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Working Paper

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Bank of Finland Research Discussion Papers, No. 10/2023

Provided in Cooperation with:

Bank of Finland, Helsinki

Suggested Citation: Benk, Szilárd; Gillman, Max (2023) : Identifying money and inflation expectation shocks on real oil prices, Bank of Finland Research Discussion Papers, No. 10/2023, ISBN 978-952-323-442-0, Bank of Finland, Helsinki

This Version is available at:

<https://hdl.handle.net/10419/273074>

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Bank of Finland Research Discussion Papers
10 • 2023

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Bank of Finland
Research

Bank of Finland Research Discussion Papers
Editor-in-Chief Esa Jokivuolle

Bank of Finland Research Discussion Papers 10/2023
15 June 2023

Szilard Benk – Max Gillman:
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ISBN 978-952-323-442-0, online
ISSN 1456-6184, online

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Identifying Money and Inflation Expectation Shocks on Real Oil Prices*

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April 14, 2023

Abstract

The paper adds money supply and inflation expectations shocks to a well-known three-variable structural model that identifies oil price shocks through fundamentals affecting the oil market. Impulse responses show the significance of our two additional monetary shocks in impacting real oil prices. By subtracting from the money supply the temporary Federal Reserve swaps that were used to increase liquidity during the 2008 and 2020 bank crises, shocks upwards in both the adjusted M1 money supply and to inflation expectations significantly increase real oil prices; with the unadjusted M1 aggregate there is no significant effect of money supply shocks on real oil prices. Decomposition of historical oil price shocks shows a significant role played by inflation expectations and the money supply shocks during major oil shock episodes. These shocks partially replace roles previously attributed to the precautionary oil demand shock and the aggregate demand shock during the three major oil shock periods of the 1970s-1980s, post-2008 and during the 2020-2021 pandemic. The results show that both real oil price shocks and expected inflation shocks cause real GDP to fall.

JEL Classification: Q41, Q43, E31, E52

Keywords: Real Oil Price Shocks, SVAR, Money Supply, Inflation Expectations.

*We are grateful for discussion at the International Symposium on Environment & Energy Finance Issues, and to Lutz Kilian and Zack Miller, and to the Bank of Finland when Gillman was a visiting scholar. We also are grateful for support from the University of Missouri Hayek Chair endowment fund.

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1 Introduction

Oil price fluctuations have been identified as being caused by fundamental shocks that affect the supply and demand for oil. These fundamental shocks in turn have been shown to cause negative effects on real US output (Kilian, 2009). Along a monetary line of approach, money supply growth and inflation expectations are found to Granger predict oil prices. The motivation for this paper is to see if these same monetary variables that Granger predict oil prices also identify as significant shocks that determine oil price shocks, in addition to the fundamental shocks. This test of whether such monetary factors help identify oil shocks has yet to be performed.

Our paper builds on the influential Kilian (2009) framework of identifying three fundamental shocks that determine real oil price fluctuations in a structural vector autoregression model (SVAR). Kim and Vera (2019) update the Kilian (2009) work with a more recent data period. We add money supply and inflation expectations shocks to the 3-variable model to build our 5-variable model. Our results contribute a robust identification of these two additional monetary shocks that significantly explain oil price shocks along with identification of the three fundamental shocks as found previously. Our 5-variable uses a monthly sample period from 1978 through 2021 and also shows a historical decomposition of the real oil price fluctuations by the five shocks over this period. We find that money supply and inflation expectations play significant role during crisis episodes of oil price increases. In particular, the inflation expectations is the dominant shock to oil prices in the 1970s-1980s, while the money supply shock is dominant after 2008 and during the 2020-2021 pandemic.

For robustness we replicate the Kilian (2009)/Kim and Vera (2019) identification of the three fundamental shocks in their 3-variable model of oil shocks, using their monthly data samples and also as updated to the end of 2021. We find similar impulse response significance for the fundamental shocks in the 3-variable model variations that also match the qualitative significance of the three fundamental shocks in our 5-variable model. We extend this comparison by showing similar historical profiles for each of the three fundamental shocks, across a set of alternative identifications, which in turn are also similar to the three fundamental shocks as identified in our 5-variable model.

One wrinkle to the analysis is that we show significance of the money supply shock by adjusting it through subtraction of Central Bank Liquidity Swaps that are counted

as reserves in the US monetary base. These swaps with other central banks temporarily increased the monetary base at a time when oil prices fell dramatically in 2008, and again in 2020 during the recession, oil price decline and bank crash in April-May of 2020. As Aizenman et al. (2022) detail for the Covid-19 use of swaps, these were for temporary liquidity injections. And while small overall relative to the size of US monetary aggregates, the swaps caused a temporarily reverse relation between oil prices and the money supply. By subtracting out these swaps, Granger predictability of real oil prices is robustly established; with the swaps including during these crises the Granger predictability fails (Benk and Gillman, 2020). We show the same result in terms of the identification of oil shocks: the positive money supply shocks as defined with swaps subtracted causes significant increases in real oil prices, as do inflation expectations; without the temporary swaps subtracted the significance of money supply shocks is lost.

We supplement the main results by following the Kilian (2009)/Kim and Vera (2019) focus of the quarterly effects of the structural shocks on real GDP that extend the seminal work of Hamilton (1983), while including the additional variables of the swap-adjusted money supply and inflation expectations. Here we find that an increase in inflation expectations causes a significant prolonged decrease in real GDP, while the money supply causes a significant increase in CPI inflation but not in real GDP. By closing the loop as in Hamilton (1983) through a second model to find how shocks effect real GDP, we find that not only do oil price shocks themselves cause significantly lower real GDP, but so do shocks upwards in inflation expectations. The inflation expectations shock drives up real oil prices that in turn cause lower real GDP.

A literature review follows in Section 2, the data description in Section 3, and the SVAR methodology in Section 4. The results follow in Section 5 and the following Section 6 presents robustness of the results. Section 7 discusses the results and Section 8 concludes.

2 Literature Review

Monetary significance has been shown previously in terms of strong Granger predictability of oil and gold prices by the swap-adjusted monetary base and M1 aggregates, by inflation and by expected inflation, in Benk and Gillman (2020). Aizenman et al. (2022) explain

in depth how the Central Bank Liquidity Swaps provide temporary liquidity. Granger predictability of monetary factors to oil prices was found previously by Gillman and Nakov (2009) and Alquist et al. (2013), which in turn supplied evidence for hypothesis of oil prices being driven in part by monetary factors in Barsky and Kilian (2002).

Using the same types of monetary factors, our paper builds on the influential Kilian (2009) framework of identifying three fundamental shocks that determine oil shocks in a structural VAR (SVAR) model. Kim and Vera (2019) update the Kilian (2009) work by showing on an extended data set up to 2015 that the three fundamental shocks of Kilian (2009) are similar in identification and significance. This shows the robustness of the Kilian (2009) approach. Because of this approach becoming a standard in this literature, we add two monetary factors to the three fundamentals of the oil market using the SVAR framework and show that the three fundamental shocks remain the same in our 5-variable model, even as the money supply and inflation expectations shocks are significant in impulse responses and alter the historical decomposition of the explanation of oil shocks such that monetary factors play a key role partially in place of the three fundamental shocks.

Kilian and Zhou (2022c) review this literature, so we mention only some key milestones of this modeling approach. Kilian (2009) constructed his Real Economic Activity index to help identify oil price supply and demand shocks and estimates a three-variable structural VAR model to identify oil supply shocks, aggregate oil demand shocks and precautionary demand shocks. Kilian and Murphy (2014) add oil inventories to capture speculative demand for oil and use sign restrictions to identify the key oil supply and demand shocks, in contrast to the short-run exclusion restrictions of the 2009 model. Baumeister and Hamilton (2019) extend this method further through Bayesian analysis to ameliorate restrictions, finding bigger supply side effects on oil prices, with speculative demand shocks being less important than what was found by Kilian and Murphy (2014).

With our additional monetary variables we opt here for the more parsimonious specification of Kilian (2009), and we use the Real Economic Activity data for estimation to compare directly to that model. Extensions of this type of variable include Baumeister et al. (2020), who find world industrial production important in predicting real oil prices as well as their new index of economic conditions.

Baumeister and Kilian (2016a) review historical oil shocks back through the 1970s

and Baumeister and Kilian (2016c) explain the drop in oil prices after 2014 as being due to supply and demand fundamentals, and to some extent to oil price expectations, but without taking into consideration any monetary factors. We supplement this by including inflation expectations and thereby present an alternative explanation for the drop in oil prices in 2014 relative to Baumeister and Kilian (2016c). While the Baumeister and Hamilton (2019) extension of SVAR methodology increases the importance of supply shocks, and finds less importance to inventory shocks, we focus on whether the monetary factors affect oil shocks in the more parsimonious model of Kilian (2009) that did not consider the role of inventories. With this initial set of nominal influences, we leave for future extension the prospect of examining monetary influences using the alternative sign restriction approach of Kilian and Murphy (2014), the Baumeister and Hamilton (2019) methodology, other measures of economic activity, or possibly inventories as future research.

While Benk and Gillman (2020) demonstrate Granger predictability of real oil prices by the swap-adjusted M1 and inflation expectations, the structural oil market models have generally omitted the inclusion of monetary aggregates and inflation expectations. Some related investigations are between global liquidity measures and oil prices, as in Anzuini et al. (2012), Ratti and Vespignani (2013), Ivan et al. (2022), but without use of money supply itself and without considering the swap-adjustment to the monetary aggregates. Similarly, Kilian and Zhou (2022a) estimate the link between oil prices, exchange rates, and interest rates, but without considering monetary aggregates. The role of inflation expectation has been considered by the literature typically in the context of causality from the oil prices toward inflation expectations, such as Coibion and Gorodnichenko (2015), or Kilian and Zhou (2022b), the latter of which demonstrate effects of gasoline price shocks on households' inflation expectations.

We focus instead on how money and inflation-expectation shocks effect oil prices, as well as real GDP following the Hamilton (1983) focus on the effects of oil prices on GDP. Baumeister and Kilian (2016b) find that the post-2014 oil price decline helped boost US real GDP. While including our monetary variables, we find a similar boost in real GDP from a shock upwards in the supply of oil. We also find that positive shocks to inflation expectations lower real GDP, a nominal effect on GDP not identified previously in the literature. This result complements our new SVAR findings of inflation expectations

raising real oil prices while lowering real GDP, whereas money supply growth raises inflation expectations and oil prices but has no effect on real GDP.

3 Data

Our data sample is monthly from 1978:1 to 2021: 12. The key limiting variable of the data period length is inflation expectations which begins in 1978. Given the demise of the Bretton Woods gold standard in 1971 and the ending of fixed exchange rates in 1973, this means that oil prices throughout the period after 1978 are variable rather than under fixed price contracts. Before 1973, oil prices were mostly constant and based on US dollar contracts that were formulated with the US dollar being stable in terms of \$35 per ounce of gold.

In replication of Kilian (2009) and Kim and Vera (2019), we use their monthly data sample periods for 1973 to 2007 and 1974 to 2015, respectively. In these models there are 24 lags assumed, unlike the 3 lags in our model found from information criteria, so their estimates start in 1975 and 1976, respectively. We report results for these models with both 24-lags and 3-lags.

With the steadily increasing inflation and money supply growth rates during the Vietnam War, the US was exporting inflation to other Bretton Woods countries under the gold standard. The nearly constant nominal oil prices meant that the real oil price steadily declined for fifteen years from 1958 to 1973. After the high inflation induced France to finally trade-in US dollars for gold at the US Treasury, Nixon ended the gold window in August 1971, the fixed exchange rates broke down in 1973, and oil and gold prices both became highly volatile and were Granger-predicted by money supply growth, inflation and inflation expectations after the end of the gold standard.

Our monthly one-year inflation expectations data is from the University of Michigan (EXPMICH), which starts in 1978. This limits our sample period but includes a good part of the high inflation rates of that era. The 5-variable model therefore has a data sample period of 1978-2021.

Most of the monthly and quarterly data are extracted from the FRED database (Federal Reserve Economic Data Base of the Federal Reserve Bank of St. Louis), with the FRED code indicated in parentheses. Oil production data are supplied by the U.S.

Energy Information Administration, while the index of real economic activity is sourced from Kilian's website.

The Fed redefined M1 in 2020 to include money market savings accounts, making it close to M2, so we adjusted the M1 for 2020 to 2021 to make it consistent with pre-2020 data. For our 5-variable model, we restrict the data sample based on the inflation expectations data (EXPMICH) starting in 1978. For replication of other studies we use data going to 1973. The following lists each of the variables and the sample period that we use.

MBTOTSA: Money Base (BOGMBASE, 1973m1 - 2021m12), with seasonal adjustment;

SWP: Central Bank Liquidity Swaps (SWPT, 2003m1 - 2021m12);

M1: M1 Money Stock (M1SL, 1976m1 - 2020m4): To get a revision consistent with earlier data we calculate M1 for 2020m5-2021m12 by subtracting the estimated amount of the added deposits from the redefined M1, which eliminates a structural break in May 2020 of M1 due to the redefinition;

CPI: CPI for all urban consumers (CPIAUCSL, 1973m1 - 2021m12);

WTI: Spot Crude Oil Price WTI (WTISPLC, 1973m1 - 2021m12);

EXPMICH: University of Michigan Inflation Expectation (MICH, 1978m1 - 2021m12);

PROD: Monthly World Oil Production, reported by the US Energy Information Administration (1973m1 - 2021m12);

REA: Index of global real economic activity, as reported by Lutz Kilian on his website: <https://sites.google.com/site/lkilian2019/research/data-sets> (1973m1 - 2021m12).

4 Structural VAR Model: Identification of Components of Oil Price Shocks

We augment the model set forth in Kilian (2009), which identifies demand and supply shocks on the oil market through three variables, by adding the money supply growth rate and inflation expectations variables. We estimate a five-variable VAR to identify five underlying shocks that includes three oil demand and supply shocks. The latter are shocks to the current physical availability of crude oil ("oil supply shocks"), shocks to the current demand for crude oil driven by fluctuations in the global business cycle

("aggregate demand shocks"), and shocks driven by shifts in the precautionary demand for oil ("precautionary demand shocks") that are oil market-specific shocks arising from the uncertainty about shortfalls of expected supply relative to expected demand.

Let z_t denote a vector $z_t = (\Delta m_t, exp_t, \Delta prod_t, rea_t, rpo_t)$ that includes monthly data on the following five variables: the percentage change of the (adjusted) money supply, the expected inflation rate, the percentage change in global crude oil production, Kilian's (2009) index of real economic activity, and the real price of oil. The VAR representation can be written as

$$A_0 z_t = \alpha + \sum_{i=1}^p A_i z_{t-i} + \varepsilon_t, \quad (1)$$

where ε_t represents a vector of serially uncorrelated errors. The reduced-form error e_t can be decomposed as $e_t = A_0^{-1} \varepsilon_t$.

$$e_t = \begin{bmatrix} e_t^{\Delta m} \\ e_t^{exp} \\ e_t^{\Delta prod} \\ e_t^{rea} \\ e_t^{rpo} \end{bmatrix} = \begin{bmatrix} a_{11} & 0 & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} & 0 \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} \end{bmatrix} \begin{bmatrix} \varepsilon_t^{ms} \\ \varepsilon_t^{exp} \\ \varepsilon_t^{oilsply} \\ \varepsilon_t^{aggdem} \\ \varepsilon_t^{ospecdem} \end{bmatrix} \quad (2)$$

The identifying restrictions on A_0^{-1} include the short run identification assumptions set forth by Kilian (2009), extended according to the behavior attributed to shocks to the money supply and inflation expectations. Hence, our short run identification restrictions rely on the following assumptions. Money supply shocks are assumed to be exogenous and these shocks do not respond to any other innovation within the same month. Inflation expectations respond only to money supply shocks within the same month, while they react to other shocks only with a delay of at least one month. Crude oil supply shocks are assumed to react to demand for oil and to unpredicted changes in oil prices only with a lag, which is a plausible assumption given the time needed to adjust the production capacities, especially when adjusting production is costly. Global real economic activity responds to all of the shocks within the same month except those changes in oil prices that are driven by uncertainties in the oil market.

5 Results

Figure 1 shows the historical evolution of the five structural shocks implied by the model. The monthly series are aggregated and presented here at an annual frequency to facilitate visualization. Since 2000, money supply shocks feature three notable increases: one that occurs after 2002 for several years, a much bigger spike upwards after 2008, and the one with the Covid crisis. The money supply shock is negative during the 2008 crisis and for several years after 2014. Following somewhat in tandem to the money supply shocks, the inflation rate expectations shocks have recent notable movements in the 2009 decrease, then a continuum of small positive shocks between 2010 and 2014, a decrease after 2014 and then again after 2019 once real GDP rises sharply and then Covid hits. After 2020, inflation expectation surged to levels unseen since the 1970s.

The remaining three shocks reproduce well Kilian's (2009) shocks that he identified up to 2007. Beyond that date, we found evidence for an increasing oil supply shock up until 2015, after which oil supply was shocked downwards as may be consistent with the fall in real oil prices after inflation expectations fell. The oil supply then starts rising from depths achieved in 2020. Aggregate oil demand has been hit by negative shocks after 2008, then turned into positive during recovery, and negative during Covid. Oil-specific demand shocks have been positive between 2009-2014, with a fall in 2014, with surges until turning sharply negative after the outbreak of Covid crisis.

5.1 Impulse Responses

The money aggregate chosen for estimation matters when considering the response of model variables to money supply shocks. The upper two panels of Figure 2 show the monthly response of the expected inflation rate to monetary shocks, on the left with M1 adjusted by swaps, and on the right with unadjusted M1. The striking result is that inflation expectations significantly respond positively to money shocks, as seen by the red-dashed confidence intervals being above zero for all but the first period. However this significance is lost when using M1 with swaps included, as they are in Fed data. Only the money growth increase without the liquidity injection from swaps during the 2008 and 2020 crises effectively increases inflation expectations.

The lower panel of Figure 2 shows that an increase in the expected inflation rate cause

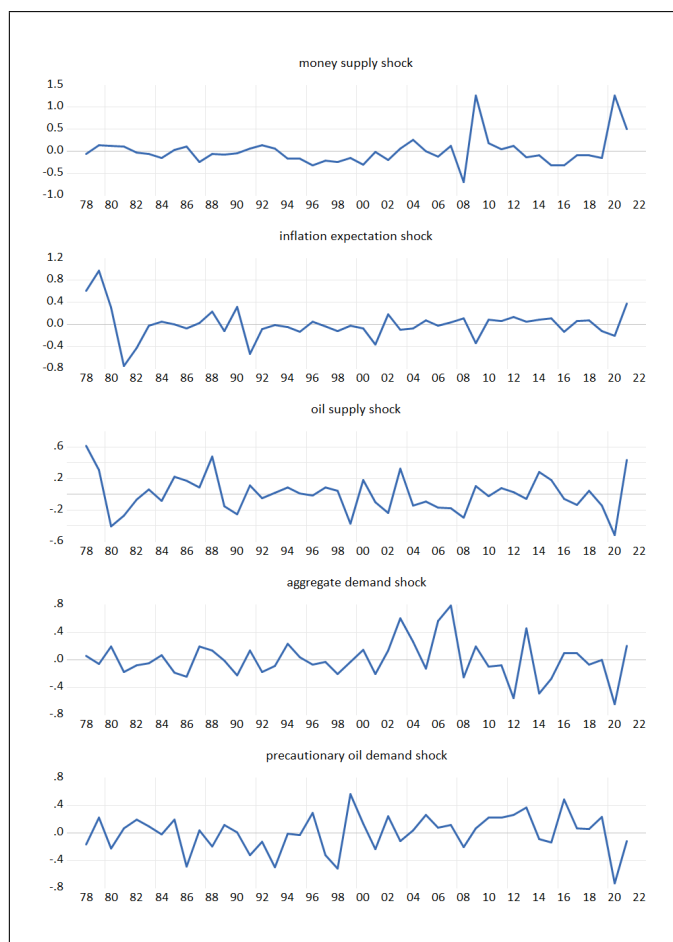


Figure 1: Historical Evolution of the Structural Shocks: money shock, inflation expectation shock, oil supply shock, aggregate demand shock, precautionary oil demand shock

an increase in real oil prices. For example, looking at Figure 1, this was ongoing up to 2014, after which the decrease in the expected inflation rate would by these results have contributed to the decrease in the real oil price. Once excess reserves held at the Fed finally peaked and began to decline in 2014 without inflation rising, inflation expectations fell as did real oil prices, although other factors may have also contributed to the decline in oil prices after 2014.

Figure 3 compares the monthly response of real economic activity to the swap-adjusted M1 shock and to the unadjusted M1 shock. In the lower panels, it compares the response of the real price of oil to the swap-adjusted money and to the unadjusted M1 money shock. For both of these cases, only an increase in the M1 minus swaps causes a significant increase in both real economic activity and in the real price of oil. The impulse responses with the unadjusted M1 are insignificant. These results show a strong prolonged effect of the money supply growth on economic activity and oil prices, given the subtraction of the

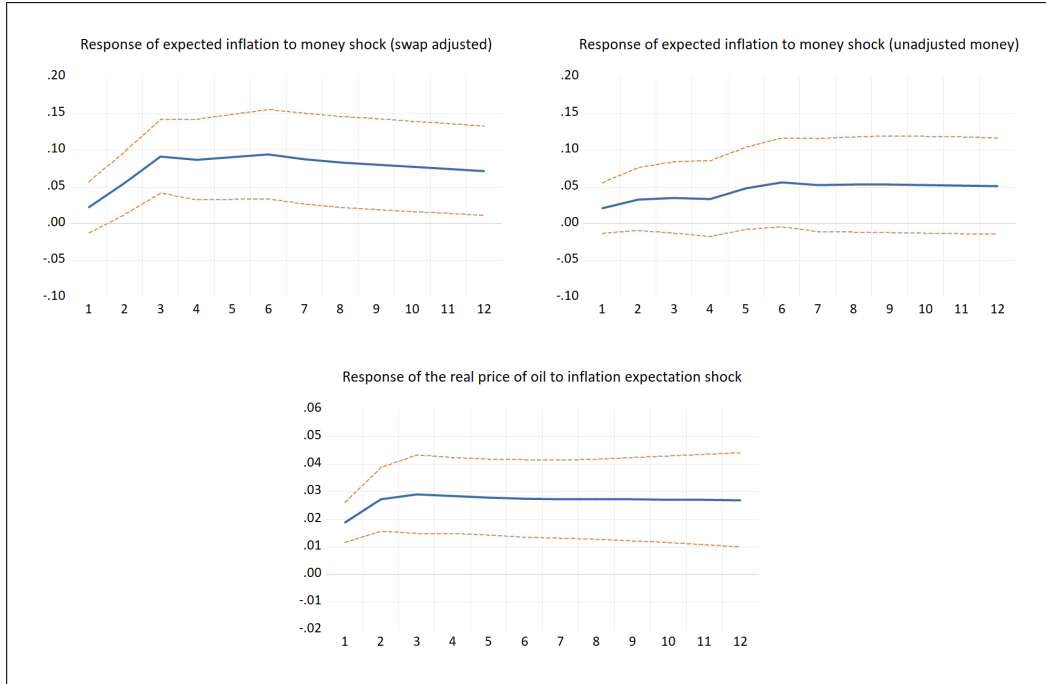


Figure 2: Impulse responses of Expected Inflation to Money (with and without Swap adjustment) and Response of Real Oil Prices to Inflation Expectation shock

swaps, while the previous Figure 2 shows a similar effect on oil prices from the expected inflation rate. Another result presented in Online Appendix A.2 Figure 15 is that oil-specific demand shocks feed back into the inflation expectations with a one-month lag, though this feedback fades out after several months.

A full set of impulse responses are given in the Online Appendix in Figures 15, 16, 17 and 18. There the "real block" of the model (the responses of the global oil production, real economic activity and the real price of oil to the oil supply shocks, aggregate demand shocks, and oil-specific demand shocks) remains essentially unchanged, regardless of the type of monetary aggregate used for estimating the five-variable model. More importantly, the impulse responses of the real block look qualitatively similar to the findings of Kilian (2009) estimated on a sample ending in 2007.

5.2 Historical Decomposition of Episodes of Oil Price Shocks

Figure 4 shows the historical decomposition of fluctuations of the real price of oil (grey-shaded), by each of the five historical shocks given in Figure 1 that are also cumulated (solid lines). Here the money supply is defined as M1 minus swaps as in the baseline model. The relative contribution of each of the five structural shocks varies significantly

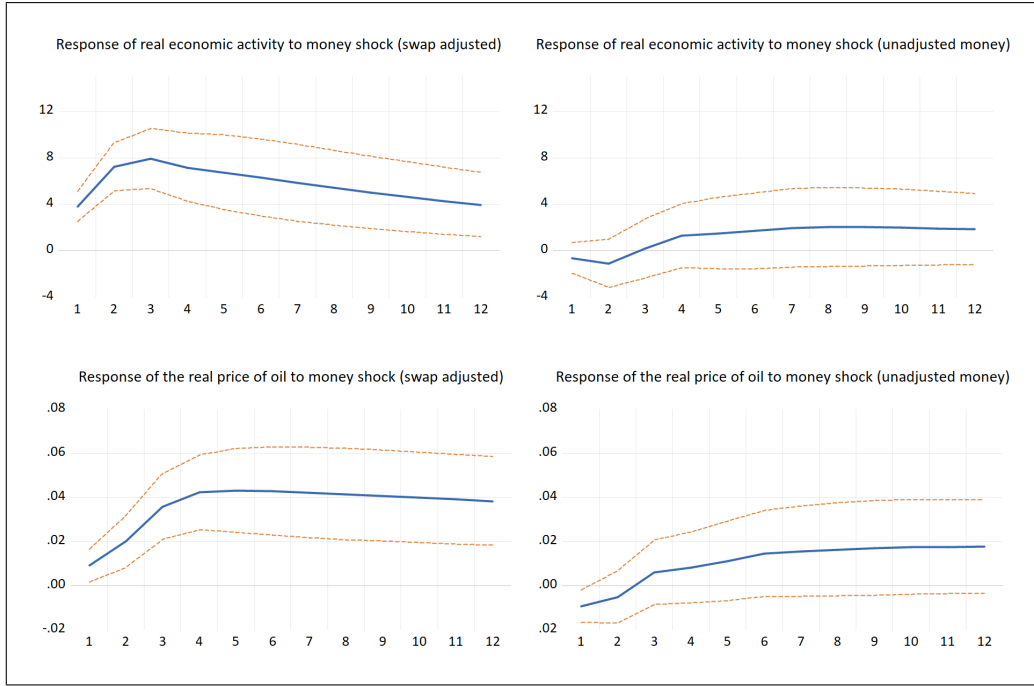


Figure 3: Impulse responses of Global Real Economic Activity and Real Oil Prices to money shocks, taken with (1st column) and without SWAPS (2nd column)

across different episodes so that the sum of the shocks by construction explain the movement in the oil price exactly. There are different contributions of each of the shocks across the various episodes of oil price movements, both upwards and downwards.

There are three main episodes of oil price shocks, in the 1970s-1980s, after 2001, and during the Covid pandemic. First, in the late 1970s and early 1980s oil price rise, the inflation expectations shock (gold) explains most of the magnitude of the increase, during this period that was the largest oil price shock up until those after 2001. The money supply shock (blue) also contributed substantially to the oil price increase then.

The post-2001 period can be divided into two episodes because the Great Recession coincided with a crash in oil prices that rebounded after this economic downturn. After 2001 and up until 2008, the inflation expectations shock was gradually rising in magnitude but the biggest contributors to the oil price increase were the aggregate demand shock (red) and the precautionary oil demand shock (black).

During the Great Recession, the money supply shock played a large role in driving down oil prices, along with the precautionary oil demand shock, and a decrease in inflation expectations.

After 2008 and the Great Recession, monetary factors again played a sizeable role. But there was a role reversal of these two shocks as compared to the 1970s-1980s. Instead

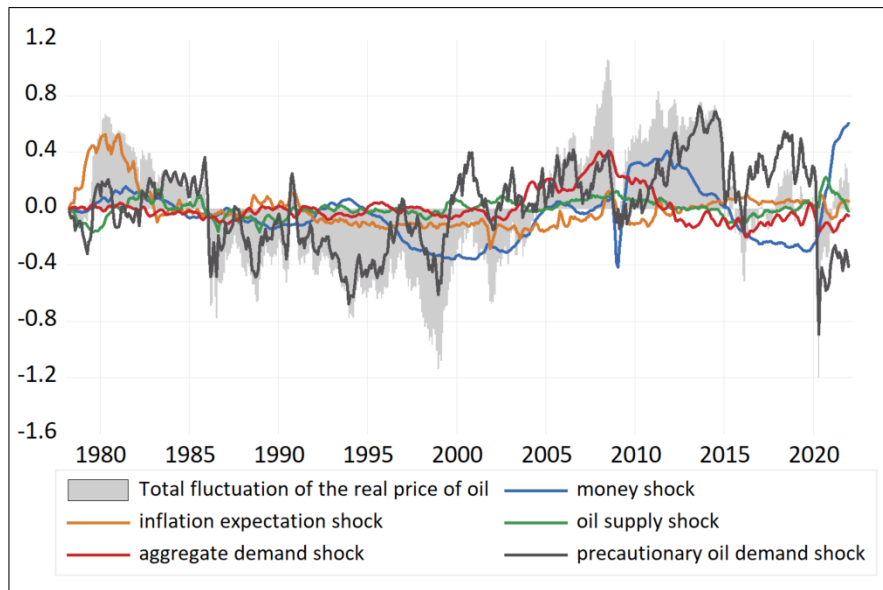


Figure 4: Historical decomposition of real price of oil. Note: money data was measured by the Swap-adjusted M1.

of the inflation expectations shock being the main driver of the oil price increase as in the 1970s-1980s, the money supply shock initially took on that role. After 2008, as the Fed accelerated the money supply growth rate these money shocks cumulated to become the main cause of the higher oil prices. However since much of this money supply increase was kept out of circulation, as excess reserves held at the Fed, this sterilization of the money supply left the inflation expectations shock muted.

The reversal of roles was that the money supply shock was the largest contributor of high oil prices after 2008, instead of the inflation expectations shock of the 1970s-1980s. The money supply shock remained the largest component of the oil price increase after the Great Recession up until 2012. After that time, the Fed decelerated the money supply growth rate and the money supply shock fell in magnitude. Then the precautionary oil demand shock (black) continued to rise in magnitude and become the main contributor to the oil price increase after 2012.

This difference in the impact of these monetary shocks over these two major episodes of oil price increases was due to the paying of interest on excess reserves for the first time in US history after 2008. In the 1970s, before interest was paid on reserves, as close to zero excess reserves as possible was held by banks and the money multiplier was in full force, causing inflation expectations to jump. After 2008, the money multiplier became dependent upon when banks chose to draw down excess reserves, which was

unpredictable. This de facto sterilization of the money supply acceleration post-2008, through the build-up of excess reserves, reversed the roles of the money supply shock and the inflation expectations shock.

The inflation expectations shock did modestly rise in magnitude after 2008 right up until 2014, after which this magnitude began to trend down while excess reserves began falling after their September 2014 peak of \$2.7 trillion. This trend down in the inflation expectations shock continued until the Covid crisis. As the aggregate demand shock steadily fell in magnitude after 2008, the precautionary oil demand shock caused oil gradually rose in magnitude and became the primary contributor to high oil prices. After 2014 this latter shock fell sharply and was the main contributor to the decline in oil prices.

Leading up to the Covid-19 pandemic, the precautionary oil demand shock was of high magnitude and offset mainly by the increasingly negative effect of the money supply shock as the money supply growth rate continued to fall. During the Covid-19 pandemic, these roles between the money supply shock and the precautionary oil demand shock reversed. Instead, the money supply shock was the main driver upwards on oil prices, while the precautionary oil demand shock most strongly tempered that oil price increase through strongly negative magnitudes. The unprecedented money supply shock upwards also saw the expected inflation rate shock remain muted. This occurred as reserves were built up to even higher levels than their previous peak in 2014, rising to a peak above \$4 trillion in November 2021. So again, during the ongoing payment of interest on reserves, during the pandemic the money supply ended up being the main contributor to the upward increase in oil prices, rather than the inflation expectations shock as in the 1970s-1980s.

The other noteworthy historical decomposition facts concern the effects of the shocks in pushing oil prices *downwards*. In the late 1980s and up until 2000, the precautionary demand oil shock most visibly pressured oil prices down. However, there is also a large role played by the money supply, with increasingly negative money supply shocks after the mid-1990s. The money supply shock remained increasingly negative until 2001, after which until 2008 its negative effect was increasingly less as the money supply accelerated.

5.3 The effect of Oil Shocks on the US Economy

Having identified shocks driving the real price of oil, there has been interest since Hamilton (1983) in how these structural innovations influence key macroeconomic aggregates such as real GDP growth (Δy_t) and CPI inflation (π_t). The latter two variables are not part of model (1) for a number of reasons. Computationally, two additional variables would have complicated the model further. Second, GDP is available only at a quarterly frequency, while switching to a quarterly model from the current monthly specification would have masked important dynamics and would have restricted our number of observations to the point of making the estimation infeasible.

Therefore, to consider these effects we replicate the method used by Kilian (2009). Because GDP is measured at quarterly frequency, the structural innovations estimated from the monthly SVAR need to be aggregated into quarterly frequencies by averaging the monthly innovations for each quarter:

$$\widehat{\zeta}_{jt} = \frac{1}{3} \sum_{i=1}^3 \widehat{\varepsilon}_{j,t,i}, \quad j = 1, 2, 3, 4, 5, \quad (3)$$

where $\widehat{\varepsilon}_{j,t,i}$ denote the estimated j -th structural shock in the month i of quarter t , and $\widehat{\zeta}_{jt}$ denotes the aggregated quarterly j -th structural shock of quarter t .

Kilian (2009) argues that his structural shocks can be treated as predetermined with respect to real GDP growth and inflation. Accepting his identifying assumptions that these shocks are predetermined in relation with Δy_t and π_t , the effects on the structural shocks on the macro aggregates can be determined by running the regressions:

$$\Delta y_t = \alpha_j + \sum_{i=0}^{12} \phi_{ji} \widehat{\zeta}_{jt-i} + u_{jt}, \quad j = 1, 2, 3, 4, 5. \quad (4)$$

$$\pi_t = \delta_j + \sum_{i=0}^{12} \psi_{ji} \widehat{\zeta}_{jt-i} + v_{jt}, \quad j = 1, 2, 3, 4, 5. \quad (5)$$

Figure 5 shows the responses of the real GDP and CPI levels to each of the five structural shocks, estimated from equations (4) and (5), with the structural shock estimated using money data measured by the swap-adjusted M1. The impulse responses reveal several key results.

First, the money supply shocks have no statistically significant effect on the level of real

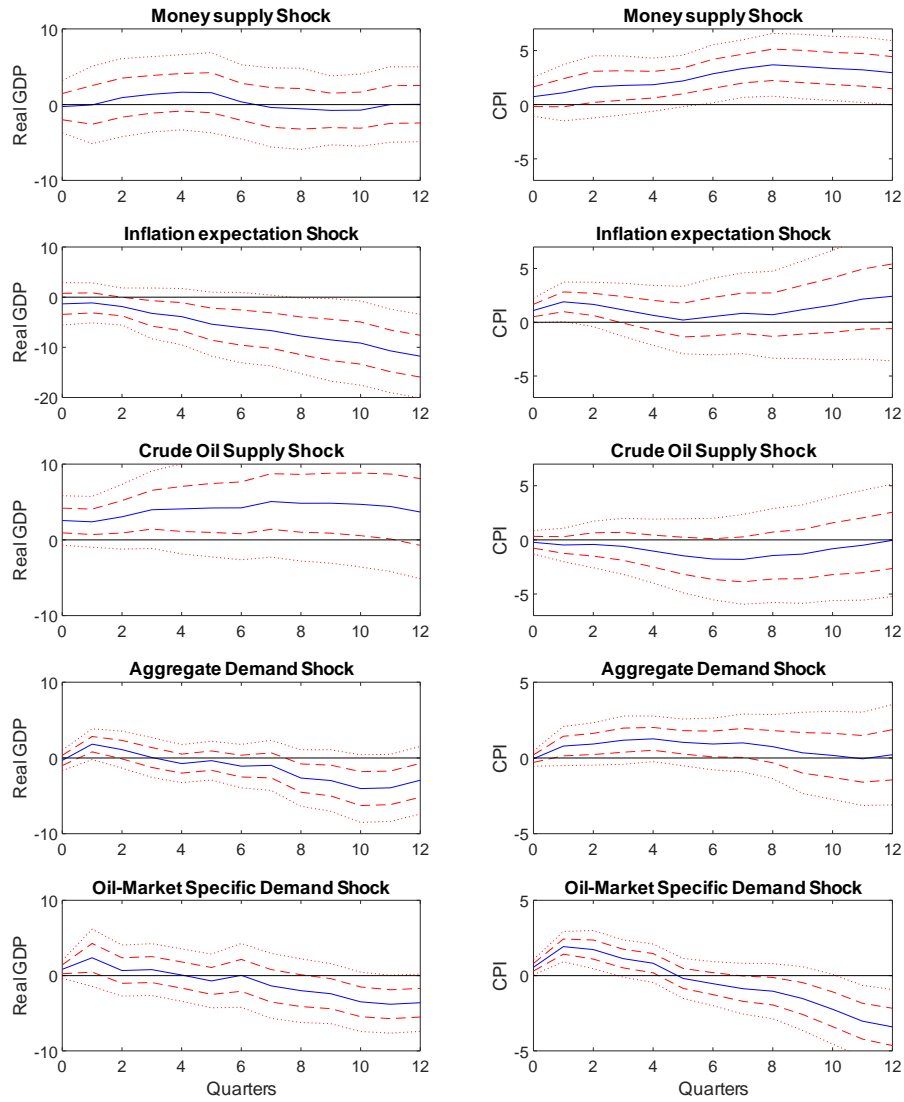


Figure 5: Responses of real GDP and CPI level to structural shocks. (Note: money is measured by M1 adjusted by Swaps)

GDP, while money shocks permanently increase price levels in the long run. Second, while inflation expectation shocks generate inflation in the short run, their detrimental effect on real GDP becomes stronger over the 3-year horizon in Figure 5. This provides evidence in support of having long-term benefits from stable inflation expectations through a disciplined monetary policy.

Third, unanticipated disruptions in oil supply drag down real GDP. Although it is significant with respect to the one standard error band only, this effect persists on longer run as well. On the other hand, the effect of the supply shocks on the aggregate price level is minimal.

Fourth, an increase in the demand for crude oil would induce fluctuations in GDP, with an initial positive response, which eventually turns into negative. Finally, unanticipated oil market-specific demand also results in a gradual decrease in GDP after a temporary positive response. Such a shock causes an initial increase in the price level, after which prices would fall in the 3-year horizon. This indicates that such precautionary oil demand shocks may cause volatility in the real economy, to which inflation rate expectation shocks add a further effect.

6 Robustness

Further robustness checks can be performed by considering alternative model specifications. We do this in four ways. First, we derive alternative specifications for the historical shock series for the three fundamental shocks by replicating the Kilian (2009) 3-variable model in six different variations while comparing these to those of our five-variable model. These variations comprise estimating the model over three different data samples and two different lag length structures. Using the variations of the 3-variable models, we then compare the impulse responses of the three fundamental shocks on oil price shocks to our like impulse responses as found in our 5-variable model. Third, we present the historical decomposition of the shocks using the 3-variable model over the full data sample and compare these results to the historical decomposition above using the 5-variable model. Finally, we present the SVAR impulse response results while using an alternative money supply aggregate, that of the monetary base both swap-adjusted and unadjusted.

6.1 Alternative Shock Identification of Three Fundamental Shocks

First, we replicate the Kilian (2009) 3-variable model as estimated with his original data sample up to 2007, both with his original 24 month lag specification and with the lag length of 3 months as we selected based on the information criteria. Next we estimate the same Kilian (2009) model on the longer data sample running up to 2015, which is a replication of Kim and Vera (2019), both for 3 lags and for 24 lags. Thirdly, we do the same exercise with data up through 2021, with data identical to that used for estimating the 5-variable model. There are three structural shocks identified from each of these six alternative models. We also have these same three shocks to oil supply, aggregate demand, and precautionary oil demand identified from our baseline 5-variable model, with data up to 2021, and starting in 1978. This gives a total of seven alternative identifications of each of the three fundamental non-monetary shocks of Kilian (2009).

We compare these seven by bringing them together in a single graph for each of the fundamental three shocks to aggregate demand, precautionary oil demand, and oil supply. These are presented in Figure 6 with legends indicating our 5-variable model (blue) and the various ending periods and lag lengths of our 3-variable model replications.

These robustness exercises show that the shocks identified from the seven different models are visually close to each other, and qualitatively similar to those published by Kilian (2009) and Kim and Vera (2019). This adds to the strength of our 5-variable model addition of the two monetary shocks in that it shows that our model estimates the three fundamental shocks in the same fashion historically as does the three variable model. This means that the additional importance in the impulse responses above in Section 5.1 comes even as the three fundamental shocks are estimated with a near-exact form as is found in the 3-variable Kilian (2009)/Kim and Vera (2019).

Further it shows robustness of the 3-variable model itself, by showing that under different time horizons and with two alternative lag structures the three fundamental shocks are estimated to be very similar. Altogether this shows, through comparison of the three fundamental shocks as estimated in the 5-variable model with those estimated with the 3-variable model in alternative forms that any added importance of the two monetary shocks, the money supply and inflation expectations shocks, comes without sacrificing the identification of the three fundamental shocks. This added importance as seen in the impulse responses above and next is shown in terms of the historical

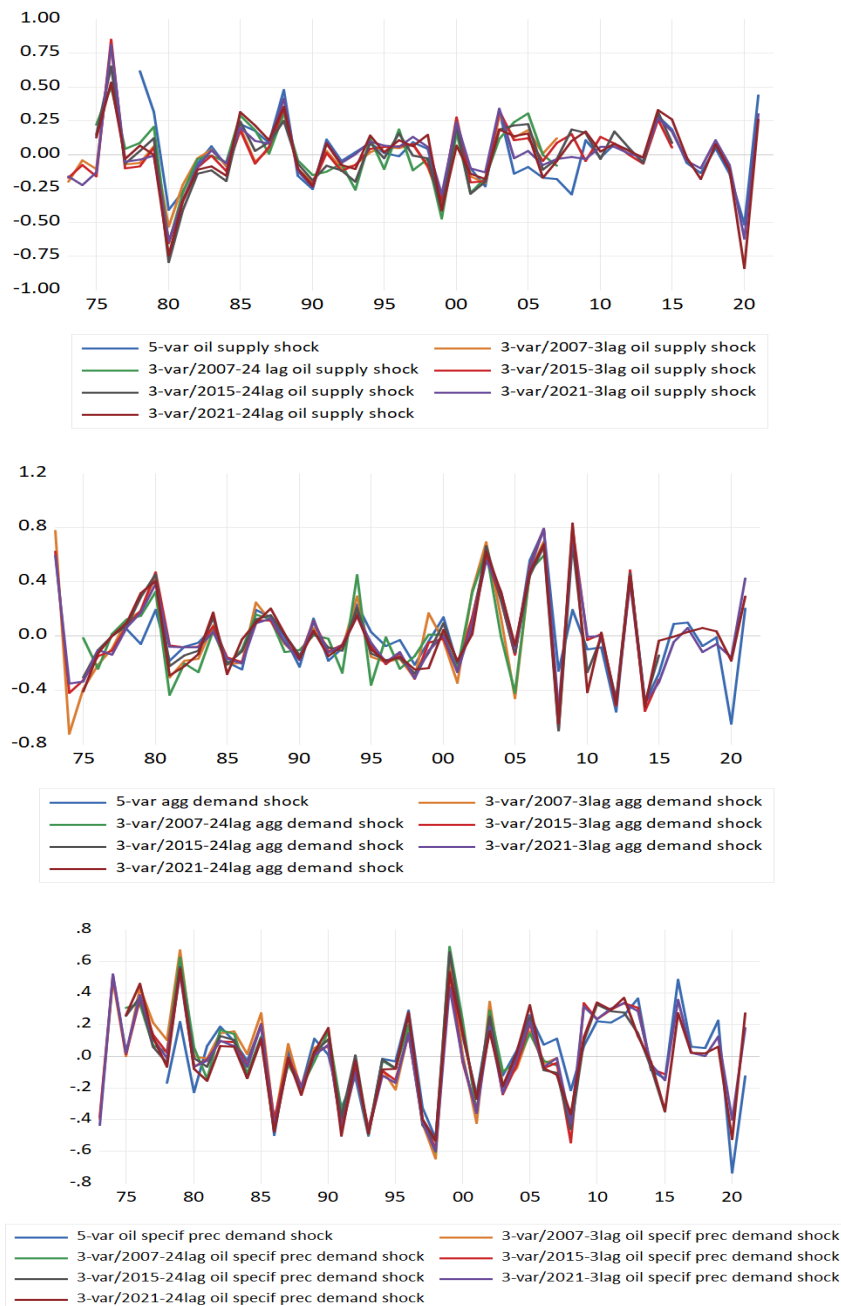


Figure 6: Oil supply shocks, aggregate demand shocks and oil specific demand shocks in various model specifications: - baseline 5 variables model with money and inflation expectations;- Kilian (2009) 3 variables model up to 2007, with 3 lags in the VAR (lag length selected based on information criteria); - Kilian (2009) 3 variables model up to 2007, with 24 lags in the VAR (Kilian's lag specification); - Kilian (2009) 3 variables model up to 2015, with 3 lags in the VAR; - Kilian (2009) 3 variables model up to 2015, with 24 lags in the VAR (a replication of Kim and Vera, 2019); - Kilian 3 variables model up to 2021, with 3 lags in the VAR; - Kilian 3 variables model up to 2021, with 24 lags in the VAR.

decomposition of the real price of oil using the 3-variable Kilian (2009)/Kim and Vera (2019) model.

6.2 Comparison of Impulse Responses of 3-Variable Model to 5-Variable model

The full set of impulse responses for the six variations of the 3-variable model are found in the Online Appendix A.1 Figures 9 to 14. The response of oil prices to the three shocks is similar across all 3-variable model iterations. The striking result of this exercise is that the 3-variable model oil price shock impulse responses are very similar to those found in our 5-variable model. We demonstrate this by comparing the impulse responses from the 5-variable model to those from the 3-variable model estimated on the full sample up through 2021 and 24 lags.

Figure 7 shows in this comparison that the impulse responses of the three fundamental shocks have the same qualitative significance in both the 3-variable model and in the 5-variable model, for each of the shocks. The magnitudes also are only slightly different. The only alteration in shock significance is that the positive oil supply shock's negative effect on real oil prices is significant only through 7 months in the 3-variable model while it remains significant throughout the 10 months in the 5-variable model, making that shock slightly more robust in the 5-variable model.

6.3 Historical Decomposition of Oil Shocks with 3 Variable Model

Finding similar shocks for the original 3 fundamental shocks of Kilian (2009)/Kim and Vera (2019) allows us to take an additional step in showing the robustness of the contributions of the structural shocks to the fluctuations in the real price of oil. In particular, we can do an alternative historical decomposition of the contribution of the three fundamental shocks using the 3-variable model. Then we can compare that decomposition to the one above for the 5-variable model in Figure 4.

In the historical decomposition of oil prices using the 3-variable model, oil prices are again exactly explained by construction with the three shocks. Here we build the findings in Figure 6 that show that the three fundamental shocks of our 5-variable model are very similar to the three fundamental shocks as estimated in the 3-variable model even when

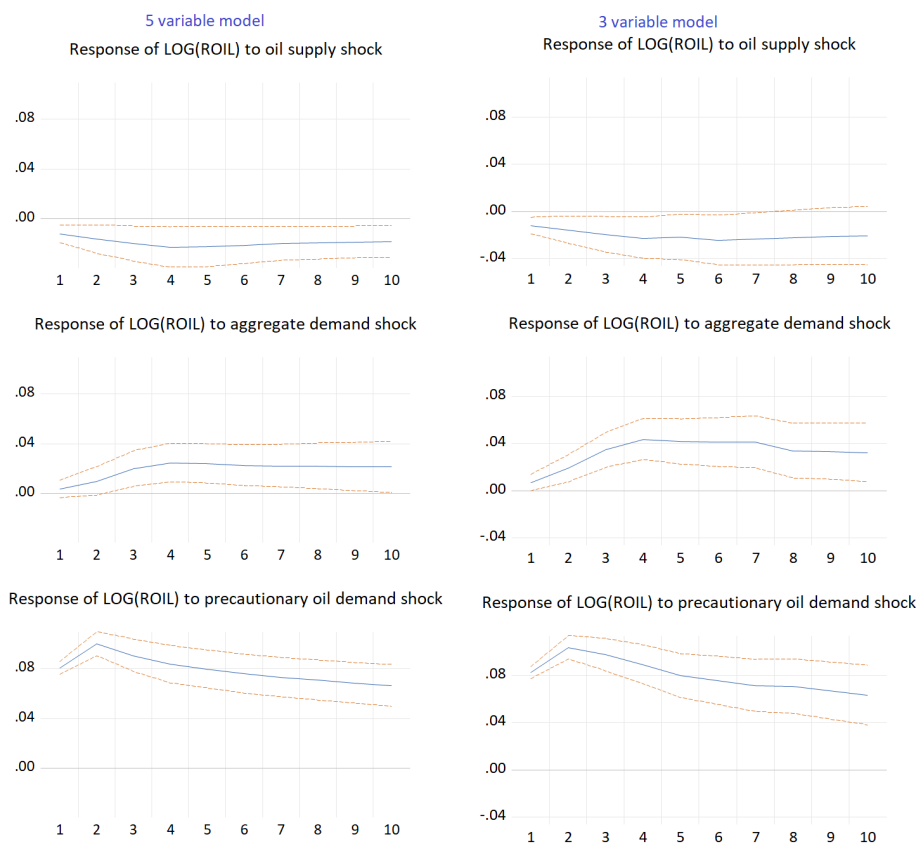


Figure 7: Impulse responses of the three fundamental shocks have the same qualitative significance in both the 3-variable model and in the 5-variable model.

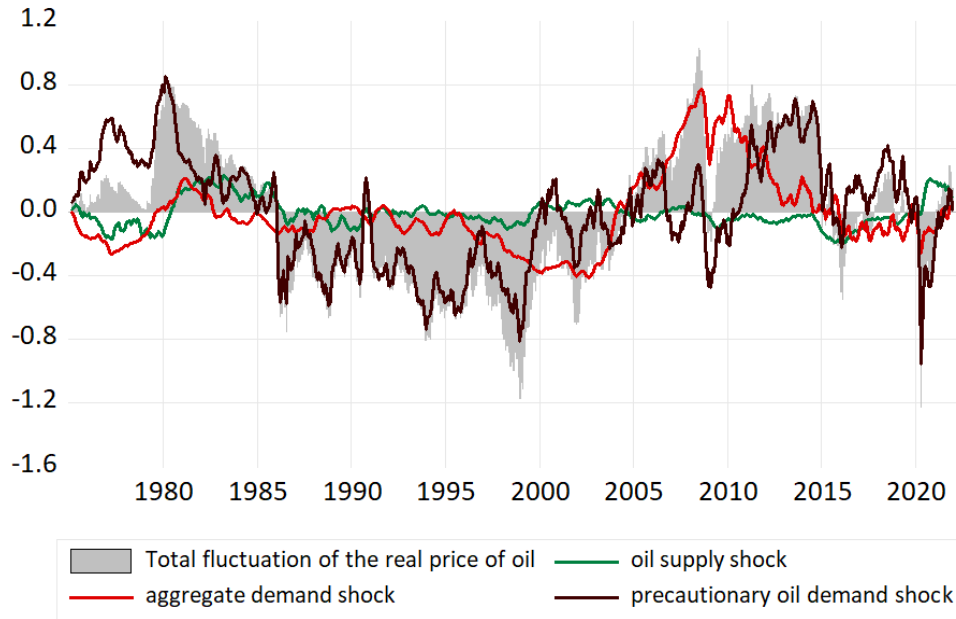


Figure 8: Historical decomposition of real price of oil in the 3-variable model of Kilian (2009).

using different lag lengths and sample sizes. Then we build the 3-variable historical decomposition that can in turn be compared to that decomposition above with the five shocks. This comparison of the two alternate historical decompositions would then show how our two additional monetary shocks replace in part the contributions of the three fundamental shocks.

Figure 8 presents this alternative historical decomposition, which is conducted here using the updated sample of 1978-2021, as in our 5 variable model. This comparison between Figures 4 and 8 of our 5-variable model and the Kilian (2009)/Kim and Vera (2019) models, respectively, shows the following: In the 3-variable model much of the fluctuations in the real price of oil are attributed to aggregate demand shocks and precautionary demand shocks. In contrast, in the 5-variable model some of the fluctuations attributed to these two latter shocks are actually due primarily to money supply shocks, and secondarily, to inflation expectation shocks. This is true even though the 3 fundamental shocks are estimated in a similar fashion in both the 5-variable model and the 3-variable model.

One can go selectively once again through the episodes of the main oil price jumps and specify how these are explained differently in the 5-variable model as compared to

the 3-variable model. Consider the two big shock periods of the first part of the period and after 2008. In the late 1970s to early-1980s period, the 3-variable model shows that it is the precautionary oil demand shocks (black) that contribute decisively to the oil price increases. In contrast, the 5-variable model decomposition in Figure 4 shows that the main role for that oil price increase is instead due to the inflation expectations shock.

Following the Great Recession, the 3-variable historical decomposition shows that the aggregate demand shock (red) mainly explains the surge of the oil prices up until 2012, after which the precautionary oil demand shock plays the dominant role in the price rise up to 2014 and then its decline after that. Figure 4 shows nearly the exact same role is played by the precautionary oil demand shock in both historical decompositions. But in the 5-variable model it is the money supply shock rather than the aggregate demand shock in the 3-variable model that plays the major role in explaining the oil price increase up to 2012. More precisely, the aggregate demand shock explains the major part of the increase in oil prices up until the financial crisis hits in 2008 in both 3-variable and 5-variable models, but in the 5-variable model the aggregate demand shock steadily decreases in magnitude after 2007. In the 3-variable model decomposition without the money supply shock, the aggregate demand shock ends up jumping up again after 2008 to explain the large spike in oil prices. But this latter jump-up in the aggregate demand shock to explain oil prices after 2008 is replaced in the 5-variable model by the money supply shock jumping upwards.

This diminished role of the aggregate demand shock, and main role by the money supply shock, is consistent with several aspects of the aggregate economy after 2008. The huge money supply increase after 2008 was combined with a tepid economic recovery post-2008. The real GDP growth rate remained well below its post-1953 trend in contrast to typical business cycle recoveries. This is also seen in the Gross Private Domestic Investment share of GDP rising slowly over six years from its trough in 2009 to reach above its 1978-2021 trend of 17.7% only in 2015. This marks another measure of the slow recovery as seen in a key demand component of GDP. And this investment share of GDP remained close to this trend mark right up through 2021, rather than recovering cyclically well above trend as in typical business cycles.

These results imply that after the Great Recession, the initial real oil price increases can be attributed to a lesser extent to aggregate demand than previously found, and to

a greater extent by monetary factors that account for the main part of this surge.

Finally during the pandemic after 2019, the 3-variable model shows that the precautionary oil demand shock explains both the fall in oil prices and their rise, the latter of which is aided by the oil supply shock. In contrast, the 5-variable decomposition affirms the role of the precautionary oil shock in explaining the decline in oil prices but explains the rise after 2020 from the money supply shock, which then plays an outsized role compared to all the other shocks.

6.4 Monetary Base as Alternative to M1

A final robustness check is conducted by using alternative monetary aggregates to test the importance of the money supply and expected inflation shocks on oil prices. We do this by using the monetary base (MB) which is defined as currency plus reserves, the latter of which played a large role in sterilizing the increase in the money supply after 2008 once interest was paid on excess reserves. As with M1 (which excludes reserves since it equals currency plus demand deposits), we present the impulse responses both for the swap-adjusted MB and for the MB without subtracting the Central Bank Liquidity Swaps.

The impulse responses are presented in the Online Appendix A.2 Figures 17 and 18 in the Appendix for the swap-adjusted MB and MB, respectively. We find that our impulse responses estimated by using monetary base data are qualitatively similar to our results estimated by using M1 data, shown comparably here in Figures 15 and 16. This strengthens our results by finding now that either of the adjusted money supply aggregates, MB or M1, increases oil prices along with inflation expectations and real economic activity.

We found that all three oil fundamental shocks are significant in effect on real oil prices, as well as that both the swap-adjusted MB and inflation expectations significantly effect real oil prices. A notable difference between the two specifications was that money shocks generated a faster response in real economic activity and in the real price of oil when identified from swap-adjusted M1, compared to money shocks identified from swap-adjusted monetary base. That said, the patterns identified on Figures 2 and 3 remain robustly valid for the alternative monetary aggregate (money base instead of M1).

7 Discussion

First note the nature of the Central Bank Liquidity Swaps which are subtracted from the M1 aggregate, and the alternative of using the monetary base aggregate. These occur when the Fed for example gives US dollars to the Bank of Japan in return for Japanese yen. The Fed' increase in its yen holdings then counts as part of the reserves at the Fed. In sum, the Fed gives US dollars to other central banks in return for their foreign currency, uses the foreign currency to increase its reserves, and then agrees to sell back the foreign currency for dollars in the near future so that dollars replace the foreign currency in the reserves of the Fed. These swaps propped up reserves while increasing the money supply during the bank run crises to shore up liquidity in the banking system; see Aizenman et al. (2022). This liquidity increase caused a temporary increase in the money supply while market asset prices including oil prices were crashing in 2008 and in 2020, causing during these bank-crisis-periods an inverse movement of the US money supply and the real US-denominated oil prices. Including these short-lived liquidity swaps as part of the money supply obscures the effect of sustained money supply shocks on real oil prices.

Robustness is then focused on estimating the original 3-variable Kilian (2009)/Kim and Vera (2019) SVAR model across a range of alternative data periods and lag lengths, as in the literature. Then we compare these shocks to the three fundamentals that we identify in our 5-variable model. First, the same qualitative significance of the impulse responses of the three fundamental shocks on oil prices is found across the various 3-variable SVARs, as is found in our 5-variable SVAR for those same three fundamental shocks. Next, we show that the historical identification of each of the variously estimated 3-variable fundamental shocks are nearly identical to each other as well as to the three fundamental shocks that are historically identified in our 5-variable model. Finally, we present a historical decomposition of the explanation of oil price using the 3-variable model, to compare it to the historical decomposition using the 5-variable model.

The historical decomposition comparison using the 3-variable model and the 5-variable model illustrates that a significant amount of the importance of the three fundamental shocks is replaced by the two monetary shocks. This is true even as the historical profile of the three fundamental shocks of the 5-variable model is very close to the historical profile of the three fundamental shocks estimated for the alternative 3-variable models. This shows both robustness of the three fundamental shocks, and the added importance

across episodes of the monetary shocks. In particular, the inflation expectations shock in the 1970s-1980s replaces the importance of the precautionary oil demand shocks. Once the Federal Reserve began sterilizing part of the money supply increase through the build-up of excess reserves post-2008 that enabled inflation to remain subdued (until 2020), instead of the inflation expectations playing a dominant role post-2008, it is the money supply shocks themselves that become a major factor in explaining oil price shocks after 2008 and during the pandemic. The money supply shock replaces the dominance of the aggregate demand shock for part of the post-2008 period and replaces that of the precautionary oil demand shock during 2020-2021.

The results of the paper are important because monetary factors have largely been discounted as factors that affect real oil prices. This was true in the 1970's, despite the increase in US money supply fueled by the Fed buying Treasury debt at an increasing rate that was sufficient to break down the Bretton Woods gold standard that had started after World War II, with a gold standard of more classical forms dating back to the founding of the American colonies and embodied in the US Constitution. That the US Constitution took on the problem of having a federal means of taxation to avoid reliance on the inflation tax as did the Continental Congress shows how important the issue of money and inflation has been to US history. It is unsurprising to find results that real oil prices, just as do real gold prices, are Granger-predicted by US money, inflation and expected inflation since these build in the expected inflation rate to avoid a reduction in real price levels, such as the decline in the real oil price from 1958 to 1973 when oil prices were largely fixed through long term contracts.

Here monetary evidence of the effect of inflation on oil prices is added on top of the Granger-predictability evidence by using perhaps the best-known framework to estimate oil shocks in an SVAR model. The results show that inflation expectations and money supply shocks, with the latter adjusted to take out the swaps used mainly during the bank panics of 2008 and 2020, cause increases in the real oil price. The data set goes back to 1978 and so captures a significant part of the first large oil shock, and it also includes those since 2000. The post-2008 oil shock was seen as being a non-monetary event since inflation was kept in check through the effective sterilization of a large part of the money supply through the increase in excess reserves brought about through paying interest on excess reserves for the first time in US history. Yet inflation expectations

did increase and Granger predicted oil prices in data from the 1970s to 2019 (Benk and Gillman, 2020). Now this paper shows that increased inflation expectations indeed do shock oil prices upwards even when accounting for the fundamental supply and demand factors in the oil market as studied here.

Seeing oil prices rise after 2020 when the money supply was accelerating is consistent with the monetary thesis of both the money supply and inflation expectation shocks causing oil price increases. Supply-chain problems often arise during rising inflation as wages fall behind the growth in prices, and workers seek new jobs where they can get back a higher real wage. The contribution of supply issues can be real and can affect oil market fundamentals. This paper in contrast presents evidence that oil price increases can be understood in part because of money and inflation.

It might also be expected that an increase in inflation expectations causes a decrease in real GDP in the SVAR model in that econometric evidence has found that inflation causes lower real output growth and unemployment in the long run (Gillman et al., 2004; Haug and King, 2014). While inflation is a tax that is never neutral in the classical dichotomy sense, it might be added that not only is the dictum that money causes inflation one for the ages but evidence of inflation lowering economic growth is likewise strong. This means that putting the burden on oil price increases for lowering economic growth may be misplaced if rather the source of the oil price increase is from the Fed buying Treasury debt that increases the money supply and inflation rate expectations, which in turn raise real oil prices.

Despite continual findings of Granger-predictability of inflation by the money supply growth rate (Haug and Dewald, 2012), a qualification to the quantity theory dictum is that the money supply increase may be sterilized through a build up of excess reserves that does not enter circulation and so does not cause inflation. This occurred after 2008 and these reserves only began entering circulation significantly in 2014. Reserves entered circulation more rapidly again after the interest on excess reserves was steadily raised from 2016 to 2019 and again when M1 minus reserves shot up after 2020. This suggests that a modification for further investigation of how the money supply affects oil price fluctuations could be to not only adjust M1 or MB modestly by subtracting swaps, but more significantly by also subtracting reserves that do not enter circulation. That latter is left for future research.

It would be useful to task the monetary shocks found here in significantly effecting oil prices by additionally using extensions found in the literature to study oil price and related shocks. The strength of the results here in terms of significance suggest that these monetary sourced shocks would be robust to alternative ways of measuring the fundamentals in the oil market. Another dimension left open is that since real oil prices move similarly to real gold prices with both Granger predicted by swap-adjusted M1, inflation and inflation expectations (Benk and Gillman, 2020), it raises the possibility of the non-uniqueness of oil price shocks since these may also be related to such shocks in the gold market, the stock market, or other havens in times of crisis (Basher et al., 2012, 2018; Dibooglu et al., 2022). Results of this paper show that monetary factors are significant driving forces in real oil prices and they may also be in real gold prices or related assets when using an SVAR model to identify shocks, or using a Markov-switching SVAR model (Basher et al., 2016).

The results also offer a potentially complementary factor to the Baumeister and Kilian (2016c) explanation of the drop in oil prices in 2014. They use a real time forecast based on a Bayesian VAR (BVAR) and find that supply and demand factors could predict more than half of the oil price change. They attribute the 2014 oil price drop to a decrease in aggregate demand, an increase in oil supply, and a decrease in oil price expectations. The aggregate demand and oil supply factors are found to be predictable, while the oil price expectations was found to be unpredictable. Our results suggest that their unpredictable oil price expectations may possibly be explained within their framework by the money supply growth and inflation expectations.

Figure 4 shows a significant role of monetary factors, in particular from the money supply shock steadily falling in magnitude from 2014. This is consistent with the Federal Reserve Bank's "tapering" of the money supply growth rate starting around 2012 and continuing through 2014 and up until 2020. While the role of the inflation expectations shock in our Figure 4 is of small magnitude, it shows that the magnitude of this shock was rising up to 2014, around which it peaks and starts to decline. This offers that both the money supply policy and the resulting inflation expectations contributed to the decline in the oil price after 2014. It would be a topic of further research to include these factors in the BVAR real time forecasting framework to see if these factors would be born out in that framework.

Finally, it is worth noting that we find convincing that money supply should be ordered first in the SVAR as being contemporaneously exogenous. However, others could dispute this, say money supply growth was caused by fiscal distress from exogenous oil price shocks unrelated to monetary factors, and so would hypothesize that money should be ordered after the oil market supply shock and the aggregate demand shock. We examined these results although they go against our priors based on Granger predictability of real oil prices by money supply and inflation expectations. As presented in Online Appendix A.3, we found that ordering the money supply shock and inflation expectations shocks third and fourth of the given variables still show the same qualitative significance of all five shocks and similar contributions of the shocks to oil prices in the historical decomposition of Section 5.2. The only modification found in the experiment was that the money supply shock played a less dominant role after the 2008 rise in oil prices in the historical decomposition.

8 Conclusion

The paper shows the significance of monetary factors for real oil prices in terms of impulse responses once the basic elements of supply and demand are already included as in Kilian (2009). A structural decomposition of the real price of crude oil into the five shock components of the expected inflation rate, the money supply, oil supply, aggregate demand and precautionary oil demand shows significance of each of these shocks as found previously for the fundamental non-monetary shocks. The new aspect is also showing significance of the monetary shocks.

The historical decomposition of the real oil price fluctuations by each of the five shocks shows that monetary factors especially play a role during the major real oil price episodes in history since the 1970s. The results have potentially important policy implications since inflation and inflation expectations have risen again globally along with real oil prices. The paper's results imply that a decreased growth in the swap-adjusted M1 and monetary base would cause less pressure on inflation, inflation expectations, and real oil prices.

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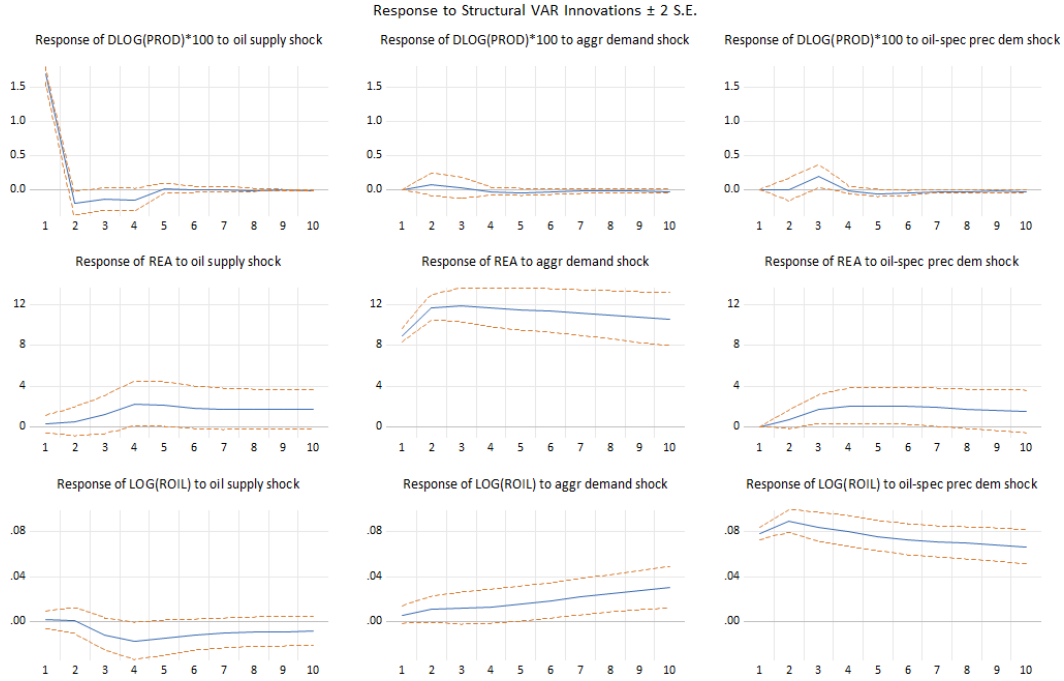


Figure 9: Impulse responses: Kim & Vera - Kilian 3 variable model up to 2007, with 3 lags in the VAR (lag length selected based on information criteria)

A Online Appendix

A.1 3-Variable Model Full Set of Impulse Responses

Figures 9, 10, 11, 12, 13 and 14 show the impulse responses of the 3-variable model ordered with shocks 1, 2 and 3 being the oil supply shock, the aggregate demand shock, and the precautionary oil demand shock, respectively, with two different time periods and two lag lengths as found in the literature, plus the updated sample through 2021 found in this paper. Figures 9 and 10 show the 1973 to 2007 period with 3 lags and 24 lags; Figures 11 and 12 show the 1976 to 2015 period with 3 lags and 24 lags; Figures 13 and 14 show the 1978 to 2021 period with 3 lags and 24 lags. The results show similar significance among the set of six impulse responses for three fundamental non-monetary shocks. And these in turn are similar to what we found for the 5-variable model, as presented in the following Section.

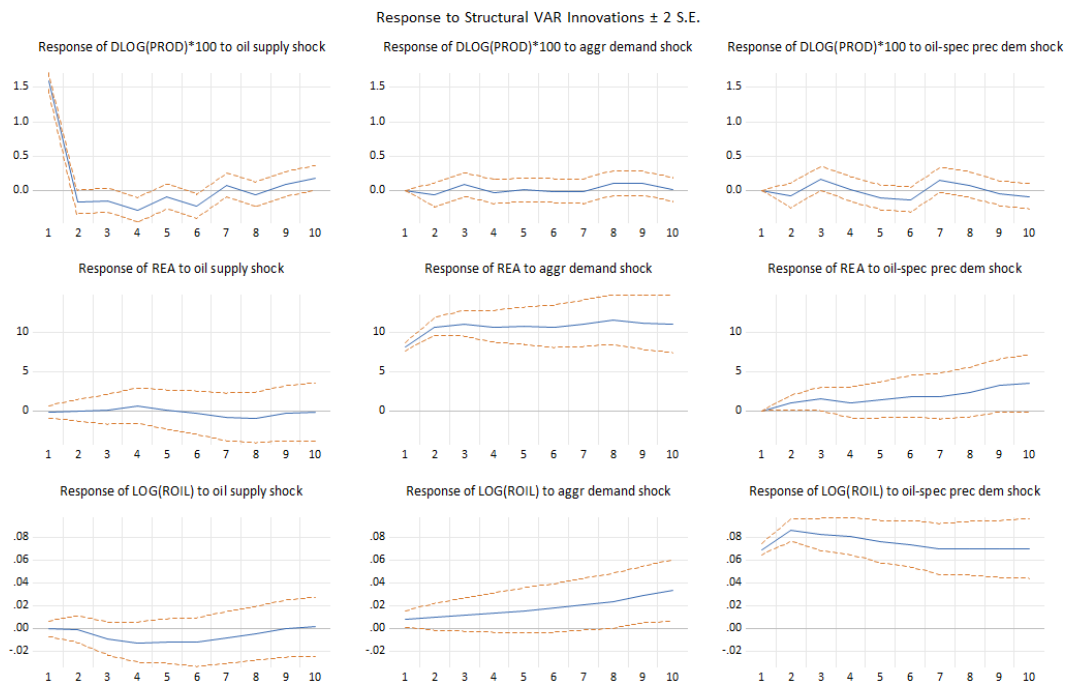


Figure 10: Impulse responses: Kim & Vera - Kilian 3 variable model up to 2007, with 24 lags in the VAR (Kilian's lag specification)

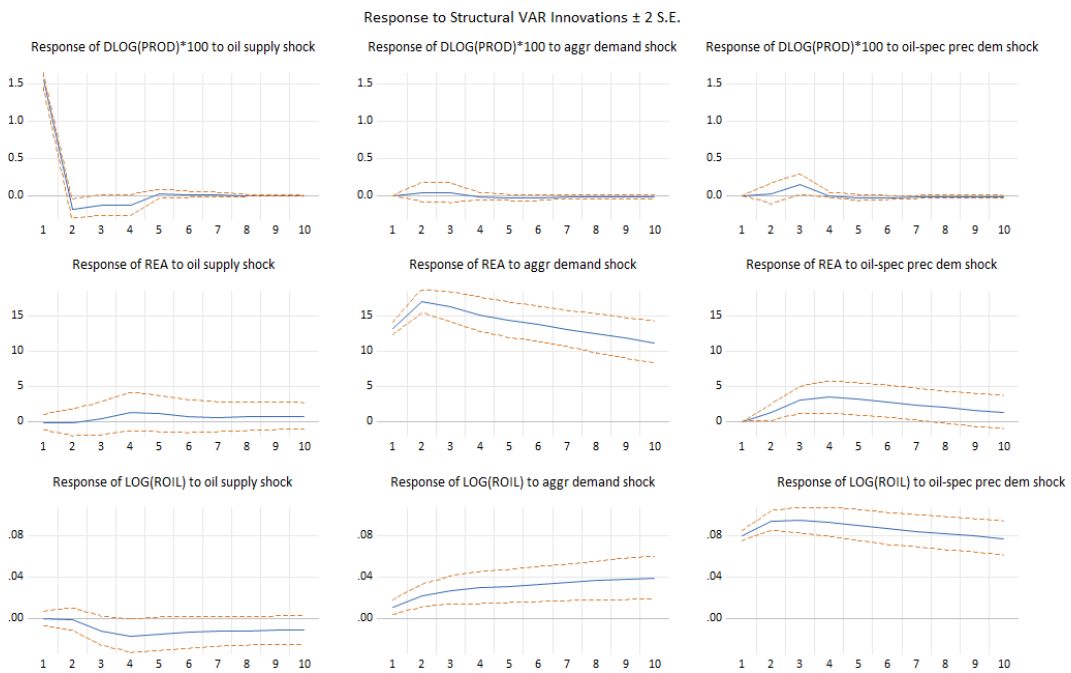


Figure 11: Impulse responses: Kim & Vera - Kilian 3 variable model up to 2015, with 3 lags in the VAR

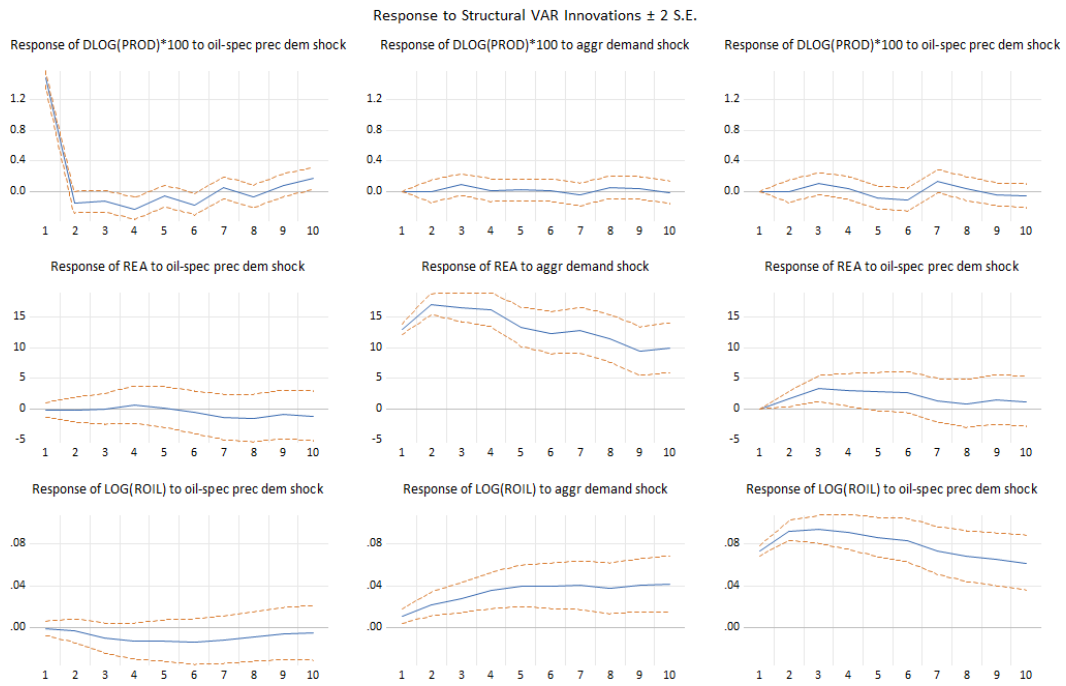


Figure 12: Impulse responses: Kim & Vera - Kilian 3 variable model up to 2015, with 24 lags in the VAR (a replication of Kim and Vera (2019))

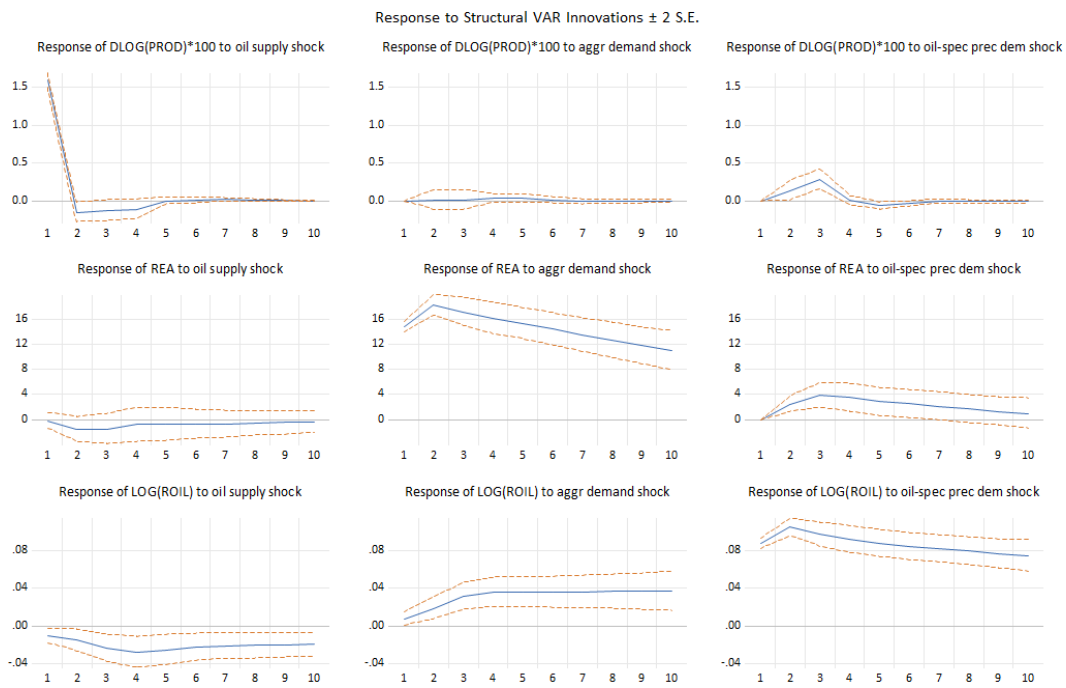


Figure 13: Impulse responses: Kim & Vera - Kilian 3 variable model up to 2021, with 3 lags in the VAR (lag length selected based on information criteria)

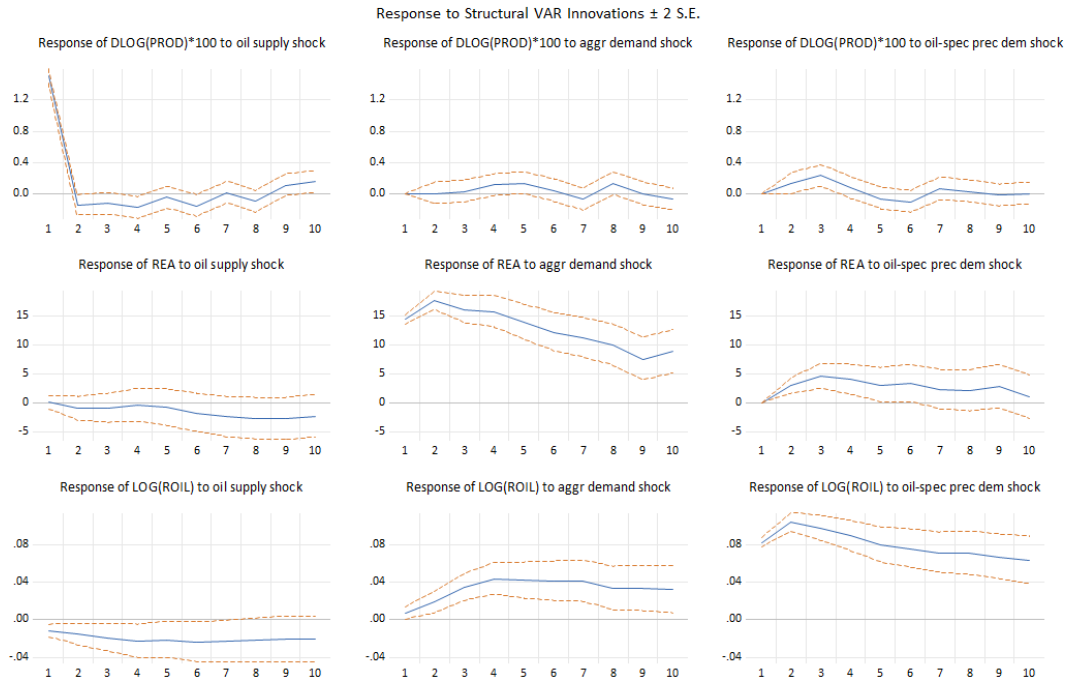


Figure 14: Impulse responses: Kim & Vera - Kilian 3 variable model up to 2021, with 24 lags in the VAR

A.2 5-variable Model Impulse responses: Alternative Monetary Aggregates

The Appendix shows the full set of impulse responses for the 5-variable model, which were estimated using four alternative measures for money. Figures 15, 16, 17 and 18 show these results for the Swap-adjusted M1, M1-unadjusted, Swap-adjusted Monetary Base (MB), and the MB-unadjusted, respectively. Our baseline above is the Swap-adjusted M1.

Significance of the two monetary shocks results using both the swap-adjusted M1 aggregate and the swap-adjusted MB. Insignificance of the money supply aggregate results using the unadjusted M1 and MB aggregates.

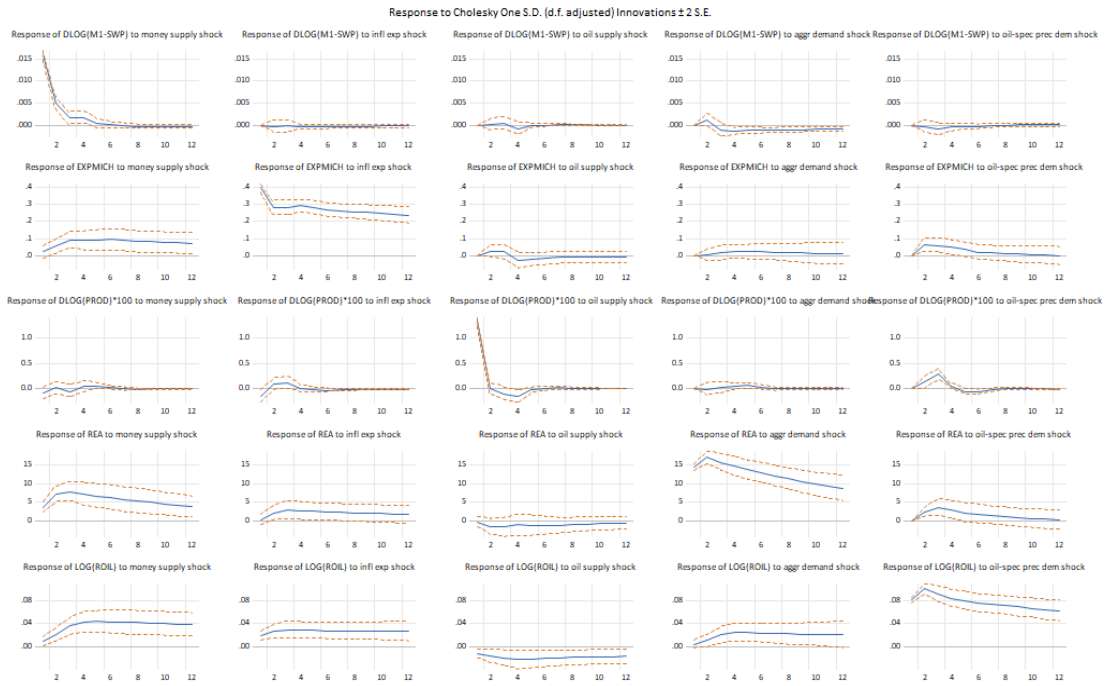


Figure 15: 5-variable Model: Impulse responses to money (M1 swap adjusted), inflation expectation, oil supply, aggregate demand and oil specific demand shocks

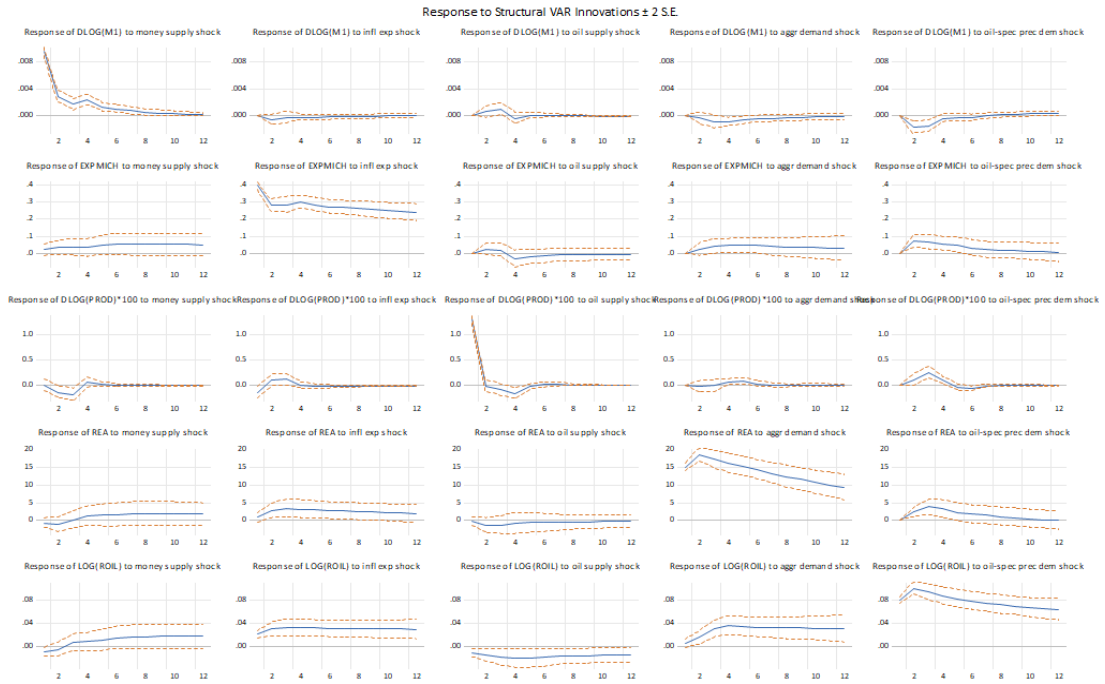


Figure 16: 5-variable Model: Impulse responses to money (M1), inflation expectation, oil supply, aggregate demand and oil specific demand shocks

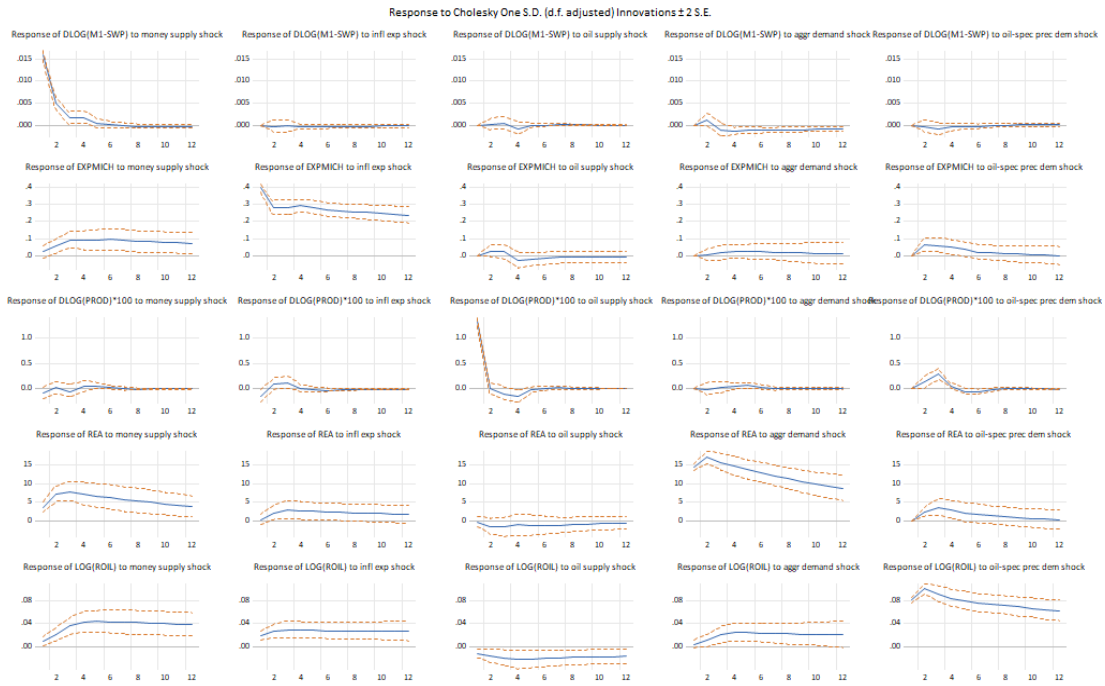


Figure 17: 5-variable Model: Impulse responses to money base (MB swap adjusted), inflation expectation, oil supply, aggregate demand and oil specific demand shocks

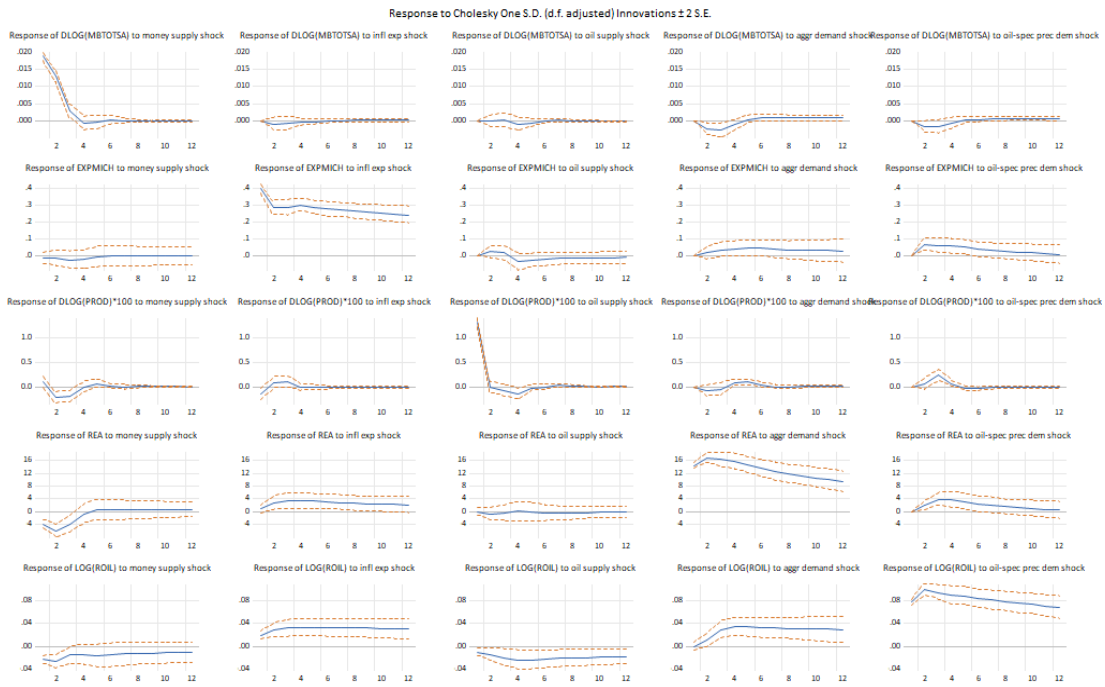


Figure 18: 5-variable Model: Impulse responses to money base, inflation expectation, oil supply, aggregate demand and oil specific demand shocks

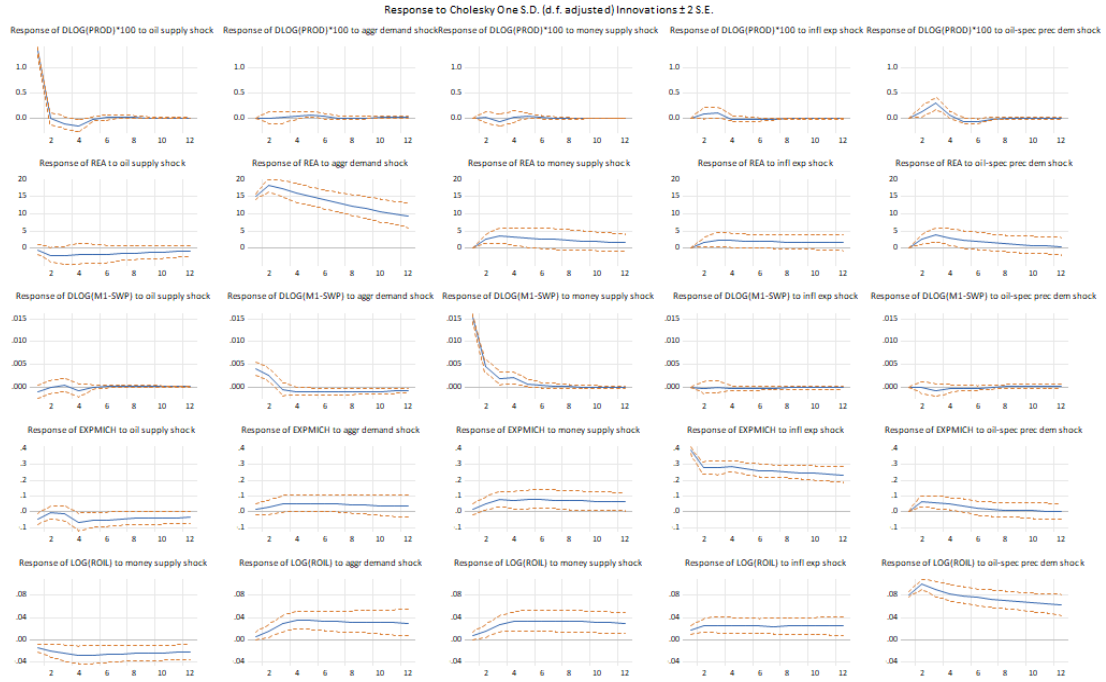


Figure 19: 5-variable Model: Similar Significance of Impulse Responses with Money Supply and Inflation Expectation Shocks Alternatively Ordered 3rd and 4th, respectively.

A.3 Alternative Shock Ordering for 5-variable Model

Figure 19 shows the full set of impulse responses with the swap-adjusted M1 money supply shock ordered third in the SVAR, and the inflation expectations shock ordered fourth. Significance of all shocks is similar to above results. Note that the last column is the precautionary oil demand shock. Figure 20 shows the corresponding historical decomposition of oil price shocks by the five shocks, with similar qualitative results as described above except for less dominance of the money supply shock after 2008.

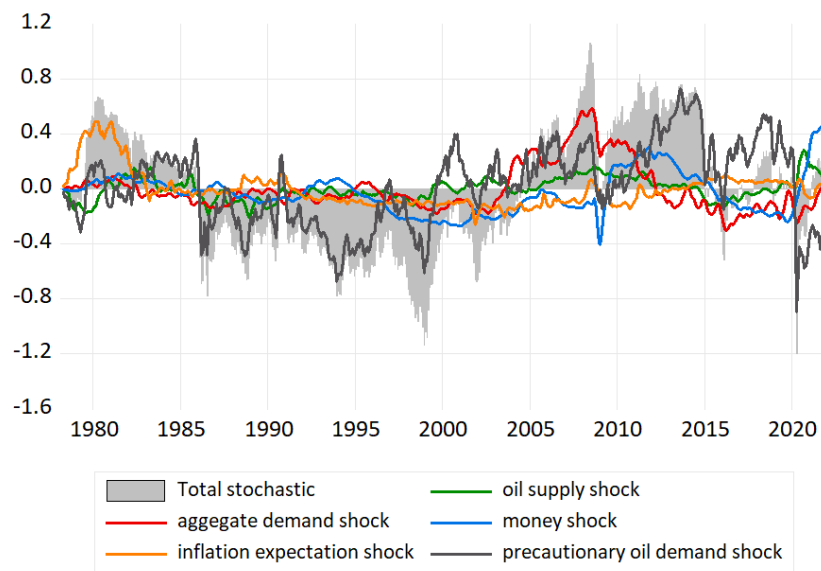


Figure 20: 5-variable Model: Historical Oil Price Shock Decomposition with Money Supply and Inflation Expectation Shocks Alternatively Ordered 3rd and 4th, respectively.

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