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Shahriyar Aliyev

Evžen Kočenda

FFA Working Paper 8/2022

UNIVERSITY OF ECONOMICS AND BUSINESS PRAGUE

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FACULTY OF FINANCE AND ACCOUNTING

Bibliographic information:

Aliyev S., Kočenda E. (2022). ECB monetary policy and commodity prices. FFA Working Paper 8/2022, FFA, Prague University of Economics and Business, Prague.

This paper can be downloaded at: wp.ffu.vse.cz

Contact e-mail: ffawp@vse.cz

ECB monetary policy and commodity prices

Shahriyar Aliyev[a] and Evžen Kočenda[b]

Abstract

We assess the impact of ECB monetary policy on global aggregate and sectoral commodity prices over 2001–2019. We employ a SVAR model and separately assess periods before and after the global financial crisis. Our key results indicate that contractionary monetary policy shocks have positive effects on commodity prices during both conventional and unconventional monetary policy periods, indicating the effectiveness of unconventional monetary policy tools. The largest impact is documented on fuel and food commodities. Our results also suggest that the effect of ECB monetary policy on commodity prices transmits through the exchange rate channel, which influences European market demand.

JEL-Classification: C54, E43, E58, F31, G15, Q02

Keywords: European Central Bank, commodity prices, short-term interest rates, M2 stock, monetary aggregate, unconventional monetary policy, Structural Vector Autoregressive model, exchange rates.

[a] Institute of Economic Studies, Charles University, Opletalova 26, 110 00 Prague 1, Czech Republic. Email: 48097242@fsv.cuni.cz.

[b] Corresponding author: Institute of Economic Studies, Charles University, Opletalova 26, 110 00 Prague 1, Czech Republic; Department of Banking and Insurance, Faculty of Finance and Accounting, Prague University of Economics and Business, W. Churchilla 4, 13067 Prague; Institute of Information Theory and Automation of the CAS, Prague; CESifo Munich; IOS Regensburg; and the Euro Area Business Cycle Network. E-mail: evzen.kocenda@fsv.cuni.cz.

We are grateful for useful comments we received from Hamid Beladi, Roman Horváth, Karel Janda, Fredj Jawadi, Sharon Kozicki, Satoshi Mizobata, Julien Pinter, Milan Ščasný, two anonymous referees, and presentation participants. We are thankful to Cynthia Wu for her update on shadow-rate data. This research has been supported by the Czech Science Foundation within the EXPRO Program "Frontiers in Energy Efficiency Economics and Modelling - FE3M": [Grant Number 19-26812X]; travel secondments were supported from the European Union's Horizon 2020 Research and Innovation Staff Exchange programme under the Marie Sklodowska-Curie grant agreement No 681228 (GEMCLIME-2020). This support is acknowledged. The usual disclaimer applies.

1. Introduction and motivation

Developments on financial markets and specifically the inclusion of dynamics in commodity prices into monetary policy decisions has attracted the attention of researchers and policy makers in recent decades (Bernanke et al., 1997; Jacks et al., 2011). The seminal theoretical framework of Frankel (1986) demonstrated the overshooting of agriculture and food prices with respect to monetary policy contraction and initiated further discussions and seminal empirical analyses on the nexus between monetary policy and commodity prices (Frankel, 2008; Akram, 2009).[1] The two main strands of related empirical research aim at (i) analyzing the effects of country-specific (US and Chinese) monetary policy shocks on global commodity prices (Angell, 1992; Hua, 1998; Frankel, 2008; Akram, 2009; Anzuini et al., 2013; Belke et al., 2014; Klotz et al., 2014; Scrimgeour, 2014; Hammoudeh et al., 2015; Jawadi et al., 2017 among others), and (ii) assessing the impact of global liquidity on commodity prices (Belke et al., 2010; Brana et al., 2012; Belke et al., 2013; Beckmann et al., 2014; Ratti and Vespignani, 2015). In both strands of the research, a majority of the results support Frankel's (1986, 2008) overshooting theory, where contractionary monetary policy (increase in interest rates and decrease in liquidity) negatively affects global commodity prices. The impact of monetary policy on commodity prices might materialize via domestic and international channels that are involved, since monetary policy is effected at national level while commodities are priced globally (Frankel, 2008; Belke et al., 2014). Despite the research outlined above, to the best of our knowledge, the nexus has not been investigated with respect to the monetary policy of the European Central Bank (ECB).

This is surprising given the following evidence. First, according to the International Merchandise Trade Statistics Section (IMTSS) of the United Nations Statistics Division (UNSD), on global commodity trade data, the combined euro area members (EU-19) are the world's largest commodity importers. They accounted for 25.26% of world commodity imports in 2019, a considerably higher percentage than the individual proportions of other major commodity importers such as the US (13.2%) and China (10.9%).[2] Hence, commodity imports by euro area countries create ample potential for the transfer of ECB monetary policy onto commodity prices. Second, empirical evidence shows that during recent years ECB monetary policy exhibits substantial spillover effects on the output, price levels, and exchange rates of non-euro area

[1] The rationale behind the overshooting framework of Frankel (1986) can be summarized as follows. A positive monetary policy shock is represented by an exogenous increase in the central bank interest rate that corresponds to contractionary monetary policy, causing bond prices to fall and bond yields to increase. For investors, commodities and bonds can be seen as instruments to store wealth and a portfolio can be created from both instruments. The expected return of a commodity is its expected price increase. Portfolio arbitrage theory usually asserts that moves in the expected return of one instrument leads to moves in the expected returns of other instruments. Hence, departing from an equilibrium situation, if the expected return of a bond (yield) increases, the expected return of one unit of a commodity must increase, too. Investors will divest of the commodity if its return is not big enough, until the price of the commodity decreases and its expected return increases. In other words, for a given expected price of a commodity in the future, commodity prices have to fall today after an increase in the bond rate (yield) triggered by a central bank increase in the interest rate. The above "arbitrage condition that must hold in the commodity markets" is at the core of the effect of monetary policy on commodity prices as argued by Frankel (1986).

[2] Considering the spillover effects of the ECB's monetary policy to surrounding countries, the proportion is even larger for non-euro area countries (EU-28), which imported 31.86% of world commodity imports in 2019. Updated data is available at: https://unstats.un.org/unsd/trade/data/tables.asp#monthly.

countries (Égert and Kočenda, 2014; Kucharcukova et al., 2016; Hájek and Horváth, 2018; Kočenda and Moravcová, 2019), as well as on financial markets and oil prices (Haitsma et al., 2016; Dieppe et al., 2018). Therefore, it is sensible to hypothesize that monetary policy innovations in the euro area should have an impact on global trade, especially on commodity prices; there is empirical evidence that monetary policy decisions influence aggregate demand and hence commodity prices (Anzuini et al. 2013; Filardo and Lombardi, 2014). Third, the empirical literature mainly concentrates on the responses of the aggregate commodity price index to policy shocks. Exceptions are Frankel (2008), Hammoudeh et al. (2015), and Klotz et al. (2014), who found heterogeneous results for group commodity prices. In this light and considering the heterogeneity and volatility differences in the data of group commodity prices, we believe that an analysis of individual commodity impacts is necessary for optimal and proper policy decision-making.

In his further development of the theoretical framework, Frankel (2008) proposes to add commodity prices to the list of variables that central banks monitor, regardless of their regime and target. From this perspective, the outcomes of our research are relevant for ECB inflation-targeting measures because Filardo et al. (2020) show that when monetary authorities are unable to accurately identify the global nature of the shocks driving commodity prices, they can minimize some of the adverse feedbacks from misdiagnosis by targeting core inflation. In the same manner, Aoki (2001) shows that central banks should target prices that are sticky, i.e. precisely the kinds of prices that are highly weighted in measures of core inflation. The relevance can be also extended to policy decisions that involve foreign trade, exchange rates, and real economy effects. Further, and quite importantly, the distinction between conventional and unconventional monetary measures in our analysis is an essential source of information for the debate related to the efficiency of ECB unconventional measures (e.g. Bluwstein and Canova, 2016, McMahon et al., 2018 or Ambler and Rumler, 2019, among others).

Based on the above motivation, we investigate the effects of ECB monetary policy on global aggregate and sectoral commodity prices. We analyze two separate periods: (i) the conventional monetary policy period starting from the full circulation of the euro until the Global Financial Crisis (GFC) in 2008 (2001M01 – 2008M07) and (ii) the unconventional monetary policy period starting at the end of GFC and going to the end of our sample (2009M04 – 2019M08). We employ the Structural Vector Autoregression (SVAR) model to capture the effects of ECB monetary policy innovations on aggregate as well as sector commodity prices, namely food, fuel, metals, agricultural raw material, and beverage prices.

Our key results indicate that contractionary monetary policy shocks have positive effects on aggregate and sectoral commodity prices during both conventional and unconventional monetary policy periods. The effect is statistically significant for aggregate commodity prices during the post-crisis period. In terms of sectoral impact, the effect is statistically significant for food and metal prices in both periods, and for fuel prices in the post-crisis period, with fuel commodities experiencing the largest impact; other commodities display positive but statistically insignificant responses. Further, we show that an appreciation of the euro has an immediate positive effect on commodity prices. Our findings are in contrast with the results of Frankel (1986, 2008), Hammoudeh et al., (2015), and Belke et al., (2014), where contractionary US monetary policy has a negative effect on commodity prices, but they resonate with the importance of demand and supply fundamentals for the commodity price fluctuations observed by Gruber and Vigfusson (2018) since 2003. We believe that our results can be explained by exchange rate differences, where an appreciation of the euro causes euro-priced commodities to be relatively cheap and induces an increase in demand in the euro area. In other words, a rise in short-term interest rates is associated with an appreciation of the euro and increases the domestic demand for commodities traded in other currencies, which results in an increase in the price of commodities.

The novelty of our research and our contribution to the literature is threefold. First, to the best our knowledge, our empirical study is the first assessment of the effects of both conventional and unconventional ECB monetary policy on aggregate and sectoral commodity prices. Second, we demonstrate that the impact of ECB monetary policies on commodity prices increased considerably after the GFC, indicating the effectiveness of unconventional monetary policy tools on the real economy. This result is even more important now when the crisis associated with the Coronavirus pandemic will surely prompt further implementation of unconventional monetary policy tools. Third, our findings suggest that the effect of ECB monetary policy on commodity prices transmits through the exchange rate channel, which influences the European market demand directly.

The remainder of this paper is organized as follows. Section 2 reviews the related theoretical and empirical literature. Sections 3 and 4 present the data and methodology, respectively. We display and discuss empirical results in Section 5. Finally, Section 6 concludes.

2. Literature Review

The international literature is abundant with research concerning the macroeconomic and spillover effects of both conventional and unconventional monetary policies on economic activity (Schenkelberg and Watzka, 2013; Meinusch and Tillmann, 2016), price levels (Sims, 1992; Bernanke et al. 2005; Ono, 2017), asset prices (Bernanke and Gertler, 2000; Mishkin, 2001; Ricci, 2015), and bank performance (Mamatzakis and Bermpei, 2016; Imbierowicz et al. 2021). Along with theoretical studies analyzing links between monetary policy and commodity prices initiated in the 1980s (Frankel, 1986; Angell, 1992), empirical studies have a more recent history (Frankel, 2008; Beckmann et al. 2014; Hammoudeh et al. 2015). In this Section, we demonstrate the theoretical and empirical approaches to the nexus between monetary policy and commodity prices.

Frankel (1986) developed a theoretical explanation for overshooting commodity prices, drawing on Dornbusch's (1976) famous exchange rate overshooting theory. The assumption of Frankel's (1986) theory is based on the fixed-price stickiness of manufactured goods and services, while commodities traded in fast-moving auction markets have flexible prices that respond instantaneously to macroeconomic shocks. Therefore, a change in monetary policy creates more-than-proportionate price effects on commodity prices, and as a result, commodity prices overshoot their new long-run equilibria. In addition, Angell (1992) and Browne and Cronin (2007) argue that commodity prices are useful pieces of information in formulating monetary policy because they enter the production process at the early stages and therefore have an impact on general prices like producer or consumer price indices. In other words, changes in monetary policy that affect general price indices also have impacts on commodity prices. In his further theoretical framework, Frankel (2008) explained the relationship between real interest rates and commodity prices in a more detailed manner, where higher interest rates decrease the demand for storable commodities and increase the supply through three different channels: "(1) by increasing the incentive for extraction today rather than tomorrow (think of the rates at which oil is pumped, zinc is mined, forests logged, or livestock herds culled); (2) by decreasing firms' desire to carry inventories (think of oil inventories held in tanks); (3) by encouraging speculators to shift out of commodity contracts (especially spot contracts) and into treasury bills" (Frankel, 2008; p. 295). With respect to the above, Gruber and Vigfusson (2018) show that the correlation among commodity prices increases as the interest rate decreases, most significantly for the highly storable metal prices, and stress the importance of physical supply and demand fundamentals for the explanation of commodity price correlation.

Given the fact that commodity prices are extremely volatile and difficult to predict, along with monetary policy changes the fluctuations in commodity prices can be caused by many short-term factors like exchange rates. In this manner, the empirical study of Chen et al. (2010) offers a theoretical resolution by emphasizing the usefulness of information in exchange rate fluctuations to forecast global commodity prices. Moreover, in their recent study, Devereux and Smith (2021) show weak but robust correlation between countries' (Australia, New Zealand, and Canada) commodity price indices and their nominal exchange rates, which are determined by current and expected future values of relative monetary policy indicators.

In the last two decades, there were several studies empirically testing the commodity price overshooting model. By employing bivariate regression analyses on US annual data 1950–2005, Frankel (2008) found that commodity prices overshoot significantly with respect to changes in real interest rates. In particular, he found that since 1950 three major commodity price indices (Commodity Resource Board, Moody's, and Dow Jones) exhibit a negative and strong relationship with real interest rates. Specifically, 11 out of 23 individual commodity prices have statistically significant inverse relationships with real interest rates. Akram (2009) used a structural VAR model with quarterly US data covering the period 1990–2007 to analyze the effects of real interest rates on different commodity prices. He shows that lower interest rates in the US increase commodity prices via an exchange rate channel. Moreover, real oil and industrial raw material prices show an overshooting behavior in response to real interest rate shocks, while real food and metal prices show a delayed response. Further, both broad commodity price indices and all their components react positively to US expansionary monetary policy shocks with limited direct effects (Anzuini et al., 2013). The similar effects as those in the above-mentioned studies were found also by Belke et al. (2014), who, over the period 1970–2008, proxied the policy rate with quarterly data for the three-month treasury bill rates of 19 developed economies (the United States, the euro area, Japan, the United Kingdom, Canada, Korea, Australia, Switzerland, Sweden, Norway, and Denmark). The existing international literature investigated mostly the effects of US interest rates on international commodity price indices, while Klotz et al. (2014) and Sun et al. (2019) analyzed the nexus for China's policy rates and did not find significant evidence of a causal relationship.

Apart from the investigations of US and China policy rates, there is significant empirical research interested in the impacts of global liquidity on commodity prices (Belke et al. 2010; Brana et al. 2012; Belke et al. 2013; Belke et al. 2014; Beckmann et al. 2014; Ratti and Vespignani, 2015; Kang et al. 2016). For the determination of global liquidity, in their sequential studies, Belke et al. (2010) and Belke et al. (2013) used a broad range of nominal monetary aggregates M2 for US and Japan and M3 and M4 for the euro area and other emerging economies. They analyzed the nexus between global liquidity, food, and aggregate commodity price indices by using standard and cointegrated VAR models, and found a significant long-run positive relationship. Intuitively, when central banks of all major economies are running an expansionary monetary policy to enhance or stabilize their economies, this causes a rise in global liquidity, which results in commodity and food price increases. Similar results are found in Beckmann et al. (2014), where monthly data is used for the same countries and monetary aggregates and a Markov-switching vector error correction model (MS-VECM) is employed for the period of 1980:01–2012:06. In order to exploit monthly data, they used industrial production as a measure of output rather than GDP, and besides finding a long-run, significant positive relationship, commodity prices responded more quickly to global liquidity shocks as compared to consumer prices, which favors the overshooting hypothesis. Following the economic framework in above studies of Belke et al. (2013) and Beckmann et al. (2014), but employing an SVAR model, Kang et al. (2016) find a more salient impact of global liquidity on commodity prices after the GFC (2008:M01) in comparison to the total estimation period of 2004:01–2014:04. Interestingly, in the investigation of Ratti and Vespignani (2015), the positive liquidity shocks of BRIC (i.e., Brazil, Russian, Indian, and Chinese M2) countries were larger than the shocks of G3 (US, EU, and Japanese M2) for most individual commodity price indices. The impacts of BRIC liquidity shocks were larger in energy, mineral and metal, and raw material prices, while the effects on precious metal prices were larger in G3 liquidity for the same monthly data over the period of 1999–2012.

Hammoudeh et al. (2015) compared the effects of US conventional monetary interventions on broad and sector commodity price indices to unconventional QE policy interventions. By employing a Structural VAR (SVAR) model, the research displays a negative response on aggregate and sector commodity prices (with some variations) to innovations in federal fund rates in both conventional and unconventional monetary policy periods. Here, differing from the conventional policy period measured from 1957 to 2008, as a policy proxy they substituted the M2 growth rate with the central bank reserve growth rate, and the federal funds rate with the interest rate spread (the difference between long-term and short-term interest rates) for the unconventional policy period from April 2008. The empirical study of Jawadi et al. (2017) also show that commodity prices are responsive to M2 of the Fed since commodity prices respond immediately and positively to the expansionary monetary policy shocks. The interest rate variable used for capturing the unconventional period varies among the researchers due to the zero lower bond (ZLB), where some studies relied on the interest rate spread (Hammoudeh et al., 2015; Chen et.al., 2016; Hanabusa, 2017) while others (Hafemann and Tillmann, 2017; Hajek and Horvath, 2018; Caraiani and Calin, 2020) preferred to use the shadow policy rates introduced either by Wu and Xia (2016) or by Krippner (2013).

As this last strand of the literature lacks any analysis of the impact of ECB monetary policy on commodity prices, we aim to provide such an analysis in the present study.

3. Data

We intentionally deviate from standard practice and introduce our data before the methodology, as this helps us better describe our empirical strategy. For our empirical analysis we use monthly data on monetary policy, economic development, and commodity prices covering the period from January 2001 to August 2019. Despite the fact that the euro was launched on January 1, 1999, we do not employ data before 2001, because the euro was fully in circulation only from 2001; our approach is similar to that of Hajek and Horvath (2018). We divide our data and subsequent analysis into two parts: (i) the pre-crisis period covering the effects of conventional monetary policy shocks 2001M01–2008M07 and (ii) the post-crisis period capturing the effects of unconventional monetary policy 2009M04–2019M08. The division allows isolation of the impact of conventional and unconventional policy instruments and coincides also with the existing structural break in the data associated with the Global Financial Crisis (GFC) in 2008. The graphical presentation in Figure 1, confirmed by the results of the Chow breakpoint test, shows a structural break in a majority of the variables starting from August 2008. In order to avoid inaccurate inferences, we exclude data from the period 2008M08-2009M03. The division is also in line with the theoretical mechanism of overshooting and going back to equilibrium, albeit from a medium-term perspective when the real interest rate goes back to equilibrium in the post-crisis period.[3]

First, we introduce the monetary policy instruments: interest rate and monetary aggregate. Similar to Potjagailo (2017) or Sousa (2010), for the pre-crisis period we employ the euro area three-month interest rate from the ECB database that is a representative short-term interest rate and a benchmark rate for the euro area money market. However, after the GFC and due to the ZLB, the ECB introduced unconventional monetary policy measures. Therefore, for the post-crisis period we use the short-term shadow policy rate designed by Wu and Xia (2016), which was used as a policy tool proxy in recent analyses (Hafemann and Tillmann, 2017; Hajek and Horvath, 2018; Galariotis et al., 2018). For our robustness checks, we employ interest rate spread data from the ECB, obtained from the difference between short-term interest rates and 10-year government bond yields. Further, we use alternative short-term shadow rates calculated by the method of Krippner (2013) that are available from the Reserve Bank of New Zealand.[4] For the monetary aggregate we follow the approach of Belke et al. (2013, 2014), Beckmann et al. (2014), Ratti and Vespignani (2015) and employ the M2 stock of the euro area obtained from the ECB.

Second, we introduce our data on economic development. The economic activity, monetary aggregate, and inflation indicator (X_{1t} elements) are based on the industrial production index of the EU19 countries, and the harmonized consumer price index (HICP), respectively. All three variables are working-day and seasonally adjusted data obtained from the ECB; the same data are used by Hammoudeh et al. (2015), Klotz et al. (2014), Ratti and Vespignani, (2015), Belke et al. (2014), Beckmann et al. (2014), and Anzuini et al. (2013).[5] Further, we use the Economic Sentiment Indicator (ESI) that proxies for the perception of the economic developments in the euro area. It is calculated based on five weighted confidence indicators of industry (40%), services (30%), consumers (20%), construction (5%), and retail trade (5%). It is seasonally adjusted and sourced from the Eurostat database of the European Commission.[6]

Finally, we introduce our price data, variables that respond contemporaneously to the policy shocks (X_{2t} elements). First, it is the price of foreign exchange. We employ the nominal exchange rate of 19 trade partner currencies against the euro quoted by the ECB. Specifically, the exchange rate variable is defined as the monthly average of trade partner currencies against the euro (e.g., XXX/EUR). By this definition, an increase (decrease) in the exchange rate means an appreciation (depreciation) of the euro. Further, we use commodity price indices that are sourced from the International Monetary Fund (IMF).[7] Specifically,

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[3] In our analysis we intentionally do not cover the most recent period, although we are aware that the Coronavirus pandemic yields high volatility in commodity prices due to supply and demand shocks. However, an assessment of the ECB's reactions to these shocks is beyond the scope and purpose of our analysis.
[4] The Reserve Bank of New Zealand updates the shadow rates for the US, Japan, the euro area, and the UK at https://www.rbnz.govt.nz/research-and-publications/research-programme/additional-research/measures-of-the-stance-of-united-states-monetary-policy/comparison-of-international-monetary-policy-measures.
[5] European Central Bank Statistical Data Warehouse at https://sdw.ecb.europa.eu/home.do;jsessionid=50F29F9952C346B9B74C34E96412B1E0.
[6] European Commission, Eurostat at https://ec.europa.eu/eurostat/web/products-datasets/product?code=teibs010.
[7] The IMF Primary Commodity Prices are downloadable from: https://www.imf.org/en/Research/commodity-prices.

the IMF Primary Commodity Prices data portal provides the broadly defined primary commodity price index (PCPI) and specific group commodity price indices that are divided into several categories (specific index code is shown in parentheses): (1) all commodity prices index (PALLFNF); (2) food price index (PFOOD) that includes cereal, vegetable oils, meat, seafood, sugar, and other food (apples, non-citrus fruits, bananas, chickpeas, fishmeal); (3) beverage price index (PBEVE) including coffee, tea, and cocoa; (4) agricultural raw materials price index (PRAWM) including timber, cotton, wool, rubber, and hides; (5) all metals price index (PALLMETA) including gold, silver, palladium, platinum, aluminum, cobalt, copper, iron ore, lead, molybdenum, nickel, tin, uranium, and zinc, and (6) fuel price index (PNRG) including crude oil (petroleum), natural gas, coal price and propane indices. The IMF primary commodity price index (PCPI) is a weighted average of select commodity price indices, based on identified benchmark prices that are representative of the global market. The weight is calculated based on the global import share over a 3-year period (2014-2016) and is normalized to 100 at 2016 prices; all benchmark prices are denominated in US dollars. Normalized prices are calculated by dividing the nominal commodity price by the base price, where the base price is taken to be the average price in 2016 for that commodity, so that the values of the normalized price and the PCPI are equal to 100 in 2016.[8] The calculation approach means that each individual commodity price index value effectively accounts for exchange rate movements in various currencies in which commodities are traded, despite the fact that the majority of the volume of traded commodities is invoiced in US dollars. Group indices are then weighted averages of individual commodity price indices where respective commodity weights are derived from their import trade values relative to the total world import trade as reported in the UN Comtrade database. Both aggregate and sectoral commodity price indices are reported as non-seasonally adjusted and for that we further transform the commodity indices into seasonally adjusted data by the Seasonal and Trend decomposition using the Loess method (STL decomposition) and use the transformed data in our analysis.

All variables in the analysis are expressed in natural logarithms, except for interest rates. With exception of the interest rate ($\boldsymbol{i}_t$), all other variables are identical for both conventional and unconventional policy periods. The dummy variable captures the effects of large variation in commodity prices (see Figure 1) and exchange rates for the period of 2014M09–2016M06 (post-crisis analysis) due to the sharp decrease in crude oil prices.

4. Methodology

Our goal is to evaluate the dynamic responses in commodity prices due to unexpected shocks in policy variables while exploiting the rich dynamic relationships among variables. Hence, for our empirical assessment, we follow the works of Hammoudeh et al. (2015), Sousa (2010), Cover and Mallick (2012),

[8] Calculation details of commodity prices are reported in the technical document published by the IMF and updated in 2019 that is available at https://www.imf.org/~/media/Files/Research/CommodityPrices/TechnicalDoc.ashx.

and Afonso and Sousa (2012), and we employ the Structural Vector Autoregressions (SVAR) model that has become common practice for researchers to analyze the effects of monetary policy shocks on the real economy. Moreover, commodities were initially employed in a Vector Autoregressive (VAR) framework by Sims and Zha (2006) as an information variable to solve the price puzzle for the impulse responses to monetary policy shocks.

Our choice of SVAR model is motivated by the early theoretical works of Phillips and Durlauf (1986), Stock (1987), West (1988), Sims et al. (1990), Philipps (1991), and Toda and Yamamoto (1995) and later by Barigozzi et al. (2021), who developed an analytical framework for co-integrated and non-stationary data in VAR and demonstrated its advantages with respect to the VECM.[9] The use of the SVAR model is further motivated by our target to obtain the short-run impulse response functions of the short-term (monthly) effects. The impacts of monetary policy shocks are transitory and effective mainly during the short-run horizons. In the short-run focus, the theoretical studies of Fanchon and Wendel (1992), Naka and Tufte (1997) and Barigozzi et al. (2021) show that co-integrated non-stationary variables perform equally in VAR and VEC models. Naka and Tufte (1997) argue that abandoning VAR for short horizon analysis is premature; in their Monte Carlo experiment, they show that the performance of the two methods is nearly identical and even poorer in the VEC model. Further, in the analysis of the cointegrated non-stationary price variables, Fanchon and Wendel (1992) show that VAR monthly price forecasts over a nearly five-year horizon exhibit the lowest mean square errors along with better forecasting performance over the first seven months when compared to a VEC model; it is fair to say that their results are presumably specific to a particular data set and historical context, though. Such an approach yields consistent estimates and potential finite sample bias becomes small (if there is any). Finally, our methodology choice is motivated by its empirical use, in the similar context to ours, by Hammoudeh et al. (2015), Sousa (2010), Cover and Mallick (2012), Afonso and Sousa (2012), Sims and Zha (2006), as well as effective use of the SVAR approach in estimating monetary policy shocks with co-integrated non-stationary variables demonstrated by Akram (2009) and Dungey and Fry (2009).

We analyze the effects of the ECB monetary policy on commodity prices by estimating the following SVAR;

$$\Gamma(\mathbf{L})\,\boldsymbol{X_t} = \Gamma_0\,\boldsymbol{X_t} + \Gamma_1\boldsymbol{X_{t-1}} + \Gamma_2\boldsymbol{X_2} + \ldots\ldots\ldots = \mathbf{C} + \boldsymbol{\varepsilon_t}\,, \tag{1}$$

where $\varepsilon_t\,|X_s$, s < t~N ($\underline{0}$, Λ) and Γ(L) is an *n* by *n* matrix polynomial in the lag operator L, *n* is the number of variables in the system, and ε_t is the vector of shocks of economic fundamentals that span the space of innovations of *n* by 1 vector X_t. Therefore, the reduced form can be estimated as:

$$\Gamma_0^{-1}\Gamma(\mathbf{L})\,\boldsymbol{X_t} = \mathrm{B}\,(\mathbf{L})\,\boldsymbol{X_t} = \boldsymbol{\alpha} + \boldsymbol{\upsilon_t} \sim \mathrm{N}(0,\,\Sigma), \tag{2}$$

[9] An alternative with non-stationary and co-integrated variables is to use VEC model to achieve stationarity and use an error correction term to replace the long-run potential information loss from differencing (Fanchon and Wendel, 1992).

where $\sum = \Gamma_0^{-1} \Lambda (\Gamma_0^{-1})'$ and $\upsilon_t = \Gamma_0^{-1}\varepsilon_t$ is the vector of VAR innovations. The characterization of monetary policy in the model is:

$$\boldsymbol{i_t} = \boldsymbol{f(\Omega_t)} + \boldsymbol{\varepsilon_t^i}, \tag{3}$$

where the central bank policy rate $\boldsymbol{i_t}$ depends on the f linear function of Ω_t information set and ε_t^i interest rate shock.

For the identification restrictions in the Γ_0 matrix, we decided to separate X_t into three groups, $X_t = [X_{1t}, \boldsymbol{i_t}, X_{2t}]'$, similarly to Christiano et al. (2005), Sousa (2010), and Hammoudeh et al. (2015). The groups are (i) X_{1t}, a subset of n_1 variables that do not respond contemporaneously to the policy shocks but rather with a certain lag; (ii) $\boldsymbol{i_t}$, a monetary policy instrument; and (iii) a subset of n_2 variables, X_{2t}, which respond contemporaneously to the policy shocks. Therefore, the structural shocks are identified by imposing restrictions on the contemporaneous matrix Γ_0:

$$\Gamma_0 = \begin{bmatrix} \underbrace{\gamma_{11}}_{n_1\times n_1} & \underbrace{0}_{n_1\times 1} & \underbrace{0}_{n_1\times n_2} \\ \underbrace{\gamma_{21}}_{1\times n_1} & \underbrace{\gamma_{22}}_{1\times 1} & \underbrace{0}_{1\times n_2} \\ \underbrace{\gamma_{31}}_{n_2\times n_1} & \underbrace{\gamma_{32}}_{n_2\times 1} & \underbrace{\gamma_{33}}_{n_2\times n_2} \end{bmatrix}. \tag{4}$$

Specific variables corresponding to the above recursive assumptions are contained in the set of variables X_{2t}, consisting of the exchange rate and commodity price index, which respond contemporaneously to policy shocks. The economic sentiment index (ESI), monetary aggregate M2, industrial production and price level respond with a lag and constitute set X_{1t}. Therefore, the vector of endogenous variables can be ordered in the following Structural Decomposition order as:

$X_t =$ $[\mathrm{ESI}_t, \mathrm{M2\ Stock}_t, \mathrm{Industrial\ Production}_t, CPI_t,$ $\mathrm{Interest\ Rates}_t,$ $\mathrm{Exchange\ Rates}_t,$ $\mathrm{Commodity\ Price}_t]$'.

According to our variable ordering, commodity prices are assumed to respond contemporaneously to all the shocks of the preceding variables. On the other hand, the CPI responds to interest rate shocks with a certain lag, but faster than industrial production, monetary aggregate, and ESI. Business cycle fluctuations or the economic sentiment indicator (ESI) are assumed to be affected later than the monetary aggregate. With respect to M2, a number of studies related to our analysis assume that the monetary aggregate responds to interest rates contemporaneously, following the original arguments of Sims (1980). In terms of the VAR specification, such an approach makes sense if monetary policy is assumed to decrease interest rates by increasing central bank reserves. However, central banks, including the ECB, often set the interest rate and accommodate the demand for bank reserves (which is proportional to broad money) at this rate (Borio and Disyatat, 2010). Such an approach means that it takes time for a decrease in interest rate to affect the money aggregate. In terms of the VAR specification, a one-month lag should effectively capture the time needed for the reaction to travel between the interest rate and the monetary aggregate. The optimal lag lengths are chosen based on several information criteria. The variable ordering conforms to that used in the mainstream literature (Anzuini et al., 2013; Belke et al. 2013; Belke et al. 2014; Hammoudeh et al., 2015 and others) and is robust with respect to alternative approaches as shown in Section 5.3.

5. Empirical Results

5.1 The pre-crisis period: effects of conventional monetary policy on commodity prices

In this Section, we initially show the results for unit-root and co-integration tests together with optimal lag length selection criteria. Then, we provide the results for the impact of conventional monetary policy shocks on the aggregate (broad) commodity price index and on sectoral commodity price indices.

5.1.1 Unit root test, co-integration test, and lag selection criteria

We used three standard unit root test techniques to test for the stationarity of variables in the model covering the period 2001M01–2008M07. The results of the Augmented Dickey-Fuller (ADF), Phillips-Perron (PP), and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests are displayed in Table A1 (Appendix). We observe that all series to be used for the pre-crisis period analysis are non-stationary in their levels (with or without an intercept). Further, we perform a VAR optimal lag selection based on the formal lag criterion for each commodity model. Except for the LR information criterion, the other lag order selection criteria (FPE, AIC, SC, and HQ) suggest a maximum optimal lag length of one (Table A2).

5.1.2 Impulse-response functions for the pre-crisis period

Impulse-response functions are a useful tool for analyzing the interactions between variables and their reactions to policy shocks. They demonstrate the reaction of a one-standard-deviation shock occurring in a variable to other variables or to itself. In our analysis, we first display and discuss the responses of aggregate commodity prices to the innovations in all variables of the model (Figure 2). Further, we discuss the responses of group commodity price indices to the innovations in short-term interest rates (Figure 3). The impulse-response function is represented as a blue line, while the red dashed lines with ±2 standard deviation error bands show the 5% significance level.

During the pre-crisis period, aggregate commodity prices display statistically insignificant responses to ESI, M2 stock, industrial production, short-term rates, and exchange rates (Figure 2). The response to the CPI stands as an exception since one standard deviation of the positive shock in CPI has an immediate price-increasing effect on aggregate commodity prices. The initial magnitude of the impact is about 2% but decreases towards 1% close to the end of the period. Still, the initial response is substantially larger than the impact of global CPI shown in Ratti and Vespignani (2015, p. 31). Overall, the sensitivity of the aggregate commodity price index to CPI innovations reflects a general sensitivity of global commodity prices to macroeconomic innovations in euro area economies (Smiech et al. 2015).

Prevalent statistical insignificance precludes drawing firm inferences from Figure 3, but an effect of interest rate shock is observed for food and metal commodities. We first discuss the price-increasing response of food prices to short-term interest rate shocks that appears persistent and statistically significant after the third period with a stable 0.5% effect. Moreover, food prices show faster and contemporaneous reaction to M2 shocks until the third period with gradually decreasing -0.5% effect. From this point of discussion, it is useful to indicate that the positive impacts of interest rate shocks have economically equal interpretation to the negative impacts of M2 shocks: where positive interest rate shock represents contractionary monetary policy, while positive M2 shock represents expansionary monetary policy. The impact of both monetary policy tools on food prices states that contractionary monetary policy produces price increasing effects on food prices. Food prices also display a similar response to the euro appreciation after the first period as shown in Figure A1 (Appendix). We believe that the reason for the above responses might be driven by differences in the currencies in which commodities are traded. We observe that a positive exchange rate shock (appreciation of the euro) has a price-increasing effect on aggregate and food commodity prices (Figure A1). In other words, the appreciation of the euro, which is associated with a contractionary monetary policy, has a price-increasing impact on food prices. A stronger euro means that food commodities priced in other currencies become cheaper and the demand for relatively cheaper food in the European market priced in euro increases, pushing food prices up. It is also reflected in the effects of M2 stock, where a positive shock in liquidity (expansionary policy) leads to the depreciation of euro currency and has a negative impact on aggregate and other group commodity prices.[10]

Then, in Figure 3, we also see that metal prices demonstrate immediate and negative responses to the increase in interest rate (positive policy shock); a decline in metal prices amounts to about 1% and it is persistent for all estimated periods. The response is in line with the existing historical inverse relationship between interest rates and the prices of commodities that are primarily needed in manufacturing. The inverse link is grounded in the cost of holding inventory since a low interest rate means also lower costs of inventory (the cost of carry) and vice versa. Understandably, it is cheaper to store metals needed in manufacturing when the cost of money is low. As a result, when interest rates increase (positive policy shock), the commodity prices tend to decline. Our result is also supported by evidence from Akram (2009; Fig. 9, p. 848) showing a lagged negative response of the industrial metal price index to the one-month US Libor rate shock specifically during the pre-crisis period or Scrimgeour (2014) showing a large negative response of metals to an increase in the Fed policy rate.

[10] It seems that commodity prices react inversely to expansionary monetary policy, which is not in line with previous studies such as Frankel (2008), Hammoudeh et al. (2015), and Belke et al. (2014), who found negative effects of US short-term interest rates on commodity prices. However, we argue that the seemingly different result can be explained when we account for the effect of the exchange rate. The exchange rate pass-through of monetary policy is broadly inferred in Akram (2009) who shows that lower interest rate in the US increases commodity prices via an exchange rate channel.

5.2 The post-crisis period: the effects of unconventional monetary policy on commodity prices

Following the empirical steps in Section 5.1, in this section, we first discuss the results of unit-root and co-integration tests along with the lag selection criteria, and then display the outcomes of impulse response functions for the shocks in unconventional monetary policy on commodity prices covering the period 2009:04–2019:08. Similar to the pre-crisis-period variables, the results of unit-root tests in Table A3 (Appendix) demonstrate the non-stationarity of variables in their levels. For all of the models we select an optimal lag of one based on the results of several lag selection criteria reported in Table A4.

5.2.1 Impulse-response functions for the post-crisis period

In this section (similarly as in Section 5.1.2), we display the impulse-responses of aggregate commodity prices to structural shocks in all macroeconomic variables in the model (Figure 4) and the responses of group commodity prices to short-term shadow policy and M2 shocks only (Figure 5).

Beginning with the policy instrument (Figure 4), the positive shock in the short-term shadow policy rate has statistically insignificant price-increasing impact on aggregate commodity and group commodity prices. In contrast, aggregate commodity prices respond negatively to a positive increase in the M2 stock; the response is effective for the displayed horizon after the first period with 0.8% magnitude. The result implies that a contractionary policy shock, in terms of negative M2 stock, would result in an increase in commodity prices, a reaction similar to a contractionary policy shock in the form of an interest rate increase.

The immediate responses to the exchange rate shocks of aggregate commodity prices are positive (with a 0.9% impact) over five periods and then they vanish by the end of the period. Additionally, the impact of exchange rate appreciation is price-increasing, contemporaneous, and statistically significant on food, fuel, metals, and agricultural raw material prices (Figure A2, Appendix). The sensitivity of commodity prices to the euro area CPI reflects a similar significant and immediate positive effect as in the pre-crisis period with the same magnitude of an initial 2% which decreases to 1% by the end of the displayed horizon. Increase in industrial production have price increasing effects on aggregate commodity prices after the first period for five consecutive periods with 1% magnitude. Moreover, positive economic and business conditions represented by the ESI exhibit a price-increasing impact (0.8%) on aggregate commodity prices.

The impact of shadow policy shocks on sectoral commodity prices in Figure 5 reflects similar effects to aggregate prices. Food, fuel and beverage prices react negatively to positive M2 shocks. The outcomes in food and fuel prices are also similar to the results of Hammoudeh et al. (2015). The magnitude of the M2 shock to fuel prices is higher than others -- an effective -1% response is observed that increases to -1.2% after the second period and exhibits persistent effect around -1%. Also, the beverage commodity index shows a persistent -0.3% price-decreasing response that becomes statistically significant after the seventh period. However, other group commodities display statistically insignificant effects.

Like in the pre-crisis period, even with more solid results, we rely on the causes of the combination of interest rate, liquidity, and exchange rate channels. Namely, an increase in M2 (expansionary shock) causes an appreciation of the euro that attracts relatively cheap commodities to the euro area and subsequently results in an increase in commodity prices. It should be noted that relatively cheap commodities signal deteriorating terms of trade in commodity exporting countries and their inclination to diversify their international reserves towards big four currencies, meaning towards the euro as well (Aizenman et al., 2020), which is in line with euro appreciation.

In the next stage we proceed to provide a clear explanation of how we identify the transmission mechanism. We perform a sequential analysis of the impulse-response functions (IRF) where monetary policy shocks are followed by the reaction of the exchange rate. We also couple this step with what is done in the literature. First, we present the exchange rate transmission channel of monetary policy shocks by sequential IRF of the above commodity models followed by the exchange rate reactions shown in Figure 6. We find that, during both periods, the euro exchange rate initially reacts negatively to the expansionary M2 aggregate shock, but the reaction is statistically significant only during the post-crisis period. The subsequent reaction of the exchange rate to the contractionary interest rate shock is missing before the crisis, but during the post-crisis period reaction it is positive and rises towards 1% in magnitude from period two to five. A complementary test shows causal link running from shadow rates to exchange rates during the post-crisis period at 5% significance level, while the causality is not detected in the opposite direction (details are reported in Table A5).

The reactions to both monetary policy instruments show that expansionary monetary policy has a depreciative effect on euro currency, which is in line with the related empirical works of Kearns and Manners (2006), Cecioni (2018), Inoue and Rossi (2019), and Yang and Zhang (2021), among others. Other valuable evidence rests in the positive shocks of CPI demonstrating the immediate depreciative effects on exchange rate fluctuations. Such a reaction indicates that an increase in domestic prices (which is the signal to expect expansionary monetary policy innovations) produces depreciative pressure on euro currency. The stronger and more sensitive impacts of the policy innovations during the unconventional monetary policy years is also reported in the recent relevant work of Cecioni (2018) and Ferrari et al. (2021) for the ECB and Yang and Zhang (2021) for the Fed.

The above results can be linked to theory along with relevant empirical evidence. The theoretical framework introduced by Frankel (1986, 2008) demonstrates the negative impacts of monetary tightening on commodity prices. This is supported by further empirical work, such as Akram (2009), Anzuini et al. (2013), and Hammoudeh et al. (2015), who tested the link for the US case. Our empirical study, in contrast, infers the transmission of the ECB's monetary policy shocks through the exchange rate channel. Although we find direct positive impacts of monetary aggregate on commodity prices, we are not convinced that the global commodity prices are sensitive to the M2 stock innovations in the euro area. Rather, we believe that the commodity prices are sensitive to changes of the euro exchange rate due to a greater market size (the euro area being the largest importer), positive interest rate shocks have appreciative impacts on the euro exchange rate, and an appreciated euro has demand-increasing and price-increasing effects on commodities. The exchange rate contains useful information to forecast global commodity prices, which is emphasized by Chen et al. (2010) and Devereux and Smith (2021), especially when the currency (i.e., the euro) has a significant global import share. The exchange rate channel in our findings supports Dornbusch's (1976) overshooting theory, which states that the increase in the short-term interest rate appreciates the domestic currency and impacts the terms of trade by increasing imports.

Generally speaking, a positive (contractionary) monetary policy shock in both conventional and unconventional policy periods exhibits a price-increasing impact on aggregate and sectoral commodity prices. The impact of short-term policy rates is statistically significant especially during an unconventional policy period, which could be due to the growing influence of ECB policy decisions and euro area trade on the global economy as well as on global commodity prices.

5.3 Robustness checks and alternative approaches

Variable ordering in our model might be subject to alternative approaches and for that we perform some robustness checks. In our baseline model, we assume that the M2 aggregate reacts to the interest rate with a short delay (earlier we provided reasoning for this assumption). As a second step, we also account for the popular assumption of a contemporaneous response of the M2 aggregate to the interest rate; as a robustness check, we estimate a similar model specification as Sims (1992) or Hammoudeh et al. (2015). We find that the contemporaneous responses of commodity prices to an M2 aggregate increase are not materially different from those of our baseline model, but they largely lack statistical significance (not reported, available upon request). We believe that the assumed contemporaneous link between the interest rate and the M2 aggregate imposes some limits on the propagation of response between commodity prices and the M2 shock.

Next, we modify the ordering to account for other potentially contemporaneous impacts. For example, it might be reasonable to assume that prices within CPI that capture fuel often move close to instantaneously with the raw commodity prices, and the same may be the case for some food commodity prices. A second example has to do with the value of the US dollar. Movements in the value of the US dollar might be assumed to affect the weighted exchange rate series and the commodity price series simultaneously. For that we adjusted ordering and re-estimated our baseline model. However, the results show (not reported, available upon request) that responses in CPI and in other model elements exhibit almost the same patterns as our baseline model with variable ordering, reflecting mainstream studies (Anzuini et al., 2013; Belke et al., 2013; Belke et al., 2014; Hammoudeh et al., 2015, and others).

Further, in the analysis of the unconventional monetary policy period we used Wu and Xia (2016) shadow policy rates. As a robustness check, we replaced our policy instrument with both (i) a short-term interest rate representative of the euro area (in the pre-crisis period) and short-term shadow rates developed by Krippner (2013). The results based on the standard short-term rates displayed heterogeneous and statistically insignificant outcomes. Results based on alternative short-term shadow rates calculated by the method of Krippner (2013) displayed, in general, the same impact as those using the Wu and Xia (2016) shadow policy rates (not reported but available upon request).

In addition to the statistically and economically motivated division of the data into pre-crisis and post-crisis periods, we also performed our analysis over the whole period as if the structural breaks did not exist. In terms of a policy instrument, we analyzed the model separately with three policy instruments: short-term interest rates, interest rate spread, and shadow policy rates of Krippner (2013). We had to exclude the shadow policy rates of Wu and Xia (2016) because their data is available only from 2004. While this analysis did not produce statistically significant results for the short-term interest rates and shadow rates of Krippner (2013), we found that the interest rate spread shows a positive and immediate effect on commodity prices, which is in line with our core results.

Moreover, we also estimated the model with a trend in both periods and accounted for the presence of two lags based on the values of the LR and AIC information criteria. These adjustments did not further improve our results in terms of statistical significance.

In order to investigate how the structural shocks of model variables contribute to fluctuations in aggregate and group commodity prices, we used forecast error variance decomposition (FEVD) over the fifty-month forecasting horizon (Appendix Figures A3 and A4). During both periods, we observe a comparatively large contribution of the CPI, interest rate, and exchange rate variables on commodity price fluctuations over the whole forecast horizons. In the long run, the share attributable to interest rate shocks on commodity aggregate prices increases up to 25% during both periods, but it increases up to 40% for food price fluctuations over the post-crisis period. Quite substantially, the share of CPI shocks rises up to 50% for commodity aggregate and fuel price fluctuations over the short, medium and long run horizons; the finding indicates substantial sensitivity of fuel commodities to shocks from general price level. The overall results of the FEVD analysis show that shocks originating from CPI, interest rates and exchange rates demonstrate significantly larger contributions on commodity price fluctuations than the shocks of M2 stock, ESI, and industrial production.

Further, as a further robustness check, we also adopt the identification of shocks through a different approach. As an alternative to the recursive identification scheme, we applied several combinations of zero and sign restrictions on the impacts of monetary policy shocks. We follow the work of Anzuini et al. (2013), Georgiadis (2015), Chen et al. (2017), and Benecka et al. (2020) and adopt the approach where negative sign restrictions are imposed directly on the impulse responses of industrial production, CPI and M2 stock to the contractionary monetary policy shocks after one month. The zero restrictions are alternatively used for the impacts on exchange rates and commodity prices to account for the lagged reaction to the monetary policy shocks. As we focus on the response of commodity prices, we do not impose restrictions on this variable, similarly as in Anzuini et al. (2013) and Hammoudeh et al. (2015). The alternative identification schemes do not demonstrate differing impacts of monetary policy shock on commodity prices during either conventional or unconventional policy periods. More specifically, negative sign restrictions mainly show statistically insignificant responses of commodity prices to the policy shocks, while zero restriction does not show materially different results from our baseline results.

Finally, we perform recursive and rolling window time-varying techniques following the works of Narayan and Sharma (2018), Inoue et al. (2017), and Prüsser and Schlösser (2020) in order to discover structural changes in impulse-responses that may evolve with respect to time. We selected various window sample sizes during both pre-crisis and post-crisis periods and estimated the baseline model under the same recursive identification assumptions. For the pre-crisis period time-varying analysis, we find that the effectiveness of the ECB's monetary policy measures increases with respect to time; i.e., aggregate, fuel and beverage commodity prices respond positively to a short-term interest rate shock after four months and with rising magnitude further on in the selected 48-month (2004M07-2008M08) window (see Figure 6). However, time-varying post-crisis analysis does not show significant impulse-response differences over time or in specifically chosen time-frames. Our core outcomes show statistically significant responses of commodity prices to the monetary policy shocks mainly during the post-crisis period, while during the pre-crisis period the responses are significant only in food and metal prices. The results of the time-varying approach indicate the rising effectiveness of ECB monetary policy before the GFC. This effect can be linked to increasing trade volume resulting from the expanded market size of the growing number of euro area member states, which increases the demand elasticity for commodities and its reactions to macroeconomic changes in the euro area.

6. Conclusions

We analyzed the impact of ECB monetary policies on global aggregate and sectoral commodity prices. In an SVAR model, we employed monthly data and separately covered the period before and after the GFC to capture the effects of conventional and unconventional monetary policies. We used three-month short-term interest rates as a monetary policy instrument for the conventional policy period, while short-term shadow policy rates from Wu and Xia (2016) were used for the unconventional policy period due to the ZLB. We analyzed not only the effects of interest rate shocks on aggregate commodity price indices, but we also assessed the individual responses of each sector commodity price index, covering the commodities of food, fuel, beverage, metals, and agricultural raw materials.

Our empirical findings indicate that contractionary monetary policy shocks have price-increasing effects on the aggregate commodity prices during mainly unconventional monetary policy period. The aggregate commodity prices responded negatively to the positive M2 shocks during the post-crisis period. Moreover, during the pre-crisis period, only food and metal commodity prices exhibit a statistically significant response to policy shocks; other commodities do not. However, during the post-crisis period, food, beverage, and fuel commodity prices show price-increasing responses to contractionary policy shocks, with a certain delay. We find that interest rate shocks are ineffective on commodity prices during both periods.

The outcomes of our empirical study for food and fuel prices are consistent with the results of Hammoudeh et al. (2015), but for aggregate commodity prices they contrast with the results of Frankel (1986, 2008), Belke et al. (2014), and Hammoudeh et al. (2015), where contractionary US monetary policy has a negative effect on commodity prices. To the best of our knowledge, the relationship has not yet been investigated for ECB policy interventions. Hence, our results are not directly comparable. The divergence of inferences might stem from a sensible cause, though. Since the EU is the largest importer of world commodities, we believe that the positive effects of ECB conventional and unconventional monetary policies on aggregate and sectoral commodity prices are driven by exchange rate differences. We found that an appreciation of the euro has an immediate and positive effect on commodity prices in both periods, which causes euro-priced commodities to be relatively cheap and in demand in the European market. In an economic sense, our exchange rate pass-through inference is in line with the reasoning of Akram (2009) and Hammoudeh et al. (2015).

Our main contribution to the literature on monetary policy and commodities is threefold. First, it is the first empirical study assessing the effects of ECB conventional and unconventional monetary policy shocks on aggregate and sectoral commodity prices. Second, it demonstrates that the impact of ECB monetary policies on commodity prices increased remarkably after the GFC, indicating the effectiveness of unconventional monetary policy tools on the real economy in comparison with conventional tools. This result resonates with the general assessment of Borio and Zabai (2018), who on the other hand warn that unconventional monetary policy measures are likely to be subject to diminishing returns. Third, the results suggest that the effect of ECB monetary policy on commodity prices transmits through the exchange rate channel, which influences European market demand directly.

We believe that monetary policy authorities should consider the inverse effects of interest rate policy decisions on global commodity prices transmitted through exchange rates. It is also a valuable information source in designing and implementing inflation targeting policies, where expansionary (contractionary) monetary policy would have a weak inflationary (deflationary) effect on overall prices due to expensive (cheap) commodities. Specifically speaking, decision-making during a time of unconventional policy measures should entail immediate commodity price effects caused mainly by food and fuel prices.

Our results are timely in many aspects. For example, the Coronavirus pandemic again opens the door for the implementation of unconventional monetary policy tools. In addition, the current energy crisis emphasizes the importance to include prices of fuel commodities in central bank decision-making.

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Figure 1

Raw data for the total period 2001M1-2019M8, with the indication of period break and dummy usage.

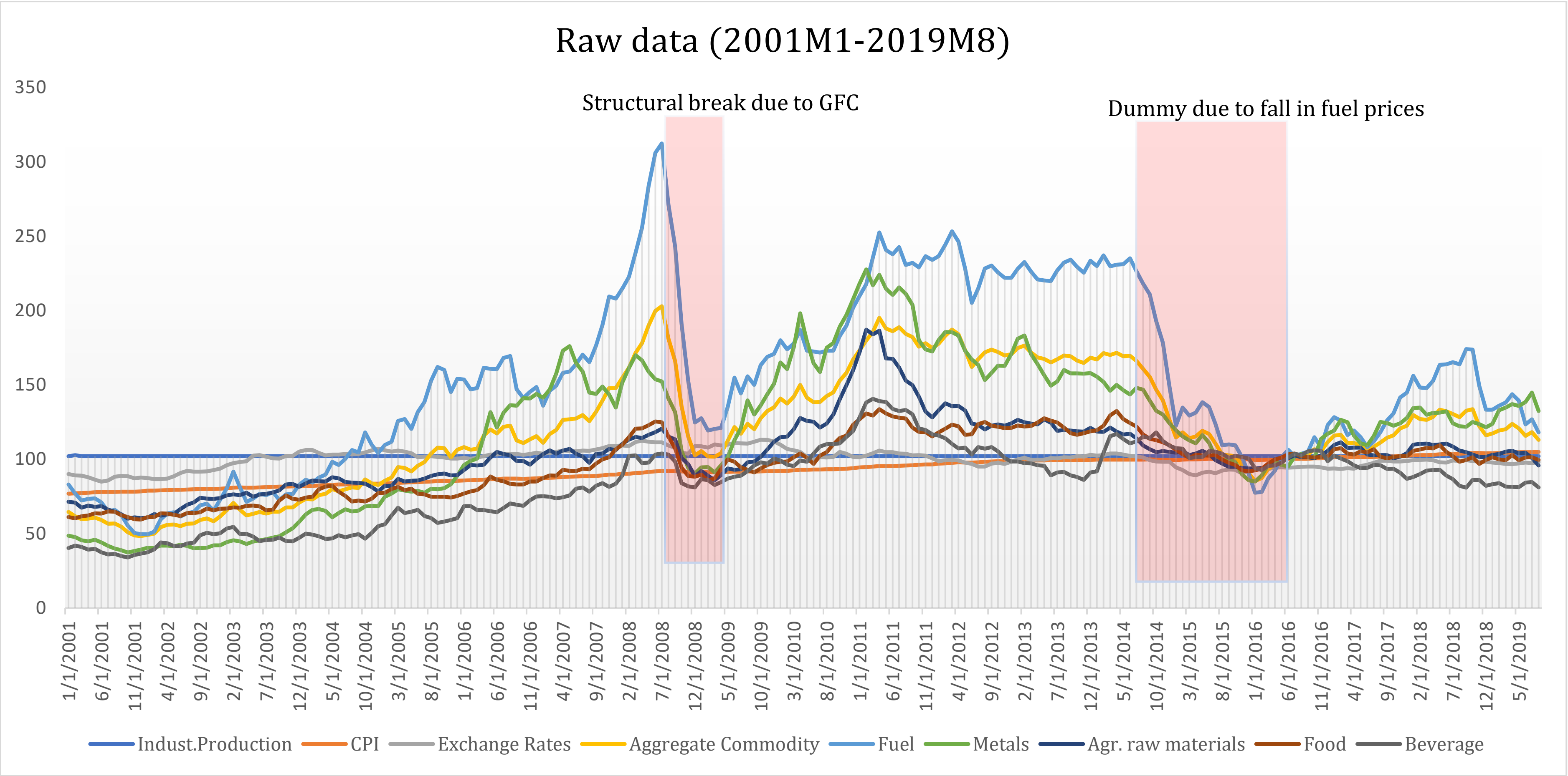
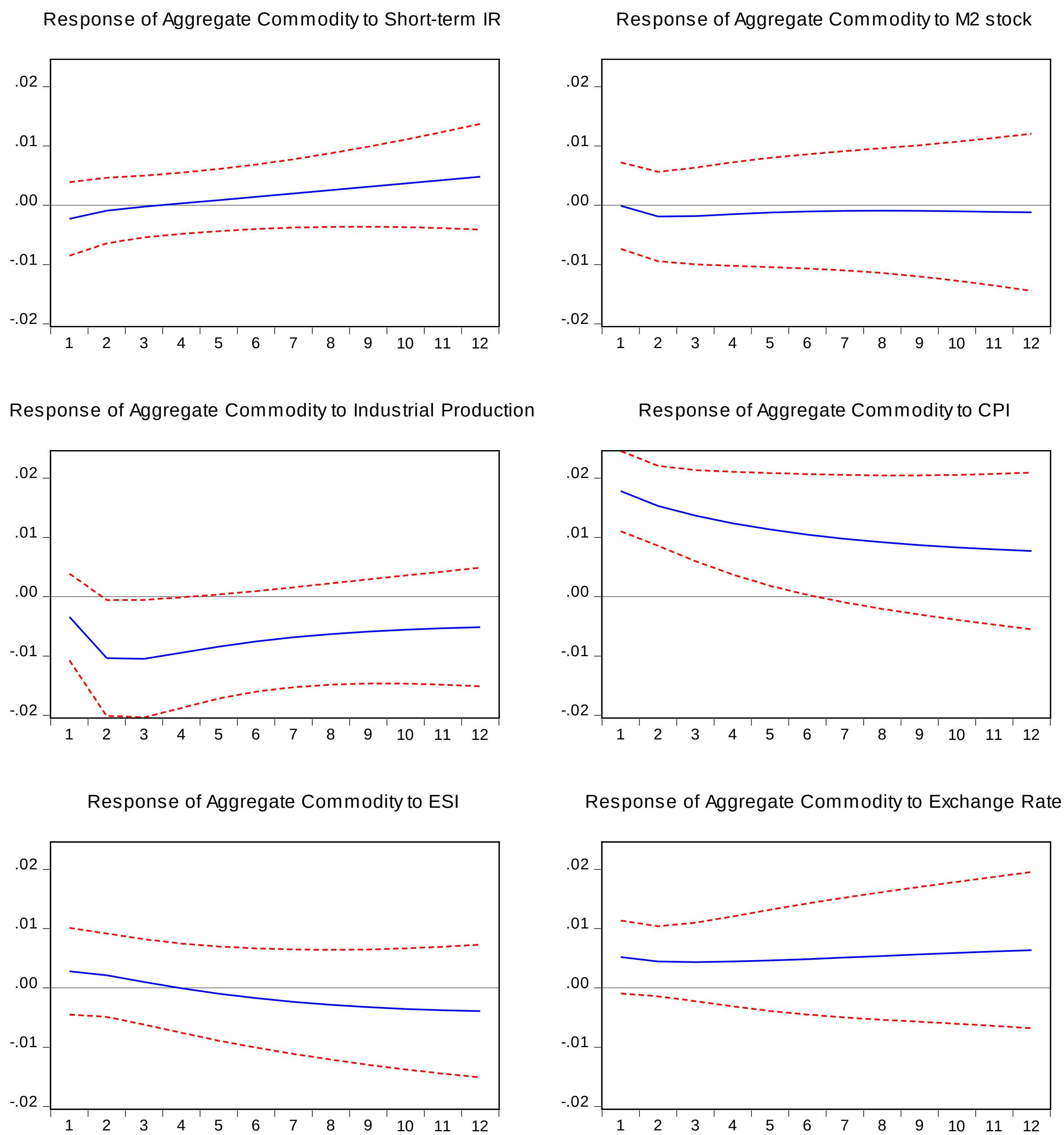


Figure 2

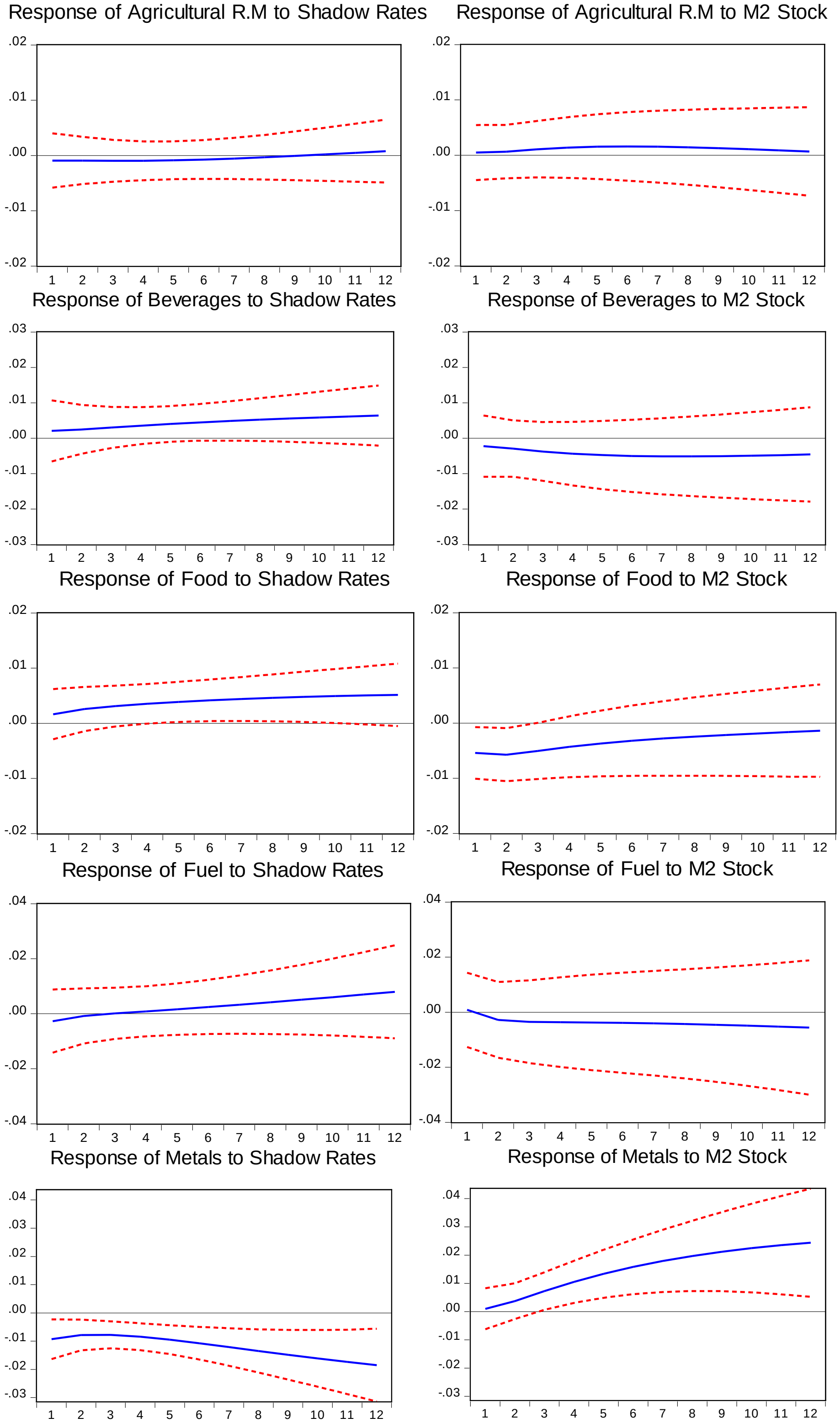
Impulse response functions to all positive macroeconomic shocks during pre-crisis period: aggregate commodity prices.



Note: solid line – average response; dashed lines – error bands of ±2 standard deviation (5% significance level).

Figure 3

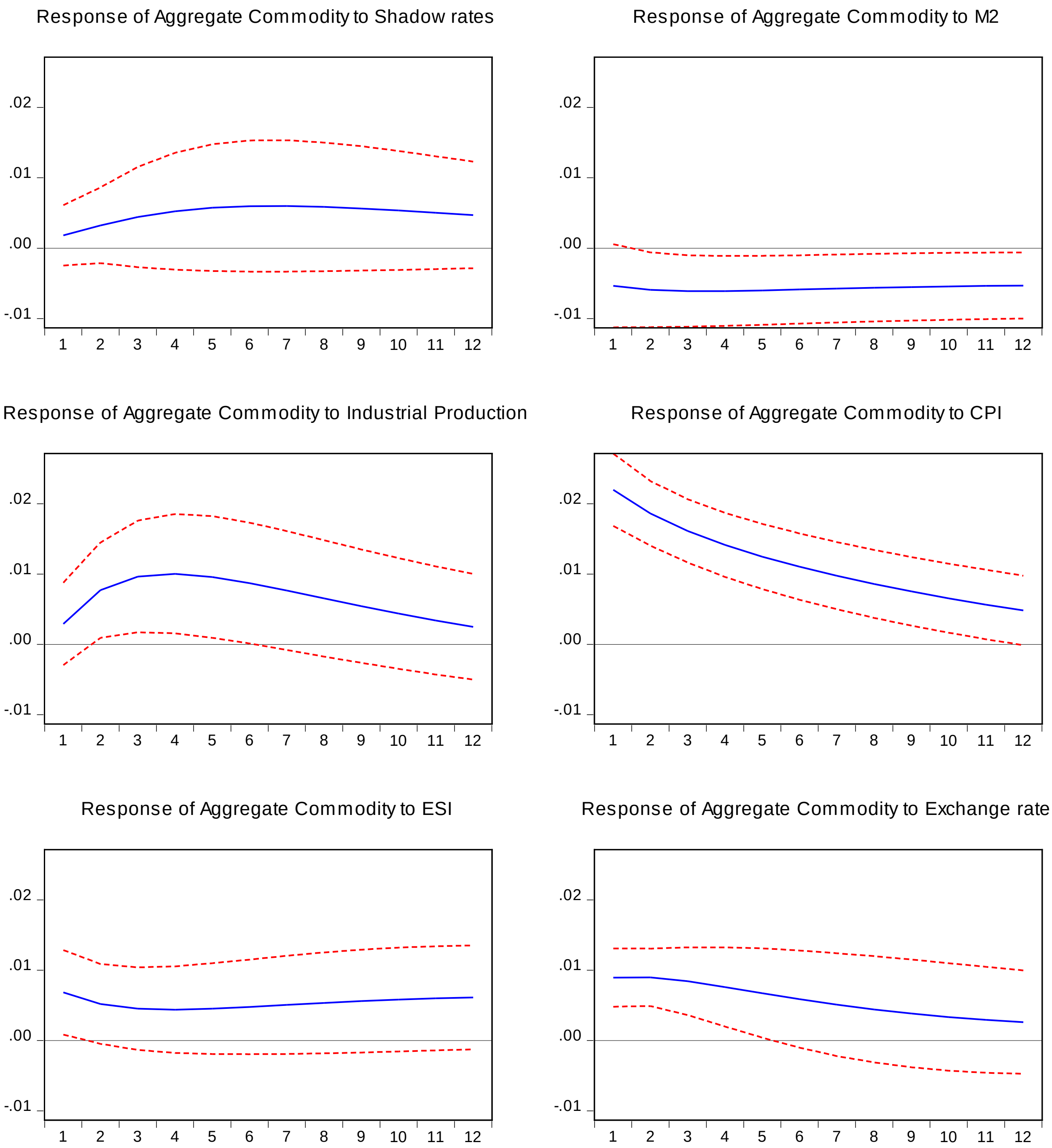
Impulse response functions to positive interest rate and M2 stock shocks during pre-crisis period: sectoral commodity prices.



Note: solid line – average response; dashed lines – error bands of ±2 standard deviation (5% significance level).

Figure 4

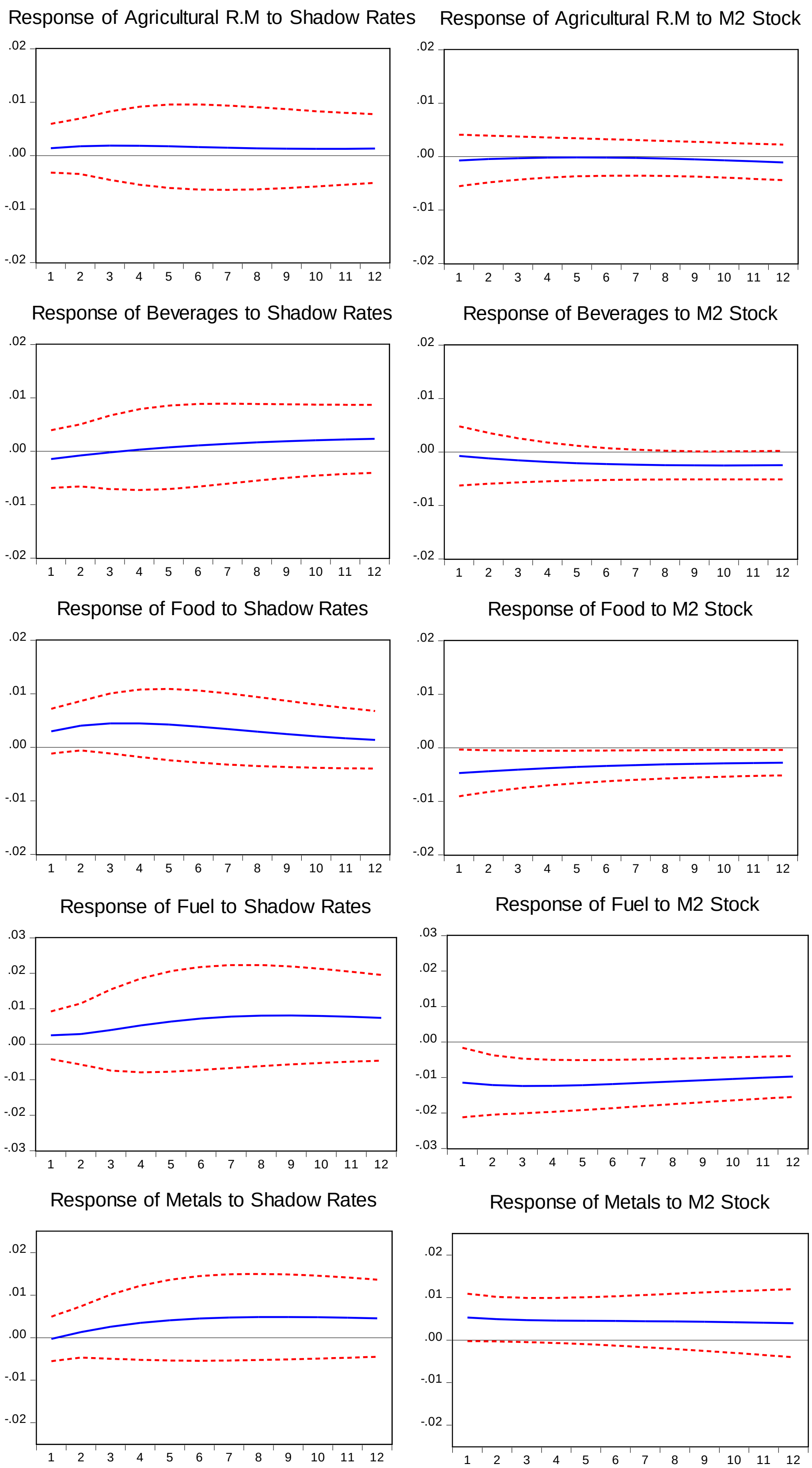
Impulse response functions to all positive macroeconomic shocks during post-crisis period: aggregate commodity prices.



Note: solid line – average response; dashed lines – error bands of ±2 standard deviation (5% significance level).

Figure 5

Impulse response functions to positive interest rate and M2 stock shocks during post-crisis period: sectoral commodity prices.

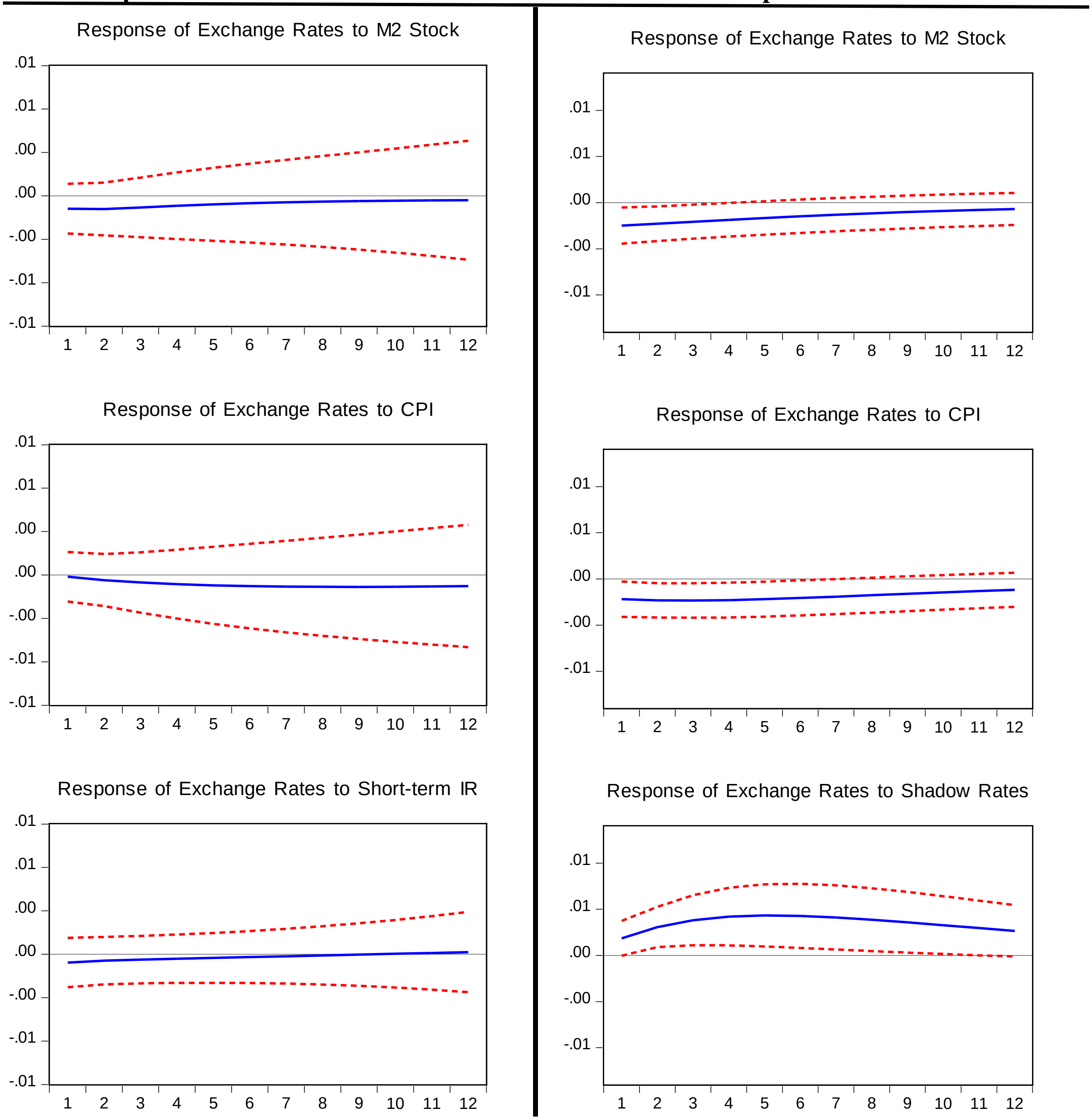


Note: solid line – average response; dashed lines – error bands of ±2 standard deviation (5% significance level).

Figure 6

Responses of euro exchange rate to monetary policy shocks and CPI during both periods.

Pre-crisis period **Post-crisis period**



Note: solid line – average response; dashed lines – error bands of ±2 standard deviation (5% significance level).

APPENDIX

Table A1

Augmented Dickey-Fuller (ADF), Phillips-Perron (PP) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) unit root tests: Pre-crisis period

TESTS	**Augmented Dickey-Fuller**		**Phillips-Perron**		**KPSS**
	None (Levels)	Intercept (Levels)	None (Levels)	Intercept (Levels)	Intercept (Levels)
Variable		**t-Statistics**			**LM-Statistic**
Log (ESI)	-0.792	-1.575	-0.910	-2.040	0.506
Log (M2)	21.85	3.804	17.80	4.25	1.234
Log (Industrial Production)	1.363	-0.156	1.470	-0.315	1.088
Log (CPI)	12.48	1.650	12.48	1.431	1.248
Log (Short-term Rate)	-0.163	-1.218	-0.162	-0.867	0.343*
Log (Exchange Rate)	1.498	-1.105	1.700	-0.743	0.972
Log (Comm_Aggregate)	3.304	2.031	3.149	1.861	1.204
Log (Comm_Agri_Raw)	1.956	0.023	1.926	0.001	1.185
Log (Comm_Beverage)	2.510	0.361	2.510	0.357	1.183
Log (Comm_Food)	3.238	1.668	2.880	1.473	1.138
Log (Comm_Metals)	2.863	0.347	2.594	0.239	1.197
Log (Comm_Fuel)	2.118	1.080	2.190	1.131	1.173

Note: ADF and PP test critical values with intercept (and none): 1% level = - 3.505 (-2.591), 5% level = - 2.894 (-1.944), 10% level = - 2.584 (-1.614). Asymptotic critical values for KPSS test with intercept: 1% level = 0.739, 5% level = 0.463 and 10% level = 0.347.

Table A2

Unrestricted VAR lag selection criteria: Conventional monetary policy period (Pre-crisis period)

Dependent Variable	**LR**	**FPE**	**AIC**	**SC**	**HQ**
Log(Commod_All)	2	1	2	1	1
Log(Commod_Agri_Raw)	3	1	1	1	1
Log(Commod_Beverage)	1	1	1	1	1
Log(Commod_Food)	3	2	2	1	1
Log(Commod_Metals)	2	1	1	1	1
Log(Commod_Fuel)	2	1	1	1	1

Note: LR: sequential modified Likelihood-Ratio test statistic (each test at 5% level), FPE: Final prediction error, AIC: Akaike information criterion, SC: Schwarz information criterion, HQ: Hannan-Quinn information criterion

Table A3

Augmented Dickey-Fuller (ADF), Phillips-Perron (PP) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) unit root tests: Post-crisis period

TESTS	Augmented Dickey-Fuller		Phillips-Perron		KPSS
	None (Levels)	Intercept (Levels)	None (Levels)	Intercept (Levels)	Intercept (Levels)
Variable		**t-Statistic**			**LM-Statistic**
Log (ESI)	0.817	-3.208*	1.079	-3.920*	0.827
Log (M2)	7.196	4.933	9.940	4.016	1.344
Log (Industrial Production)	1.441	-2.123	1.529	-2.558	0.779
Log (CPI)	4.548	-1.777	6.094	-1.805	1.239
Log (Short-term Rate)	2.194	0.813	2.627	1.169	1.261
Log (Exchange Rate)	-0.667	-2.360	-0.681	-2.135	0.751
Log (Comm_Aggregate)	-0.117	-1.297	0.108	-1.520	0.608
Log (Comm_Agri_Raw)	-0.155	-1.613	0.071	-1.881	0.565
Log (Comm_Beverage)	-0.302	-1.552	-0.222	-1.587	0.514
Log (Comm_Food)	0.067	-1.823	0.195	-1.859	0.379*
Log (Comm_Metals)	0.469	-1.948	0.705	-2.277	0.536
Log (Comm_Fuel)	-0.266	-1.305	-0.099	-1.356	0.605

Note: ADF and PP test critical values with intercept (and none): 1% level = - 3.505 (-2.591), 5% level = - 2.894 (-1.944), 10% level = - 2.584 (-1.614). Asymptotic critical values for KPSS test with intercept: 1% level = 0.739, 5% level = 0.463 and 10% level = 0.347.

Table A4

Unrestricted VAR lag selection criteria: Unconventional monetary policy period (Post-crisis period)

Dependent Variable	LR	FPE	AIC	SC	HQ
Log(Commod_All)	2	1	1	1	1
Log(Commod_Agri_Raw)	2	1	1	1	1
Log(Commod_Beverage)	2	1	1	1	1
Log(Commod_Food)	2	2	2	1	1
Log(Commod_Metals)	2	1	1	1	1
Log(Commod_Fuel)	2	1	1	1	1

Note: LR: sequential modified Likelihood-Ratio test statistic (each test at 5% level), FPE: Final prediction error, AIC: Akaike information criterion, SC: Schwarz information criterion, HQ: Hannan-Quinn information criterion

Table A5

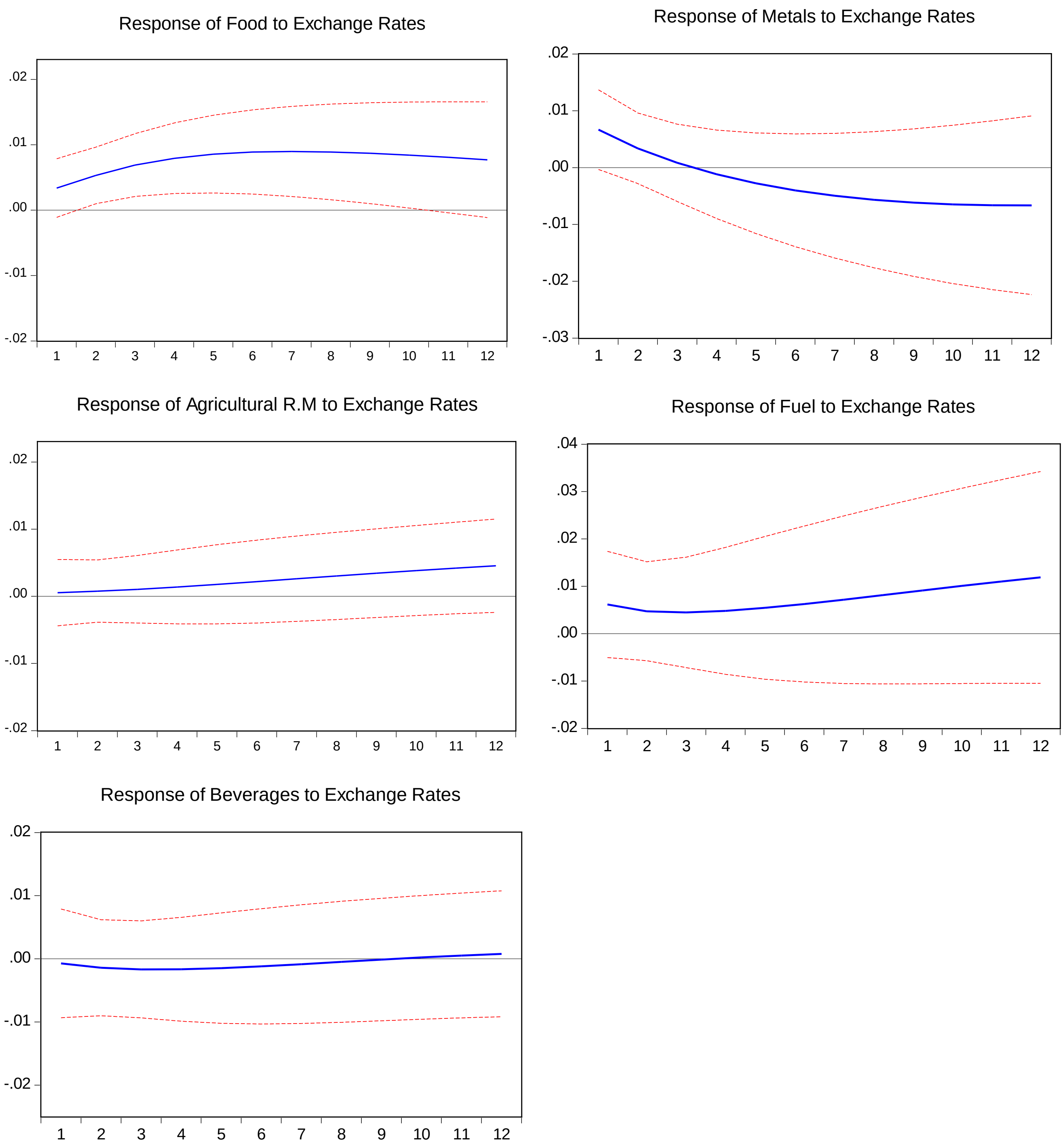
Granger-causality test: ECB policy and exchange rates

		Post-crisis period	
Variable of interest		Shadow rates → Exchange rates	Exchange rates → Shadow rates
Exchange rate	F-stat. (Prob.)	3.88** (0.049)	0.96 (0.325)

Note: Null-hypothesis (H_0): A does not Granger-cause B. The selected lag length is 1. The asterisk * corresponds to 10% significance level, ** to 5% and *** to 1% levels.

Figure A1

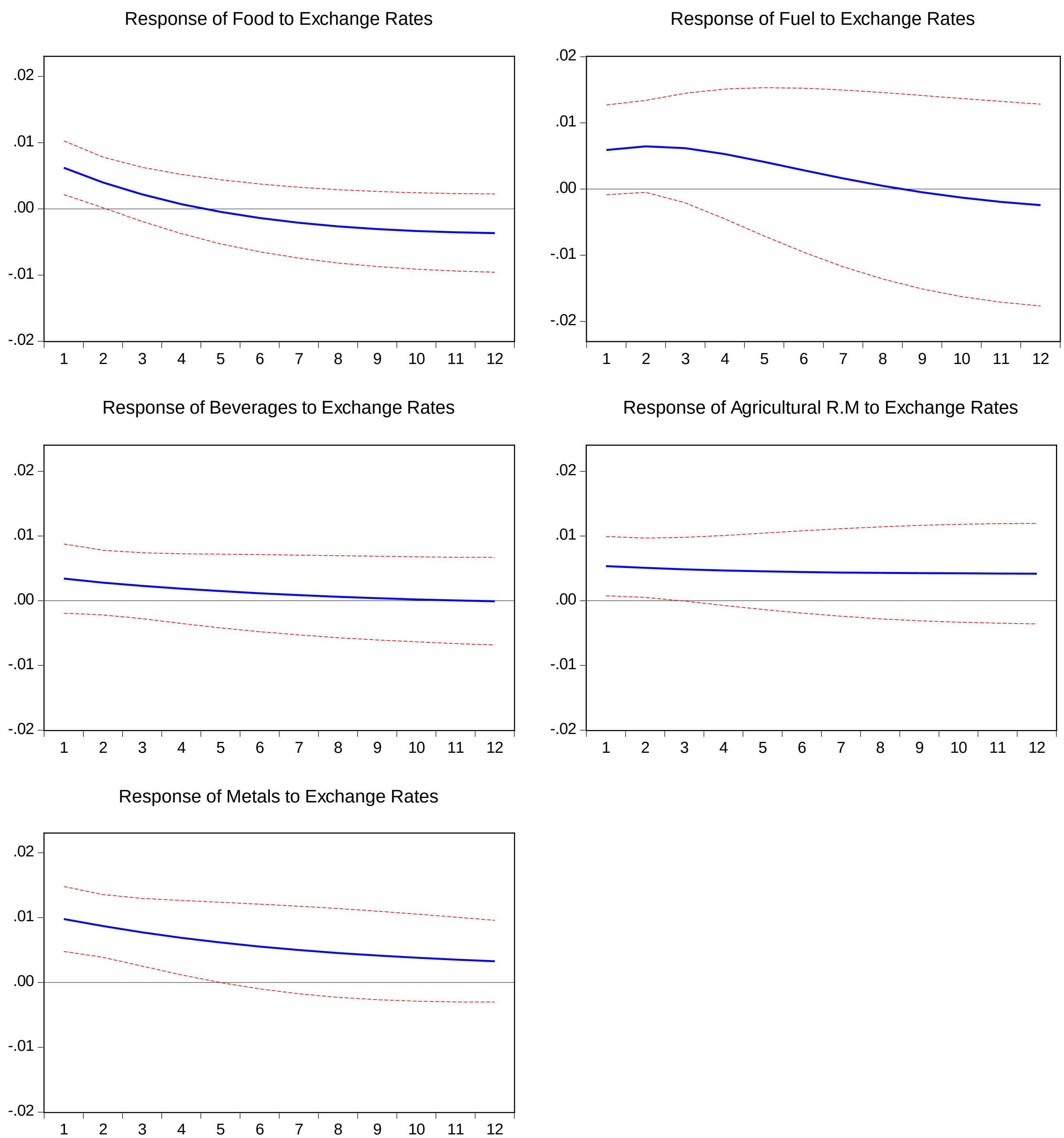
Impulse response functions to positive exchange rate shock during pre-crisis period: sectoral commodity prices.



Note: solid line – average response; dashed lines – error bands of ±2 standard deviation (5% significance level).

Figure A2

Impulse response functions to positive exchange rate shock during post-crisis period: sectoral commodity prices.



Note: solid line – average response; dashed lines – error bands of ±2 standard deviation (5% significance level).

Figure A3

Forecast Error Variance Decomposition (FVED) of commodity VAR model variables during the pre-crisis period: 2001M1-2008M8

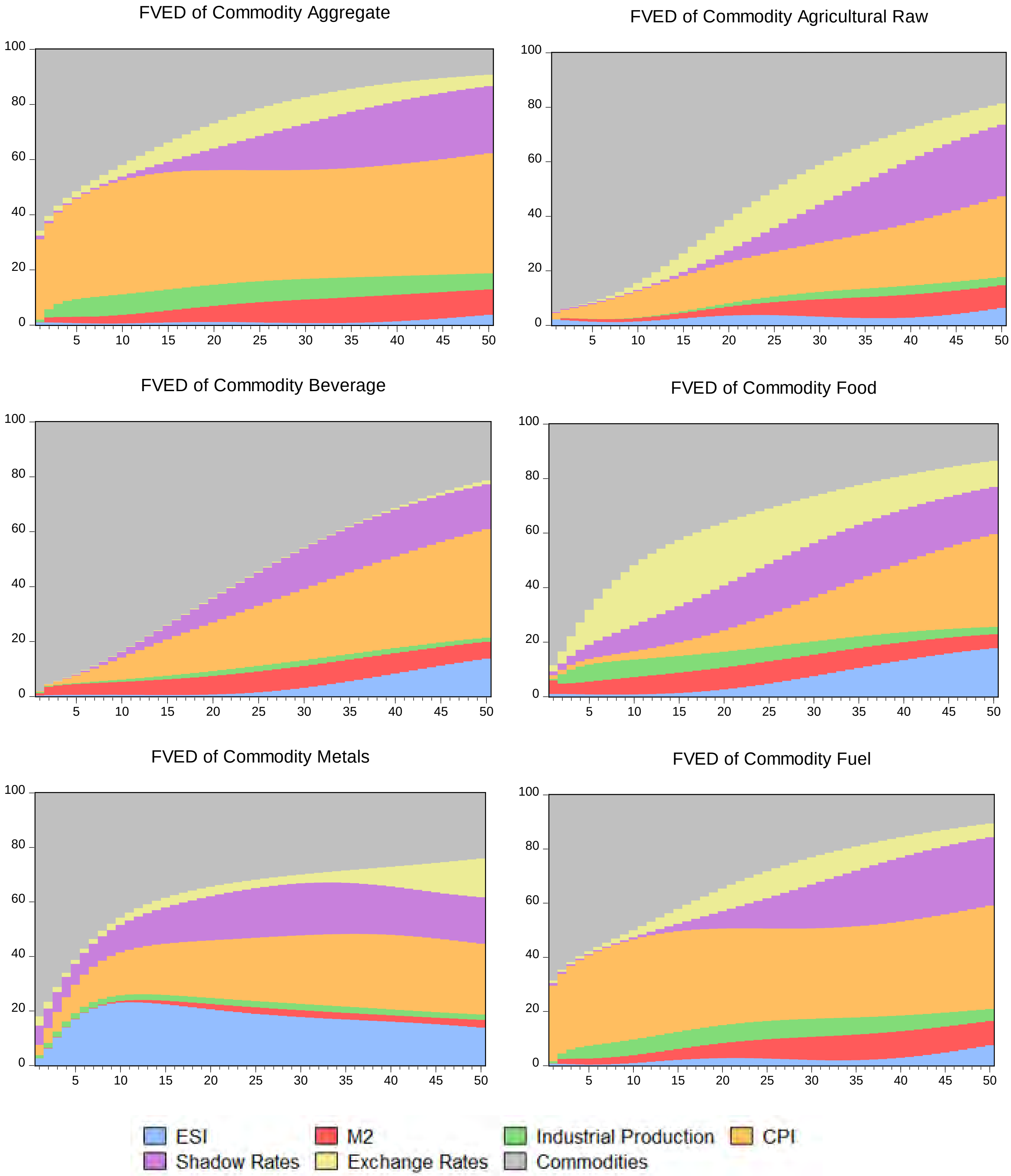
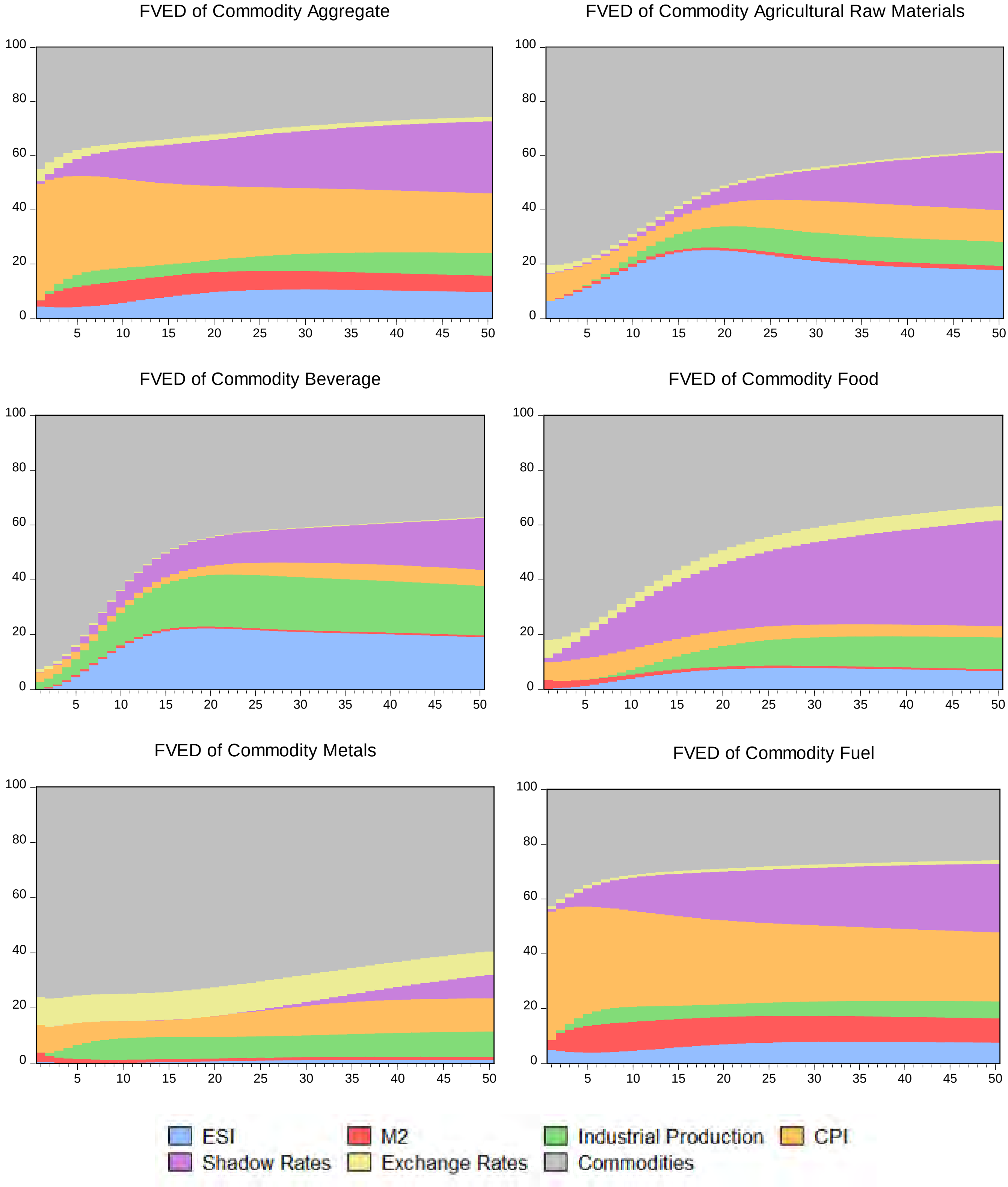


Figure A4

Forecast Error Variance Decomposition (FVED) of commodity VAR model variables during the post-crisis period: 2009M4 – 2019M8



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