proposed by Frankel (2006), suggests that their results fail to account for the transmission mechanisms of the inventory and speculative activity in the monetary policy’s effect on commodities’ prices. Besides, their sample covers the period from 1988 to 2008, excluding the US QE policy period. Wang and Chueh (2013) propose that the mechanism of the exchange rate leading from the monetary policy to the commodity price works when the Federal Reserve Board lowers the interest rate.

From the studies that investigate the relationship between the US QE policy and commodities’ prices, Kozicki et al. (2015) find no evidence that the QE policy led to a rise in the prices of metals, energy, or agricultural commodities when the Federal Reserve officially announced their intended or actual asset purchases whilst Summers (2017) finds that about half of the agricultural commodities’ returns remained at a lower level during at least one phase of the US QE policy. Moreover, Apergis et al. (2020) compare the effects of the conventional monetary policy and the US QE policy² on commodities’ prices and volatilities using an EGARCH-X model and argue that with respect to the Federal Funds rate, the coefficients of metal and crude oil’s prices are negative and significant, while the coefficients of metal and crude oil’s conditional variances are positive and significant. Nevertheless, they fail to account for the mechanism of the inventory and speculative activity in their model.

Drawing on Frankel (1986, 2006), Yao and Alexiou (2022) study the mechanism of the inventory arbitrage activity and the speculative activity for the effect of the US QE policy on commodities’ prices and their conditional volatilities by ARMA-GARCH model and demonstrate the significant and positive relationship between commodities’ prices and the real interest rates. But the deviation

² Conventional monetary policy is a set of instruments available to a central bank to control the money supply level. These include instruments that have been used by all central banks since their inception. It is structured around three axes: open market operations, standing facilities and minimum reserves (See CENTRAL CHARTS). Quantitative easing (QE) is a form of monetary policy used by central banks to increase the domestic money supply and spur economic activity. In QE, the central bank purchases government bonds and other financial instruments, such as mortgage-backed securities (MBS). Quantitative easing is typically implemented when interest rates are near zero and economic growth is stalled (See Investopedia).

from the theoretically negative relationship between the real interest rates and commodities' prices may lie in the fact that the Federal Funds rate is at the ZLB during the US QE period.³

Although Frankel (1986) sets the inflation rate as the secular rate to exclude the situation of the expansionary monetary policy in his model, Obstfeld and Rogoff (1984) and Engel and Frankel (1984) suggest that the expected secular inflation rate can be replaced by the expected short-term inflation rate without changing the model qualitatively. As such, there is scope for further exploration on the transmission mechanisms of the inventory arbitrage activity and the speculative activity for the effect of the real interest rate on commodities' real prices deviating from their long-run equilibrium in the short term under the US QE policy. In this direction, we follow Frankel's (1986, 2006) framework and extend a more recent study by Yao and Alexiou (2022) to further explore the mechanisms through which the inventory arbitrage activity and the speculative activity transmit the effect of the real interest rate onto commodities' real prices under the US QE policy, utilizing a dataset spanning the period 2003:4–2018:6.

The contribution of our study vis-à-vis Frankel's (2006) and Yao and Alexiou (2022) is multifaceted. More specifically, we generate significant evidence supporting Frankel's (2006) model of the transmission mechanisms of the inventory arbitrage activity and the speculative activity for the negative effect of the real interest rate on commodities' real prices in the short run during the US QE policy period. The speculative activity increases the effect of the interest rate on commodities' real prices in the current period, whilst the evidence regarding inventory arbitrage activity and the interest rate on commodities' real prices is rather mixed. This is the first time to our knowledge that such evidence has been provided on the transmission of the two activities in the short term under the US QE policy.

In addition, we provide novel evidence on commodities' price reversion to their long-term equilibrium in response to the shocks emanating from the interest rate and from the two activities as well as on the changes in the relationship between the interest rate, the speculative activity and commodities' real prices in the long run.

Moreover, we argue that inventory arbitrage activities' transmission for the effect of the interest rate on commodities' prices depends not only on the arbitrage condition between the commodity and the interest rate markets, but also on the futures basis, the changes of which are mainly caused by the changes in commodities' inventories and supply and demand. This evidence is strongly consistent with the viewpoint of the non-linear relationship between the inventory convenience yield (the interest-adjusted basis) and the inventory quantity (Telser, 1958; French, 1986; Fama & French, 1988; Gorton et al., 2012).

In addition, the evidence indicates that the inventory arbitrage activities of precious metals and energy commodities play a significant role in transmitting the effect of the interest rate on their prices over the long run, hence, challenging the widely-accepted point of view that it is the speculative activity that influences commodities' price variances most during the commodity market financialization period (see for example, Baldi et al., 2011; Du et al., 2011; Manera et al., 2016; Vansteenkiste, 2011). Further, we provide a new piece of evidence on the flexibility of energy commodities' price in response to the shock from the inventory arbitrage activity and the speculative activity vis-à-vis other commodities.

Finally, the nascent evidence suggests that the influence of the interest rate, the inventory arbitrage activity and the speculative activity increase rather than decrease in the de-financialization period of the commodity market i.e., during the US QE policy, compared to that in the financialization period of the commodity market when the Federal Reserve raises the interest rate from June 2004 to June 2006 and before the US QE policy.

The rest of the paper is organized as follows: Section 2 reviews the literature whilst Section 3 elaborates on the theoretical framework, data, hypotheses and the methodology used in this study. Section 4 touches on the empirical results and discussions and Section 5 provides the results of robustness checks. Finally, Section 6 provides some concluding remarks.

2. Literature review

2.1. The transmission mechanism between the monetary policy and commodities' prices

The transmission mechanism of the monetary policy is thought to take place mainly through four channels: (a) the interest rate channel, (b) the exchange rate channel, (c) the asset price channel, and (d) the credit channel (Cecchetti & Kohler, 2014; Mishkin, 1978, 1995). Taylor (1995) stresses the interest rate channel through which an increase in the nominal interest rate in excess of the expected inflation rate leads to an increase in the real interest rate. With the adjustment of goods' prices and the expectation being rational, the real GDP returns to normal and the real interest rate and the real exchange rate return to their fundamental levels in the long run. Regarding the US QE policy, Krishnamurthy and Vissing-Jorgensen (2011) identify seven channels for quantitative easing monetary policy among which is the signaling channel (signaling for lower Federal Funds rate going forward) that transmits QE1 decreasing effect on bonds' yields.⁴ Their evidence also indicates that the inflation channel (QE increasing inflation expectation) implies that real interest rates may fall dramatically for many borrowers.

In this context, Frankel (2006) narrows the transmission mechanisms to the relationship between the monetary policy and commodities' prices and envisages three mechanisms through which the interest rate's effect is transmitted onto commodities' prices: (a)

³ It should be noted that in Yao and Alexiou's (2022) model, the inventory arbitrage activity and the speculative activity are set as exogenous variables, and their coefficients are the means in the sample.

⁴ Gagnon et al. (2010) suggest that the Federal Reserve's large-scale asset purchase (LSAP) may lead to a long-lasting reduction in the long-term interest rates of securities not included in the LSAP program. Neely (2015) suggests that Federal Open Market Committee (FOMC) announcements during the Federal Reserve's period of unconventional monetary policy in 2008–2009 may have substantially reduced long-term bond yields and the U.S. dollar spot value.

the supply and demand channel - the rise in the interest rate can increase the extraction willingness today relative to tomorrow, which will in turn increase the supply and decrease the price; (b) the inventory channel - a rise in the interest rate may increase the cost of holding the commodity inventories, decreasing the demand and therefore the price; (c) the financial channel - a rise in the interest rate leads the investors to transfer the money from the commodity futures market to the bond market, thereby causing the commodity price to go down.

Frankel and Rose (2010) attribute the commodity price volatility to three drivers: the rapid expansion of global demand; the stimulation of the financial speculative activity; and shocks from the flexible monetary policy. Frankel (2014) establishes a carry trade model for storable commodities and estimates the negative effect of the interest rate on the crude oil price which can be transferred by the negative effect of the interest rate on the inventory demand. Gospodinov and Jamali (2013), using a no-arbitrage model, suggest that the surprise component of the interest rate exerts an impact on the commodity price indirectly. The impact is transmitted by the convenience yield and the risk premium. Gospodinov and Jamali (2017) replace Gospodinov and Jamali's (2013) interest rate variable with a monetary policy uncertainty variable and provide empirical evidence of a relationship between the monetary policy uncertainty and the excess speculative activity.

In addition, Yao and Alexiou (2022), using weekly data in an ARMA-GARCH framework, find that the inventory arbitrage activity may strengthen the real interest rate's effect on commodities' prices but reduce that effect on crude oil's price conditional volatilities; whilst the speculative activity may increase the real interest rate's effect on metals and crude oil's prices, as well as on crude oil's price conditional volatilities. In other words, the two activities exert mixed effects on commodities' price conditional volatilities over the sample period from 2008 to 2018.

Other studies propose other transmission mechanisms, such as the exchange rate and the economic uncertainty, function as the leading from the monetary policy to the commodity price under the QE policy (see for example, Apergis et al., 2020; Wang & Chueh, 2013).

2.2. The relationship between the monetary policy and commodities' prices

The argument about the relationship between the monetary policy and commodities' prices mainly focuses on whether the relationship is positive or negative. Studies supporting a negative relationship include Frankel (1986, 2006, 2014), Akram (2009), Frankel and Rose (2010), Hammoudeh et al. (2015), Hegerty (2016), and Alam and Gilbert (2017). Amongst those who argue for a positive relationship are Tomson and Summers (2012) and Gruber and Vigfusson (2013). Arora and Tanner (2013) provide evidence that the real interest rate contributes less than 5% of the real oil price deviations over the period 1975:1 to 2012:5.

Many studies have tried to find an efficient way to measure the monetary policy during QE. Kuttner (2001) establishes a proxy of the target surprise and suggests that the unexpected target surprise has a greater effect on market interest rates than the expected target surprise. D'Amico and Farka (2011) construct a proxy of changes in the Federal Funds rate futures to identify the monetary policy surprise. Gürkaynak et al. (2005) establish a "path surprise" using the change in the one-year-ahead Eurodollar futures rate to proxy for the FOMC's forward guidance. Glick and Leduc (2013, 2018) follow Wright (2012) to build the monetary policy surprise using the change in the long-term Treasury bill rate to proxy for the LSAP's effect on the long-term interest rate markets. Other works have tried to find an efficient proxy for the QE policy by establishing a shadow interest rate, such as Wu and Xia (2016) and Lombardi and Zhu (2018). Finally, Taylor and Williams (2009) introduce a financial model to take the counterparty risk into consideration when explaining the unusually large spread between the term Libor and the overnight interest rates in the U.S.

With the newly established proxies for the QE policy, Rosa (2014) compares the energy commodity futures price, 10 min before and 50 min after the FOMC announcements, from January 1999 to June 2011 and presents a negative response of the energy commodity price to the unexpected component of the Federal Funds target rate and unexpected asset purchase news. Basistha and Kurov (2015) test the effect of an unexpected shock to the monetary policy on the energy commodity price from January 1994 to December 2008 and demonstrate a significant response of the energy commodity price to the FOMC announcements. However, their results indicate that the contemporaneous response of the oil price to the monetary policy is not significant, according to the monthly data. Saghaian and Reed (2015) provide evidence that there is an overshooting effect from the US LSAPs on Canadian commodities' prices, especially from the second-round LSAP in 2010. However, Summers (2017) finds that about half of the agricultural commodities' returns remain at a lower level during at least one phase of the US QE policy, i.e., from 2006 to 2016. Apergis et al. (2020) compare the effects of the conventional monetary policy and the QE policy on commodities' prices and volatilities using an EGARCH-X model and argue that the coefficients of metal and crude oil's prices with respect to the Federal Funds rate are negative and significant, while the coefficients of metals and crude oil's conditional variances with respect to the Federal Funds rate are positive and significant.

Some studies focus on the effect of the US QE policy on the stock market and find no significant return drift after the FOMC announcement, such as Lucca and Moench (2015). But Gu et al. (2018) find sizable positive average stock returns after the FOMC announcements accompanied by the Economic Projections and the press conferences. However, when it comes to the commodity market, Kozicki et al. (2015) suggest there is no evidence of the QE policy leading a rise in the prices of metal, energy, and agricultural commodities when the Federal Reserve officially announces its intended or actual asset purchases, based on using an event study method for the analysis.

Apart from those studies arguing that the monetary policy plays a key role in commodities' prices and volatilities, other research papers argue that other factors (such as supply and demand, financial activity) exert impacts on commodities' prices and volatilities at the same time (see Anzuini et al., 2010; Eickmeier & Lombardi, 2012; Tan & Liu, 2015).

2.3. The speculative activity and the commodity price

Research on the relationship between the speculative activity and commodities' prices remains at the stage of proving the existence of an impact of the former on the latter. Different indices, data, and models have been used, and the empirical results offer evidence in favor of and against its existence.

Studies supporting the impact of the speculative activity on commodities' prices argue that the speculative activity has led the commodity price to rise sharply.⁵ Morana (2013) estimates that financial shocks account for 44% of the real oil price's 65% increase between 2004 and 2010, for thirty-one advanced economies and fourteen secondary emerging economies. Manera et al. (2016) suggest that short-term speculative activity has had a significant effect on the commodity price volatility since 2000. Adams et al. (2020) decompose the commodity price variances into the fundamental and financial parts and suggest that the chronology of financialization and de-financialization can be divided into before financialization (pre-2004), financialization (2004–2008) and definancialization (2008–2014). They suggest that the financialization accounts for 16% of crude oil's return change before 2004, 35% during 2004–2008 and 24% during 2008–2014; and that financialization accounts for 21% of crude oil's volatility before 2004, 56% during 2004–2008 and 29% during 2008–2014. Bianchi et al. (2020), using daily data from 1991 to 2017 in quantile regressions, provide convincing evidence of a financialization effect in the commodity market from 2004 to 2013 and supporting evidence of de-financialization after 2014 in the energy, copper, corn, soybean and wheat markets, but not in the gold and aluminum markets. There are, however, studies that oppose the effect of the speculative activity on commodities' prices finding no evidence that the speculative activity has caused commodities' prices to go up during 2003–2008.⁶

Finally, additional research takes the approach of testing the correlation between the commodity and stock markets to try to settle the argument. This includes Silvennoinen and Thorp (2013), Kawamoto et al. (2011), Lombardi and Ravazzolo (2012), Büyüksahin and Robe (2014), Kazuhiko and Tatsuyoshi (2013), Kagraoka (2016) and Bicchetti and Maystre (2012). The results confirm that the speculative activity influences both markets.

3. Framework, data, hypotheses and methodology

3.1. Theoretical framework

We follow Frankel's (1986, 2006) framework to study the relationship between the real interest rate and commodities' real prices via the inventory arbitrage activity and the speculative activity mechanisms. Frankel (1986) studies the relationship between the money supply, the interest rate and the commodity price. The inference underlying his overshooting model is that in the short run, the decrease in the money supply leads to an increase in the nominal interest rate in excess of the expected inflation rate which results in an increase in the real interest rate. The rise in the real interest rate in turn causes the investor to shift out of the commodity market and go into the bond market, leading to the decrease in the commodity price. In the meantime, commodities' price tendency to be flexible is much like that of assets (Bosworth & Lawrence, 1982; Frankel, 1984; Okun, 1975) and the prices of the raw materials respond more quickly to the changes in the money supply than do prices of the manufactured goods in the short run (Bordo, 1980).

Given the fact that the change in the money supply involves the income effect, the price effect, the inflation effect, and the liquidity effect, Frankel (1986) takes the secular growth in real income and velocity as exogenous and equal to zero whilst the manufactured product prices are fixed in the short run. In addition, Frankel (1986) sets the inflation rate as the secular rate to exclude the situation of the expansionary monetary policy in his model.

According to Obstfeld and Rogoff (1984) and Engel and Frankel (1984), the expected secular inflation rate can be replaced by other proxies such as the rate of the change of commodities' prices, the economy wide price index and the expected rate of the money growth, because these change rates are proportional to each other. The model is qualitatively unchanged if the expected long-term inflation rate is replaced by the expected short-term inflation rate. Moreover, the risk premium is set to zero or subsumed in the storage costs which are assumed constant.

In the end, Frankel (1986) presents the commodity price overshooting model as follows:

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

where Δp_c is the change of the commodity price; Δm is the change of the nominal money supply; $\Delta \mu$ is the change in the expected money growth rate; α is the weight of the manufacture prices in the overall price; while $(1-\alpha)$ is the weight for the commodity price in the overall price; λ is the semielasticity of money demand with respect to the interest rate; θ is the positive characteristic root for the

⁵ Such studies include Kaufmann and Ullman (2009), Baldi et al. (2011), Lombardi and Robays (2011), Vansteenkiste (2011), Du et al. (2011), Tang and Xiong (2012), Hong and Yogo (2012), Cheng and Xiong (2014), Singleton (2014), Juvenal and Petrella (2015), Zhang et al. (2017), Christoffersen et al. (2019).

⁶ These studies include inter alia Hamilton (2009), Korniotis (2009), Irwin et al. (2009), Alquist and Kilian (2010), Sanders et al. (2010), Stoll and Whaley (2010), Irwin and Sanders (2011), Stoll and Whaley (2011), Büyüksahin and Harris (2011), Irwin and Sanders (2012a), Irwin and Sanders (2012b), Kilian and Murphy (2014), Alquist and Gervais (2012), Baumeister and Peersman (2013), Fattouh et al. (2013), Miffre and Brooks (2013), Kilian and Lee (2014), Kim (2015), Hamilton and Wu (2015), Beidas-Strom & Pescatori (2014), Brunetti et al. (2016), Knittel and Pindyck (2016), Bruno et al. (2017), Chari and Christiano (2017).

equation. Equation (1) implies that because of the stickiness of the manufactured goods' prices and the storage cost of commodities, a change in the money supply (Δm) will lead the commodity price (Δp_c) to overshoot its long-run equilibrium in the short run (particularly agricultural commodities' prices in Frankel, 1986 empirical evidence). That is to say, $\frac{1+\theta\lambda}{1-\alpha+\theta\lambda}$ is more than one. But even when there are not any manufactured goods ($\alpha = 0$), the change in commodities' prices is affected by the growth rate of money $\lambda\Delta\mu$, other than the change of money supply (Δm).

The overshooting model can be reduced to a simple algebraic expression describing the relationship between the real interest rate and the real commodity price (see Frankel, 2006):

$$E(\Delta s) = -\theta(q - \bar{q}) + E(\Delta p) \quad (2)$$

where s is the spot price, p is the economy-wide price index, and Δp can be proxied by the inflation rate, q is the real price of the commodity, which equals $s \cdot p$, and $\bar{q}$ is the long-run equilibrium real price of the commodity. Equation (2) suggests that, when the commodity spot price is expected above or below its perceived long-run value, the expected inflation rate may influence the market participants' forecast on the commodity spot price reverting to the equilibrium over time.

Regarding the decision about whether to hold the commodity as inventory or sell at today's price to earn interest from the bank, Frankel (2006) provides the following arbitrage condition:

$$E\Delta s + c = i \quad (3)$$

where $c \equiv cy - sc + rp$ (see Frankel, 2014), cy is the convenience yield from holding the commodity, sc is the storage cost, rp is the risk premium (The risk premium is positive if taking long position is in risk, see Frankel, 2006, 2014), and i is the nominal interest rate. Equation (3) indicates that the commodity holders will decide whether to sell or hold commodities when commodities' price increases equal to the interest rate minus the total holding cost.

Combining Equations (2) and (3), we have:

$$q - \bar{q} = -\frac{1}{\theta}(i - E(\Delta p) - cy + sc - rp) \quad (4)$$

In the futures market, the inventory arbitrage activity will mean buying and selling the futures contracts before they expire, so the storage cost can be assumed to be zero. Equation (4) can be written as:

$$q - \bar{q} = -\frac{1}{\theta}(i - E\Delta p) + \frac{1}{\theta}cy + \frac{1}{\theta}rp \quad (5)$$

Although the expansionary monetary policy is excluded from Frankel's (1986) overshooting model, using the short-term inflation rate in lieu of the long-term inflation rate makes space for the study on the short-term effect of the expansionary monetary policy on commodities' real prices through the real interest rate. In view of the US QE policy since 2008, we set out to explore the relationship and the transmission mechanism between the interest rate and commodities' prices deviating from their long-run equilibrium values in the short run, as this is facilitated by the risk premium (rp) and the inventory convenience yield (cy).

3.2. Data

The difference, between the spot price of commodity j at time t S_{jt} and the futures price of time n at time t $F_{jt}^{(n)} : S_{jt} - F_{jt}^{(n)}$, is called the futures basis. When S_{jt} is lower than $F_{jt}^{(n)}$, it is called the contango of the commodity futures basis. The intuition of contango is that the adequate supply at present cannot guarantee the sufficient supply in the future. In fact, if the supply is extremely sufficient currently, the producers will reduce the production, leading the surplus to decrease and the price to rise in the future. Kaldor (1939) posits that negative futures basis (the contango) consists of two components: (a) an opportunity cost of forgone interest from having to borrow and buy the commodity and (b) a (net of insurance and storage costs) convenience yield which reflects the benefit from using the stored commodity whenever desired. Fama and French (1987) provide an explicit relationship between the negative futures basis $F_{jt}^{(n)} - S_{jt}$ and the convenience yield $CY_{jt}^{(n)}$ with the convention $CY_{jt}^{(0)} = 0$:

$$F_{jt}^{(n)} - S_{jt} = S_{jt}i_t^{(n)} - CY_{jt}^{(n)} \quad (6)$$

$CY_{jt}^{(n)}$ is the marginal convenience yield, net of insurance and storage cost of period n at time t . $i_t^{(n)}$ is the risk-free interest rate of period n at time t . Fama and French (1988) suggest adopting the "interest-adjusted basis" as the proxy for the inventory convenience yield, which is calculated as:

$$CY_{jt}^{(n)} = (1 + i_t^{(n)})S_{jt} - F_{jt}^{(n)} \quad (7)$$

Their empirical results indicate that the inventory convenience yield declines at a decreasing rate whilst the interest-adjusted basis rises at a decreasing rate as the inventory increases. We adopt the interest-adjusted basis for the proxy of the inventory convenience yield and abbreviate it as *arb*. Consequently, Equation (7) is written as follows:

$$arb_{jt}^{(n)} = (1 + 3tbr_t^{(n)})S_{jt} - F_{jt}^{(n)} \quad (8)$$

where $3tbr_t^{(n)}$ is the 3-month Treasury bill rate of period n at time t for the proxy of the risk-free interest rate $i_t^{(n)}$.

The “interest-adjusted basis” inventory convenience yield implies the arbitrage condition in the commodity and the interest rate markets. When the return of the interest rate is higher than that in the commodity price, the inventory holders will withdraw their funds from the commodity market and invest in the interest rate market; and vice versa. As it is based on the changes in the commodity inventory, the arbitrage activity is usually done by the commodity producers, as the hedgers, in the futures market (Beidas-Strom & Pescatori, 2014; Kilian & Lee, 2014; Kilian & Murphy, 2014).

An alternative view of the futures basis is from the theory of normal backwardation. The backwardation appears when the expected spot price of commodity j of period n at time t $S_{jt}^{(n)}$ is higher than the futures price of period n at time t $F_{jt}^{(n)}$. The intuition of backwardation is that when the commodity is in a short for short-term or long-term, the higher spot price can limit the demand and encourage the producers to increase the production as quickly as possible to take advantage of the higher spot delivery price. Keynes (1930) posits in the theory of normal backwardation that the investors holding a long position in a futures contract earn a risk premium to compensate for the risk of fluctuations in the spot prices. Therefore, the basis is composed of the risk premium which can be defined as:

$$\Psi_{jt}^{(n)} \equiv E_t S_{jt}^{(n)} - F_{jt}^{(n)} \quad (9)$$

Accordingly, the negative futures basis can be written as:

$$F_{jt}^{(n)} - S_{jt} = E_t S_{jt}^{(n)} - S_{jt} - \Psi_{jt}^{(n)} \quad (10)$$

Equation (10) indicates the no-arbitrage condition in the relationship between the spot price and the futures price in the commodity futures market.

As Equations (6) and (10) are alternative formulations of the futures basis, they can be combined to Equation (11) as follows (see Gospodinov & Jamali, 2013):

$$E_t S_{jt}^{(n)} - S_{jt} = S_{jt} i_t^{(n)} - CY_{jt}^{(n)} + \Psi_{jt}^{(n)} \quad (11)$$

Let $cy_{jt}^{(n)} = CY_{jt}^{(n)} / S_{jt}$, $\psi_{jt}^{(n)} = \Psi_{jt}^{(n)} / S_{jt}$ and $E_t \Delta S_{jt}^{(n)} = (E_t S_{jt}^{(n)} - S_{jt}) / S_{jt}$, we can have:

$$E_t \Delta S_{jt}^{(n)} = i_t^{(n)} - cy_{jt}^{(n)} + \psi_{jt}^{(n)} \quad (12)$$

Equation (12) demonstrates that the expected commodity spot price changes $E_t \Delta S_{jt}^{(n)}$ directly relate to the interest rate $i_t^{(n)}$, the convenience yield $cy_{jt}^{(n)}$ and the risk premium $\psi_{jt}^{(n)}$.

The US Commodity Futures Trading Commission (CFTC) classifies traders into commercial and non-commercial users of futures contracts. The extant literatures (Bessembinder, 1992; de Roon et al., 2000; Szymanowska et al., 2014; among others) consider commercial users of futures contracts to be traders or institutions using the futures contracts for hedging purposes. Schwarz (2012) proposes to classify the traders or institutions falling into the non-commercial group as the speculators. In this context, a few studies, such as Ederington and Lee (2002) and Schwarz (2012), acknowledge and discuss the difficulties in classifying the commercial users of futures contracts as the hedgers, however, a broader consensus is reached in classifying the non-commercial users as the speculators.

Ederington and Lee (2002) and Schwarz (2012) suggest using the ratio of the net long position to the total position of non-commercials as the proxy for the speculative pressure. We abbreviate it as *spe* in the following equation:

$$spe_{jt} = \frac{\text{long non-commercial position} - \text{short non-commercial position}}{\text{total non-commercial position}} * 100\% \quad (13)$$

That proxy is in fact the measurement of the buy and sell activities of the non-commercials. We adopt the speculative pressure as the proxy for the speculative activity (see Gospodinov & Jamali, 2013).

For the empirical investigation we source data for the interest rate, commodities' real prices deviating from their long-term equilibrium level (abbreviated as commodities' prices),⁷ inventory arbitrage activities, speculative activities, and TED spread for controlling.

Silvennoinen and Thorp (2013) argue that “the evidence of gradual and early increases in conditional correlations are most apparent for base metals and pre-date the most intense period of financialization from 2003–4” (p. 62). Šmiech et al. (2015), divide their sample period into three subperiods: 1997:1–2003:4, 2003:5–2008:12, and 2009:1–2013:9 which is akin to Silvennoinen and Thorp (2013).⁸

In view of the above, we use monthly data spanning the period 2003:4 to 2018:6 which includes the periods during which

⁷ We use the mean of the commodities' real prices as the long-run equilibrium value and calculate the difference between the monthly price and the mean as $q - \bar{q}$. We abbreviate commodity prices deviating from their long-run equilibrium values as commodity prices for simplicity in this paper.

⁸ The target rate is raised by the Federal Reserve on 15th December 2016, and gradually rises to 1.75%–2% on 13th June 2018.

institutional investors' capital was flowing into the commodity market between 2003:5 and 2008:12 as well as the QE policy period during 2008:12 and 2012:12 after the breaking out of the financial crisis in December 2008.

Seven commodities are used, which are classified as precious metal (silver), industrial metal (copper), energy commodities (crude oil and heating oil), textiles (cotton), and agricultural commodities (soybeans, coffee) (see Appendix-Data Source). The calculation of our variables is as follows: the real price of commodity j is calculated as $q_{jt} = \frac{S_{jt}}{(1+\text{inflation rate})}$, where t is the time, in months; S_{jt} is the spot price calculated by the continuous first month futures price of commodity j at time t ; inflation rate is calculated by US CPI downloaded from OECD.

We take Wu and Xia's (2016) shadow interest rate (abbreviated as $wxsr_t$),⁹ which is adjusted for the overall effects from the QE policy on the economy, as the proxy for the interest rate of the US monetary policy at time t ; and use the TED spread¹⁰ as the control variable, which is abbreviated as $teds$.

Accordingly, Equation (5) can be written specifically as follows with the proxies substituted in the model:

$$q_{jt} - \bar{q}_j = -\frac{1}{\theta}wxsr_t - \frac{1}{\theta}arb_{jt}^{(1)} + \frac{1}{\theta}spe_{jt} + teds \quad (14)$$

To consolidate our results, we conduct robustness checks by using Working's T (wkt in abbreviation) in lieu of the ratio of the speculative pressure (spe), and the path surprise ($paths$ in abbreviation) in place of Wu and Xia's (2016) shadow interest rate ($wxsr$).

After substituting the data with Working's T, Equation (5) is written concretely as follows:

$$q_{jt} - \bar{q}_j = -\frac{1}{\theta}wxsr_t - \frac{1}{\theta}arb_{jt}^{(1)} - \frac{1}{\theta}wkt_{jt} + teds \quad (15)$$

As to the path surprise, Gürkaynak et al. (2005) establish the path surprise as the change in the one-year-ahead Eurodollar futures rate to represent the FOMC's forward guidance. For the monthly unit of observation, Rudebusch (1998) suggests that the unexpected change ($\Delta\tilde{r}^u$) in the Federal Funds rate can be defined as the difference between the average rate in month n , ($\frac{1}{m}\sum_{d \in n}\tilde{r}_d$) and the one-month futures rate on the last day of month $n-1$, ($f_{n-1,m}^1$) (see Kuttner, 2001, p. 538): $\Delta\tilde{r}^u = \frac{1}{m}\sum_{d \in n}\tilde{r}_d - f_{n-1,m}^1$, where m is the number of days in month n ; d is the date in month n .

We calculate the path surprise with Eurodollar futures rate, in the same way as that for the target surprise in the following: $paths = \frac{1}{m}\sum_{d \in n}\tilde{edr}_d - edr_{n-1,m}^1$, where $paths$ is the abbreviation for the path surprise; edr is the abbreviation for the Eurodollar futures rate.

By taking the path surprise into Equation (5) in lieu of Wu and Xia's shadow rate, we have:

$$q_{jt} - \bar{q}_j = -\frac{1}{\theta}paths_t - \frac{1}{\theta}arb_{jt}^{(1)} + \frac{1}{\theta}spe_{jt} + teds \quad (16)$$

The cotton and agricultural commodities' real prices, and the interest-adjusted basis inventory arbitrage activity, are all seasonally adjusted¹¹ (see Descriptive Statistics in the Appendix).

We check for stationarity using an augmented Dickey-Fuller (ADF) unit root test and take first differences as indicated by the test (see ADF Test for Unit Root in the Appendix).

3.3. Hypotheses development

Frankel's (1986) commodity price overshooting model suggests that when the inflation rate increases, the nominal interest rate cannot go up immediately, which causes the real interest rate to decline in the short run and the commodity price to go up. As the manufactured goods price is inelastic in the short term, the commodity price overshoot to the change in the real interest rate.

Out of the very few research papers that explore the transmission of inventory, Geman and Nguyen (2005) suggest that soybean's return is positively related to the US soybean inventory scarcity, whilst Symeonidis et al. (2012) find a negative relationship between gold, silver, copper, crude oil, heating oil, cotton, wheat, soybean, coffee, and cocoa's prices and their inventories.

Moreover, French (1986) suggests that when the inventory is low, the current shock to supply or demand generates larger changes in the spot price than in the forward price, while the future shock to supply or demand causes larger changes in the forward price than in the spot price. When the inventory is high however, the changes in the spot and forward prices are roughly equal, no matter they are caused by the current or the future demand or supply shock. Fama and French (1988) suggest that the inventory convenience yield declines at a decreasing rate whilst the interest-adjusted basis rises at a decreasing rate as the inventory increases. Gorton et al. (2012) study the relationship between the risk premium and the inventory under the Theory of Storage and the Theory of Normal Backwardation and confirm the negative relationship between the convenience yield and the inventory when the inventory is low.

⁹ Wu and Xia's (2016) shadow rate composes of the Treasury bill rates with the assumption that the short-term interest rate is the maximum of the shadow rate and a lower bound after December 2008 when the Federal Open Market Committee (FOMC) lowered the target range for the Federal funds rate to 0 to 25 basis points.

¹⁰ The TED spread is the spread between the three-month LIBOR and the three-month Treasury bill rates.

¹¹ "Three such noteworthy characteristics of agricultural crops include the seasonality of production, the derived nature of their demand and price-inelastic demand and supply functions" (Schnepf, 2005, p. 2).

Furthermore, despite the fact that many studies have supported the positive influence of the speculative activity in driving the commodity price away from the fundamental level (Manera et al., 2016; Kaufmann & Ullman, 2009; Baldi et al., 2011; Beidas-Strom & Pescatori, 2014), very few studies have quantified the influence of the inventory arbitrage activity on the changes in commodities' prices except for Yao and Alexiou (2022) which provide the evidence that the influence of the inventory arbitrage activity is smaller than that of the speculative activity from 2008 to 2018.

In view of the above, we develop the following hypotheses:

Hypothesis 1. The real interest rate ($i - E\Delta p$) has a negative impact on commodities' real prices ($q - \bar{q}$) in the short run.

Hypothesis 2. Speculative activity (spe) increases the effect of the real interest rate on commodities' real prices.

Hypothesis 3. Inventory arbitrage activity (arb) decreases the effect of the real interest rate on commodities' real prices.

Hypothesis 4. Inventory arbitrage activity has less influence on commodities' real prices than the speculative activity.

Hypothesis 5. Speculative activity has a weaker impact on commodities' real prices in the de-financialization than the financialization period of the commodity market.

3.4. Methodology

We use a Time Varying Parameter-Stochastic Volatility-Vector Auto Regression model (TVP-VAR) to test the relationship between the real interest rate and commodities' real prices as well as the extent to which they deviate from their equilibrium price through the transmission mechanism of the inventory arbitrage activity and the speculative activity.¹² The TVP-VAR model, proposed by Primiceri (2005), is free of the assumptions of homoscedasticity and constant coefficients and uses the Markov chain Monte Carlo (MCMC) methods in the circumstance of a Bayesian inference.

We apply the TVP-VAR package of Nakajima (2011) for 10,000 sampling for each set of variables.

$$\text{TVP regression : } by_t = x_t'\beta + z_t'\alpha_t + \varepsilon_t, \varepsilon_t \sim N(0, \sigma_\varepsilon^2), t = 1, \dots, n \quad (17)$$

$$\text{Time - varying coefficients : } \alpha_{t+1} = \alpha_t + \mu_t, \mu_t \sim N(0, \Sigma), t = 0, \dots, n - 1 \quad (18)$$

$$\text{Stochastic volatility : } \sigma_t^2 = \gamma \exp(h_t), h_{t+1} = \phi h_t + \eta_t, \eta_t \sim N(0, \sigma_\eta^2), t = 0, \dots, n - 1 \quad (19)$$

where y_t is the vector of response; x_t is ($k \times 1$) vectors of covariate; β is a ($k \times 1$) vector of constant coefficients; z_t is ($p \times 1$) vectors of covariate; α_t is a ($p \times 1$) vector of time-varying coefficients; and h_t is stochastic volatility; $\alpha_0 = 0$, $\mu_0 \sim N(0, \Sigma_0)$, $\gamma > 0$, and $h_0 = 0$.

The constant coefficient β describes the effects of x_t on y_t which is time-invariant; whilst the time-varying coefficients α_t shows the effects of z_t on y_t which are assumed to change from time to time. α_t follows the first-order random walk process in equation (18), and is meant to capture possible nonlinearity, for example, a structural break or a gradual change. The disturbance ε_t follows the normal distribution. The log-volatility $h_t = \log \sigma_t^2 / \gamma$ follows the AR (1) process in Equation (19). $|\phi|$ is assumed to be smaller than one and the initial condition is set on the stationary distribution as $\eta_0 \sim N(0, \sigma_\eta^2 / (1 - \phi^2))$. When $\phi = 1$, the log-volatility follows the random walk process.

4. Empirical results and discussions

4.1. Impulse response analysis

Given the small but discernible monthly variation of each variable as suggested by the impulse responses, we calculate the average impulse responses of each variable in the current month and one to three months ahead in Table 1.¹³ Table 1 presents five important pieces of evidence for our hypotheses 1 to 4.

- (1) Six out of seven commodities' prices respond negatively to the shock from Wu and Xia's shadow rate in the current month. Crude oil's price responds positively to the shock from the interest rate in the current month. However, five out of seven commodities' prices react positively to the shock from the interest rate, meanwhile, crude oil's price responds negatively to the shock from the interest rate in one month ahead. Most commodities' prices react negatively to the shock from the interest rate in two and three months ahead, except for silver and copper (see column i-p of the current month, one month ahead, two months ahead and three months ahead). This evidence is in line with hypothesis 1 that the change in the real interest rate exerts pressure

¹² The difference between the TVP-VAR model and the GARCH model lies in that the impulse response in the TVP-VAR regression depicts the impact of adding one-unit positive shock to the disturbance term ε_t on the endogenous variables in the current period and the periods ahead; whilst, the GARCH model includes the independent variables as the exogenous and presents the means of the coefficients of the independent variables and the dependent variable's conditional variance within the sample.

¹³ For a graphical representation see also Supplemental Appendix, Figs. 4, 8, 12, 16, 20, 24, 28.

on commodities' real prices to move in the opposite direction in the current period; whilst most commodities' prices revert to their equilibrium level later by adjusting their responses to the shock from the interest rate gradually.

- (2) All commodities' speculative activities respond negatively to the shock from Wu and Xia's shadow rate in the current month and one to three months ahead (except for silver's speculative activity in the current month). All commodities' prices respond positively to the shock from their speculative activities in the current month whilst most commodities' prices respond positively to the shock from their speculative activities in one to three months ahead, except for silver, crude oil, soybean in 2012–2018¹⁴ and coffee in one month ahead. Four commodities' prices (silver, copper, crude oil and soybean in 2003–2006 and 2012–2018) in two months ahead and three (copper, crude oil and soybean) in three months ahead respond negatively to the shock from their speculative activities (see column i-s and s-p of the current month, one month ahead, two months ahead and three months ahead). The evidence is in supportive to [hypothesis 2](#) that speculative activities increase the effect of the real interest rate on commodities' prices by responding negatively to the shock from the interest rate while having positive responses from the prices.
- (3) Some commodities' inventory arbitrage activities respond positively, whilst others respond negatively, to the shock from Wu and Xia's shadow rate through the current month and one to three months ahead. Meanwhile, all commodities' prices respond positively to the shock from their inventory arbitrage activities in the current month, whilst most of commodities' prices respond negatively to the shock from their inventory arbitrage activities in one to three months ahead (see column i-a and a-p of the current month, one month ahead, two months ahead and three months ahead). This evidence does not fully support [hypothesis 3](#) because the transmission of the arbitrage activity is mixed for different commodities in different period.
- (4) Most commodities' inventory arbitrage activities respond at a less magnitude to the shock from Wu and Xia's shadow rate than their speculative activities through the current month and one to three months ahead, except for crude oil and heating oil (see the italic in the row of crude oil's real price and heating oil's real price). Moreover, crude oil and heating oil's prices respond at a higher magnitude to the shock from their inventory arbitrage activities than from their speculative activities through the current month and one to three months ahead, while other commodities' prices respond at a lower magnitude to the shock from their inventory arbitrage activities than from their speculative activities in the current month. However, more and more commodities' prices respond at a higher magnitude to the shock from their inventory arbitrage activities than from their speculative activities in one to three months ahead (see the underlined in column a-p and s-p of the current month, one month ahead, two months ahead and three months ahead). This evidence support [hypothesis 4](#) incompletely.
- (5) The impulse response of each variable in the current month is stronger than that in one to three months ahead. Compared to other commodities' prices, crude oil and heating oil's prices have the greatest response, whilst silver, copper and coffees' prices have the second highest response to the shocks from Wu and Xia's shadow rate, their inventory arbitrage activities and their speculative activities. The response of crude oil and heating oil's prices to the shock from their inventory arbitrage activities and the response of heating oil's price to the shock from its speculative activity are more than one unit in the current month (with the coefficients of 2.1389, 1.0993 and 1.0661 respectively in column a-p and s-p of the current month).

4.2. Variance decomposition analysis

[Table 2](#) summarizes the variance decomposition of commodities' prices with Wu and Xia's shadow rate, commodities' inventory arbitrage activities, commodities' speculative activities, and commodities' prices themselves.

The variance decomposition shows that all the seven commodities' prices hold the leading post in their price variances.¹⁵ The inventory arbitrage activities of silver, crude oil and heating oil account for the second of their price variances, leaving their speculative activities holding the third of their price variances; whilst the speculative activities of copper, cotton, soybean and coffee account for the second of their price variances, making their inventory arbitrage activities holding the third of their price variances.

The variance decomposition analysis provides further evidence for the conclusion in 4.1 that energy commodities' prices (crude oil and heating oil) are more influenced by their inventory arbitrage activities than their speculative activities in the short term as well as in the long term.

Although silver's price responds more intensely to the shock from its speculative activity than from its inventory arbitrage activity, the price responds intensely to the shock from Wu and Xia's shadow rate simultaneously. Moreover, the Chicago Mercantile Exchange Group (CME Group US-CME) once increased the margin limit in view of the possibility of excessive speculation in the silver's futures market after the sharp and quick rising of silver's price in June 2010. Therefore, as the inventory arbitrage activity can be affected by the changes in the interest rate and the futures basis, silver's price is more influenced by its inventory arbitrage activity than its speculative activity.

¹⁴ Some commodities have structural changes in their impulse responses. We divide the analysis into several different periods according to the time point of the structural changes.

¹⁵ The commodity price holds the leading post in the variance decomposition indicates that other factors exert a comprehensive impact on commodities' prices, such as the supply and demand, the expectation of the participants for the price based on the past data, the foreign exchange rate, the geo-politics, etc.

Table 2

Variance decomposition of commodity price for the model of Wu and Xia's shadow rate, the interest-adjusted basis arbitrage activity, the ratio of the net long position to the total position of non-commercials speculative activity and commodities' real prices.

Commodity's price	Wu and Xia's shadow rate	Arbitrage activity	Speculative activity	Price itself
silver	1.47	35.60	7.21	54.69
copper	1.68	11.70	19.39	57.31
crude oil	6.08	17.52	11.40	56.40
heating oil	4.23	15.26	11.62	62.08
cotton	4.74	2.48	10.56	74.05
soybean	5.78	8.55	19.31	63.73
coffee	2.63	13.18	29.19	54.61

Note: Data are the average of variance decomposition of sixty months ahead.

4.3. A comparison of commodities' price impulse responses in the financialization, de-financialization and post-de-financialization periods of the commodity market

We compare the impulse responses of commodities' prices to the shocks from Wu and Xia's shadow rate, the arbitrage activity and the speculative activity in the financialization, de-financialization and post-de-financialization periods of the commodity market in Table 3.

All seven commodities' prices in the current month, three (crude oil, cotton and coffee) in one month ahead, five (silver, copper, crude oil, cotton and coffee) in two months ahead, and all seven in three months ahead respond more intensely to the shocks from their speculative activities during the de-financialization period than that during the financialization period of the commodity market. The evidence is inconsistent with hypothesis 5.

Moreover, four commodities' prices (copper, crude oil, cotton and coffee) in the current month, four (silver, heating oil, cotton and coffee) in one month ahead, five (silver, crude oil, cotton, soybean and coffee) in two months ahead and four (silver, heating oil, cotton and soybean) in three months ahead react more to the interest rate shocks in the de-financialization period than that in the financialization period of the commodity market.

Furthermore, three commodities' prices (crude oil, heating oil and coffee) in the current month, four (crude oil, heating oil, cotton and coffee) in one month ahead, two (silver and crude oil) in two months ahead, and three in three months ahead respond more intensely to the shocks from the inventory arbitrage activity in the de-financialization period than that in the financialization period of the commodity market.

In addition, some commodities' prices respond more to the shocks from the interest rate, the inventory arbitrage activity and the speculative activity in the period from 2014 to 2018 than that in the de-financialization period of the commodity market from 2009 to 2013, e.g., crude oil's price in two months ahead, heating oil's price in the current month and three months ahead, soybean's price in one month ahead and coffee's price in the current month.

The average amount of commodities' commercial and non-commercial's short and long positions in the three periods of 2003:5–2008:12, 2009:1–2013:9 and 2013:10–2018:6 in Table 5A illustrates the changes in the inventory arbitrage activities and the speculative activities in the financialization, de-financialization and post-de-financialization periods of the commodity market.

The stronger influence of the interest rate, the inventory arbitrage activity and the speculative activity on some commodities' prices in the post-de-financialization period of the commodity market may be the most comprehensive result of the great change in the US monetary policy from QE to Taper in 2014¹⁶ and the world economic recovery after 2016. The Federal Reserve intended to reduce the purchase scale under the QE policy officially in December 2013 and started the Tapering policy in January 2014. It was expected that the Federal Reserve would return to the normal monetary policy by rising the Federal Funds rate in the end of 2015, but due to the slowing down of global economic growth, the Federal Reserve didn't increase the Federal Funds rate to 0.25%–0.5% until December 17, 2015, and kept the rate at that level for about one year till December 2016. Under the combined effect of the increasing demand and decreasing supply, most commodities' prices bottomed out in January 2016 and achieved a stable rebound in the first half of 2016. From January to July 2016, the commodity price index rebounded by 14.3%. From August 2016 to July 2017, the commodity price index fluctuated and consolidated, with prices of crude oil, metal and agricultural commodities rising by 7.6%, 19.1% and 4.3% respectively. From 2017 to 2018, the global economic recovery led to an acceleration in the growth rate of the commodity demand, while the supply of commodities was constrained by the insufficient investment, resulting in a stable rebound in commodities' prices. Together with the recovery of the world economy, the commercials' short position and the non-commercials' long position of most commodities fell from 2014 to 2015 and went up again over the period 2016 to 2018.

4.4. Discussion

Usually, when the inventory is low, the spot price is higher than the forward price (the basis is positive); and conversely, when the inventory is high, the spot price is lower than the forward price (the basis is negative). However, when the arbitrage condition is taken

¹⁶ The Global Financial Stability Report of IMF in April 2014 defined the Taper Panic period from 21st May 2013 to 21st March 2014 (8 months long).

into consideration, four circumstances may unfold: (a) the basis and the interest-adjusted basis are both more than zero, (b) the basis is positive while the interest-adjusted basis is negative, (c) the basis and the interest-adjusted basis are both less than zero, (d) the basis is negative while the interest-adjusted basis is positive.

In the (a) and (c) scenario, it's easy for hedgers (that is the physical cargo traders or the inventory arbitrageurs in the proxy of the interest-adjusted basis) to decide to buy or sell the futures, but not so in scenario (b) and (d). Therefore, the transmission of the inventory arbitrage activity for the interest rate on commodities' prices depends not only on the changes in the interest rate but also on the changes in the basis (or rather on the changes in the inventory and supply and demand).

Fama and French (1988) take the sign of the interest-adjusted basis as the proxy for the high/low of the inventory whilst Pirrong (2009) argues that the relationship between the inventory and the commodity price is unstable and the positive relationship between the two variables may arise because of the increased demand or the uncertainty of the supply. Our empirical results show that the sign of the interest-adjusted basis does not have a connection with the response of the interest-adjusted basis inventory arbitrage activity to the interest rate shock, nor does it have a relationship with the inventory arbitrage activity effect on the commodity price.

Therefore, the conflicting empirical evidence that relates to hypothesis 3 may reflect the convex function between the interest-adjusted basis and the inventory or the instability of the relationship between the inventory and the commodity price.

Amidst the studies having explored the relationship between the inventory arbitrage activity (the hedging) and the speculative activity, Kilian and Murphy (2014), Kilian and Lee (2014), Beidas-Strom & Pescatori (2014) and Gorton et al. (2012) suggest that the inventory arbitrage activity and the speculative activity are both based on the changes in commodities' inventory, and the speculators work as the counterparties of the arbitrageurs to undertake the reverse positions. Moreover, Hirshleifer (1988, 1989, 1990), based on the CAPM theory (Capital Asset Pricing Model) and the comparison between the risk premium of the stock market and that of the futures market, finds the response of the increased risk premium to the changes in the producers' hedging demand to be smaller if the speculators' risk tolerance is high, and vice versa.

However, Acharya et al. (2011) extend the Limits to Arbitrage¹⁷ to the commodity futures market and propose the "limits to hedging". They suggest that the limit on the risk-taking capacity of the speculators constitutes a cost of hedging of the producers, which results in the changes in the optimal inventory holding, and in turn, the commodity spot price. Therefore, the hedging demand of the producers is the common driver of the futures risk premium and the expected change in the spot price. Due to this common driver, their model predicts that the commodity convenience yield (or the futures basis) is not strongly related to the risk premium; and the increases in the speculators' capital constraints have similar effects.

Other studies illustrate the positive influence of the speculative activity in driving the commodity price away from the fundamental level (Manera et al., 2016; Kaufmann & Ullman, 2009; Baldi et al., 2011; Beidas-Strom & Pescatori, 2014). Singleton (2014) suggests that the increase in the commodity price in response to the increased demand for the long position is typically necessary because that helps to induce other investors to commit more capital to taking the opposite position of these transactions. He stresses that the participants in crude oil futures market form their expectation not only considering the expected fundamentals but also on the basis of other market participants' actions from the viewpoint of Keynes beauty contest. Furthermore, Domanski and Heath (2007) argue that the hedgers make their decisions based on the past increases in spot prices and the high roll returns. As the counterparties of the hedgers, the speculators' decisions on investing in the commodity market may also influenced by the past changes of the prices and returns. Besides, the changes in the market and the macro-economy later may also influence the speculators' decision.

Consequently, the reduction of some commodities' speculative activity for the effect of the interest rate on commodities' prices in two and three months ahead may suggest that the activity of the speculators can be influenced by the activity of the hedgers as well as other market participants to some extent.

Gorton et al. (2012) establish steeper slopes of those commodities' futures basis with their inventories which are not easy to store. This may explain the higher responses of crude oil and heating oil's prices to the shock from the inventory arbitrage activities than metal and agricultural commodities' prices. Apart from that, some studies suggest that commodities' derivatives become an alternative investment for portfolio managers (Adam & Glück, 2015; Wang et al., 2021); whilst energy commodities play an essential role in portfolio diversification and interacted with the financial market (Barsky & Kilian, 2004). And crude oil's price is one of the common dynamic factors in driving other commodities' return variations. (Kagraoka, 2016). The overshoot responses of crude oil and heating oil's prices to the shock from their inventory arbitrage activities and speculative activities may be the result of the large amount of funds flowing in the energy commodities' market ever since 2003.

5. Robustness checks

5.1. Impulse response check

The robustness check using Working's T in lieu of the speculative pressure (shown in Table 4) presents the negative response of some commodities' speculative activities to the shock from Wu and Xia's shadow rate. Three commodities' speculative activities (cotton in 2003–2011, soybean and coffee) in the current month, five (silver, copper, cotton, soybean and coffee) in one month ahead, six out of seven except for copper in two months ahead and six except for cotton in three months ahead respond positively to the shock from Wu and Xia's shadow rate. However, all commodities' prices in the current month, three (copper, heating oil and cotton) in one

¹⁷ Shleifer and Vishny (1997) propose the Limits to Arbitrage with the assertion that the arbitrage activity is limited to the incomplete market, the risk produced by the noise traders, the time and the fund limitation.

month ahead, six except for soybean in two months ahead and four (silver, copper, heating oil and cotton) in three months ahead respond negatively to the shock from their speculative activities. Most commodities' speculative activities have higher responses from their prices than the inventory arbitrage activities. Crude oil and heating oil's prices respond more intensely to the shock from the inventory arbitrage activities than to the shock from the speculative activities.

The robustness check using the path surprise in lieu of Wu and Xia's shadow interest rate (shown in Table 7) demonstrates that four commodities' prices positively respond to the shock from the path surprise in the current month. More commodities' prices respond positively to the shock from the path surprise in two months ahead. Apart from crude oil and heating oil, silver's inventory arbitrage activity responds more intensely to the shock from the path surprise than its speculative activity. The results are in line with that of the model of Wu and Xia's shadow rate and the speculative pressure.¹⁸

5.2. Variance decomposition check

Both the robustness check with Working's T model (see Table 5) and the robustness check with the path surprise model (see Table 8) confirms that the inventory arbitrage activities of silver, crude oil, and heating oil account for more than those commodities' speculative activities in their price variances.

5.3. A comparison of commodities' price impulse responses in the financialization, de-financialization and post-de-financialization periods of the commodity market check

The robustness check with Working's T model (shown in Table 6) is in line with the results of the model with the speculative pressure. In particular, five commodities' prices (copper, crude oil, heating oil, cotton and coffee) in the current month, five (copper, crude oil, heating oil, cotton and coffee) in one month ahead, five (copper, crude oil, heating oil, soybean and coffee) in two months ahead and five (silver, copper, crude oil, heating oil and cotton) in three months ahead respond more intensely to the speculative activities shocks during the de-financialization period than that during the financialization period of the commodity market.

The robustness check with the path surprise model (shown in Table 9) confirms the results of the model with Wu and Xia's shadow interest rate. Five commodities' prices (silver, crude oil, cotton, soybean and coffee) in the current month, six (silver, copper, crude oil, heating oil, cotton and soybean) in one month ahead, five (silver, copper, crude oil, heating oil, cotton and coffee) in two months ahead and four (crude oil, heating oil, soybean and coffee) in three months ahead react larger to the interest rate shocks in the de-financialization period than that in the financialization period of the commodity market.

Both the robustness checks confirm that some commodities' prices respond to the shocks from the interest rate, the inventory arbitrage activity and the speculative activity more intensely in the period from 2014 to 2018 than that in the de-financialization period of the commodity market (from 2009 to 2013), e.g., heating oil's price in three months ahead and coffee's price in two months ahead in the model of Working's T, crude oil's price in two months ahead and coffee's price in the current month in the model of the path surprise.

6. Concluding remarks

This study provides novel evidence on the transmission mechanisms of the inventory arbitrage activity and the speculative activity through the negative effect of the real interest rate on commodities' real prices in the short run during the US QE policy period. The negative effect of the interest rate on commodities' prices appears to adjust toward their long-run equilibrium gradually. For example, most commodities' prices respond positively to the shock from the interest rate in one month ahead and then respond negatively in two or three months ahead. The speculative activities increase the effect of the interest rate on commodities' prices in the current month but some change to dampen the effect in one to three months ahead.

Furthermore, the inventory arbitrage activities' transmission for the effect of the interest rate on commodities' prices depends not only on the arbitrage condition between the commodity market and the interest rate market, but also on the futures basis stemming from the changes in the inventory of commodities. Moreover, for some commodities, such as precious metals (silver) and energy commodities (crude oil and heating oil), it is the inventory arbitrage activity rather than the speculative activity that transmits primarily the effect of the interest rate on their prices. This is at odds with the widely accepted view that it is the speculative activity that influences commodities' price variances mostly during the commodity market financialization period (see for example, Baldi et al., 2011; Du et al., 2011; Manera et al., 2016; Vansteenkiste, 2011).

Additionally, we provide novel evidence pointing to a more flexible energy commodities' price (crude oil and heating oil) responses to a shock emanating from the inventory arbitrage activity and the speculative activity in view of the overshooting of their prices to the shock from the two activities in the current month.

Finally, the evidence indicates that the influence of the interest rate, the inventory arbitrage activity and the speculative activity do not abate in the de-financialization period of the commodity market (coincidentally under the US QE policy), compared to that in the financialization period of the commodity market (when the Federal Reserve raises the interest rate from June 2004 to June 2006 and before the US QE policy). Moreover, we provide additional evidence suggesting that the influence of the three variables on some

¹⁸ For a graphical representation see also Supplemental Appendix, Figs. 32, 36, 40, 54, 48, 52, 56 corresponding to Table 4, and Figs. 60, 64, 68, 72, 76, 80, 84 corresponding to Table 7.

Table 5

Variance decomposition of commodity price for the model of Wu and Xia's shadow rate, the interest-adjusted basis arbitrage activity, Working's T speculative activity and commodities' real prices.

Commodity's price	Wu and Xia's shadow rate	Arbitrage activity	Speculative activity	Price itself
silver	1.25	35.66	2.68	59.43
copper	2.82	10.92	0.06	80.47
crude oil	4.01	19.00	5.20	65.64
heating oil	4.04	15.49	0.61	72.69
cotton	5.40	3.49	3.83	79.62
soybean	4.88	8.41	10.14	73.77
coffee	2.55	13.08	20.29	63.66

Note: Data are the average of variance decomposition of sixty months ahead.

Table 8

Variance decomposition of commodity price for the model of the path surprise, the interest-adjusted basis arbitrage activity, the ratio of the net long position to the total position of non-commercials speculative activity and commodities' real prices.

Commodity's price	Paths	Arbitrage activity	Speculative activity	Price itself
silver	0.40	36.38	8.00	54.13
copper	10.19	10.16	22.33	49.25
crude oil	9.33	17.81	16.44	47.40
heating oil	11.99	21.91	15.78	42.40
cotton	3.82	9.44	16.70	68.44
soybean	18.99	10.65	18.43	44.53
coffee	8.51	14.97	26.00	44.77

Note: Data are the average of variance decomposition of sixty months ahead.

commodities' prices become even stronger after the de-financialization period (the same time when the Federal Reserve ceases the QE policy and increases the interest rate progressively).

The implications of this study are of great importance to policy makers, offering further insights into the mechanisms by which the real interest rate is transmitted onto commodities' prices under the US QE policy. Although the transmission mechanism of the inventory arbitrage activity through the impact of the real interest rate on the commodity price is mixed, our evidence suggests that the inventory arbitrage activity is the primary transmission channel, especially for the precious metals and the energy commodities, and this channel is mainly based on the fundamental factors such as the supply and demand, the change in the inventory, and the limits to arbitrage. Consequently, when formulating the appropriate monetary policy and managing the commodity market, policy makers should still focus on the fundamentals. Meanwhile, as the counterparty of the inventory arbitrage activity, speculative activity exerts a significant impact on the commodity price, particularly, in the short term, as it boosts the effect of the real interest rate on the commodity price. Therefore, policy makers should pay attention to the influence of the speculative activity on the commodity futures market.

Finally, the transmission mechanisms of the inventory arbitrage activity and the speculative activity on the effect of the real interest rate on the commodity price is consistent with our hypothesis in the short run. In the long term, however, the real interest rate, the commodity price and both activities will gradually adjust towards the long-term equilibrium level respectively. In other words, policymakers should focus on both the short-term and long-term effects of the monetary policy on the commodity physical cargos and futures markets.

Data availability

Data will be made available on request.

Appendix

Table 1A

Data Sources

Variables	Data	Data Sources
Dependent variables	7 individual commodity prices	
	silver, copper	COMEX
	light sweet crude oil, NY harbor	NYMEX
	heating oil	
	cotton, coffee	ICE U.S.
	soybean	CHICAGO BOARD OF TRADE

(continued on next page)

Table 1A (continued)

Variables		Data	Data Sources
Independent variables	7 individual commodity speculation	light sweet crude oil, NY harbor	NEW YORK MERCANTILE EXCHANGE
		heating oil	
		silver, copper	COMMODITY EXCHANGE INC.
		cotton	NEW YORK COTTON EXCHANGE
		soybean	CHICAGO BOARD OF TRADE
		coffee, copper	COFFEE, SUGAR AND COCOA EXCHANGE, ICE FUTURES U. S.
			from Reuters
			Wu and Xia (2016)
	interest rates	Euro-dollar futures rate	https://www.frbatlanta.org/cqer/research/shadow_rate.aspx?panel=1
		Shadow rate	
		U.S. 3-month treasury bill rate	FRED
			FRED
Others	the control variable inflation rate	TED spread	FRED
		U.S. CPI	OECD

Table 2A

Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
teds	183	.447	.427	.12	3.15
paths	183	.005	.111	−.824	.456
wxsr	183	.717	2.268	−2.986	5.263
silverp	183	.642	8.13	−11.843	30.824
silverarb	183	.298	1.713	−.156	16.603
silverspe	183	.522	.238	−.101	.923
silverwkt	183	1.132	.088	1.014	1.455
copperp	183	.228	1.941	−4.176	3.929
copperarb	183	.077	.125	−.027	.591
copperspe	183	.022	.288	−.661	.662
copperwkt	183	1.248	.124	1.061	1.625
crudeoilp	183	2.018	23.323	−41.041	67.027
crudeoilarb	183	.348	1.366	−4.396	4.947
crudeoilspe	183	.288	.226	−.37	.768
crudeoilwkt	183	1.111	.035	1.043	1.231
heatingoilp	183	2.64	29.695	−51.952	73.571
heatingoilarb	183	.715	1.948	−5.934	12.434
heatingoilspe	183	.157	.211	−.323	.803
heatingoilwkt	183	1.107	.05	1.016	1.258
cottonp	183	.026	.544	−.673	2.703
cottonarb	183	.011	.085	−.145	.738
cottonspe	183	.249	.348	−.638	.818
cottonwkt	183	1.151	.081	1.033	1.437
soybeanp	183	.008	.107	−.17	.281
soybeanarb	183	.005	.008	−.006	.043
soybeanspe	183	.319	.316	−.572	.789
soybeanwkt	183	1.134	.07	1.036	1.365
coffeep	183	.04	.448	−.748	1.57
coffeearb	183	−.011	.018	−.077	.045
coffeespe	183	.181	.314	−.444	.743
coffeewkt	183	1.167	.08	1.038	1.342

Note: *wxsr* refers to Wu and Xia's shadow interest rate; *commodityarb* refers to the interest-adjusted basis inventory arbitrage activity of the commodity; *commodityspe* is the ratio of the net long position to the total position of non-commercials speculative activity; *commodityp* is the price deviated from its equilibrium (average) of the commodity; *paths* means the path surprise which is in lieu of Wu and Xia's shadow interest rate; *commoditywkt* means the Working's T of the commodity which is to replace the ratio of the net long position of the total position of non-commercials speculative activity. This note is valid for all the results.

Table 3A

ADF Test for Unit Root

Date	Z(t) 5% Critical Value	p-value	d Z(t) 5% Critical Value	d p-value
teds	−3.4550	0.0092		
paths	−9.4060	0.0000		
wxsr	−0.2120	0.9371	−6.9990	0.0000
silverp	−2.5250	0.1095	−12.9850	0.0000
silverarb	−7.3770	0.0000		
silverspe	−4.4660	0.0002		
silverwkt	−4.2610	0.0005		
copperp	−2.4170	0.1369	−10.1000	0.0000

(continued on next page)

Table 3A (continued)

Date	Z(t) 5% Critical Value	p-value	d Z(t) 5% Critical Value	d p-value
copperarb	−1.4150	0.5750	−11.7560	0.0000
copperspe	−3.5230	0.0074		
copperwkt	−2.6690	0.0796	−14.9110	0.0000
crudeoilp	−2.3200	0.1657	−9.0720	0.0000
crudeoilarb	−3.1520	0.0229		
crudeoilspe	−3.8040	0.0029		
crudeoilwkt	−4.7540	0.0001		
heatingoilp	−2.4200	0.1361	−10.8890	0.0000
heatingoilarb	−9.4370	0.0000		
heatingoilspe	−4.9120	0.0000		
heatingoilwkt	−3.4360	0.0098		
cottonp	−2.9240	0.0427		
cottonarb	−7.4540	0.0000		
cottonspe	−3.4840	0.0084		
cottonwkt	−4.6380	0.0001		
soybeanp	−2.2380	0.1928	−12.9330	0.0000
soybeanarb	−5.8180	0.0000		
soybeanspe	−4.2010	0.0007		
soybeanwkt	−4.1900	0.0007		
coffeep	−2.0090	0.2827	−18.0070	0.0000
coffeearb	−5.4670	0.0000		
coffeespe	−3.0840	0.0278		
coffeewkt	−3.0840	0.0277		

$z(t) = -2.889$ at 5% critical value.

Table 4A
Lags Selection

Model	Lags	LR
teds dwxsr silverarb silverspe dsilverp	2	68.813*
teds dwxsr silverarb silverwkt dsilverp	2	56.664*
teds paths silverarb silverspe dsilverp	4	40.648*
teds dwxsr dcopperarb copperspe dcopperp	2	54.339*
teds dwxsr dcopperarb dcopperwkt dcopperp	3	38.621*
teds paths dcopperarb copperspe dcopperp	4	47.781*
teds dwxsr crudeoilarb crudeoilspe dcrudeoilp	4	44.836*
teds dwxsr crudeoilarb crudeoilwkt dcrudeoilp	3	59.891*
teds paths crudeoilarb crudeoilspe dcrudeoilp	4	55.976*
teds dwxsr heatingoilarb heatingoilspe dheatingoilp	2	63.961*
teds dwxsr heatingoilarb heatingoilwkt dheatingoilp	4	38.011*
teds paths heatingoilarb heatingoilspe dheatingoilp	2	112.63*
teds dwxsr cottonarb cottonspe cottonp	3	41.203*
teds dwxsr cottonarb cottonwkt cottonp	3	38.127*
teds paths cottonarb cottonspe cottonp	4	52.05*
teds dwxsr soybeanarb soybeanspe dsoybeanp	2	37.871*
teds dwxsr soybeanarb soybeanwkt dsoybeanp	3	39.669*
teds paths soybeanarb soybeanspe dsoybeanp	3	49.278*
teds dwxsr coffeearb coffeespe dcoffeep	4	37.777*
teds dwxsr coffeearb coffeewkt dcoffeep	3	39.486*
teds paths coffeearb coffeespe dcoffeep	4	47.827*

Note: * indicates lag order selected by the criterion; LR is the sequential modified LR test statistic (each test at 5% level); d refers to the first difference of that original data.

Table 5A

Comparison of the average amount of commercial and non-commercial's short and long positions in the financialization, de-financialization and post-de-financialization periods of the commodity market

commodity	period	short positions of commercials	long positions of non- commercials	long positions of commercials	short positions of non- commercials
silver	2003:5–2008:12	81,267	45,367	24,155	9067
	2009:1–2013:9	76,655	37,777	37,407	11,703
	2013:10–2018:6	108,881	74,834	58,974	36,148
copper	2003:5–2008:12	49,124	23,843	41,660	18,535
	2009:1–2013:9	71,676	38,429	71,437	36,324
	2013:10–2018:6	83,571	79,699	83,521	77,610
crude oil	2003:5–2008:12	598,769	155,330	577,952	125,914

(continued on next page)

Table 5A (continued)

commodity	period	short positions of commercials	long positions of non- commercials	long positions of commercials	short positions of non- commercials
heating oil	2009:1–2013:9	805,613	312,948	643,608	164,824
	2013:10–2018:6	1,018,075	565,596	632,411	190,619
	2003:5–2008:12	122,907	28,349	108,505	19,840
cotton	2009:1–2013:9	204,015	51,521	171,626	32,124
	2013:10–2018:6	211,030	76,504	191,549	68,549
	2003:5–2008:12	91,952	36,725	82,521	32,677
soybean	2009:1–2013:9	119,205	56,535	86,780	30,045
	2013:10–2018:6	145,507	88,570	90,297	36,987
	2003:5–2008:12	186,122	86,394	165,847	45,991
coffee	2009:1–2013:9	333,653	176,445	242,128	58,617
	2013:10–2018:6	368,179	201,348	345,842	131,563
	2003:5–2008:12	73,802	34,254	57,153	22,319
	2009:1–2013:9	82,496	37,902	70,931	27,347
	2013:10–2018:6	106,260	51,576	96,715	45,610

Note: The data are the average of the monthly positions of each commodity. Data source is presented in Table 1A.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.iref.2023.08.003>.

References

- Acharya, V. V., Lochstoer, L. A., & Ramadorai, T. R. (2011). *Limits to arbitrage and hedging: Evidence from commodity markets*. NBER Working Paper 16875.
- Adam, Z., & Glück, T. (2015). Financialization in commodity markets: A passing trend or the new normal? *Journal of Banking & Finance*, 60(Nov), 93–111.
- Adams, Z., Collot, S., & Kartsakli, M. (2020). Have commodities become a financial asset? Evidence from ten years of financialization, 104769 *Energy Economics*, 89, 1–20.
- Akram, F. (2009). Commodity prices, interest rates and the dollar. *Energy Economics*, 31, 838–851.
- Alam, M. R., & Gilbert, S. (2017). Monetary policy shocks and the dynamic of agricultural commodity prices: Evidence from structural and factor-augmented VAR analyses. *Agricultural Economics*, 48, 15–27.
- Alquist, R., & Gervais, O. (2012). The role of financial speculation in driving the price of crude oil. *Energy Journal*, 34(3), 35–54.
- Alquist, R., & Kilian, L. (2010). What do we learn from the price of crude oil futures? *Journal of Applied Econometrics*, 25(4), 539–573.
- Anzuini, A., Lombardi, M., & Pagano, P. (2010). *The impact of monetary policy shocks on commodity prices*. ECB working paper, No. 1232.
- 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(101536), 1–12.
- Arora, V., & Tanner, M. (2013). Do oil prices respond to real interest rates? *Energy Economics*, 36, 546–555.
- Baldi, L., Peri, M., & Vandone, D. (2011). *Spot and futures prices of agricultural commodities: Fundamentals and speculation*. Working Paper.
- Barsky, R., & Kilian, L. (2004). *Oil and the macro-economy since the 1970s*. NBER Working Paper 10855.
- Basistha, A., & Kurov, A. (2015). The impact of monetary policy surprises on energy prices. *Journal of Futures Markets*, 35(1), 87–103. January.
- Baumeister, C., & Peersman, G. (2013). The role of time-varying price elasticities in accounting for volatility changes in the crude oil market. *Journal of Applied Econometrics*, 28(7), 1087–1109.
- Beidas-Strom, S., & Pescatori, A. (2014). *Oil price volatility and the role of speculation*. IMF Working Paper, WP/14/218.
- Bessembinder, H. (1992). Systematic risk, hedging pressure, and risk premiums in futures markets. *Review of Financial Studies*, 5, 637–667.
- Bianchi, R. J., Fan, J. H., & Todorova, N. (2020). Financialization and de-financialization of commodity futures: A quantile regression approach, 101451 *International Review of Financial Analysis*, 68, 1–15.
- Bicchetti, D., & Maystre, N. (2012). *The synchronized and long-lasting structural change on commodity markets: Evidence from high frequency data*. MPRA Paper No. 37486, posted 20 March 2012.
- Bordo, M. (1980). The effects of monetary change on relative commodity prices and the role of long-term contracts. *Journal of Political Economy*, 88, 1088–1109.
- Bosworth, B., & Lawrence, R. (1982). *Commodity prices and the new inflation*. Washington DC: Brookings Institution.
- Brunetti, C., Büyüksahin, B., & Harris, J. H. (2016). Speculators, prices, and market volatility. *Journal of Financial and Quantitative Analysis*, 51(5), 1545–1574.
- Bruno, V. G., Büyüksahin, B., & Robe, M. A. (2017). The financialization of food? *American Journal of Agricultural Economics*, 99(1), 243–264.
- Büyüksahin, B., & Harris, J. H. (2011). Do speculators drive crude oil futures prices? *Energy Journal*, 32(2).
- Büyüksahin, B., & Robe, M. (2014). Speculators, commodities and cross-market linkages. *Journal of International Money and Finance*, 42, 38–70.
- 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), 1–28. Sep.
- Chari, V. V., & Christiano, L. (2017). *Financialization in commodity markets* (No. w23766). National Bureau of Economic Research.
- Cheng, I. H., & Xiong, W. (2014). Financialization of commodity markets. *Annual Review of Financial Economics*, 6(1), 419–441.
- Christoffersen, P., Lunde, A., & Olesen, K. V. (2019). Factor structure in commodity futures return and volatility. *Journal of Financial and Quantitative Analysis*, 54(3), 1083–1115.
- D'Amico, S., & Farka, M. (2011). The Fed and the stock market: An identification based on intraday futures data. *Journal of Business & Economic Statistics*, 29(1), 126–137.
- Domanski, D., & Heath, A. (2007). Financial investors and commodity markets. *BIS Quarterly Review*, March, 53–67.
- 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. *Journal of Business*, 75(2), 353–373. Apr.
- Eickmeier, S., & Lombardi, M. (2012). *Monetary policy and the oil futures market*. Deutsche Bundesbank discussion paper, No. 35/2012.
- Engel, C., & Frankel, J. (1984). The secular inflation term in open-economy Phillips curves: A comment on flood. *European Economic Review*, 24, 161–164.
- Fama, E. G., & French, K. R. (1987). Commodity futures prices: Some evidence on forecast power, premiums, and the theory of storage. *Journal of Business*, 60(1), 55–73. Jan.
- Fama, E. F., & French, K. R. (1988). Business cycles and the behavior of metals prices. *The Journal of Finance*, 43(5), 1075–1093.

- Fattouh, B., Kilian, L., & Mahadeva, L. (2013). The role of speculation in oil markets: What have we learned so far? *Energy Journal*, 34(3).
- Fisher, I. (1896). Appreciation and interest [J]. *Publications of the American Economic Association: First Series*, 11(4), 1–110.
- Frankel, J. (1984). Commodity prices and money: Lessons from international finance. *American Journal of Agricultural Economics*, 66, 560–566.
- Frankel, J. (1986). Expectations and commodity price dynamics: The overshooting model. *American Journal of Agricultural Economics*, 68(2), 344–348. May.
- 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. In *HKS faculty research working paper series RWP10-038*. John F. Kennedy School of Government, Harvard University.
- French, K. R. (1986). Detecting spot price forecasts in futures prices. *Journal of Business*, 59(2), S39–S54. Part 2: Futures and Options Markets (Apr.).
- Gagnon, J., Raskin, M., Remache, J., & Sack, B. P. (2010). *Large-scale asset purchases by the federal reserve: Did they work?*. FRB of New York Staff Report, 441.
- Geman, H., & Nguyen, V. N. (2005). Soybean inventory and forward curve dynamics. *Management Science*, 51(7), 1076–1091.
- Glick, R., & Leduc, S. (2013). *The effects of unconventional and conventional US monetary policy on the dollar*. Federal Reserve Bank of San Francisco. May.
- Glick, R., & Leduc, S. (2018). Unconventional monetary policy and the dollar: Conventional signs, unconventional magnitudes. *International Journal of Central Banking*, 103, 152, 56th issue (December).
- Gorton, G. B., Hayashi, F., & Rouwenhorst, K. G. (2012). The fundamentals of commodity futures returns. *Review of Finance*, 17, 35–105. Aug.
- Gospodinov, N., & Jamali, I. (2013). *Monetary policy surprises, positions of traders, and changes in commodity futures prices*. 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.
- Gu, C., Kurov, A., & Wolfe, M. H. (2018). Relief rallies after FOMC announcements as a resolution of uncertainty. *Journal of Empirical Finance*, 49, 1–18.
- Gürkaynak, R. S., Sack, B. P., & Swanson, E. T. (2005). Do actions speak louder than words? The response of asset prices to monetary policy actions and statements. *International Journal of Central Banking*, 1(1), 55–93.
- Hamilton, J. (2009). *Causes and consequences of the oil shock of 2007-2008*. NBER working paper, No. 15002.
- Hamilton, J. D., & Wu, J. C. (2015). Effects of index-fund investing on commodity futures prices. *International Economic Review*, 56(1), 187–205.
- 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.
- Hegerty, S. (2016). Commodity-price volatility and macroeconomic spillovers: Evidence from nine emerging markets. *The North American Journal of Economics and Finance*, 35, 23–37.
- Hirshleifer, D. (1988). Residual risk, trading costs, and commodity futures risk premia. *Review of Financial Studies*, 1(2), 173–193.
- Hirshleifer, D. (1989). Futures trading, storage, and the division of risk: A multiperiod analysis. *The Economic Journal*, 99(397), 700–719. Sep.
- Hirshleifer, D. (1990). Hedging pressure and futures price movements in a general equilibrium model. *Econometrica*, 58(2), 411–428. Mar.
- Hong, H., & Yogo, M. (2012). What does futures market interest tell us about the macroeconomy and asset prices? *Journal of Financial Economics*, 105(3), 473–490.
- Irwin, S. H., & Sanders, D. R. (2011). Index funds, financialization, and commodity futures markets. *Applied Economic Perspectives and Policy*, 33(1), 1–31.
- Irwin, S. H., & Sanders, D. R. (2012a). Financialization and structural change in commodity futures markets. *Journal of Agricultural & Applied Economics*, 44(3), 371–396.
- Irwin, S. H., & Sanders, D. R. (2012b). Testing the Masters Hypothesis in commodity futures markets. *Energy Economics*, 34(1), 256–269.
- Irwin, S. H., Sanders, D. R., & Merrin, R. P. (2009). Devil or angel? The role of speculation in the recent commodity price boom (and bust). *Journal of Agricultural & Applied Economics*, 41(2), 377–391.
- Juvenal, L., & Petrella, I. (2015). Speculation in the oil market. *Journal of Applied Econometrics*, 30(4), 621–649.
- Kagraoka, Y. (2016). Common dynamic factors in driving commodity prices: Implications of a generalized dynamic factor model. *Economic Modelling*, 52, 609–617.
- Kaldor, N. (1939). Speculation and economic stability. *The Review of Economic Studies*, 7, 1–27. Oct.
- Kaufmann, R., & Ullman, B. (2009). Oil prices, speculation, and fundamentals: Interpreting causal relations among spot and futures prices. *Energy Economics*, 31, 550–558.
- Kawamoto, T., Kimura, T., Morishita, K., & Higashi, M. (2011). *What has caused the surge in global commodity prices and strengthened cross-market linkage?*. Bank of Japan Working Paper Series, No. 11-E-3.
- Kazuhiko, O., & Tatsuyoshi, O. (2013). *Increasing trends in the excess co-movement of commodity prices*. RIETI discussion paper series, 13-E-048.
- Keynes, J. M. (1930). *A treatise on money* (Vol. II, pp. 142–144). London: Macmillan.
- Keynes, J. M. (1936). *The general theory of employment, interest, and money*. Cham: Palgrave Macmillan.
- Kilian, L., & Lee, T. K. (2014). Quantifying the speculative component in the real price of oil: The role of global oil inventories. *Journal of International Money and Finance*, 42, 71–87.
- Kilian, L., & Murphy, D. L. (2014). The role of inventories and speculative trading in the global market for crude oil. *Journal of Applied Econometrics*, 29, 454–478.
- Kim, A. (2015). Does futures speculation destabilize commodity markets? *Journal of Futures Markets*, 35(8), 696–714.
- Knittel, C., & Pindyck, R. (2016). The simple economics of commodity price speculation. *American Economic Journal: Macroeconomics*, 8(2), 85–110.
- Korniotis, G. (2009). *Does speculation affect spot price levels? The case of metals with and without futures markets*. Finance and economics discussion series, divisions of research & statistics and monetary affairs (pp. 2009–2029). Washington, D.C: Federal Reserve Board.
- Kozicki, S., Santor, E., & Suchanek, L. (2015). In *Large-scale asset purchases: Impact on commodity prices and international spillover effects* (No. 2015-21). Bank of Canada Working Paper.
- Krishnamurthy, A., & Vissing-Jorgensen, A. (2011). *The effects of quantitative easing on interest rates: Channels and implications for policy* (No. w17555). National Bureau of Economic Research.
- Kuttner, K. (2001). Monetary policy surprises, positions of traders, and changes in commodity futures prices. *Journal of Monetary Economics*, 47, 523–544.
- Lombardi, M., & Ravazzolo, F. (2012). *Oil price density forecasts: Exploring the linkages with stock markets*. Norges Bank Research working paper, 2012/24.
- Lombardi, M., & Robays, I. (2011). *Do financial investors destabilize the oil price?*. ECB working paper, No. 1346.
- Lombardi, M. J., & Zhu, F. (2018). A shadow policy rate to calibrate US monetary policy at the zero lower bound. *International Journal of Central Banking*, 305–346, 56th issue (December).
- Lucca, D. O., & Moench, E. (2015). The pre-FOMC announcement drift. *The Journal of Finance*, 70(1), 329–371.
- 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.
- Miffre, J., & Brooks, C. (2013). Do long-short speculators destabilize commodity futures markets? *International Review of Financial Analysis*, 30, 230–240.
- Mishkin, F. (1978). Efficient-markets theory: Implications for monetary policy. *Brookings Papers on Economic Activity*, 9(3), 707–752. Jan.
- Mishkin, F. (1995). Symposium on the monetary transmission mechanism. *The Journal of Economic Perspectives*, 9(4), 3–10. Fall.
- Morana, C. (2013). Oil price dynamics, macro-finance interactions and the role of financial speculation. *Journal of Banking & Finance*, 37, 206–226.
- Nakajima, J. (2011). Time-varying parameter VAR model with stochastic volatility: An overview of methodology and empirical applications. *Monetary and Economic Studies*, 107–142.
- Neely, C. J. (2015). Unconventional monetary policy had large international effects. *Journal of Banking & Finance*, 52, 101–111.
- Obstfeld, M., & Rogoff, K. (1984). Exchange rate dynamics with sluggish prices under alternative price-adjustment rules. *International Economic Review*, 25, 159–174.
- Okun, A. (1975). Inflation: Its mechanics and welfare costs. *Brookings Papers on Economic Activity*, (2), 351–401.
- Pirrong, C. (2009). *Stochastic fundamental volatility, speculation, and commodity storage*. Technical Report, University of Houston.
- Primiceri, G. E. (2005). Time varying structural vector autoregressions and monetary policy. *The Review of Economic Studies*, 72, 821–852.
- de Roon, F. A., Nijman, T. E., & Veld, C. (2000). Hedging pressure effects in futures markets. *The Journal of Finance*. LV. No. 3, June.

- Rosa, C. (2014). The high-frequency response of energy prices to U.S. monetary policy: Understanding the empirical evidence. *Energy Economics*, 45, 295–303.
- Rudebusch, G. D. (1998). Do measures of monetary policy in a VAR make sense? *International Economic Review*, 39(No. 4), 907–931.
- Saghalian, S., & Reed, M. (2015). Spillover effects of U.S. Federal Reserve's recent quantitative easing on Canadian commodity prices. *The International Journal of Food and Agricultural Economics*, 3(1), 33–43.
- Sanders, D. R., Irwin, S. H., & Merrin, R. P. (2010). The adequacy of speculation in agricultural futures markets: Too much of a good thing? *Applied Economic Perspectives and Policy*, 32(1), 77–94.
- Schnepf, R. (2005). *Price determination in agricultural commodity markets: A primer*. CRS-Congressional Research Service-Report for Congress, RL33204.
- Schwarz, K. (2012). Are speculators informed? *Journal of Futures Markets*, 32(1), 1–23.
- Shleifer, A., & Vishny, R. W. (1997). The limits of arbitrage. *The Journal of Finance*, LII(1), March.
- Silvennoinen, A., & Thorp, S. (2013). Financialization, crisis and commodity correlation dynamics. *Journal of International Financial Markets, Institutions and Money*, 24, 42–65.
- Singleton, K. J. (2014). Investor flows and the 2008 boom/bust in oil prices. *Management Science*, 60(2), 300–318.
- Śmiech, S., Papież, M., & Dąbrowski, M. A. (2015). Does the euro area macroeconomy affect global commodity prices? Evidence from a SVAR approach. *International Review of Economics & Finance*, 39, 485–503.
- Stoll, H. R., & Whaley, R. E. (2010). Commodity index investing and commodity futures prices. *Journal of Applied Finance*, 20(1), 1–68.
- Stoll, H. R., & Whaley, R. E. (2011). Commodity index investing: Speculation or diversification? *Journal of Alternative Investments*, 14(1), 50–60.
- Summers, P. (2017). *The effect of quantitative easing on commodity futures prices*. ResearchGate Working Paper. April 2017.
- Symeonidis, L., Prokopczuk, M., Brooks, C., & Lazar, E. (2012). Futures basis, inventory and commodity price volatility: An empirical analysis. *Economic Modelling*, 29(6), 2651–2663.
- Szymanowska, M., de Roon, F., Nijman, T., & van den Goorbergh, R. (2014). An anatomy of commodity futures risk premia. *The Journal of Finance*, 69(1), 453–482. Feb.
- Tang, K., & Xiong, W. (2012). Index investment and the financialization of commodities. *Financial Analysts Journal*, 68(6), 54–74.
- Tan, F., & Liu, J. (2015). The effects of real interest rate and oil inventory on the price of crude oil. *Review of Investment Studies*, 34(Nov), 4–21.
- Taylor, J. (1995). The monetary transmission mechanism: An empirical framework. *The Journal of Economic Perspectives*, 9(4), 11–26. Fall.
- Taylor, J. B., & Williams, J. C. (2009). A black swan in the money market. *American Economic Journal: Macroeconomics*, 1(1), 58–83.
- Telser, L. G. (1958). Futures trading and the storage of cotton and wheat. *Journal of Political Economy*, 66(3), 233–255 (Jun.).
- Tomson, A., & Summers, P. (2012). The effect of monetary policy on real commodity prices: A re-examination. *Journal of Economics*, 38(1), 1–21.
- Vansteenkiste, L. (2011). *What is driving oil futures prices? Fundamentals versus speculation*. ECB working paper, No. 1371/August 2011.
- Wang, L., Ahmad, F., Luo, G. L., Umar, M., & Kirikkaleli, D. (2021). Portfolio optimization of financial commodities with energy futures. *Annals of Operations Research*, 313, 401–439.
- Wang, S., & Chueh, L. (2013). Dynamic transmission effects between the interest rate, the US dollar, and gold and crude oil prices. *Economic Modelling*, 30, 792–798.
- Wright, J. H. (2012). What does monetary policy do to long-term interest rates at the zero-lower bound? *The Economic Journal*, 122(564), F447–F466.
- Wu, J. C., & Xia, F. D. (2016). Measuring the macroeconomic impact of monetary policy at the zero lower bound. *Journal of Money, Credit, and Banking*, 48(2–3), 253–291.
- 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*, 80, Article 102027.
- Zhang, Y. J., Chevallier, J., & Guesmi, K. (2017). “De-financialization” of commodities? Evidence from stock, crude oil and natural gas markets. *Energy Economics*, 68, 228–239.