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Abstract

This paper investigates how different commodity prices are affected by unconventional monetary policies (UMP) implemented by the Federal Reserve of the United States as a response to the Global Financial Crisis. We analyze impulse responses using local projections proposed by Jordà (2005) and follow Swanson (2017)'s identification strategy for UMP shocks. We show that forward guidance (FG) and large-scale asset purchase (LSAP) shocks lead to distinct responses from commodity prices. We find that asset-like commodities, such as gold and silver, respond to these UMP shocks most aggressively. While an easing FG shock leads to increases in their prices, an easing LSAP shock has the opposite effect. This differential response suggests that these asset-like commodities are being used as inflation and exchange rate hedges. In contrast, production-like and agricultural commodities respond to UMP shocks in the same way as conventional monetary policy shocks. Consistent with previous literature, we find that easing LSAP shocks, to some extent, signal a negative economic outlook. Policymakers can exploit these different commodities when evaluating the effectiveness of monetary policy in different sectors of the economy.

Keywords: Unconventional monetary policy; Commodity price; Impulse response analysis.

JEL: E44, E52, C54, Q02.

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1. Introduction

Before the onset of the Global Financial Crisis, central banks around the world typically used open market operations as the main operating procedure for monetary policy. During normal times, one could view an easing of monetary policy as either a decline in short-term interest rates or as an expansionary open market operation that increases the money supply. However, after reducing the policy interest rate close to zero by the end of 2008, the Federal Reserve had very limited capacity to stimulate the economy using conventional tools. As a result, the Federal Reserve, among other central banks, started to implement unconventional monetary policies (UMPs) as a way to stimulate the economy. In the United States, these non-standard monetary policies included forward guidance (FG), a situation where the central bank communicates the state of the economy and likely future course of monetary policy. The central bank also implemented large scale asset purchases (LSAPs) programs, which involves the purchase of assets that are not traditionally present in its portfolio.[1] Since these unconventional monetary tools were implemented, the literature has tried to quantify the impact of these policies on economic activity and financial markets.[2] Much less attention, however, has been paid to the consequences of these policies on commodities. This paper adds to this literature.

Analyzing the effects of UMPs on commodities can be quite informative as they capture different sectors of the economy. Some commodities (raw materials) are important inputs to the production process of different sectors in the economy. Thus, these commodities provide insights on how these policies affect industrial activity. Other commodities (agricultural products) reflect parts of households' consumption basket, and hence capture how the demand side reacts to UMPs. Finally, other commodities, such as gold and silver, are part of the households' financial portfolios. As a result, one can gather complementary information regarding the evolution of financial markets once UMPs are announced and implemented. Thus, by separately considering these different types of commodities, we can quantify the impact of UMPs on parts of the *real* economy as well as financial markets. We derive

[1] The Federal Reserve bought an unprecedented large amount of public debt of much longer maturities, as well as private mortgage backed securities.

[2] The effect of UMPs on financial markets has been studied extensively in the literature (see Neely, 2015; Swanson, 2017, and reference therein).

the impulse responses using local projections proposed by Jordà (2005) and employ the high-frequency identification strategy of Swanson (2017) to disentangle three monetary policy shocks. By focusing on changes in commodity prices in a narrow window after each unconventional monetary policy announcement, we can isolate their effects on commodity prices. The motivation of such an empirical strategy is that rational agents trading in commodity markets incorporate all public and relevant information, which are reflected in prices. Thus, price changes shortly after a UMP announcement can help us evaluate how this new information is perceived by producers, consumers, and investors, depending on what type of commodities we examine. In contrast, to have a clean identification, lower-frequency time series analyses should control for other factors affecting prices directly. Using such identification to perform an impulse response analysis, allows us to capture the instantaneous effect of such policies and provide an estimate of the persistence of UMP shocks.

We find that *asset-like* commodities, such as gold and silver, respond to the UMP shocks most aggressively. An easing LSAP shock leads to drops in gold and silver prices. However, the equity market has an opposite response to the same shock. This differential reaction between *asset-like* commodities and equity suggests that these precious metals are used as a hedge against equity market risk. Interestingly, an easing FG shock leads to increases in the price of gold both before and during the zero lower bound (ZLB) period. For silver, we find similar results, but only during the ZLB period. These findings suggest two possible channels through which such response operates. The first is the inflation expectation channel, whereby an easing FG shock (represented by lower long-run interest rate) increases future inflation expectations. Hence, in this situation, precious metals can be used as an inflation hedge. The second one is the exchange rate channel, where lower long-run interest rate makes the US dollar less attractive relative to foreign investments. Under such circumstances, precious metals can be used as a hedge against US dollar depreciation risk.

For production and agricultural commodities, the effects of UMPs are similar to those found under conventional monetary policies prior to the global financial crisis. We show that in most cases, the price of production and agricultural commodities rises in response to an easing UMP shock. This is consistent with a situation where households and firms see an easing UMP as a way to stimulate the

economy. Hence households increase consumption, leading to more production. As a result, prices of production-like commodities rise in the long-run. Our results are consistent with the findings of Frankel (2006), Hammoudeh et al. (2015), Scrimgeour (2014) and Alam and Gilbert (2017). Unlike these studies we employ high frequency identification with three policy shocks on individual commodity prices rather than a commodity index.

The remainder of the paper is organized as follows. Section 2 provides a review of the literature. Section 3 reviews the key events during the period when UMPs were enacted, and describes the data on commodity prices and the identification of monetary policy shocks. Section 4 investigates the effect of UMPs on commodity prices. Finally, Section 5 summarizes our findings and concludes.

2. Literature

This paper connects with two strands of literature: one that studies the impact of unconventional monetary policies on financial markets, and the other that examines how monetary policies affect commodity prices.

There has been a growing body of literature investigating the effects of UMPs on financial markets and the real economy.[3] Earlier work focuses on how LSAPs change the medium and long-term interest rates and Treasury yields. Prominent examples include Gagnon et al. (2011), D'Amico and King (2013), Krishnamurthy et al. (2011), Wright (2012) and Swanson and Williams (2014), which mostly examine the first two rounds of LSAP. The majority of studies consistently find that long-term interest rates and Treasury yields fall in response to easing UMP shocks. However, Swanson and Williams (2014) briefly discuss the notion that the Fed's forward guidance and LSAP could lead to different effects for intermediate and longer maturity treasury yields. Within this spirit, Swanson (2017) extends Swanson and Williams (2014) in two respects. First, the author uses a novel approach to extract the first few principal components across the term structure to identify two separate UMP shocks; namely, the FG and the LSAP shocks.[4] Second, in addition to Treasury bond yields, Swanson (2017) also examines

[3] Bhattarai and Neely (2016) offer a comprehensive and excellent review of existing studies on this topic.
[4] This high frequency identification strategy follows Gürkaynak et al. (2017).

the effects of UMP shocks on equity, exchange rates, and corporate bonds.[5] The author finds that FG was more effective than LSAPs at moving short-term Treasury yields, while LSAPs were more effective than forward guidance and the federal funds rate at moving longer-term Treasury and corporate bond yields.

Other authors have also analyzed the impact of UMPs implemented by other central banks. For instance, Bowman et al. (2015a) and Joyce et al. (2011) discuss the quantitative easing program of the Bank of Japan and the Bank of England, respectively. Although the Bank of Japan's reserve injections boosted bank liquidity significantly, much of the effect was offset as banks reduced their lending to each other. For the United Kingdom, the authors find that quantitative easing significantly lowered government bond yields by around 50 or so basis points. When international spillover effects of Fed's UMPs are considered, Bauer and Neely (2014) and Neely (2015) find that the jump depreciation of the US dollar is fairly consistent with estimates of the impacts of previous equivalent monetary policy shocks. The policy announcements do not appear to have reduced yields by reducing expectations of real growth. The authors also find that unconventional policy can reduce international long-term yields and the value of the dollar, even at the ZLB.

The literature studying the effects of UMPs on commodity markets is much smaller. Existing research on commodity markets usually only consider composite indices instead of individual commodity price series (Hammoudeh et al., 2015; Amatov and Dorfman, 2017; Glick and Leduc, 2012; Hayo et al., 2012). In contrast, Zhu et al. (2018) and Papadamou and Sogiakas (2018) examine how the UMP implemented by the Bank of England, Bank of Japan, and the European Central Bank (ECB) affects the prices of gold and silver. Their results show that the effects of UMPs are country-specific. Scrimgeour (2014) also examines the effects of monetary policy surprises on individual commodity prices prior to the ZLB period. The empirical findings on how the commodity market responds to the UMP shocks are divided. Some studies, such as Frankel (2006); Scrimgeour (2014); Amatov and Dorfman (2017); Hammoudeh et al. (2015), find that an easing monetary policy, represented by lower interest rate or higher level of money supply, leads to increase in commodity price indices. In contrast, Glick and

[5]Other studies focus on financial markets include Neely (2015), Kiley (2014).

Leduc (2012) show that commodity prices tend to fall in response to an easing LSAP announcement.[6] Moreover, they find that positive US monetary surprises led to declines in commodity prices, even as long-term interest rates fell and the US dollar depreciated. In contrast, on days of negative US monetary surprises, commodity prices tended to increase.

3. Data

To analyze the impact of UMPs on commodities prices, we require data on policy announcements, commodity prices, and monetary policy shocks. Below we provide information regarding the various time series and dates of different monetary policy actions.

3.1. Policy Announcements

We first review the major monetary policy announcements since the Zero Lower Bound was in place, and unconventional monetary policies were implemented. These range from November 2008 to December 2014. All dates and event descriptions are sourced from the Federal Reserve website (`www.federalreserve.gov`) and reconciled with Kozicki et al. (2011), Fawley and Neely (2013), Bowman et al. (2015b) and Swanson (2017). This information is summarized in Table 1.

*** TABLE 1 HERE ***

Since we use a high-frequency identification strategy to estimate the structural UMP shocks, these dates are going to be crucial in helping us measure the effects of UMP announcements on commodity prices.

3.2. Commodities

We consider three different commodity types. The first group is referred to as *asset-like* and includes gold and silver. Although the prominent role of gold has declined among central banks since the

[6] These authors use an event study approach to investigate the changes in a range of Goldman Sachs commodity indices during the first two rounds of LSAP.

collapse of Bretton Woods in the early 1970s, it is still an important asset for households' and central banks' portfolios. This is the case as gold is a store of value and a hedge against different types of risk and uncertainty. In times of financial distress, investors rebalance their portfolios by reducing their exposure to risky assets. This cross-market hedging strategy is sometimes referred to as a flight-to-safety (flight-to-quality). The literature has identified gold as a dollar hedge (Zagaglia and Marzo, 2013), as an inflation hedge (Zhu et al., 2018), as a hedge for stock market crises (Hood and Malik, 2013), or as a hedge for sovereign crises. Similar properties are also found for silver but to a lesser extent. Thus, prices of *asset-like* commodities reflect their fundamental value as well as the value associated with the alternative use as a financial asset to hedge various risks.

The second group of commodities is denoted as *production-like*. These include palladium, platinum, and copper. These commodities are typically used as inputs in different sectors of the economy. Palladium has numerous applications in industrial production, including car manufacturing, electronics, medicine, chemical applications, among its many other uses. Similar to palladium, platinum is also heavily used for vehicle emission control devices, electrical applications, and chemical production. In addition, due to its scarcity and resistance to corrosion, platinum is more widely used than palladium in jewelry making. The major applications of copper are electrical wire (60%), roofing and plumbing (20%), and industrial machinery (15%).[7] These *production-like* commodities contain information regarding real productive activities. Finally, the last group of commodities is referred to as *agricultural*, which captures elements of the households' consumption basket. In this latter group, we consider cocoa in the benchmark analysis, and corn, soybean, and wheat for robustness analysis due to their shorter sampling period.

For each of these commodity types, we collect daily price data from 1^{st} January 1991 to 30^{th} June 2016. Gold and silver prices represent the London fixing price at London Bullion Market Association (LBMA).[8] Prices are set per troy ounce and are in US dollar. Copper prices represent daily transactions of Grade A Copper at the London Metal Exchange (LME) in US dollar per Metric Tonne. The LMBA Platinum and Palladium prices are the fixing price in US dollar from London Platinum and Palladium

[7] https://en.wikipedia.org/wiki/Copper#Applications

[8] These are considered as the international standard for the pricing of gold and silver.

Market, which is also administered by LME. Cocoa is transacted at International Cocoa Organization (ICCO) and is denominated in US dollar per Metric Tonne. The choice of commodities examined in this paper is driven by their data availability.

3.3. Monetary Policy Shocks

To identify monetary policy shocks, we use the methodology developed by Swanson (2017). More precisely, the author extracts a number of asset prices on 213 Federal Open Market Committee (FOMC) announcement days from July 1991 to October 2015.[9] It is commonly accepted that the interest rate futures and Treasury yields are highly responsive to changes in monetary policy. Hence only price changes within the 30-minute window around the FOMC announcement time are considered.[10] The first three principal components are extracted from these eight series of 30-minute asset price changes to identify monetary policy shocks. These are then mapped into the Federal Funds Rate (FFR), FG, and LSAP shocks. The identification assumptions used by Swanson (2017) are as follows. The first restriction is that LSAPs shocks do not affect the federal funds rate contemporaneously. The second assumption is that FG shocks do not affect federal funds rates contemporaneously. Hence the FG shock is defined as surprises to the future path of short-term interest rates over and above surprises to the federal funds rate itself. Lastly, the LSAP shock is minimized before the ZLB period. The three identification restrictions combined, lead to a unique rotation of the first three principal components. In addition to this full-sample identification, Swanson (2017) also implements a split-sample identification, assuming there are only two factors (FFR and FG shocks) before the ZLB period, and two factors (FG and LSAP shocks) during the ZLB period. The empirical results obtained using the split-sample identification are qualitatively similar to the benchmark case. Hence we only discuss the monetary policy shocks identified using the full-sample scheme in the following analyses.

*** FIGURE 1 HERE ***

[9] These include 1-month and 3-month federal funds futures, 2-quarter, 3-quarter and 4-quarter ahead Eurodollar futures, and 2-year, 5-year, and 10-year Treasury yields. These eight assets do not contain any overlapping contracts in order to avoid high correlation by construction.

[10] The 30-minute window starts from 10-minute before the announcement, and finishes at 20-minute after the announcement.

The three structural shocks identified by Swanson (2017) are plotted in Figure 1. These shocks are normalized such that positive (negative) values represent a tightening (easing) in monetary policy. As we can see, the FFR shock is negligible after December 16, 2008, when the FOMC cut the federal funds rate to 0-0.25% and reached the ZLB. Moreover, the effect attributed to FG shock dramatically increased on the same day. It is also worth noting that the largest LSAP factor occurred on March 18^{th} 2009, which corresponds to the announcement by the Federal Reserve of large purchases in Treasury bills and mortgage backed securities. The correlations among these three structural shocks are essentially zero as they are extracted from orthogonal principal components. There are very weak serial correlations but mostly insignificant up to the 12^{th} order. We refer the reader to Swanson (2017) for more detailed discussions on the identification schemes and some summary statistics of the identified shocks.

4. Empirical Strategy

In order to provide some evidence that links FOMC announcements and their impact on the real economy and financial markets, we use two different approaches. We first consider structural breaks in the price series of the various commodities, and match them with the key monetary policy events. We then estimate impulse responses of high frequency commodity prices to the monetary policy shocks of interest using local projections proposed by Jordà (2005).

4.1. Structural Break Tests

We first examine whether commodity prices react to the various policy announcements by testing for breaks in each of the price series. In particular, we estimate the dates of structural breaks in commodity prices July 1, 2008 to June 30, 2016, identified by four commonly used tests due to Carrion-i Silvestre et al. (2005), Lee and Strazicich (2003), Bai and Perron (2003) and Lumsdaine and Papell (1997), and match them with days of key monetary policy announcements as listed in Table 1. Table 1 includes all the major announcements between November 2008 and December 2014, including speeches made by the Fed's Chairman Ben Bernanke, such as the ones made in Austin, Jackson Hole, and Boston, along with the major FOMC announcements. This yields 51 major communication signals between

July 1, 2008, to December 31, 2014, which we match with our structural break dates. While there were more than 55 FOMC meetings during this period, a few of them did not release much new information. Hence, our table includes almost all announcements except these few. For this type of analysis, we need to define a proximity measure associated with the break test. We can then determine, by looking at the various dates, whether commodity prices were impacted by policy announcements. The window we use is seven days before or after each announcement. Dates before announcements capture anticipation effects by market participants. The results of the various break tests and dates of policy announcements are reported in Table 2.

*** TABLE 2 HERE ***

As Table 2 shows, the majority of the structural breaks in commodity prices happened during the second stage of the LSAP program, and during the period between May 2013 and April 2015. Furthermore, most of the breaks in commodity prices were observed after the announcement dates. This suggests that the anticipation effect by market participants was less pronounced. It is also worth noting that out of all commodities, most of the breaks that coincide with policy announcements are associated with *asset-like* commodities. This is not too surprising as financial assets quickly reflect additional information in their prices when compared to other types of commodities that are more directly linked to real activity. For example, almost all of the break dates for gold occur immediately after the policy announcements. This highlights the important role of gold as a hedging instrument. Our break results provide some preliminary and suggestive evidence that FOMC announcements have a substantial influence on commodity prices. Moreover, responses commodities of different types respond differently to the various policy announcements.

4.2. Impulse Response Analysis

We follow Swanson (2017) and examine the persistence of the effects of various monetary shocks on commodity prices. Therefore, in addition to the immediate responses, we are also interested in the dynamic effects of different UMP shocks on commodity prices. An impulse response analysis enables

us to capture the follow-through of the complete response paths of commodity prices. The impulse responses are estimated using the local projections proposed by Jordà (2005). The baseline model is given by

$$\log y_{t-1+h} = \beta_0 + \beta_1 \log y_{t-1} + \phi_{1,h}\varepsilon_{FFR,t} + \phi_{2,h}\varepsilon_{FG,t} + \phi_{3,h}\varepsilon_{LSAP,t} + u_{t,h}, \tag{1}$$

where y_t denotes the commodity price on announcement day t, h represents the day after the announcement for the 3 monetary policy shocks, ε_{FFR}, ε_{FG} and ε_{LSAP}. The effects of these structural shocks on commodity prices are captured by coefficients $\phi_{i,h}$, $i = 1, 2, 3$ for $h = 1, 2, \ldots, 60$. Clearly for $h = 1$ the estimated coefficient $\phi_{i,1}$ captures the instantaneous effect of shock i on the price of the commodity.

This local projection method proposed by Jordà (2005) is an alternative way of estimating impulse responses relative to a structural vector autoregressive model (SVAR). As shown in equation (1), it essentially uses direct multi-step forecasting at each horizon h. In sharp contrast, the structural VAR approach uses iterated forecasting calculated from the estimated VAR coefficients, which is only optimized for one-step ahead forecasting. In addition, VAR usually only represents a linear approximation of the true data generating process (DGP), such approximation errors can be compounded with forecast errors in long horizons, leading to inaccurate estimates of the corresponding impulse responses. The main advantage of the local projection method is that we don't need to specify and estimate the underlying multivariate dynamics to obtain the impulse responses. Hence it is more robust to misspecification. Jordà (2005) also established the consistency and asymptotic normality of the impulse responses estimated using local projections. The interval estimates are obtained using heteroskedasticity and autocorrelation consistent (HAC) standard errors, as the residual from the local projection (1) is a moving average of the forecast errors. Other applications and discussions of local projections can be found in Jordà et al. (2013); Ramey and Zubairy (2018); Stock and Watson (2018), among others.

4.2.1. Instantaneous Effects

Since break tests suggested that FOMC announcements had some larger effects on *asset-like* commodities, we also analyze the S&P500 index as a benchmark comparison. It is worth highlighting that in

addition to their use as a store of value, gold and silver can also be used as hedging instruments. This alternative use is particularly important when agents face uncertainty, while other financial assets provide low returns and/or high volatility. Table 3 reports the magnitude and significance of the coefficients associated with the three monetary policy shocks for the S&P500 index and various commodities for $h = 1$, *i.e.* the instantaneous announcement effect.

*** TABLE 3 HERE ***

The first column of Table 3 shows that the instantaneous effects of the monetary policy shocks on the S&P500 index have the same sign and similar magnitudes as those estimated in Swanson (2017). In the pre-ZLB period, monetary tightening, through either raising federal funds rate or forward guidance, causes the stock market index to fall. During the ZLB period, the FG shock has an even larger negative effect on stock prices, although it is statistically insignificant. Moreover, the LSAP shock has a small positive impact on the S&P500 index in the impact period.

During the pre-ZLB period, both gold and silver prices increase in response to tightening monetary policy shocks, whilst the stock market index decreases. These distinct responses highlight the role of gold and silver as a hedging instrument. This is consistent with the negative estimates for precious metals found by Hillier et al. (2006). Prices of precious metals are commonly driven up during crisis times as investors "fly to safety". From July 2, 2007 to March 9, 2009, the S&P500 stock index lost 55%, while gold rallied by 40%. However, since the beginning of the ZLB, gold price responds to the two monetary policy shocks in the same direction as the S&P500 index. This might reflect the fact that the US stock market and gold share similarity hedging properties against the European sovereign crises. It is worth recalling that at the time, this was the major source of risk. More precisely, in July 2011, the Eurozone approved a rescue package to Greece, and in August, European Central Bank (ECB) started significant purchases of Spanish and Italian sovereign bonds under its Securities Markets Programme. The easing LSAP policy on August 9, 2011, by the Fed led to a 4.6% gain in S&P500. At the same time, the gold price also increased by almost 3.5% due to persistent fears about the economic outlook in the Eurozone. Similarly, in October 2011, as the Bank of England injected £75 billion into its economy, and

the Eurozone reached a deal on the second Greek bailout package, the gold price steadily increased. Meanwhile, the S&P500 experienced an increase under a series of Fed easing LSAP policies.

The only statistically significant instantaneous effect occurs with the LSAP shock on the gold price. In particular, an easing policy (negative shock) leads to a sizable drop in the price of gold. This indicates that UMP successfully reduced the risk in the economy. With regards to production and agricultural commodities, while none of their instantaneous response is significant, the magnitude remains positive. However, our previous structural break test results show significant breaks in these commodity prices around the quantitative easing event dates.

4.2.2. Longer Lasting Effects

Impulse responses based on local projections enable us to capture the follow-through of these price responses. We now provide a complete characterization of response paths from commodity prices to different UMP shocks. More precisely, we estimate the impulse responses for up to 60 days after an announcement day, i.e. almost 3 months. Table 4 summarizes the estimated impulse responses for all commodities and their corresponding HAC standard error estimates. We only report the results for every 5-day interval due to space limitation. Plots of point and interval estimates of these impulse responses are presented in Figures 2–8.

*** TABLE 4 HERE ***

Asset-Like Commodities

We first present the impulse responses of the S&P500 index in Figure 2 to contrast with those of precious metals. Before the ZLB period, S&P500 index responds negatively to both monetary policy shocks, *i.e.* monetary tightening through either raising federal funds rate or forward guidance. These negative effects from FFR and FG shocks remain statistically significant up to about 5 weeks and 3 weeks, respectively. During the ZLB period, the longer term dynamic effects of the FG shock are mostly close to 0 and are insignificant. On the other hand, the LSAP shock has initially a small positive

impact on the S&P500 index, but the effect becomes negative after 3 weeks. Not only the magnitude of the response becomes larger in the long-term, it is often statistically significant from 5 weeks onward. As the LSAP shocks are mostly negative during the ZLB period, representing monetary easing policies, it causes the stock market to increase in the weeks following the shock. Therefore, prior to the ZLB period, the two monetary policy measures, FFR and FG, have similar effects on the equity market. In contrast, during the ZLB period the LSAP shock has much stronger and more long-lasting effect than the FG shock.

*** FIGURES 2–4 HERE ***

The impulse responses of gold and silver prices are presented in Figures 3 and 4, respectively. Prior to the ZLB period, the FFR shock does not have any statistically significant effect on gold prices. Notably, the FG shock always has negative impact on the price of gold in both sub-sample periods. These results are most likely capturing inflation and dollar hedges. A positive (tightening) FG shock, higher long-run interest rate, will lead to lower future inflation expectations. This also makes the US dollar more attractive relative to foreign investments. Therefore, as the demand for inflation and dollar hedges fall, the price of gold will drop. Such effects are stronger during the ZLB period, and remain mostly statistically significant for 7-8 weeks after a FG shock.

As for the LSAP shock, an easing policy (negative shock) leads to a sizable drop in the price of gold. This indicates that quantitative easing policies can successfully reduce the risk in the economy. This effect becomes statistically significant and peaks at 4-5 weeks after a LSAP shock. At the same time, the S&P500 index increases in response to an easing LSAP shock in the long-run. This asymmetric movements suggests that gold can still be used to diversify risk stemming from the equity market during the ZLB period. Note that the price of gold responds differently to the FG and LSAP shocks during the ZLB period. Moreover, gold price is more sensitive to FG shocks. An easing monetary policy could be a combination of both, with the FG shock causing gold price to rise, and the LSAP shock causing gold price to fall. As a result, the overall effect on gold price depends on the magnitude

of these shocks. Thus, our results are not inconsistent with the findings of Zhu et al. (2018) that reports that the return on gold usually increases after a quantitative easing announcement.

The demand for silver as a government reserve or private investment is not as high when compared to gold. The estimated impulse responses of silver prices to various monetary policy shocks are depicted in Figure 4. These look very similar to those found for gold prices. Prior to ZLB, both the FFR shock and the FG shock have negative effects on silver prices. The effect of FFR shock is statistically significant 4-5 weeks after a shock, whereas the response to FG shock is mostly insignificant. Weaker responses to FG shock than gold price indicate that, although silver can also be used to hedge against inflation risk as a precious metal, gold has a more prominent role. During the ZLB period, the responses of silver price to both shocks are usually larger than those of gold price, but have less statistically significant cases. Once again these results highlight how gold and silver can be used as a store of value and as a hedge against inflation and other financial risks. These results also emphasize the leading role of gold among precious metals as the preferred commodity hedge.

Production-like Commodities

As pointed out by Hillier et al. (2006), the prices of industrial materials are largely determined by the state of the economy. Before the global financial crisis, previous studies find that a tightening shock, typically represented by a rise in interest rate, leads to a reduction in the price of industrial commodities. However, the effects of UMPs are rarely discussed. We expect that palladium, platinum and copper prices fall in response to tightening monetary policy shocks both before and after the ZLB.

*** FIGURES 5–7 HERE ***

The impulse responses of palladium, platinum and copper corresponding to the three monetary policy shocks are presented in Figures 5, 6 and 7, respectively. Prior to the ZLB period, palladium is much more responsive to the FFR shock than the FG shock. The FG shock does not have a statistically significant effect on the price of palladium up to 60 days after the shock. This is also the case for platinum and copper. On the other hand, increasing the federal funds rate leads to a drop in the

palladium price. This effect is particularly large at around 5 weeks after a FFR shock. Such negative response is consistent with conventional wisdom when the central bank did not pursue unconventional monetary policies. A tightening monetary policy slows down economic activity, and prices of production materials drop as a result. The prices of platinum and copper also respond negatively to the FFR shock, although their impulse responses are mostly statistically insignificant. Hammoudeh et al. (2015) similarly find a persistent reduction in the metal price index as a result of a positive interest rate shock.

During the ZLB period, forward guidance becomes the new monetary policy norm, and accordingly, the FG shock has large negative effect on the prices of palladium and platinum. These effects are mostly significant 2-5 weeks after a FG shock. Expecting a future increase in the interest rate (as implied by a positive (tightening) FG shock) decreases prices of production-like commodities. Frankel (2006) also finds that for a 1 percent increase in the real interest rate is associated with the Thomson Reuters CoreCommodity CRB index decreasing by 6 percent with a speed of adjustment of 0.16 per year. These results largely contradicts the findings of Glick and Leduc (2012), who find that easing US monetary surprises lead to declines in prices of commodities like metals. They argue that LSAP announcements are likely to involve signaling effects about future economic activity, which leads investors to downgrade their US economic growth forecasts, and results in a decline in commodity prices. Our results suggest that in the long run, easing UMPs lead to increased prices of palladium and platinum. Since such policies are aimed at stimulating the economy, one would expect a future increase in the demand for production materials. It is important to note that Glick and Leduc (2012) do not examine the long-run effects of UMP shocks, and hence their results are more comparable to the instantaneous effects, rather than the long-run impact of such policies.

Copper reacts to the FG and LSAP shocks differently compared with palladium and platinum during the ZLB period. Although the FG shock has negative effects on copper price for 4-5 weeks, it reverts to positive at 5 weeks after a FG shock. In addition, none of the effects has any statistical significance at 5% level. The LSAP shock, on the other hand, does show some significant negative impact in the mid to long-run.

Agricultural Commodities

Due to limited availability of agricultural commodity price data, we only analyze cocoa. A few other agricultural commodities have data that cover part of the announcement period from 1991 to 2015; we use them for robustness checks in the next section. The impulse responses of coca price to the monetary policy shocks are depicted in Figure 8.

*** FIGURE 8 HERE ***

The left column of Figure 8 shows that prior to the ZLB period, a positive (tightening) FFR shock leads to large but mostly insignificant drop in the price of cocoa, while the FG shock doesn't seem to have much of an impact. This is largely consistent with the finding of Scrimgeour (2014) that unexpected interest rate movements lead to decrease in the prices of agricultural commodities. Alam and Gilbert (2017) analyze the price dynamics of corn, wheat, oat and soybean, and find that monetary easing leads to higher commodity prices. Moreover, the authors find that, even before 2003, co-movements are more pronounced in major agriculture commodities.

The left column of Figure 8 shows that during the ZLB period, the FG shock has negative effects on the price of cocoa. In particular, the magnitude increases gradually, and becomes statistically significant roughly 2 months after a FG shock. Bamba and Reed (2004) use monetary supply as a policy instrument and also find a negative impact on the price of cocoa at the 3-month horizon. On the other hand, the long-run effect of the LSAP shock on the price of cocoa is positive, although it is smaller in magnitude than the effect of the FG shock. The price of agricultural commodities are also heavily affected by other factors that tend to exhibit strong seasonal patterns. Moreover, households' demand for food products is fairly constant over the business cycle. Hence monetary policy shocks do not have strong influence on their prices.

4.3. Robustness Analysis

We implement a wide range of experiments to determine the robustness of our results. The first one is to use an alternative model specifications when constructing the local projections to estimate the impulse responses. We consider higher order lags of $\log y_t$ as additional control variables on the right hand side of equation (1), and we find them to be mostly insignificant. We also estimate a restricted model with $\beta_0 = 0$ and $\beta_1 = 1$, as these two coefficients are almost always close to 0 and 1, respectively. In addition, t-test shows that these coefficients are not statistically different from 0 and 1. The impulse responses obtained from the restricted model are very similar to those shown in the previous section. These results are available upon request.

Given that different financial markets are closely inter-connected, we introduce the S&P500 index and VIX as additional control variables to control for potential model mis-specification. We estimate local projections in two different ways. The first one uses the single-equation model that includes S&P500 index and the VIX as two additional control variables, which is given by

$$\log y_{t-1+h} = \beta_0 + \beta_1 \log y_{t-1} + \beta_2 \log SP_{t-1} + \beta_3 \log VIX_{t-1} + \phi_{1,h}\varepsilon_{FFR,t} + \phi_{2,h}\varepsilon_{FG,t} + \phi_{3,h}\varepsilon_{LSAP,t} + u_{t,h}. \quad (2)$$

A second alternative is to use multi-equation vector autoregression (VAR) model within each sub-group of commodities. Specifically, we build a VAR system with gold, silver, the S&P500 index and VIX. We consider another VAR with palladium, platinum, copper, the S&P500 index and VIX.[11] This effectively includes other commodity prices from the same sub-group as control variables when estimating the local projections. We find that the impulse responses obtained in these two alternative models are very similar to the baseline case.

As the identified monetary policy shocks cover a long time period from July 1991 to October 2015, our previous empirical analyses only use commodity prices that have data available for the entire sample period. There are a few other commodity price series that are available only after 1996. We

[11] We do not estimate VAR for cocoa as the estimated impulse response will be the same as the single-equation model for cocoa.

conduct the same estimation procedure with this shorter sample. This is especially relevant for agricultural commodities. As a result, we have a shorter pre-ZLB period starting from January 1996 (113 announcements). However, the ZLB period, where UMP shocks operate, is the same as before (55 announcements). We extract daily data on the front month continuation price on corn, soybean and wheat from Chicago Board of Trade (CBOT), and implement local projections using these commodity prices. Their corresponding impulse responses are tabulated in Tables 3 and 4, and are depicted in Figures 9–11.

*** FIGURES 9–11 HERE ***

Corn, soybean and wheat prices exhibit similar responses to monetary policy shocks. The corresponding instantaneous responses, found in in Table 3, almost always have the same sign. In particular, easing monetary policy shocks tend to lead to a price increase in agricultural commodities, except for the LSAP shock. An easing LSAP shock seems to be viewed more as a signal of a negative future economic outlook. Hence it leads to drops in all commodity prices on the day of the shock occurrence. Such differential impacts of the FG and LSAP shocks during the ZLB period, once again highlight the importance of disentangling the two UMP shocks. In terms of long-lasting effects of various monetary policy shocks, most of our previous cocoa results carry through to corn, soybean and wheat prices.

Last but not least, we verify that commodity prices are indeed responding to monetary policy shocks. To do so we consider a counterfactual exercise. We construct shocks from weather data on days of the FOMC made announcements. Then we estimate the responses of commodity prices to these weather shocks. We expect these shocks to be orthogonal to monetary policy shocks, and should not induce any meaningful changes in commodity prices. This is especially the case for non-agricultural commodities, where weather does not affect their supply.

Weather data are obtained from the National Centers for Environmental Information website.[12] We use daily observations on precipitation, snowfall, maximum and minimum temperature for the weather station USW00013743 at Washington Reagan National Airport, from 1^{st} January 1991 to 30^{th}

[12] https://www.ncdc.noaa.gov/cdo-web/search

June 2016. Take the daily minimum temperature as an example. It is regressed against all monthly dummies to control for seasonality, as well as 50 lags of all 4 time series of daily weather data to control for autocorrelation and cross-correlation, the residual is then taken as the shock to daily minimum temperature, denoted as $\varepsilon_{MIN,t}$. The maximum temperature shock, $\varepsilon_{MAX,t}$, is obtained using a similar procedure, except that $\varepsilon_{MIN,t}$ is also added to the list of control variables to ensure orthogonality of these shocks. The third weather shock we construct is daily precipitation, which is orthogonalized against both $\varepsilon_{MIN,t}$ and $\varepsilon_{MAX,t}$.[13] Once these 3 weather shocks are computed, we extract their values on the same set of 213 FOMC announcement dates, and use them in a local projection regression to estimate the corresponding impulse responses. The correlation between the weather shocks and monetary policy shocks are very close to zero, and statistically insignificant.

*** FIGURES 12–14 HERE ***

The responses of each commodity prices to the three weather shocks are depicted in Figures 12–14. The scale on the y-axis has been normalised to [-2, 2] to facilitate comparisons across different panels. Comparing with the impulse responses to the 3 monetary policy shocks, the weather shocks have little effect on commodity prices. In addition, almost all the responses are statistically insignificant, with only a few exceptions. This supports our argument that changes in commodity prices cannot be attributed to other factors such as weather shocks. Given the high frequency identification of the monetary policy shocks, it is unlikely that other shocks would occur in such a short time frame and in a similar fashion. The near-zero responses of commodity prices to the set of weather shocks corroborate such conjecture.

5. Conclusion

This paper investigates how commodity markets are affected by unconventional monetary policies implemented by the Federal Reserve of the United States. We use the high frequency identification

[13] Given the strong seasonality feature of snowfall, it is not used to construct a weather shock here.

strategy proposed by Swanson (2017) to extract three distinct monetary policy shocks, namely, the federal funds rate (FFR), the forward guidance (FG) , and the large-scale asset purchase (LSAP) shocks. In addition to implementing structural break tests and estimating the instantaneous effects, we employ local projections to estimate impulse responses using daily data. The commodities we analyze belong to three categories: (1) *asset-like* commodities (gold and silver), which are commonly used to hedge various financial risks; (2) *production-like* commodities (copper, palladium and platinum), which are commonly used as inputs for industrial production; (3) and finally *agricultural* commodities (cocoa, corn, soybean, wheat) that are mainly consumption goods.

We find that *asset-like* commodities respond to UMP shocks most aggressively. However, the FG and LSAP shocks tend to have opposite effects. An easing LSAP shock leads to drops in gold and silver prices, which is consistent with the findings of Glick and Leduc (2012). Relative to an easing LSAP shock, the equity market responses is opposite to that of gold and silver prices. This suggests the role of precious metals as hedge against equity market risk. Interestingly, an easing FG shock leads to increases in the price of gold both before and during the zero lower bound (ZLB) period. This is also the case for silver during ZLB. There are two possible channels through which such response operates. The first is the inflation expectation channel. An easing FG shock, represented by lower long-run interest rate, increases future inflation expectations. Precious metals act as an inflation hedge in this situation. The second one is the exchange rate channel, where lower long-run interest rate makes the US dollar less attractive than foreign investments. Precious metals then serve as a US dollar hedge.

For production and agricultural commodities, the effects of UMPs are similar to those associated with conventional monetary policies prior to the global financial crisis. Nevertheless, the FG shock appears to be more effective than the LSAP shock in changing commodity prices. We find that in most cases, the price of production and agricultural commodity rises in response to an easing UMP shock. One possible explanation for such results is that easing UMPs stimulate economic activity. This lead to an increased demand for goods. As a result, prices of production and agricultural commodities rise in the long-run. In this paper we find that different monetary policy shocks differently affect commodities that capture production, consumer and financial markets. Policymakers can exploit these

different commodities when evaluating the effectiveness of monetary policy in different sectors of the economy.

Our analyses on individual commodity prices complement the studies on the effects of UMPS on financial markets by Glick and Leduc (2012), Amatov and Dorfman (2017) and Swanson (2017). Left for future research is to determine the relative importance of different structural shocks in the forecast error variance decomposition of the local projections. The economic turbulence caused by COVID-19 in early 2020 is yet another interesting avenue to study the impact of unconventional monetary policies in response to this large and negative shock.

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Table 1: Major US unconventional monetary policy (UMP) announcements

Date	Event(s)	Notes
First LSAP		
11/25/2008	FOMC Statement	Fed announces purchases of $100 billion in GSE debt and up to $500 billion in mortgage-backed securities (MBS).
12/01/2008	Speech(Austin)	FED Chairman Bernanke mentions that the Fed could purchase long-term Treasuries.
12/16/2008	FOMC Statement	Target federal funds rate decreased to between 0 and 0.25%. FOMC statement first mentions possible purchase of long-term Treasuries.
1/28/2009	FOMC Statement	FOMC statement says that it is ready to expand agency debt and MBS purchases, as well as to purchase long-term Treasuries.
03/18/2009	FOMC Statement	FOMC will purchase an additional $750 billion in agency MBS, to increase its purchases of agency debt by $100 billion, and $300 billion in long-term Treasuries.
04/29/2009	FOMC Statement	The Federal Reserve will purchase a total of up to $1.25 trillion of agency mortgage-backed securities and up to $200 billion of agency debt by the end of the year. In addition, the Federal Reserve will buy up to $300 billion of Treasury securities by autumn.
06/24/2009	FOMC Statement	The Fed Reserve will purchase a total of up to $1.25 trillion of agency MBS and up to $200 billion of agency debt by the end of the year. In addition, the Federal Reserve will buy up to $300 billion of Treasury securities by autumn.
08/12/2009	FOMC Statement	Fed restate purchase of MBS and agency debt by end-2009 and it is in the process of buying of Treasury securities.
09/23/2009	FOMC Statement	Fed's purchases of $300 billion of Treasury securities will be completed by the end of October 2009.
11/04/2009	FOMC Statement	The amount of agency debt to be purchased by the Fed reduced to $175 billion. MBS and agency debt purchases are to be completed by end-2010Q1.
12/16/2009	FOMC Statement	To provide support to mortgage lending and housing markets and to improve overall conditions in private credit markets, the Federal Reserve is in the process of purchasing $1.25 trillion of agency mortgage-backed securities and about $175 billion of agency debt.
01/26/2010	FOMC Statement	To provide support to mortgage lending and housing markets and to improve overall conditions in private credit markets, the Federal Reserve is in the process of purchasing $1.25 trillion of agency mortgage-backed securities and about $175 billion of agency debt
03/16/2010	FOMC Statement	To provide support to mortgage lending and housing markets and to improve overall conditions in private credit markets, the Federal Reserve has been purchasing 1.25 trillion of agency mortgage-backed securities and about $175 billion of agency debt; those purchases are nearing completion, and the remaining transactions will be executed by the end of this month

04/28/2010	FOMC Statement	The Committee will maintain the target range for the federal funds rate at 0 to 1/4 percent and continues to anticipate that economic conditions, including low rates of resource utilization, subdued inflation trends, and stable inflation expectations, are likely to warrant exceptionally low levels of the federal funds rate for an extended period.
08/10/2010	FOMC Statement	Fed will keep constant its holdings of securities at their current level by reinvesting principal payments from agency debt and agency MBS in longer-term Treasury securities. FOMC will continue to roll over the Fed's holdings of Treasury securities as they mature.
Second LSAP		
08/27/2010	Speech (Jackson Hole)	Chairman Bernanke names "conducting additional purchases of longer-term securities" as a tool, "is prepared to provide additional monetary accommodation through unconventional measures ..."
09/21/2010	FOMC Statement	FOMC statement indicated willingness to "provide additional accommodation if needed."
10/15/2010	Speech (Boston)	Chairman Bernanke states the Fed will continue keeping interest rates low and mentions further quantitative easing.
11/03/2010	FOMC Statement	Fed intends to purchase a further $600 billion of longer-term Treasury securities by the end of 2011Q2, a pace of about $75 billion per month.
12/14/2010	FOMC Statement	The Committee intends to purchase $600 billion of longer-term Treasury securities by the end of the second quarter of 2011, a pace of about $75 billion per month.
01/26/2011	FOMC Statement	The Committee is maintaining its existing policy of reinvesting principal payments from its securities holdings and intends to purchase $600 billion of longer-term Treasury securities by the end of the second quarter of 2011.
03/15/2011	FOMC Statement	the Committee is maintaining its existing policy of reinvesting principal payments from its securities holdings and intends to purchase $600 billion of longer-term Treasury securities by the end of the second quarter of 2011.
04/27/2011	FOMC Statement	Committee restate its position of purchasing longer-term Treasury securities by the current quarter.
06/22/2011	FOMC Statement	QE2 finishes: treasury purchases will wrap up at the end of month, as scheduled; principal payment will continue to be reinvested.
Maturity Extension Program		
08/09/2011	FOMC Statement	FOMC assured that interest rates would remain "exceptionally low" through mid-2013.
08/26/2011	Speech (Jackson Hole)	Fed ChairmanâĂŹs remarks left the door open for additional accommodation.
09/21/2011	FOMC Statement	Fed announced that it would reallocate $400 billion from the short to long-term Treasuries.

12/13/2011	FOMC Statement	To support a stronger economic recovery and to help ensure that inflation, over time, is at levels consistent with the dual mandate, the Committee decided today to continue its program to extend the average maturity of its holdings of securities as announced in September.
04/25/2012	FOMC Statement	The Committee decided to continue its program to extend the average maturity of its holdings of securities as announced in September.
06/20/2012	FOMC Statement	Maturity extension program extended: The FED will continue to purchase long-term securities and sell short-term securities through the end of 2012. Purchases/sales will continue at the current pace, about $45 billion/month.
Third LSAP		
08/22/2012	FOMC Minutes	FOMC members judged additional monetary accommodation would likely to warrant.
08/31/2012	Speech (Jackson Hole)	Chairman Bernanke hints at QE3: "The Federal Reserve will provide additional policy accommodation as needed to promote a stronger economic recovery and sustained improvement in labor market conditions in a context of price stability."
09/13/2012	FOMC Statement	The Fed will purchase additional agency MBS at a pace of $40 billion per month.
12/12/2012	FOMC Statement	QE3 expanded: the FED will continue to purchase $45 billion of long-term Treasuries per month but will no longer sterilize purchases through the sale of short-term treasuries.
Events in 2013–2015		
03/20/2013	FOMC Statement	FOMC improved its assessment of economic and labour market conditions
05/01/2013	FOMC Statement	The Committee decided to continue purchasing additional agency mortgage-backed securities at a pace of $40 billion per month and longer-term Treasury securities at a pace of $45 billion per month.
05/22/2013	FOMC Minutes and Testimony	Fed Chairman remarked about a potential âĂIJstep-downâĂİ in the pace of asset purchases.
06/19/2013	FOMC Statement	FOMC assessed economic and labour market conditions with optimism.
07/11/2013	FOMC Minutes and Speech (NBER)	Fed Chairman remarked about risks to growth and labour market.
07/31/2013	FOMC Statement	FOMC the Committee decided to continue purchasing additional agency mortgage-backed securities at a pace of $40 billion per month and longer-term Treasury securities at a pace of$45 billion per month.
09/18/2013	FOMC Statement	The Committee decided to continue purchasing additional agency mortgage-backed securities at a pace of $40 billion per month and longer-term Treasury securities at a pace of $45 billion per month
10/30/2013	FOMC Statement	FOMC assessed economic and labour market conditions with optimism.
12/18/2013	FOMC Statement	Fed announced a $75 billion decline in the pace of asset purchases beginning in January.

01/29/2014	FOMC Statement	Fed announced a $10 billion decline in the pace of asset purchases beginning in February. It will reduce the pace of asset purchases at future meetings. A ”balanced approachâĂİ will be taken to assess the policy rate. Current target funds rate will remain âĂIJwell past the time that the unemployment rate declines below 6.5%, especially if inflation continues to run below the Committee's 2% goal.”
03/19/2014	FOMC Statement	Fed announced a $10 billion decline in the pace of asset purchases beginning in April. The current target funds rate will depend on âĂIJa wide range of informationâĂİ and will be maintained ”for a considerable time after the asset purchase program ends.”
05/30/2014	FOMC Statement	Fed announced a $10 billion decline in the pace of asset purchases beginning in May.
06/18/2014	FOMC Statement	Fed announced a $10 billion decline in the pace of asset purchases beginning in July. Economic conditions may keep policy rate 'below normal' levels, even after long-run employment and inflation goals are reached.
07/30/2014	FOMC Statement	Fed announced a $10 billion decline in the pace of asset purchases beginning in August. Reductions will continue upon labour market improvement and price stability.
09/17/2014	FOMC Statement	Fed announced a $10 billion decline in the pace of asset purchases beginning in October.
10/29/2014	FOMC Statement	Asset purchase program concluded, but principal payments will continue to be reinvested. Economic activity expanding at a moderate pace.
12/17/2014	FOMC Statement	FOMC announces that, ”it can be patient in beginning to normalize the stance of monetary policy.”

Note: These are the major announcements by FED between September 2008 to December 2014. Dates,statements and announcements are sourced from Federal Reserve website on `www.federalreserve.gov` and reconciled with Dates, statements are reconciled with Kozicki et al. (2011), Fawley and Neely (2013), Bowman et al. (2015b) and Swanson (2017).

FIGURE 1: THREE COMPONENTS OF US MONETARY POLICY SHOCK IDENTIFIED BY SWANSON (2017)

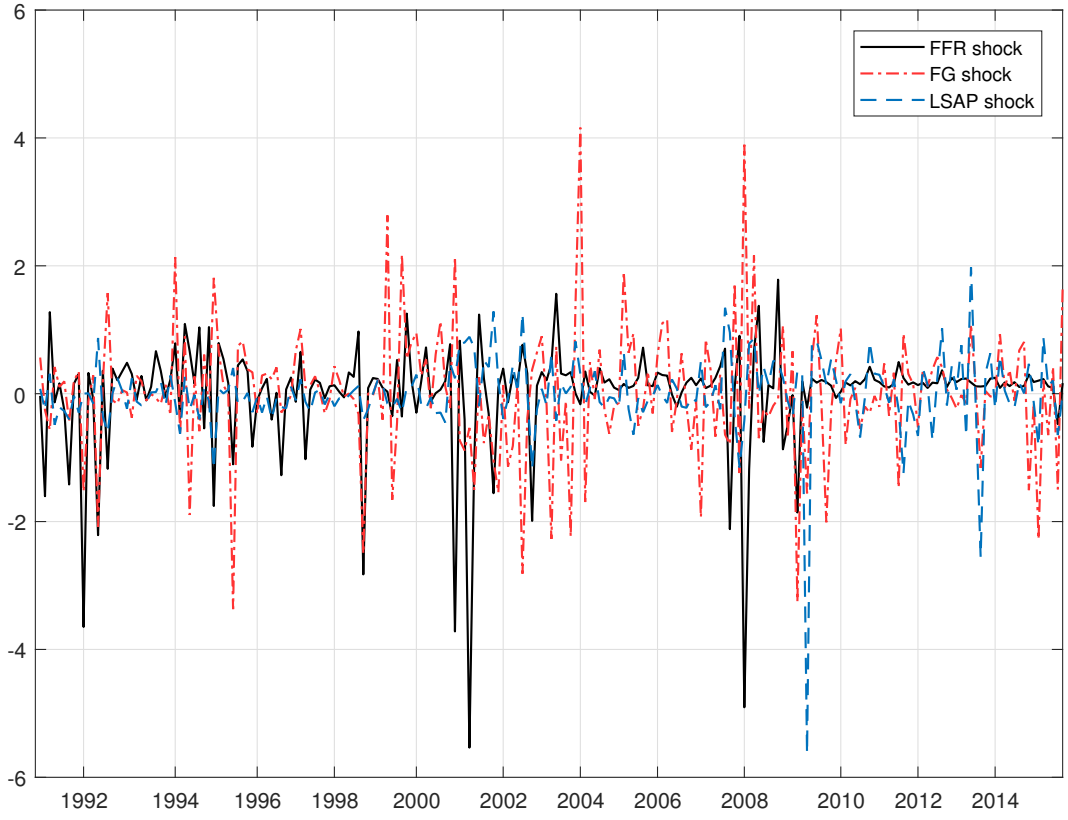

Table 2: Structural break dates around policy events from July 1, 2008 to June 30, 2016

Tests	S&P500	Gold	Silver	Platinum	Palladium
Carrion-i-Silvestre (2005)	Apr 29, 10(+1) Aug 18, 11 Jun 27, 12(+1) Jan 03, 14 Jul 29, 15	Nov 25, 09 Oct 13, 10(-2) Aug 15, 11(+6) Jul 05, 12 May 22, 13(0)	Apr 23, 09(-6) Aug 23, 11(-3) Nov 20, 12 Jun 03, 13 Nov 06, 14	May 20, 10 Aug 08, 11(-1) Jun 29, 12 May 28, 13(+6) Mar 14, 14(-5)	Jul 13, 09 Jul 20, 11 Jun 01, 12 May 30, 13 Jul 31, 14(+1)
Lee & Strch (2003)	Aug 10, 10(0) Oct 09, 13	Aug 11, 11(+2) Apr 10, 13	Dec 07, 10(-7) Apr 10, 13	Apr 16, 09 May 03, 11(+6)	Mar 19, 09(+1) Oct 29, 10(-5)
Bai & Perron (2003)	Sep 09, 09 Nov 22, 10 Feb 03, 12 Apr 19, 13 Jul 01, 14	Nov 04, 09(0) Jun 22, 11(0) Apr 15, 13 Sep 18, 14(+1)	Apr 06, 10 Jun 20, 11(-2) Apr 15, 13 Sep 22, 14(+5)	Nov 16, 09 Sep 26, 11(+5) Jun 13, 13(-6) Mar 09, 15	Dec 29, 09 Mar 18, 11(+3) Apr 20, 15
Lums. & Papell(1997)	Jun 01, 12 Nov 05, 14(+7)	Jul 05, 11 Apr 10, 13	Feb 11, 11 Mar 28, 13	Nov 25, 10 Aug 16, 12(-6)	Aug 01, 11 Feb 04, 14(+6)

Tests	Copper	Cocoa	Corn	Soybean	Wheat
Carrion-i-Silvestre (2005)	Apr 17, 09 Feb 02, 10(+7) Nov 19, 10 Nov 20, 12 Oct 17, 13	May 18, 09 Mar 12, 10(-4) Jan 04, 11 Jun 27, 12(+7) Dec 17, 14(0)	Apr 22, 09(-7) Feb 15, 10 Jan 09, 11 Jun 20, 12(0) Jun 09, 13	Jan 05, 09 Dec 18, 09(+2) Dec 19, 11(+6) Sep 17, 13(0) Jun 29, 15	Oct 19, 08 Jul 23, 10 Jan 13, 12 Aug 29, 13 Dec 16, 14(-1)
Lee & Strch (2003)	Apr 23, 09(-6) May 06, 11	Jul 16, 09 Dec 12, 11(-1)	Mar 3, 11 May 13, 13	Jul 12, 13 Aug 14, 14	Aug 07, 08 Aug 04, 10(-6)
Bai & Perron (2003)	Sep 11, 09 Nov 22, 10 Mar 18, 13(-2) Jan 13, 15	Sep 11, 09 Sep 22, 11(+1) Sep 16, 13(-2) Apr 21, 15	Sep 11, 09 Nov 24, 10 May 01, 12(+6) Jul 15, 13(+4) Sep 28, 14	Nov 02, 08 Aug 28, 10(+) Dec 30, 11 May 07, 13(+6) Sep 17, 14	Oct 30, 08 Jul 28, 10 Jul 08, 12 Oct 15, 13 Feb 23, 15
Lums. & Papell(1997)	Jul 29, 11 Jul 31, 13(0)	Jan 27, 10(0) Sep 06, 11	Aug 29, 12 Nov 12, 13	Sep 10, 09 Jul 15, 12	Feb 17, 09 Jul 16, 12

Note: Coloured are the break dates that fell within a week of an event with days prior and post events (+-Days) in the parentheses. Red for QE1, Blue for QE2 and maturity extension, Orange for QE3 and Green for other dates from May 2013 to April 2015. Lee & Strch (2003) and Lums. & Papell (1997) stand for Lee and Strazicich (2003) and Lumsdaine and Papell (1997), respectively. Since all the years are post 2000, to conserve space we use only last two digits to represent the year.

Table 3: The instantaneous effects of monetary policy shocks

Shock	S&P500	Gold	Silver	Palla	Plat	Copper	Cocoa	Corn	Soybean	Wheat
Pre-crisis (Jul.1991–Dec.2008)										
FFR	-0.43**	0.07	0.09	-0.47	-0.03	-0.04	-0.21	-0.26	-0.15	-0.28
	(0.19)	(0.07)	(0.12)	(0.35)	(0.14)	(0.12)	(0.14)	(0.19)	(0.12)	(0.17)
FG	-0.33**	0.04	0.17	0.17	0.06	-0.11	-0.07	-0.49**	-0.25*	-0.44**
	(0.16)	(0.09)	(0.14)	(0.18)	(0.08)	(0.14)	(0.19)	(0.20)	(0.13)	(0.20)
Post-crisis (Jan.2009–Oct.2015)										
FG	-0.47	-0.15	0.30	0.13	0.20	0.38	0.02	-0.60**	-0.34	-0.94**
	(0.42)	(0.19)	(0.34)	(0.27)	(0.15)	(0.29)	(0.23)	(0.28)	(0.31)	(0.37)
LSAP	0.10	0.21**	0.22	0.19	0.09	0.23	0.14	0.19	-0.00	0.62***
	(0.21)	(0.10)	(0.21)	(0.12)	(0.12)	(0.17)	(0.13)	(0.23)	(0.24)	(0.18)

Note: HAC standard errors are in parentheses. *, ** and *** indicates significance at 10%, 5% and 1%, respectively. Data on corn, soybean and wheat only start from January 1996.

TABLE 4: **Local Projections**

	S&P500 index				Gold price			
	Pre-ZLB		ZLB		Pre-ZLB		ZLB	
Day	FFR Shock	FG Shock	FG Shock	LASP Shock	FFR Shock	FG Shock	FG Shock	LASP Shock
0	-0.43**	-0.33**	-0.47	0.10	0.07	0.03	-0.15	0.21**
	(0.19)	(0.16)	(0.42)	(0.21)	(0.07)	(0.09)	(0.19)	(0.10)
5	-0.43**	-0.51***	-0.46	0.22	-0.08	-0.07	-1.08**	0.11
	(0.21)	(0.19)	(0.58)	(0.40)	(0.24)	(0.24)	(0.54)	(0.33)
10	-0.96***	-0.55**	-0.14	0.18	-0.04	-0.26	-2.10***	0.42
	(0.22)	(0.22)	(0.56)	(0.46)	(0.31)	(0.21)	(0.73)	(0.40)
15	-1.11***	-0.37	-0.37	0.18	-0.13	-0.44*	-2.26***	1.17**
	(0.34)	(0.25)	(0.51)	(0.51)	(0.31)	(0.26)	(0.56)	(0.58)
20	-1.17***	-0.18	-0.11	-0.64	0.05	-0.58**	-2.51***	1.49***
	(0.41)	(0.34)	(0.42)	(0.48)	(0.31)	(0.24)	(0.79)	(0.57)
25	-1.03**	0.15	-0.07	-0.56	-0.41	-0.74***	-2.25***	1.32***
	(0.45)	(0.40)	(0.47)	(0.54)	(0.40)	(0.28)	(0.78)	(0.46)
30	-0.99	-0.14	0.13	-1.11*	-0.37	-0.79**	-2.06***	0.95*
	(0.63)	(0.50)	(0.69)	(0.57)	(0.50)	(0.38)	(0.67)	(0.56)
35	-0.65	-0.09	0.08	-1.55***	-0.40	-0.87**	-1.65**	0.57
	(0.49)	(0.48)	(0.59)	(0.58)	(0.48)	(0.36)	(0.77)	(0.43)
40	-0.54	0.11	0.04	-1.09**	-0.72	-0.65	-1.98**	1.02**
	(0.54)	(0.58)	(0.55)	(0.50)	(0.53)	(0.41)	(0.81)	(0.44)
45	-0.74	0.14	-0.63	-1.07*	-0.32	-0.97**	-1.66	0.84
	(0.61)	(0.59)	(0.77)	(0.61)	(0.40)	(0.44)	(0.94)	(0.53)
50	-0.45	0.18	-0.65	-1.38***	-0.17	-0.98***	-1.18	0.39
	(0.59)	(0.71)	(0.91)	(0.53)	(0.37)	(0.36)	(1.07)	(0.72)
55	-0.15	0.07	0.12	-1.63***	-0.00	-0.93***	-0.35	0.73
	(0.68)	(0.82)	(1.11)	(0.54)	(0.42)	(0.30)	(0.99)	(0.63)
60	-0.33	0.02	0.06	-1.48**	-0.00	-0.76**	0.03	0.50
	(0.62)	(0.71)	(1.24)	(0.65)	(0.48)	(0.30)	(0.90)	(0.68)

Note: HAC standard errors are in parentheses. ** indicates significance at 0.05.

	Silver price				Palladium Price			
	Pre-ZLB		ZLB		Pre-ZLB		ZLB	
Day	FFR Shock	FG Shock	FG Shock	LASP Shock	FFR Shock	FG Shock	FG Shock	LASP Shock
0	0.09	0.17	0.30	0.22	-0.47	0.17	0.13	0.19
	(0.12)	(0.14)	(0.34)	(0.21)	(0.35)	(0.18)	(0.27)	(0.12)
5	-0.29	-0.32	-1.38	0.32	-0.49	0.26	-1.04	0.27
	(0.35)	(0.36)	(1.19)	(0.81)	(0.25)	(0.21)	(0.83)	(0.64)
10	-0.48	-0.43	-3.18**	1.36	-1.71**	0.18	-2.37*	1.05
	(0.54)	(0.34)	(1.55)	(0.83)	(0.52)	(0.40)	(1.38)	(0.82)
15	-0.62	-0.31	-3.91***	2.34***	-1.25	0.08	-4.19**	1.26*
	(0.49)	(0.39)	(1.28)	(0.88)	(0.76)	(0.61)	(1.66)	(0.74)
20	-0.84*	-0.35	-3.50**	2.36**	-1.45	0.33	-3.59*	0.66
	(0.44)	(0.36)	(1.40)	(0.94)	(0.91)	(0.57)	(1.86)	(1.02)
25	-1.20**	-0.34	-3.18**	2.18**	-2.43**	0.85	-2.78	0.57
	(0.56)	(0.56)	(1.55)	(0.99)	(1.19)	(0.63)	(1.72)	(0.91)
30	-1.53*	-0.27	-2.22	1.05	-2.34*	1.75**	-1.80	0.58
	(0.85)	(0.68)	(1.60)	(1.06)	(1.37)	(0.83)	(1.75)	(0.98)
35	-1.50*	-0.46	-2.04	0.23	-1.14	1.44*	-1.29	-0.51
	(0.85)	(0.78)	(1.62)	(0.75)	(1.09)	(0.86)	(1.61)	(0.77)
40	-1.72*	-0.03	-2.69	1.27	-0.56	1.26	-2.12	1.26
	(0.99)	(0.97)	(1.85)	(0.98)	(1.21)	(1.03)	(1.73)	(0.92)
45	-1.22	0.69	-2.33	0.98	-0.30	1.14	-0.94	1.62
	(0.76)	(0.98)	(1.77)	(1.34)	(1.11)	(1.04)	(1.51)	(1.05)
50	-0.89	-0.72	-1.08	-0.05	-0.02	1.51	-1.43	1.50
	(0.66)	(1.03)	(1.88)	(1.85)	(1.13)	(1.16)	(2.05)	(1.29)
55	-0.70	-0.70	0.30	-0.26	0.09	1.86	-0.79	0.92
	(0.78)	(0.70)	(1.83)	(1.61)	(1.25)	(1.18)	(1.99)	(0.99)
60	-0.65	-0.74	1.18	-0.02	0.46	1.79	0.51	-0.04
	(0.88)	(0.63)	(1.90)	(1.37)	(1.32)	(1.10)	(2.05)	(1.06)

Note: HAC standard errors are in parentheses. ** indicates significance at 0.05.

	Platinum price				Copper Price			
	Pre-ZLB		ZLB		Pre-ZLB		ZLB	
Day	FFR Shock	FG Shock	FG Shock	LASP Shock	FFR Shock	FG Shock	FG Shock	LASP Shock
0	-0.03	0.06	0.20	0.09	-0.04	-0.11	0.38	0.23
	(0.14)	(0.08)	(0.15)	(0.12)	(0.12)	(0.14)	(0.29)	(0.18)
5	-0.28	0.10	-0.83	-0.20	-0.03	-0.29	-0.73	0.63
	(0.26)	(0.19)	(0.84)	(0.65)	(0.24)	(0.30)	(0.92)	(0.61)
10	-0.69	-0.05	-2.14*	0.44	-0.03	-0.56	-1.50	0.78
	(0.51)	(0.31)	(1.18)	(0.90)	(0.40)	(0.38)	(1.21)	(0.96)
15	-1.05	-0.24	-2.75***	0.37	-0.31	-0.05	-0.94	-0.77
	(0.78)	(0.44)	(1.04)	(0.88)	(0.56)	(0.61)	(1.23)	(1.03)
20	-1.25	0.07	-2.98**	0.13	-0.68	-0.06	-0.60	-1.52
	(0.90)	(0.47)	(1.35)	(1.13)	(0.61)	(0.71)	(1.39)	(1.14)
25	-1.78*	0.13	-2.48*	0.33	-0.51	0.33	-0.05	-0.63
	(1.05)	(0.45)	(1.42)	(0.91)	(0.72)	(0.72)	(1.34)	(0.86)
30	-1.97*	0.42	-1.78	0.41	-0.60	0.29	0.78	-0.92
	(1.18)	(0.54)	(1.24)	(0.63)	(0.90)	(0.68)	(1.57)	(0.85)
35	-1.40	0.08	-0.95	-0.29	-0.42	0.48	0.60	-1.19
	(1.01)	(0.52)	(1.28)	(0.70)	(0.79)	(0.73)	(1.39)	(0.79)
40	-1.17	-0.20	-1.05	0.61	-0.24	0.72	0.79	-0.12
	(1.02)	(0.64)	(1.24)	(0.85)	(0.82)	(0.67)	(1.47)	(0.85)
45	-0.87	-0.32	-0.49	0.40	-0.37	0.69	1.76	-0.50
	(1.00)	(0.58)	(1.22)	(1.06)	(0.93)	(0.70)	(1.16)	(0.98)
50	-0.59	-0.32	-0.17	-0.40	-0.29	0.26	0.96	-1.24
	(1.08)	(0.60)	(1.31)	(1.35)	(1.06)	(0.75)	(1.24)	(0.99)
55	-0.75	-0.29	0.28	-0.21	-0.48	0.38	1.60	-1.23
	(1.28)	(0.58)	(1.34)	(1.42)	(1.19)	(0.78)	(1.25)	(0.89)
60	-0.51	-0.09	0.75	-0.82	-0.52	0.40	1.36	-1.48*
	(1.29)	(0.63)	(1.55)	(1.24)	(1.28)	(0.73)	(1.21)	(0.89)

Note: HAC standard errors are in parentheses. ** indicates significance at 0.05.

	Cocoa price				Corn Price (Jan.1996–Oct.2015)			
	Pre-ZLB		ZLB		Pre-ZLB		ZLB	
Day	FFR Shock	FG Shock	FG Shock	LASP Shock	FFR Shock	FG Shock	FG Shock	LASP Shock
0	-0.22	-0.07	0.02	0.14	-0.26	-0.49**	-0.61**	0.19
	(0.14)	(0.19)	(0.23)	(0.13)	(0.19)	(0.20)	(0.28)	(0.23)
5	-0.56*	-0.40	-0.27	-0.44	0.42	-0.12	-1.59***	0.31
	(0.32)	(0.34)	(0.52)	(0.45)	(0.40)	(0.35)	(0.45)	(0.29)
10	-0.64	-0.48	-0.53	-0.27	0.49	0.13	-1.82*	0.44
	(0.61)	(0.47)	(0.81)	(0.50)	(0.50)	(0.56)	(1.00)	(0.72)
15	-0.73	-0.12	-0.52	-0.09	0.39	0.30	-1.93	0.12
	(0.73)	(0.61)	(0.83)	(0.53)	(0.62)	(0.53)	(0.13)	(0.89)
20	-1.16	0.07	-0.99	0.61	0.70	0.39	-1.97	0.78
	(0.78)	(0.69)	(1.01)	(0.60)	(0.79)	(0.63)	(1.50)	(0.96)
25	-1.76**	0.34	-0.68	1.43*	0.15	0.56	-2.72	-0.22
	(0.84)	(0.74)	(1.26)	(0.84)	(0.79)	(0.47)	(1.75)	(1.36)
30	-1.98*	0.20	-0.78	1.48*	0.52	0.48	-2.48	-0.37
	(1.14)	(0.94)	(1.45)	(0.89)	(0.83)	(0.49)	(1.54)	(1.73)
35	-1.74	0.06	-0.93	1.08	0.27	0.86	-1.39	-0.40
	(1.22)	(0.97)	(1.31)	(0.85)	(1.11)	(0.58)	(1.75)	(1.67)
40	-1.51	0.07	-1.84	1.98**	0.53	0.44	-1.12	-1.35
	(1.42)	(1.04)	(1.20)	(0.89)	(0.87)	(0.66)	(1.90)	(1.58)
45	-0.94	-0.23	-2.23*	2.04**	0.14	0.78	-1.37	-1.14
	(1.14)	(1.01)	(1.18)	(0.87)	(0.89)	(0.76)	(2.19)	(1.42)
50	-0.88	0.16	-2.97***	1.70	0.28	0.43	-1.57	-0.95
	(0.99)	(0.95)	(1.11)	(1.29)	(0.86)	(0.66)	(2.35)	(1.39)
55	-0.53	0.07	-4.15***	2.03	0.18	1.19*	-2.32	-0.98
	(0.91)	(0.99)	(1.34)	(1.63)	(1.07)	(0.62)	(2.35)	(1.42)
60	-0.95	0.15	-3.35***	1.43	-0.38	1.45*	-2.40	-0.78
	(1.17)	(0.92)	(1.25)	(1.52)	(1.40)	(0.75)	(2.67)	(1.42)

Note: Robust standard errors are in parentheses. ** indicates significance at 0.05.

	Soybean price (Jan.1996–Oct.2015)				Wheat Price (Jan.1996–Oct.2015)			
	Pre-ZLB		ZLB		Pre-ZLB		ZLB	
Day	FFR Shock	FG Shock	FG Shock	LASP Shock	FFR Shock	FG Shock	FG Shock	LASP Shock
0	-0.15	-0.25*	-0.34	-0.00	-0.28	-0.44**	-0.94**	0.63***
	(0.12)	(0.20)	(0.31)	(0.18)	(0.17)	(0.20)	(0.37)	(0.18)
5	0.11	-0.29	-0.47	-0.15	-0.01	-0.67	-1.31**	0.39
	(0.21)	(0.32)	(0.73)	(0.59)	(0.29)	(0.41)	(0.59)	(0.33)
10	-0.07	-0.39	-0.48	0.59	-0.69	-1.12**	-1.12	0.58
	(0.47)	(0.49)	(1.02)	(0.73)	(0.58)	(0.55)	(1.67)	(1.02)
15	-0.47	-0.22	-1.12	0.17	-0.89	-0.82	-1.37	-0.41
	(0.61)	(0.51)	(0.96)	(0.97)	(0.85)	(0.68)	(1.27)	(0.88)
20	-0.72	-0.18	-1.73	-0.48	-0.16	-0.94	-0.74	0.42
	(0.68)	(0.65)	(1.11)	(0.90)	(0.87)	(0.70)	(1.47)	(1.17)
25	-1.11	-0.02	-1.45	-1.39	-0.17	-1.00	0.03	-0.10
	(0.79)	(0.59)	(1.20)	(1.06)	(0.97)	(0.66)	(1.91)	(1.42)
30	-1.04	0.30	-1.29	-1.40	-0.34	-0.73	0.06	-0.32
	(0.87)	(0.72)	(1.03)	(0.87)	(1.51)	(0.72)	(1.87)	(1.55)
35	-1.12	0.63	-0.54	-0.93	-0.19	-0.98	1.39	-0.22
	(1.02)	(0.72)	(1.19)	(0.99)	(1.49)	(0.71)	(2.12)	(1.51)
40	-0.52	0.08	-0.11	-2.27**	0.08	-0.38	1.50	-1.15
	(0.68)	(0.76)	(1.21)	(1.06)	(1.49)	(0.78)	(1.94)	(1.38)
45	-1.01	0.17	-0.44	-2.18**	-0.11	-0.25	0.82	-1.39
	(0.65)	(0.88)	(1.10)	(1.08)	(1.72)	(0.90)	(2.17)	(1.15)
50	-0.50	-0.45	-0.92	-2.10**	0.19	-0.76	-0.09	-0.32
	(0.64)	(0.83)	(1.33)	(1.04)	(1.39)	(0.72)	(2.32)	(1.23)
55	-0.32	0.35	-0.75	-2.24*	0.19	-0.67	-0.12	-1.07
	(0.66)	(0.79)	(1.48)	(1.34)	(1.63)	(0.75)	(2.38)	(1.30)
60	-0.28	0.07	-1.43	-2.21	0.31	-1.26	0.45	-1.64
	(0.71)	(0.85)	(1.60)	(1.37)	(1.53)	(0.64)	(2.58)	(1.31)

Note: Robust standard errors are in parentheses. ** indicates significance at 0.05.

FIGURE 2: RESPONSE OF S&P500 INDEX TO THE THREE COMPONENTS OF US MONETARY POLICY SHOCK

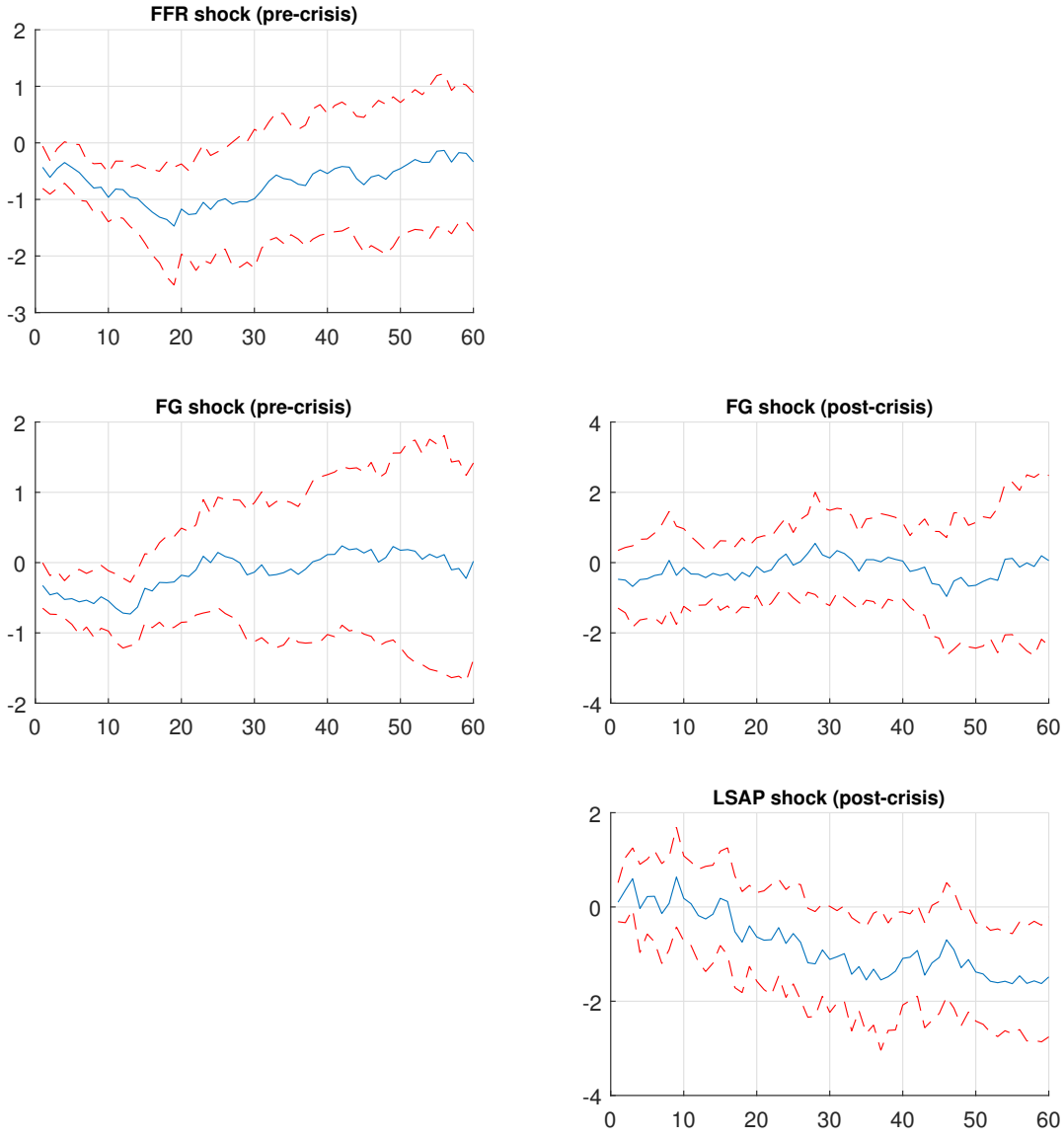

FIGURE 3: RESPONSE OF GOLD PRICE TO THE THREE COMPONENTS OF US MONETARY POLICY SHOCK

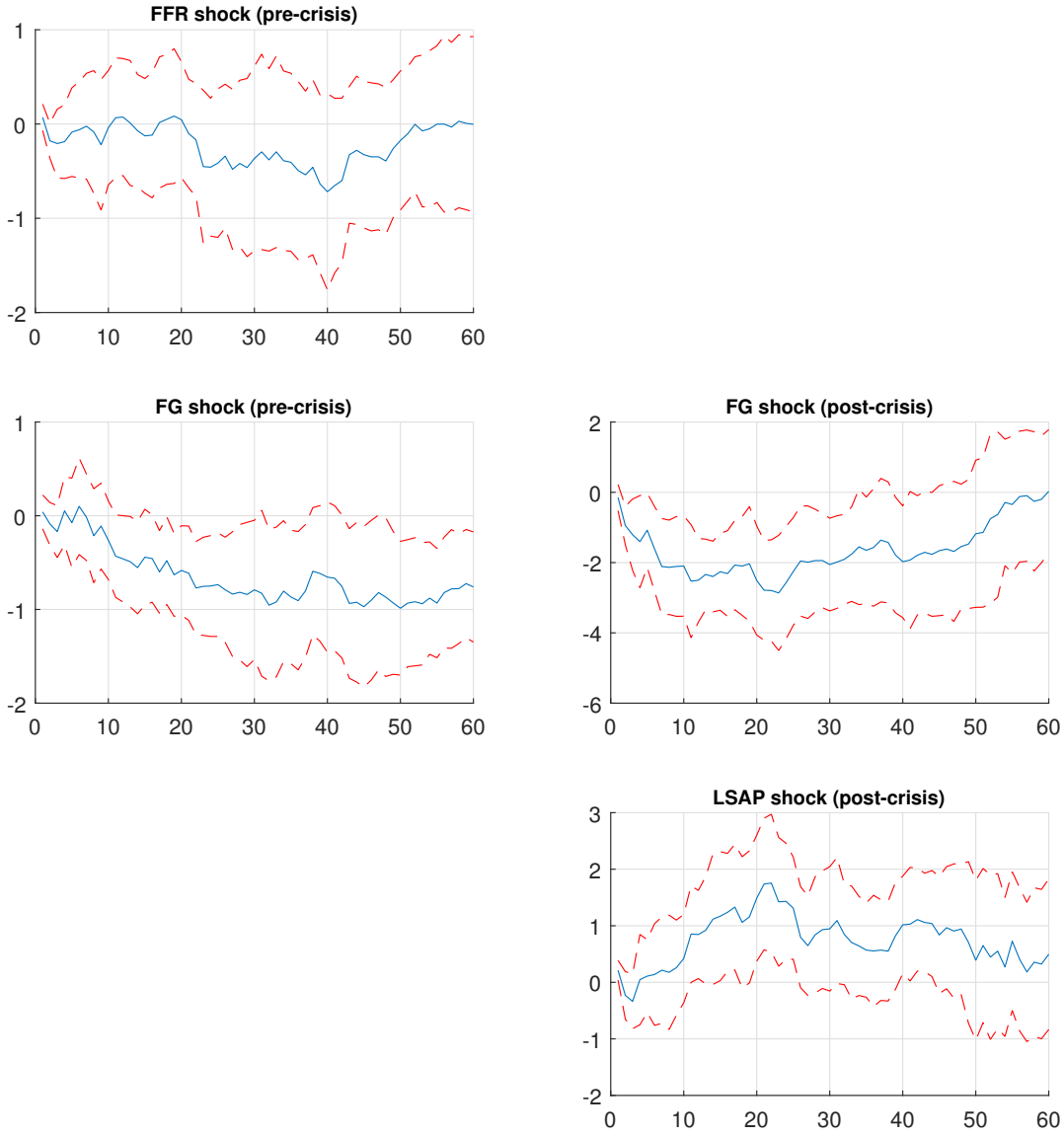

FIGURE 4: RESPONSE OF SILVER PRICE TO THE THREE COMPONENTS OF US MONETARY POLICY SHOCK

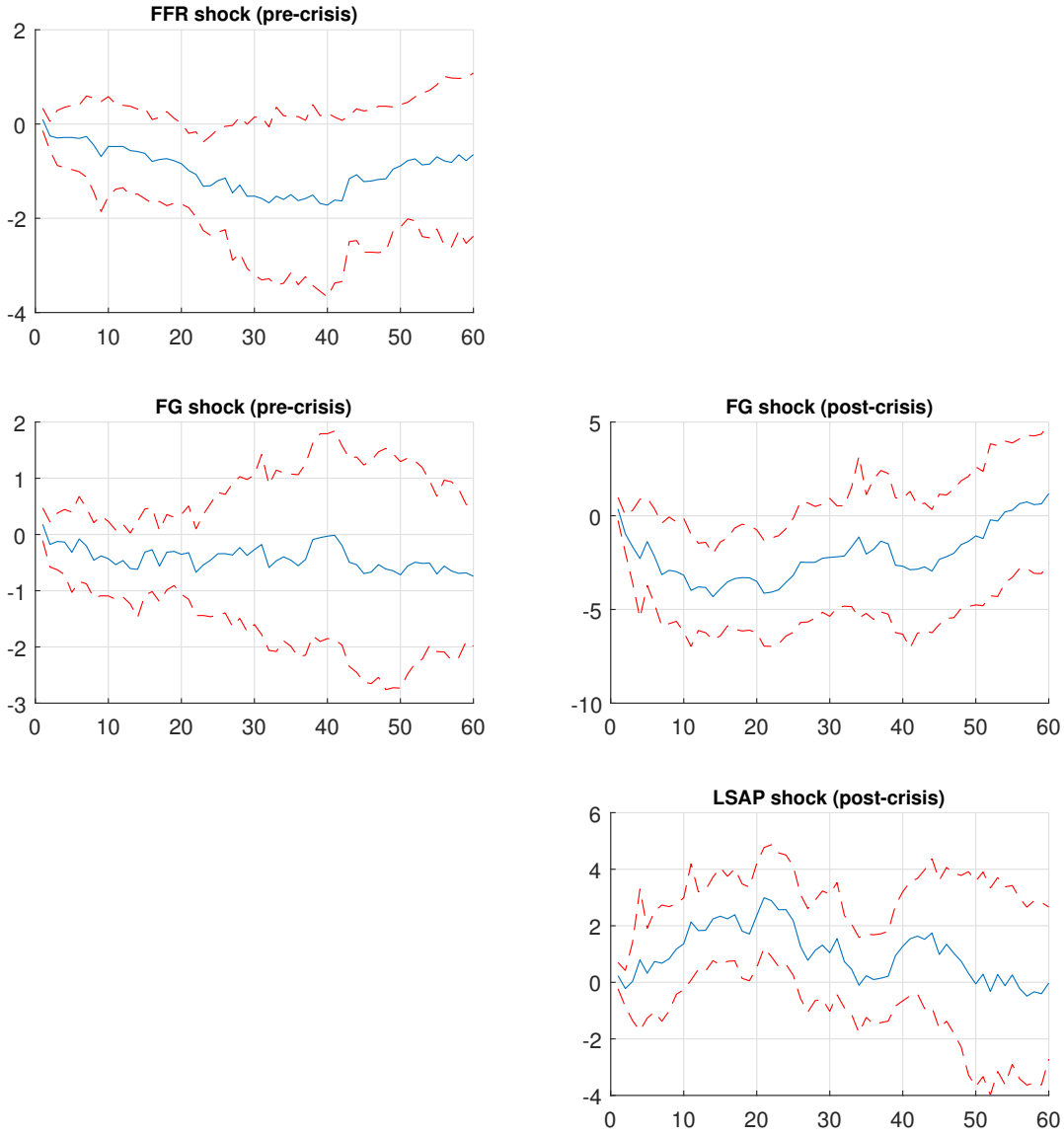

FIGURE 5: RESPONSE OF PALLADIUM PRICE TO THE THREE COMPONENTS OF US MONETARY POLICY SHOCK

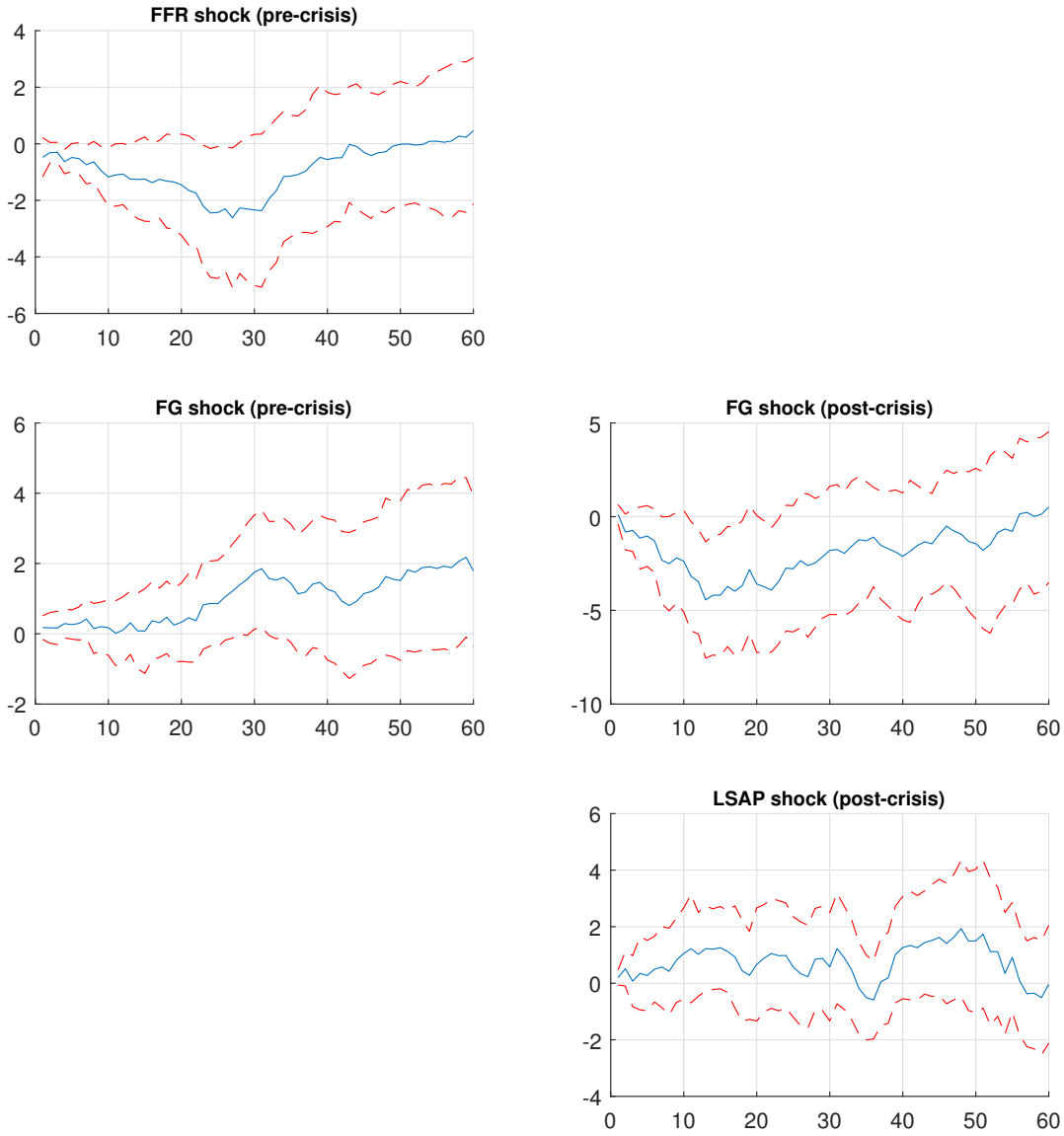

FIGURE 6: RESPONSE OF PLATINUM PRICE TO THE THREE COMPONENTS OF US MONETARY POLICY SHOCK

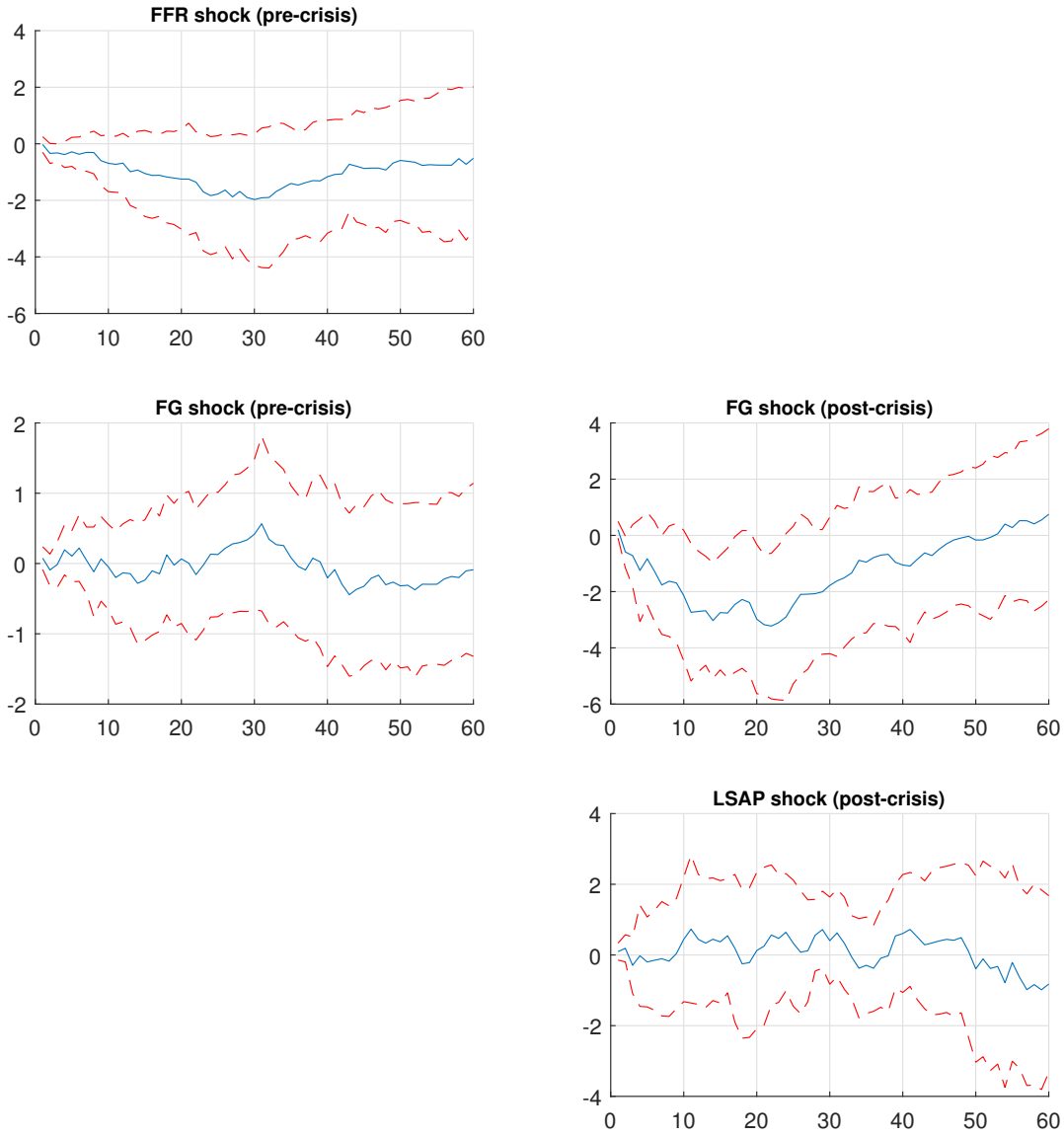

FIGURE 7: RESPONSE OF COPPER PRICE TO THE THREE COMPONENTS OF US MONETARY POLICY SHOCK

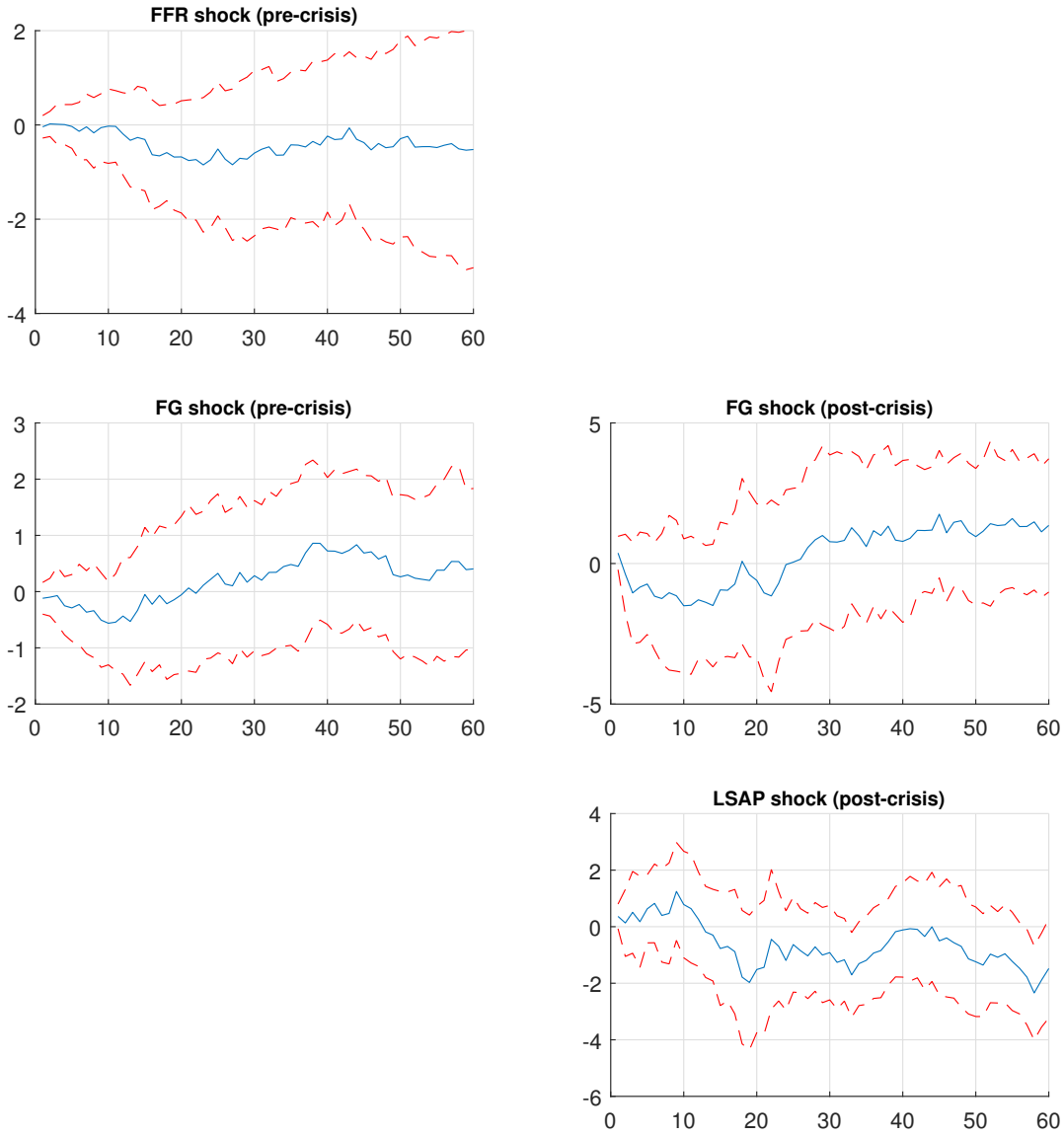

FIGURE 8: RESPONSE OF COCOA PRICE TO THE THREE COMPONENTS OF US MONETARY POLICY SHOCK

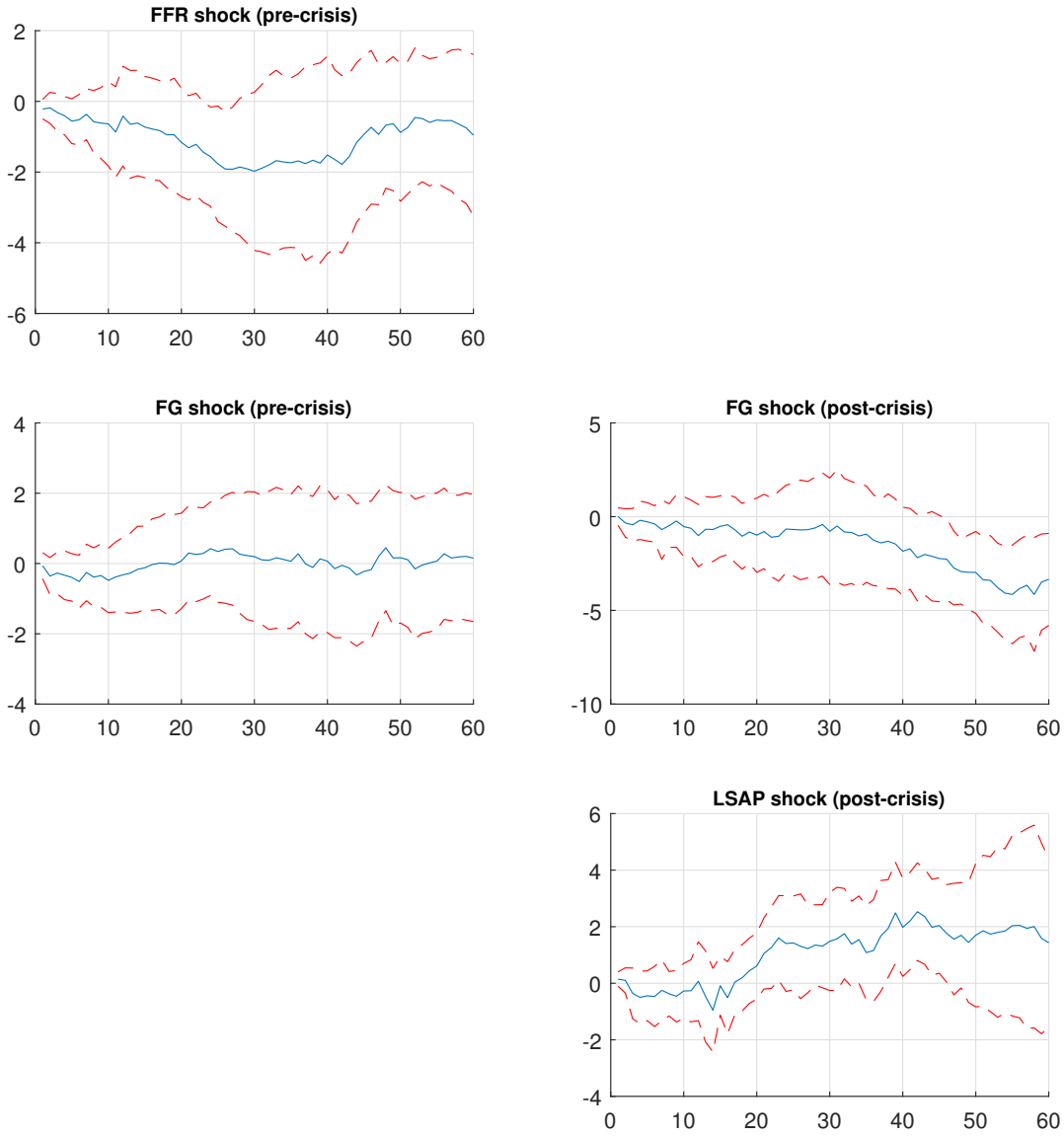

FIGURE 9: RESPONSE OF CORN PRICE TO THE THREE COMPONENTS OF US MONETARY POLICY SHOCK (FROM JANUARY 1996 TO OCTOBER 2015)

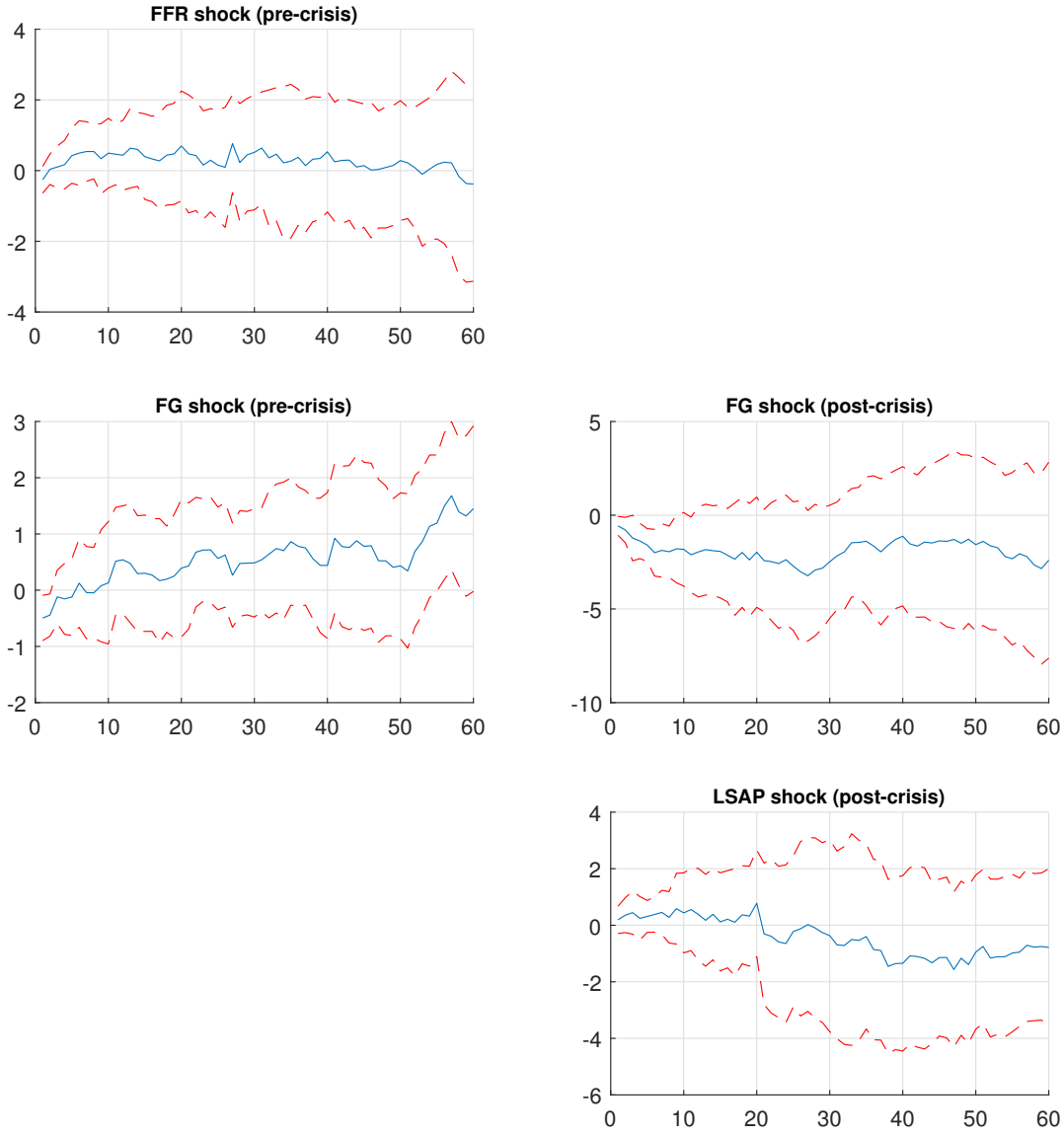

FIGURE 10: RESPONSE OF SOYBEAN PRICE TO THE THREE COMPONENTS OF US MONETARY POLICY SHOCK (FROM JANUARY 1996 TO OCTOBER 2015)

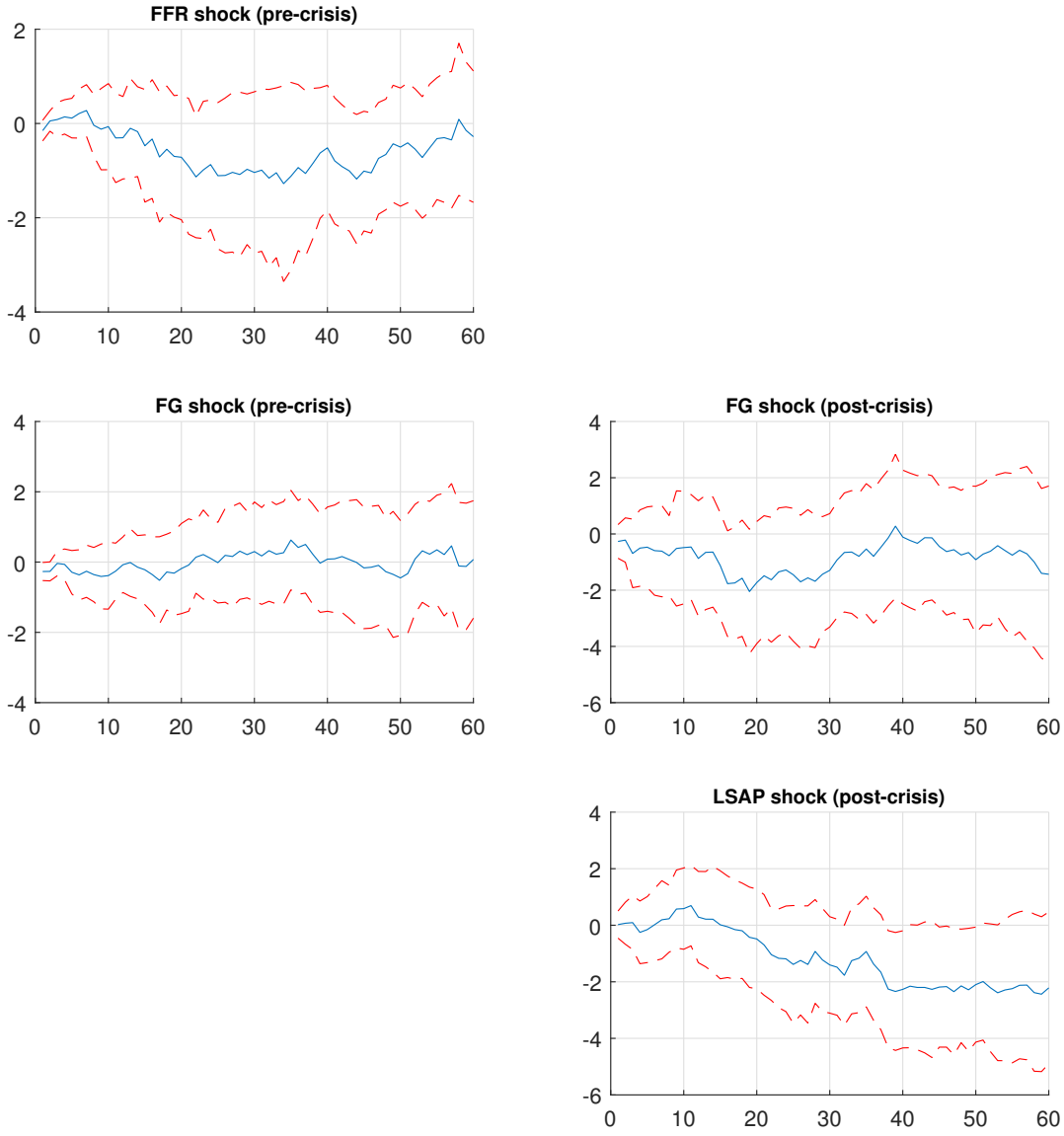

FIGURE 11: RESPONSE OF WHEAT PRICE TO THE THREE COMPONENTS OF US MONETARY POLICY SHOCK (FROM JANUARY 1996 TO OCTOBER 2015)

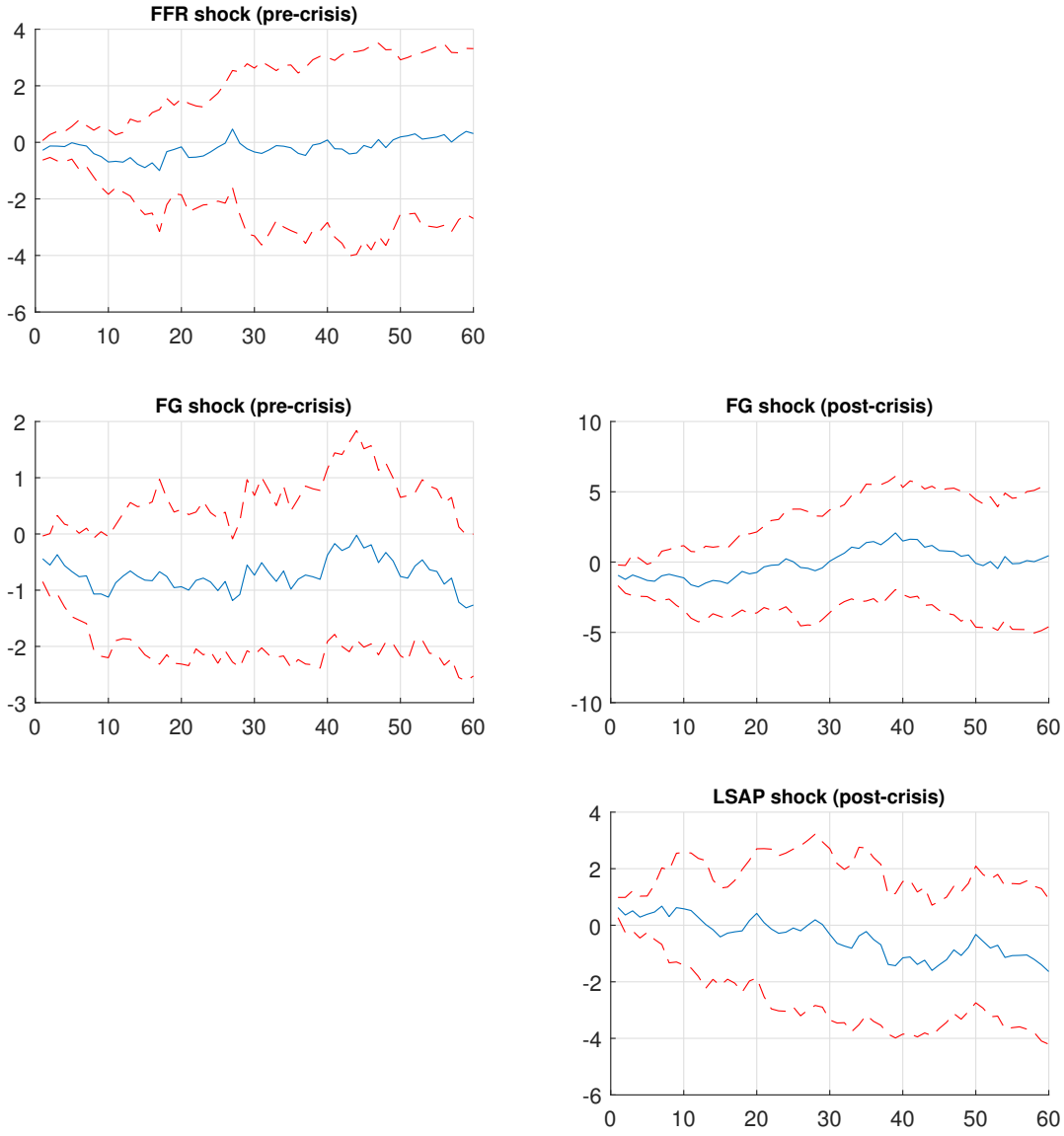

FIGURE 12: RESPONSE OF COMMODITY PRICES TO HIGH TEMPERATURE SHOCK

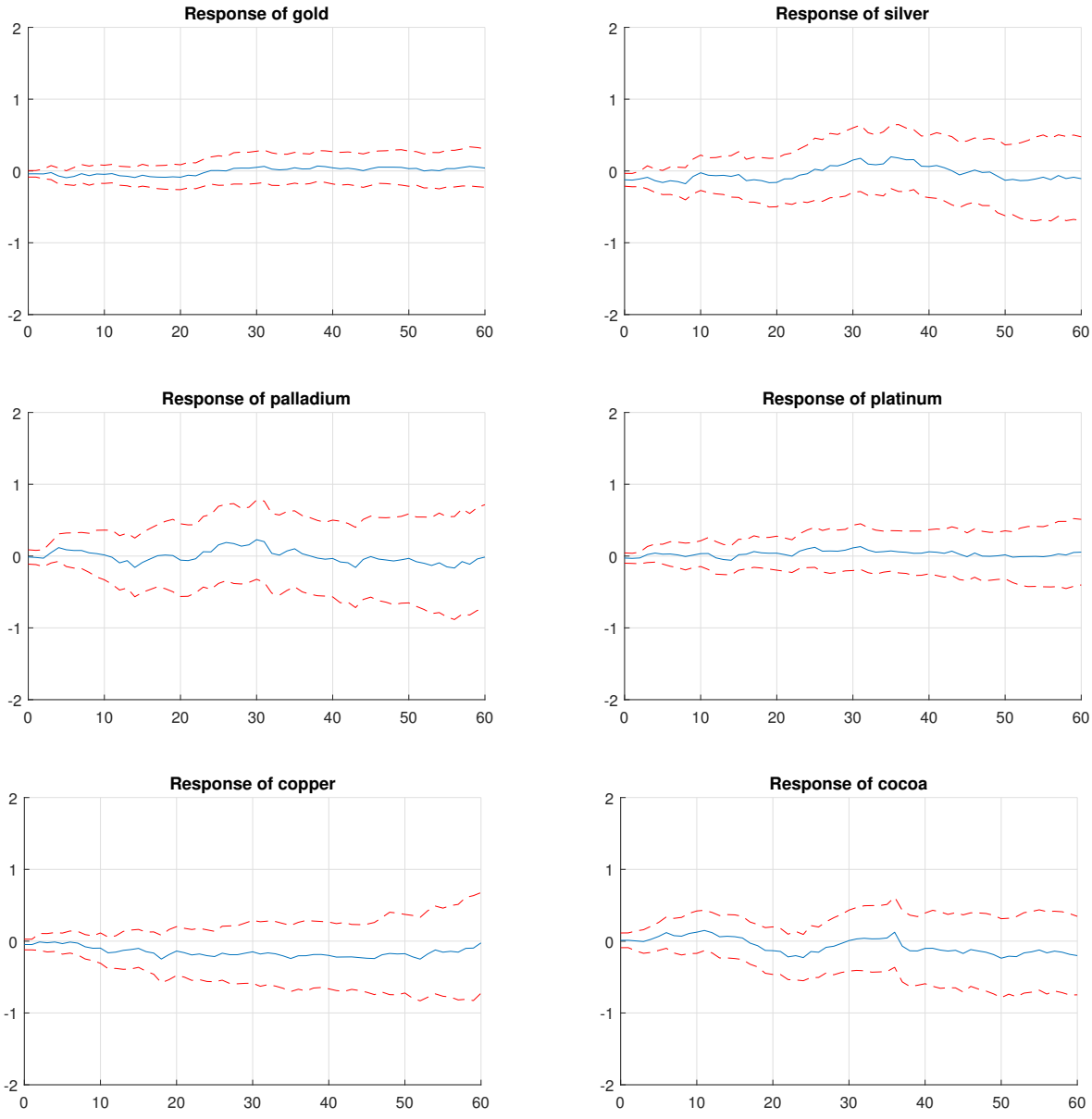

FIGURE 13: RESPONSE OF COMMODITY PRICES TO LOW TEMPERATURE SHOCK

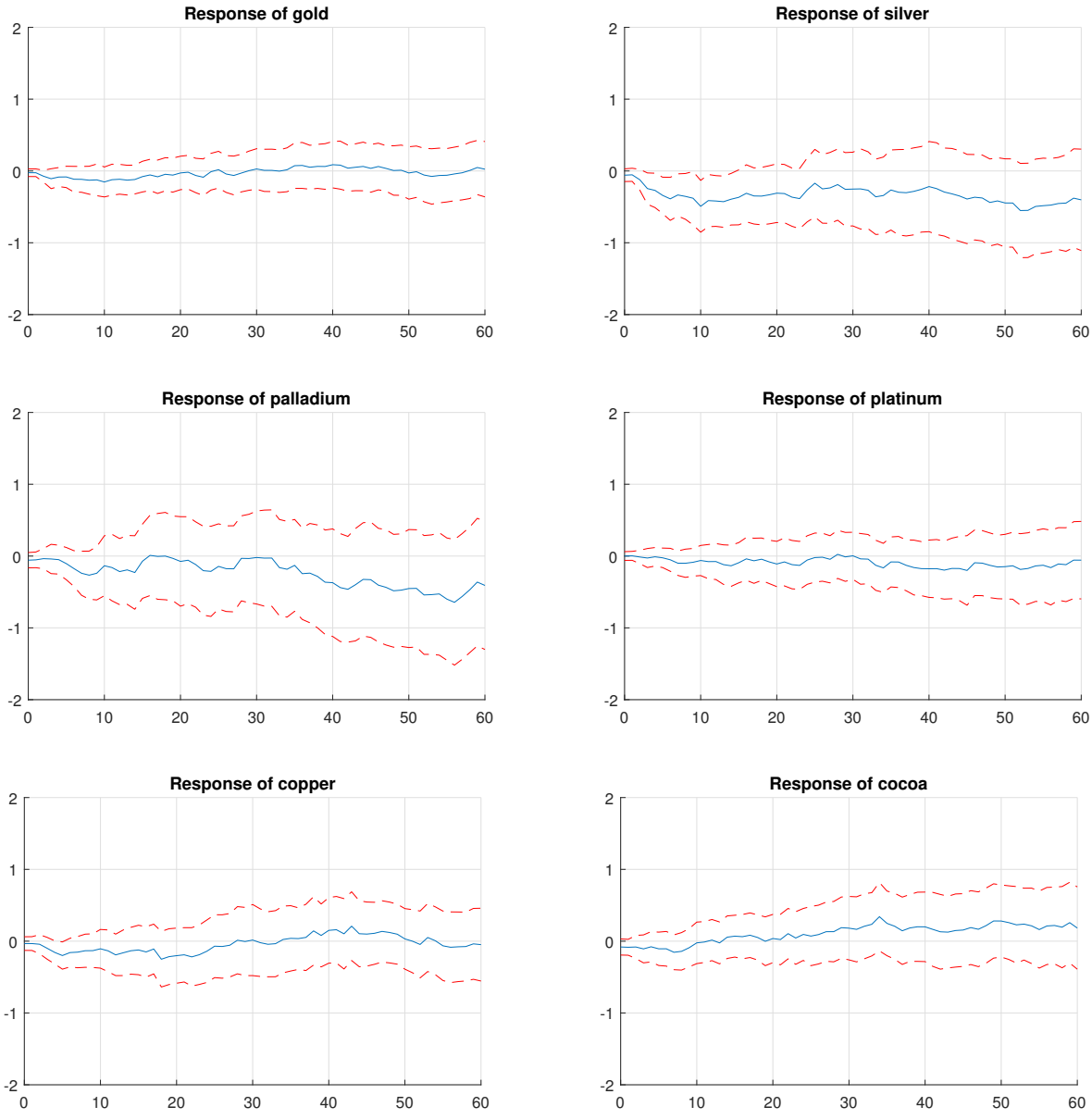

FIGURE 14: RESPONSE OF COMMODITY PRICES TO PRECIPITATION SHOCK