BANK FOR INTERNATIONAL SETTLEMENTS

BIS Working Papers
No 725

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Monetary and Economic Department

May 2018

JEL classification: C32, E44, G12, G15

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This publication is available on the BIS website (www.bis.org).

ISSN 1020-0959 (print)
ISSN 1682-7678 (online)

Identifying Oil Price Shocks and Their Consequences: the Role of Expectations in the Crude Oil Market*

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May 2018

Abstract

This paper proposes a simple but comprehensive structural vector autoregressive (SVAR) model to examine the underlying factors of oil price dynamics. The distinguishing feature is to explicitly assess the role of expectations on future aggregate demand and oil supply in addition to the traditional realized aggregate demand and supply factors. Our empirical analysis shows that identified future demand and supply shocks explain about 30-35 percent of historical oil price fluctuations. In particular, future oil supply shocks are more than twice as important as realized and future demand shocks in accounting for oil price developments. The empirical result indicates that the influence of oil price shocks on global output varies according to the nature of each shock. We also show that the financial factors and the development of shale-oil technology are additional relevant sources of oil price fluctuations.

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* We are grateful for helpful comments from Stijn Claessens, Andrew Filardo, Leonardo Gambacorta, Boris Hofmann, Emanuel Kohlscheen, Marco Lombardi, Akito Matsumoto, Elmar Mertens, Taisuke Nakata, Yoshio Nozawa, Hyun Song Shin, Nathan Sussman, Toshiaki Watanabe and seminar participants at the Bank of Canada, the Bank of Japan, the Bank for International Settlements, and the 11th International Conference on Computational and Financial Econometrics. The views expressed herein are those of the authors alone and do not necessarily reflect those of the Bank of Japan or the Bank for International Settlements.

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1. Introduction

There is growing interest among academics, policy makers and market practitioners in the causes and consequences of oil price fluctuations (eg Arezki and Blanchard (2015) and World Bank (2015)). Various supply and demand factors are known to drive oil prices. Changing oil prices can affect the economy in different ways, depending on the factors driving the change. The ability to infer the respective drivers has important implications for the appropriate policy response to changing macro-financial conditions from both global and domestic perspectives (eg Gospodinov and Ng (2013), Filardo and Lombardi (2014) and Filardo et al (2018)).

A seminal paper, Kilian (2009), develops an econometric framework to identify supply and demand shocks that drive oil prices. However, the role of each driver is still difficult to assess empirically for recent years, in particular the forward-looking supply and demand factors. Davig et al (2015) show that a large fraction of the recent oil price drop in 2014 is unexplained by those traditional supply and demand shocks, and discuss that the unexplained part reflects changes in expectations and uncertainty about future oil supply and demand.

There are several characteristics of the commodity market with which expectations can affect prices. For instance, as oil is storable, not only realized demand and supply but also inventories affect investors' expectations about future oil supply and demand. Also, as oil is financialized, financial market developments can potentially be major drivers of the oil price. Because of these aspects, expectations and uncertainty about future demand and supply can play a significant role in determining the oil price. It makes the standard decomposition of oil price fluctuations to demand and supply factors more challenging.[1]

The aim of this paper is to fill this gap. We develop an extended structural vector autoregressive (SVAR) model which incorporates the role of expectations about future global aggregate demand and future oil supply, in addition to the traditionally-used factors, realized aggregate demand and oil supply. We identify expected aggregate demand shocks and expected future oil supply shocks, exploiting revisions of global economic growth by professional forecasters and changes in oil inventory, respectively, in order to examine their impacts on the oil price in an endogenous manner.[2] Using our proposed model, we identify five shocks driving oil price fluctuations, namely: realized oil supply shocks,

[1] For example, see Bernanke (2016) and Davig et al (2015).

[2] Kilian and Hicks (2013) examine the relationship between the revision of professional GDP growth forecasts and the oil price, using the model in which the revision of the growth rate is treated as an exogenous shock.

realized aggregate demand shocks, future aggregate demand shocks, future oil supply shocks, and oil price-specific shocks. We then disclose the mechanism of oil price developments as well as these shocks' influence on global industrial output.

The existing studies seem to have reached a consensus that various factors, including expected future oil demand and supply, have contributed to the oil price decline. There is, however, no consensus regarding the extent to which each of those factors has contributed quantitatively. In addition, there is intense discussion as to why the positive impact of the oil price decline on the global economy has not clearly materialized. We contribute to these discussions by identifying the shocks in the proposed approach and quantitatively examining their impact on the real oil price as well as global industrial output.

Our main findings based on data from 2005 to 2016 are twofold.

- Our analysis sheds new light on the effects of expectations on the oil market: expected future oil supply shocks and expected aggregate demand shocks have a significant effect, compared with realized supply and demand shocks. An estimated variance decomposition shows that future demand and supply shocks account for about 30-35 percent of oil price variance over twelve months, while realized demand and supply shocks explain only about 5 percent. In particular, future oil supply shocks are more than twice as important as realized and future aggregate demand shocks.
- We show that the effects of oil price dynamics on the global economy depend on the factors behind them: for example, an unexpected increase in global oil supply will cause a small increase in global output. Both realized and expected negative aggregate demand shocks bring global output down. More interestingly, both positive expected future oil supply shocks and negative oil price-specific shocks initially push global output down, probably reflecting the contractions in upstream investments of crude oil. Almost one year later, however, global output increases.

We also investigate two other expectation-oriented factors driving oil price fluctuation. First, we consider the role of the financial factors in the oil market. Financialization in the commodity market and its influence on commodity prices has been a central issue (eg Chari and Christiano (2017)). This factor aims to capture the role of changes in investors' expectations (or speculation). We use information about investors' position in the oil futures market to identify shocks associated with financial factors that drive the spot oil price. Second, future oil supply shocks caused by news about shale-oil technology are examined. That is, we quantify the role of the development of shale-oil technology. A rapid evolution in shale-oil extraction technology has been said to raise expectations of more potential future supply with its relatively cheaper cost of production than traditional oil production technologies, which could affect the oil price. Our analysis addresses these points as part of a robustness check of the main result.

The remainder of this paper is organized as follows. In section 2, we briefly review the existing literature. Section 3 describes the methodology and data to identify shocks as key determinants of real oil price dynamics. Section 4 provides empirical results, mainly focusing on the influence of shocks on the real oil price. We also investigate other relevant sources of oil fluctuations and robustness In addition, we investigate the influence of those shocks on global aggregate demand. Section 5 concludes.

2. A brief literature review on SVAR analysis for oil prices

Among the literature regarding the oil price shocks and their influence on economic activity, one of the most distinguished is Kilian (2009). He proposes a novel SVAR model to identify three contributing factors in accounting for oil price fluctuations: flow demand shocks, flow supply shocks, and other factors involving oil-specific demand. The last component is designed to include any factors affecting swings in the real price of oil after controlling for oil supply and global demand shocks. He shows that those three shocks have considerably different effects on the oil price and economic activity.

Along with this seminal paper, a wide variety of extensions have been proposed. Among them, Ratti and Vespignani (2013) extend the SVAR model by incorporating a monetary factor such as global real money stocks. They point out that global real money stocks have a statistically significant effect on oil prices, and that their historical impact is sizable in the phase of increasing oil prices from 2009 to 2011.

Kilian and Murphy (2014) and Kilian and Lee (2014) refine the original approach to allow for an explicit role of the speculative oil demand using oil inventories data. A key intuition of Kilian and Murphy (2014) is that there exist some factors that are not captured by realized (or flow) demand and supply shocks, and that one of them can be “any expectations of a shortfall of future oil supply relative to future oil demand.” They show in their empirical study that the future supply shock has a significant effect on the oil price, consistent with this paper. Departing from them, we explicitly identify the role of future demand.

According to Kilian (2014), the empirical studies following Kilian (2009) provide the evidence that oil demand shocks associated with the global business cycle explain a major component of oil price fluctuations, while oil supply shocks sometimes play a non-negligible role. In addition to the demand and supply factors, financial factors of oil future trade provide an alternative transmission channel of expectations on the oil price. Basak and Pavlova (2016) imply that the activity of financial investors in the oil futures market amplifies earlier realized and expected shocks. However, the quantitative significance of this amplification mechanism is an open question according to Kilian (2014).

More recently, there has been an increasing number of studies that focus on the causes and consequences of the large fall in oil prices from mid-2014 to 2016. World Bank (2015) raises the following four causes of sharp oil price drop: a trend of greater-than-anticipated supply and less-than-anticipated demand, changes in OPEC objectives, fading geopolitical concerns about supply disruptions, and US dollar appreciation. While this World Bank's address is qualitative, several studies have examined quantitative assessments. On one hand, Baumeister and Kilian (2015) show the evidence that more than half of the price decline from mid-2014 to 2016 was predictable as of June 2014, because it owes to the adverse shocks that hit the oil market prior to June 2014. On the other hand, Davig et al (2015) decompose the oil price fluctuation with the technique of Kilian (2009) and find that oil-specific or precautionary demand shocks mostly drove the oil price decline.

The finding of Davig et al (2015) clearly reveals the limitation of the methodology developed in Kilian (2009): it is not well defined enough to identify factors driving oil price-specific shocks, although we assume that it potentially reflects changes in expectations and uncertainty about future oil supply and future global real activity as well as financial shocks. Since "not all oil price shocks are alike", as is pointed out in Kilian (2009), it would be difficult to examine the causes and consequences of the recent declines in oil prices without identifying factors that involve oil price-specific shocks. Our methodology aims to address this limitation by systematically employing the expectation-oriented factors that have been discussed in the previous literature into one simple but comprehensive model. This model enables us to decompose the contributions of oil price-specific shocks into the role of changes in expectations and uncertainty about future oil supply and future global real activity.

3. Methodology and data

This section presents our proposed model to describe oil price fluctuations. We begin with the approach of the three-variable SVAR model proposed by Kilian (2009) and discuss the limitations. Then, we propose our new methodology with additional variables to address the issue.

3.1 Kilian (2009)

Kilian (2009) proposes the three-variable SVAR model to identify underlying demand and supply shocks in the oil market. Specifically, the representation is expressed as

$$A_0 z_t = \alpha + \sum_{i=1}^{k} A_i z_{t-i} + \varepsilon_t, \tag{1}$$

where ε_t refers to the vector of serially and mutually uncorrelated innovations, and $z_t = (\Delta\mathrm{prod}_t, \mathrm{rea}_t, \mathrm{rpo}_t)'$, where $\Delta\mathrm{prod}_t$ represents the change in global crude oil production, rea_t the index of real economic activity, and rpo_t the real price of oil. Let e_t denote the reduced form VAR innovations such that $e_t = A_0^{-1}\varepsilon_t$. The innovations are derived from the reduced innovations by imposing recursive exclusion restrictions on A_0^{-1}.

The identification restrictions on A_0^{-1} are imposed as follows:

$$e_t \equiv \begin{pmatrix} e_t^{\Delta\mathrm{prod}} \\ e_t^{\mathrm{rea}} \\ e_t^{\mathrm{rpo}} \end{pmatrix} = \begin{bmatrix} a_{11} & 0 & 0 \\ a_{21} & a_{22} & 0 \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{pmatrix} \varepsilon_t^{\text{oil supply}} \\ \varepsilon_t^{\text{aggregate demand}} \\ \varepsilon_t^{\text{oil-price specific}} \end{pmatrix}.$$

The oil supply shocks are designed as unexpected innovations to global oil production. Innovations to global economic activity that cannot be explained by realized oil supply shocks refer to aggregate demand shocks. Finally, by construction, innovations to the real oil price could represent *any* factors having an impact on the real price of oil after controlling for those oil supply and aggregate demand shocks.

Although the method of Kilian (2009) is simple and straightforward, it has some limitations: there are many possible interpretations of the oil market-specific shocks. That is, it is not well defined enough to identify factors driving oil price-specific shocks. One possible explanation is that oil-specific demand shocks may capture changes in the precautionary demand for oil, as mentioned by Kilian (2009) and Davig et al (2015). We could assume that it potentially reflects fluctuations in market expectations on availability of future supply or demand.[3] However, the method proposed by Kilian (2009) does not

[3] Davig et al (2015) provide an example of this interpretation.

allow us to quantify the roles of expectations on future oil supply or aggregate demand in accounting for the effects and consequences of oil price fluctuations.

As is discussed by Kilian (2009), each shock should have a different dynamic impact on real oil prices and the real economy. In order to better quantify the causes and consequences of oil price fluctuations, it is required to disentangle each shock and properly separate the effects of each. In particular, it is well acknowledged that the main driver of declines in oil prices from mid-2014 to 2016 should be oil-specific demand shocks, as in Davig et al (2015). Our empirical analysis using Kilian (2009)'s approach, which is reported below, shows that oil supply and aggregate demand shocks explain only about 10 percent of the decline in oil prices and the remaining 90 percent is contributions of oil price-specific shocks. This fact motivates us to identify the factors driving the oil price-specific shocks in an economically important way.

3.2 Our methodology

To address the limitations explained above, we extend the method by introducing two additional variables into the VAR model (1), which allows us to identify shocks on "expectations" about the future oil supply and aggregate demand. We use the oil inventory to address the future oil supply, and professional forecasts about global GDP growth to address the future aggregate demand. We use the terminology *realized* oil supply and demand shocks for the original variables in Kilian (2009) and *future* oil supply and demand shocks for the newly proposed factors in this paper.

This idea is implemented with a five-variable SVAR model with $z_t = (\Delta\mathrm{prod}_t, \mathrm{rea}_t, \Delta\mathrm{CF}_t, \Delta\mathrm{Stock}_t, \mathrm{rpo}_t)'$, where $(\Delta\mathrm{prod}_t, \mathrm{rea}_t, \mathrm{rpo}_t)$ are the same as above, $\Delta\mathrm{CF}_t$ denotes the forecast revisions of the global GDP growth, and $\Delta\mathrm{Stock}_t$ the change in the oil inventory. Based on Equation (1), we identify five shocks in the model as

$$\begin{pmatrix} e_t^{\Delta\mathrm{prod}} \\ e_t^{\mathrm{rea}} \\ e_t^{\Delta\mathrm{CF}} \\ e_t^{\Delta\mathrm{Stock}} \\ e_t^{\mathrm{rpo}} \end{pmatrix} = \begin{bmatrix} a_{11} & 0 & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} & 0 \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} \end{bmatrix} \begin{pmatrix} \varepsilon_t^{\text{realized supply}} \\ \varepsilon_t^{\text{realized demand}} \\ \varepsilon_t^{\text{future demand}} \\ \varepsilon_t^{\text{future supply}} \\ \varepsilon_t^{\text{oil-price specific}} \end{pmatrix}. \tag{2}$$

For simplicity of the terminology, we label original oil supply shocks and aggregate demand shocks as realized supply and demand shocks, respectively.

A rationale for the ordering of the variables is as follows. The realized supply shocks are defined as unexpected innovations to global oil production as in Kilian (2009).

Oil production is assumed not to respond to other shocks within the same month due to the adjusting cost of oil production and uncertainty about the future state of the oil market. The realized demand shocks correspond to shocks to global industrial production that cannot be explained by realized supply shocks. The realized demands for crude oil are assumed not to respond to shocks on the expected future demand and supply of crude oil and other below shocks within a month. We consider this assumption reasonable also due to the uncertainty.

The future demand shocks are innovations to professional forecasts about global GDP growth which cannot be explained by realized aggregate demand and oil supply. Expected future oil supply shocks are defined as innovations to the OECD oil inventory stocks which are attributable to neither innovations to the realized supply and demand nor to expected future demand.[4] The future supply shocks are considered as shocks on the expectation of oil supply in the coming months or years. Lastly, the oil price-specific shocks are defined as innovations to the development of the real oil price after controlling for the effects from the above-mentioned factors.[5]

3.3 Data

All data are monthly, and the sample period is from March 2005 to February 2016.[6] The data set is constructed as follows and Figure 1 exhibits the time series of each variable.

Oil production (Δprod)

We use data on global oil production provided in the Monthly Energy Review of the Energy Information Administration (EIA). We take the log differences of seasonally

[4] In a simple identity, an increase in inventory implies that the current supply exceeds the current demand. The change in the inventory partly reflects unexpected changes in the realized supply and demand. Also, the inventory can change due to a revision of expected demand. These factors are captured by the parameters for contemporaneous relationship among variables in Equation (2). The innovation due to the rest of the factors to drive the inventory is identified as the future supply shock. In our approach, we cannot precisely identify whether the change in inventory is intentional or not. Further, the change in inventory can reflect a number of factors such as some lags between production and consumption due to shipping, the production cost per unit, and speculative behaviors. Because the elasticity of the inventory to these factors can vary over time, the identified expected supply shock can be partly associated with the current and expected demand factors that are not captured by the industrial production or the forecast revisions. A further analysis on this point is left for a future work.

[5] We estimate the VAR model with the order of lags set as $k = 2$.

[6] We choose March 2005 as the starting point of the sample, because the CUSUM structural break test identifies a break in the time-series of the real oil price in March 2005. While the sample period is relatively shorter than ones in the previous studies, we choose it to focus on the recent developments in oil price dynamics. Our framework can be extended to the time-varying parameter VAR (see eg Byrne et al (2017)), which remains for a future work.

adjusted, world oil production in millions of barrels pumped per day.

Global real economic activity (rea)

Our measure of global real economic activity is the index of industrial production (IIP).[7] We aggregate the IIP series for OECD countries and emerging economies, based on the PPP (Purchasing Power Parity) weights. For OECD countries, we follow the aggregated data provided by the OECD. For emerging economies such as Brazil, China, India, Indonesia, Russia and South Africa, we aggregate the individual IIP series for each country provided by CEIC. After aggregating the IIP, we take the deviation from its linear trend to obtain a gap measure.

Revision of Consensus Forecast on global GDP (ΔCF)

Following Kilian and Hicks (2013), we use the forecasts of annual real GDP growth for the next year and define the revisions of the forecast by taking the differences from the forecast delivered in the previous period. Specifically, let $CF_{i,j,t}$ denote the forecast of annual real GDP growth for the next year at month j in year t, for country i. We use the series of the Consensus Forecast provided by Consensus Economics Inc. We focus on the one-year forecast horizon because one-year forecasts are more reliable and watched more closely by market participants than longer-horizon forecasts. The revisions of forecasts on global real activity for a country i are defined as

$$\Delta CF_{i,j,t} = CF_{i,j,t} - CF_{i,j-1,t}.$$

Then, we take the weighted average for the aggregated revisions of the forecasts at month j in year t. That is, the aggregated revision $\Delta CF_{j,t}$ is defined as

$$\Delta CF_{j,t} = \sum_i \omega_{i,t} \Delta CF_{i,j,t},$$

where $\omega_{i,t}$ denotes the PPP weights for country i in year t.

Oil inventory (ΔStock)

Following Kilian and Murphy (2014), we treat OECD industry petroleum stocks as a proxy for global petroleum inventories. The series is provided by the EIA. We take the

[7] We employ the index of industrial production as a proxy for global aggregate demand, instead of using the BDI (Baltic Dry Index), a novel measure of global economic activity, proposed by Kilian (2009). Although the BDI index usefully contains much information about global aggregate demand, it also includes some elements of expectations about future aggregate demand. The purpose of this paper is to investigate the role of such expectations by explicitly incorporating the variable for future aggregate demand. Therefore, we use global IIP, which includes less expectation components than the BDI, for a better proxy for the realized aggregate demand. Actually, the correlation between global IIP and the future demand variable (revision of Consensus Forecast on global GDP) is lower than the one between the BDI and the future demand variable.

log differences of seasonally adjusted series.

Real price of oil (rpo)

We use the West Texas Intermediate (WTI) oil price as the nominal oil price. Following Kilian (2009), the original series is deflated by the US CPI and the resulting real price of oil is expressed in log-levels.

4. Empirical results

4.1 Identified shocks and the role of expectations

Figure 2 shows a historical decomposition of the real oil price, which presents the respective cumulative contributions of each shock identified by the three-variable VAR. The contribution of realized supply shocks is quite small, although the realized demand shock explains downward and upward streams of the real oil price around 2008-2009 and 2009-2010, respectively. In particular, what matters here is that most of the oil price fluctuations are left unexplained, as shown by the contributions of oil price-specific shocks. The variance decomposition estimates reported in Table 1 show that 80 percent of oil price fluctuations is unexplained by either realized supply or demand shocks over 12-month horizons. In addition, it is also notable that the large decline in the oil price from mid-2014 to 2016 is mostly left unexplained, as shown in Figure 2. From its peak in June 2014 to February 2016, the unexplained component appears to be 86 percent of the decline in the oil price.

Figure 3 plots the historical decomposition based on the shocks identified from the five-variable VAR, additionally including future supply and demand shocks to the three-variable VAR. Compared with Figure 2, the contributions of oil price-specific shocks are smaller. Most of them are accounted for by the contributions of future supply and demand shocks, which indicates that these expectations factors play important roles in explaining the oil price fluctuations. The contributions of the future supply and demand shocks are sizable. The variance decomposition estimate reported in Table 2 indicates that 30-35 percent of variance in the oil price is explained by the future supply and demand shocks. It is also remarkable that in the five-variable model, the patterns of the contributions of realized demand and supply shocks remain almost unchanged even after adding two variables to the three-variable VAR (compare the light blue and yellow areas between Figures 2 and 3), and additionally provides the contributions of future demand and supply shocks on them. This means that the proposed shocks improve the model as they explain 30-35 percent of oil-price variance for the above-mentioned unexplained 80 percent component in the original three-variable VAR. Regarding the large decline in oil price from June 2014 to February 2016, the future supply and demand shock explain about 50 percent of the decline in the historical decomposition.

Tracking the historical decomposition and several major episodes in the crude oil market tells us that the identified shocks and their contributions to the oil price are economically meaningful and reasonable. From 2007 to mid-2008, the West Texas Intermediate (hereafter WTI) hiked from 60 U.S. dollars per barrel to 140 U.S. dollars per barrel. In this period, there was a substantial positive contribution of future supply shocks, which represented the prevailing concern over the oil supply capacity in OPEC countries due to the earlier stagnation in upstream investments and political uncertainty in Middle East countries. Realized demand shocks also pushed the oil price up, indicating the demand pull stemming from the unexpected rapid growth of emerging economies, in particular China and India. At the same time, shale-oil technology came into the oil industry and expectations of excess future supply were considered to put downward pressure on the oil price, which will be formally addressed later.

In the second half of 2008, the WTI fell dramatically from 140 U.S. dollars per barrel to below 40 U.S. dollars per barrel. Our historical decomposition shows that realized demand shocks mainly drove this decline, reflecting the recession just after the Great Financial Crisis. Expected aggregate demand shocks also contributed to the decline to some extent. From 2010 to early 2012, the WTI steadily increased from around 80 U.S. dollars per barrel to over 100 U.S. dollars per barrel. The main contributors were realized demand shocks and future supply shocks. The former represented the steady growth of emerging economy and the United States after the Great Financial Crisis. The latter captured the uncertainty on oil supply stemming from the social instability in the Middle East and North Africa before and after the so-called Arab Spring. From the second half of 2013 to the first half of 2014, future oil supply shocks positively contributed to the oil price hike, representing the increasing uncertainty over the situations in the Middle East (Syria, Iran and Iraq) and Ukraine/Russia.[8]

From mid-2014, all shocks turned to decrease and push the oil price down, though the timings and magnitudes varied. This stream can be divided into two phases. The first period is from January 2014 to January 2015, when the real oil price plunged by about 50 percent. About 40 percentage points are explained by the future oil supply

[8] Caldara and Iacoviello (2017) propose a geopolitical risk index that measures geopolitical tensions and show that an increase in geopolitical tensions leads to a hike of real oil prices initially, but to a persistent decrease due to a contraction of global aggregate demand afterwards.

shocks, which can be interpreted as influences arising from the expected increase in US shale oil, the recovery of Libyan oil production and, most importantly, Saudi Arabia's public announcement that it would not act as the "swing producer."[9] A decrease in the realized demand shocks had also contributed to the decline by about 10 percentage points. The second period is June 2015 to February 2016, the real oil price further decreased by about 30 percent. In this second period, both realized and future demand shocks played major roles, which is a clear distinction from the first period. The realized and future demand shocks pulled the real oil price down by 7 and 14 percentage points, respectively.

Figure 5 shows impulse responses of the real oil price to each of the five shocks in the five-variable VAR. Note that all shocks are set to lower the real oil price and a shock size is set equal to one standard deviation. An unexpected increase of global oil supply causes a limited but certain decrease in the real oil price at the initial month and its impact on oil price turns out to be quite small afterward, which is consistent with the findings of Kilian (2009).[10] Negative shocks in both realized and future demand lead to immediate, large and statistically significant declines in the real oil price. A positive future oil supply shock immediately causes a more persistent decrease in real oil prices than demand shocks. Shifts in expected supply schedules triggered by, for example, exogenous political events, are thought to create more persistent effects on oil price developments than realized demand shocks. An effect from oil price-specific shocks is also significant and persistent.

4.2 Other relevant sources of oil price fluctuations

Although the main result shown above provides considerably plausible estimates in describing the oil price fluctuations, we explore other relevant sources behind the oil price dynamics. Based on the five-variable VAR, we consider several additional important factors that can explain the unexplained components of the oil price variance.

4.2.1 Financial factors

Financialization in commodity markets and its influence on commodity prices have been widely discussed in the literature (eg Chari and Christiano (2017)). Basak and Pavlova

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9 Arezki and Blanchard (2015) point out, "The resulting shift by the swing producer (Saudi Arabia), however trigger a fundamental change in expectations about the future path of global oil supply, in turn explaining both the timing and the magnitude of the fall in oil prices, and bringing the latter closer to the level of a competitive market equilibrium."

10 One hypothesis to explain this result is that an unexpected increase of global oil supply causes an increase of oil inventory, leading to the expectation of a decrease in future oil supply.

(2016) consider that the activity of financial investors in the oil futures market affects oil price dynamics. They propose a mechanism whereby financial investors amplify the response of the real oil price to realized aggregate demand shocks. The analysis here investigates an effect of changes in the expectations of financial investors on the oil price in our VAR setting, using the net position of non-commercial investors in the crude oil futures market.

Net position of oil (ΔNet)

We use data on the WTI Crude Oil Financial Net Non-Commercial Futures Positions provided by New York Mercantile Exchange. We take the differences of the original series.

We estimate a six-variable VAR, adding the net position in the oil futures market to the baseline five-variable VAR. We identify six shocks in the model by extending Equation (2) to the following:

$$\begin{pmatrix} e_t^{\Delta\text{prod}} \\ e_t^{\text{rea}} \\ e_t^{\Delta\text{CF}} \\ e_t^{\Delta\text{Stock}} \\ e_t^{\Delta\text{Net}} \\ e_t^{\text{rpo}} \end{pmatrix} = \begin{bmatrix} a_{11} & 0 & 0 & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 & 0 & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} & 0 & 0 \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} & 0 \\ a_{61} & a_{62} & a_{63} & a_{64} & a_{65} & a_{66} \end{bmatrix} \begin{pmatrix} \varepsilon_t^{\text{realized supply}} \\ \varepsilon_t^{\text{realized demand}} \\ \varepsilon_t^{\text{future demand}} \\ \varepsilon_t^{\text{future supply}} \\ \varepsilon_t^{\text{financial factor}} \\ \varepsilon_t^{\text{oil-price specific}} \end{pmatrix}. \tag{3}$$

We include the net position in the oil futures market as after the oil inventory (ΔStock) and before the real price of oil (rpo). Financial factor shocks are referred to as the net position in the oil futures market. We assume that expected future oil supply does not respond to financial factor shocks, while the real price of oil can respond to them. As is implied in Basak and Pavlova (2016), the financial factors capture shocks to the activity of financial investors in the oil futures market such as changes in the risk appetite of investors.

Figure 5 plots the impulse responses of the real oil price based on estimates of the six-variable VAR model. A negative innovation to the net position in the oil futures market significantly lowers the real oil price, and its response is persistent. Table 3 reports the variance decomposition of the real oil price, which indicates that financial factor shocks explain 12 percent of oil price variance. Our proposed expectation components, the shocks of future demand and supply as well as the financial factors, explain about 45 percent of oil price variance in sum, which is quite high. Figure 6 plots the historical decomposition of the real oil price for the six-variable VAR. It is remarkable that the contributions of five variables in the main result are almost the same while the financial factor shocks explain some of the unexplained part in the main result. Financial factor shocks contribute to the upward trend in the price from mid-2012 to 2013. In the large decline in the oil price from mid-2014 to 2016, financial factor shocks explain about 20 percent of the decline in the historical decomposition. It is notable that about 65 percent of the large decline is attributable to the shocks of future supply and demand as well as the financial factors.

4.2.2 Shale-oil news index

One of the important developments in the oil market since the 2000s has been technological developments in the shale-oil industry (eg Lasky (2016), Arezki et al (2017)). Existing literature and discussions in the oil market have considered that the rise of shale-oil technology has played a significant role in substituting for the production of traditional crude oil with relatively cheaper production cost. The rapid decline in costs of oil extraction raised expectations of a large increase in future oil supply. For example, around 2007 and 2008, a public discussion indicated that a development of fracking technology affected the oil price due to a large increase in shale production. These shale-oil technology developments are expected to lower the oil price.

To address this point, we construct a proxy for the behavior of the shale-oil industry by using the number of internet searches in the spirit of Sussman and Zohar (2016).[11] We download a monthly time series of the number of searches for "shale oil" in Google Trends. Figure 1 plots the time series; note that the series is a relative measure without a unit. We label this series the shale-oil news index. The plot shows that the index increases several times between 2005 and 2008, which is mainly due to the new development of shale technology. In 2015, the index hikes, probably due to the increasingly dominant role of shale-oil production and its influence on the large decline in the oil price. Our hypothesis is that an increase in shale-oil news implies expectations of more future oil supply, which lowers the oil price.

We estimate a six-variable VAR model including the shale-oil news index in addition to the five variables in the main result above. Our identification strategy is that we include innovations to the shale-oil news index, labeled as shale supply shocks, after

[11] Sussman and Zohar (2016) construct a measure for OPEC's behavior in the oil market by counting articles published in the London Times that refer to OPEC. Plante and Traum (2012) create an article count index related to OPEC to identify changes in oil price uncertainty.

future demand shocks and before future supply shocks, namely,

$$\begin{pmatrix} e_t^{\Delta\text{prod}} \\ e_t^{\text{rea}} \\ e_t^{\Delta\text{CF}} \\ e_t^{\text{Shale}} \\ e_t^{\Delta\text{Stock}} \\ e_t^{\text{rpo}} \end{pmatrix} = \begin{bmatrix} a_{11} & 0 & 0 & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 & 0 & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} & 0 & 0 \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} & 0 \\ a_{61} & a_{62} & a_{63} & a_{64} & a_{65} & a_{66} \end{bmatrix} \begin{pmatrix} \varepsilon_t^{\text{realized supply}} \\ \varepsilon_t^{\text{realized demand}} \\ \varepsilon_t^{\text{future demand}} \\ \varepsilon_\text{t}^{\text{shale supply}} \\ \varepsilon_\text{t}^{\text{future supply}} \\ \varepsilon_t^{\text{oil-price specific}} \end{pmatrix}.$$

We assume that the shale supply shock is an innovation in which future demand is controlled and that future supply shocks are now defined as innovations to expectations of future oil supply other than expectations of developments of future shale-oil supply.

Estimated impulse responses of the oil price indicate that a positive shale supply shock, which is associated with an increase in shale-oil news, appears to lower the oil price. This supports our hypothesis and indicates that the development of shale-oil technology is a relevant source of oil price fluctuations. Figure 7 plots the historical decomposition based on the six-variable VAR including shale supply shocks. Contributions of shale supply shocks turn down in the second half of 2008, which reflects the widespread expectations that future oil supply is likely to increase with the development of cheap shale-oil technology. Contributions of total future supply shocks -- the sum of shale supply and future supply shocks -- turn to apply downward pressure at that time, slightly before the plunge of oil prices from late 2008. In addition, at the time of the large oil price drop from mid-2014, it is notable that the shale supply shock explains about 20 percent of the price drop for the first half of the plunge period, from June 2014 to January 2015.

4.3 Influence of oil price shocks on global output

We examine the consequences of each shock identified in our model on global industrial output. Figure 9 shows the impulse responses of global output to shocks based on the six-variable VAR including the financial factors. Note, again, that all shocks are set to lower the real oil price and a shock size is set equal to one standard deviation. We point out four factors. First, as for the realized supply shock, an unexpected increase of global oil supply causes a small but statistically significant increase in global output in the initial two months but its impact on oil prices turns out to be insignificant afterward. Second, realized and expected negative demand shocks bring global output down significantly for almost one year. This means that if a negative demand shock hits the economy, not only the real oil price but also global output decrease simultaneously for certain periods.

Third, both positive future oil supply shocks and negative oil price-specific shocks initially push global output down, probably reflecting contractions mainly in the upstream investments of crude oil. Almost one year after these shocks, however, global output increases in a statistically-significant manner. This response of global output is considered as a positive impact on the global economy through the increase of real income or the decrease of production costs in oil-importing economies. Finally, financial factor shocks bring a small but significant (in most periods) increase in global output. We note that the negative shocks to financial factors decrease the oil price in Figure 6. Figure 9 shows that this has positive impacts on the global economy because a fall in oil prices increases the real income of oil importer economies or decreases production costs, pushing up the benefits for firms.

All of these features clearly show that "not all oil price shocks are the same" in accounting for the development of real oil prices and global output. Bearing these findings in mind, one has to identify the shocks behind an oil price decline when evaluating its consequences on global output.

Variance decomposition estimates of global output provide evidence that while about 60 percent of its variance is explained by its own shocks, ie, the realized demand shocks at a 12-month horizon, it is notable that future demand shocks explain about 30 percent of the variance. The contributions of these realized and future demand shocks decrease over the time horizon and it becomes about 30 percent in total at 60 months. On the other hand, the variance attributable to future supply, financial factors and oil price-specific shocks increases, reaching about 60 percentage points in total at 60 months. These results indicate that even if the real oil price declines due to positive future supply shocks, negative financial factors or oil price-specific shocks, it takes a relatively long time for the positive impact on global output to emerge. This delayed response of global output to these shocks partly explains the mediocre economic development since mid-2014 even under the oil price plunge.

4.4 Robustness check

This subsection examines the robustness of our main results reported so far. Based on the five-variable VAR, we examine three different exercises to check the robustness.

4.4.1 Global monthly GDP

One can argue that global IIP does not fully reflect the whole global aggregate demand. We alternatively use global monthly GDP, which is defined as a common component among real GDP growths of major advanced economies. We construct this series as follows.

Global monthly GDP

We take the first principal component of the quarterly real GDP growth rates in the United States, the United Kingdom, the euro area, and Japan and interpolate it to produce a monthly series.

Figure 1 shows the time series of global monthly GDP, which exhibits a clearer plunge during the European debt crisis from 2010 to 2013 than global IIP. For the robustness check, we use the six-variable VAR including the financial factors in section 4.2.1, where global IIP is replaced by global monthly GDP. Figure 8 plots the resulting historical decomposition of the real oil price. Compared to Figure 5, the overall picture does not change, while we can now see a downward contribution of the realized demand shocks to the oil price during the European debt crisis. The impulse responses of the oil price are almost the same as those in the main result above.

4.4.2 Oil-related IIP

Related to the previous robustness check, one can argue that if we incorporate a measure for oil-related global aggregate demand into the model it may increase the model's fit. We construct a series of "oil-related IIP," by taking the first principal component between global IIP and monthly total world consumption as provided in the EIA's Short Term Energy Outlook (STEO). We estimate the six-variable VAR model including the financial factors with global IIP replaced by oil-related IIP. The variance decomposition based on the estimates shows a slightly higher contribution of the realized demand shocks. Resulting impulse responses and historical decomposition draw almost the same pictures as the main result.

4.4.3 The orderings

As the final robustness check, we examine different orderings of the variable in the VAR system from Equations (2) and (3). We estimate the model altering the orderings of (a) future demand and supply shocks, (b) future supply and oil price-specific shocks in the five-variable VAR, and (c) financial factors and oil price-specific shocks in the six-variable VAR. Estimates from all of these alternative orderings do not significantly change the implications in the impulse responses, the variance decompositions, or the historical decompositions compared to the main result.

5. Conclusion

This paper proposes a novel SVAR model of the real oil price to shed light on the role of expectations in the crude oil market. Our model enables one to quantitatively examine the respective importance of shocks on expectations of future aggregate demand and oil supply in addition to traditionally-used realized aggregate demand and oil supply factors. We find that future demand and supply shocks explain about 30-35 percent of oil price variance and that, among those shocks, expected future supply shocks have the largest influence on the oil price. The cumulative contribution of oil price shocks based on historical decomposition reveals the mechanism behind major episodes of oil price fluctuations. We also find that the influence of oil price shocks on global output varies according to the nature of each shock, which confirms that it is important to understand the causes of oil price developments in evaluating their macroeconomic influence.

The results in this paper have clear implications for the heterogeneities of the roles of shocks on the real economy. In particular, since shocks to expectations play a significant role in accounting for the fluctuations in oil prices in the past decade, it is important for policy makers to learn more about those heterogeneities. Based on our work, it is of interest to examine the roles of expectations in the oil market on other economic and financial variables such as exchange rates. The existing literature provides evidence that exchange rates react differently to each shock in the oil market (eg Akram (2009), Chen et al (2016)). Possible future work could include assessing the influence of the future supply and demand shocks identified in our model on various currencies.

Our approach is silent on the mechanism through which the shocks affect the real economy. A richer structural VAR model is required in order to examine this link, which is left for future work.

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Table 1. Variance decomposition of the real oil price with 3 variables (in percent).

Horizon (months)	Realized Supply Shock	Realized Demand Shock	Oil-Price Specific Shock
1	0.6	3.9	95.6
12	0.1	6.1	93.8
24	0.1	7.5	92.4
60	0.2	13.7	86.0

Table 2. Variance decomposition of the real oil price with 5 variables (in percent).

Horizon (months)	Realized Supply Shock	Realized Demand Shock	Future Demand Shock	Future Supply Shock	Oil-Price Specific Shock
1	0.5	3.5	6.0	10.6	79.5
12	0.1	6.7	10.0	25.4	57.8
24	0.1	6.4	8.3	26.0	59.1
60	0.3	5.7	5.6	26.9	61.6

Table 3. Variance decomposition of the real oil price with 6 variables (in percent).

Horizon (months)	Realized Supply Shock	Realized Demand Shock	Future Demand Shock	Future Supply Shock	Financial Factor Shock	Oil-Price Specific Shock
1	0.9	3.0	6.1	10.7	20.7	58.7
12	0.2	6.1	9.1	26.0	9.9	48.6
24	0.3	5.9	7.7	26.5	10.7	48.9
60	0.5	5.5	5.1	27.2	12.0	49.7

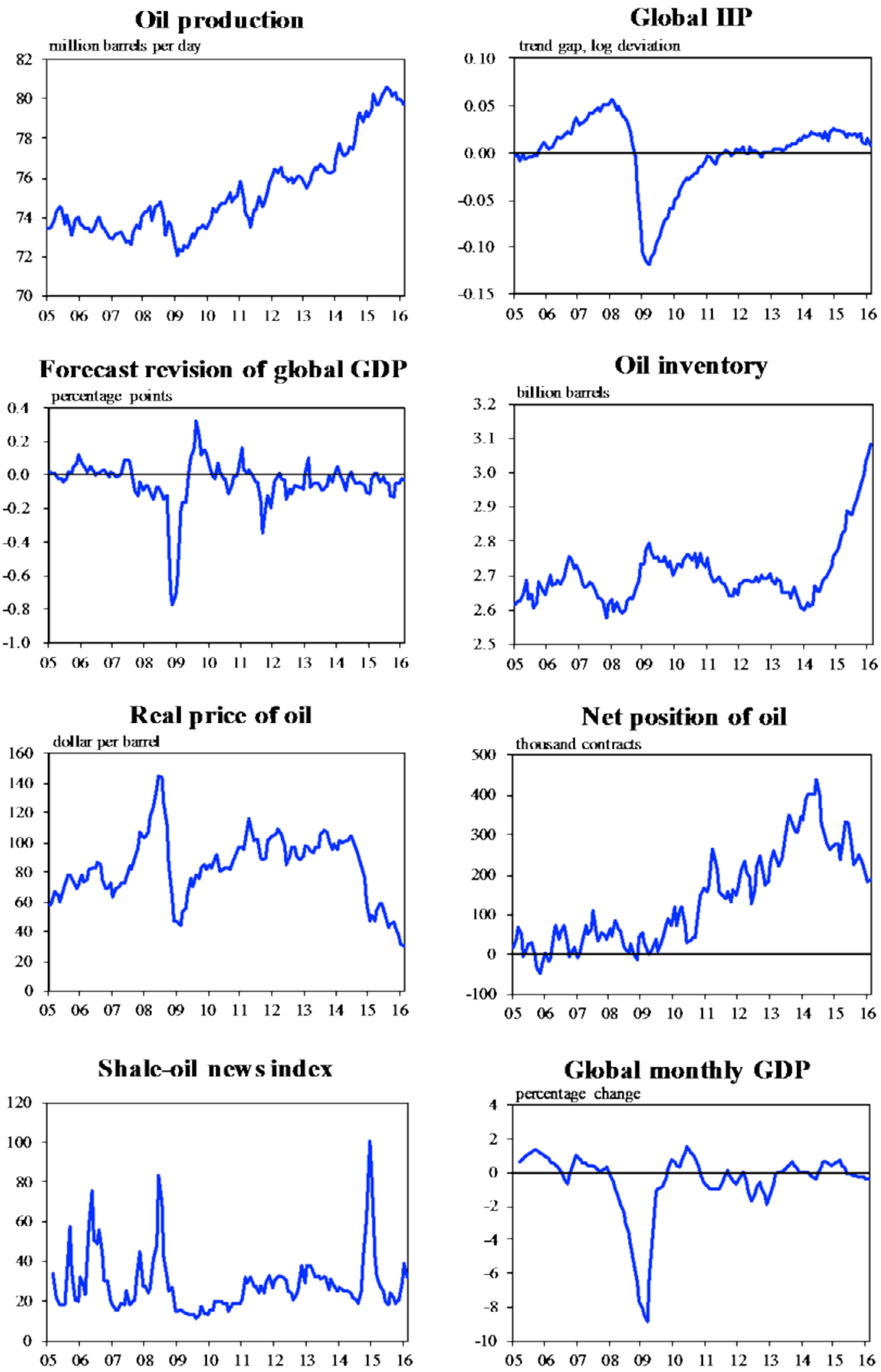

Figure 1. Time series of data.

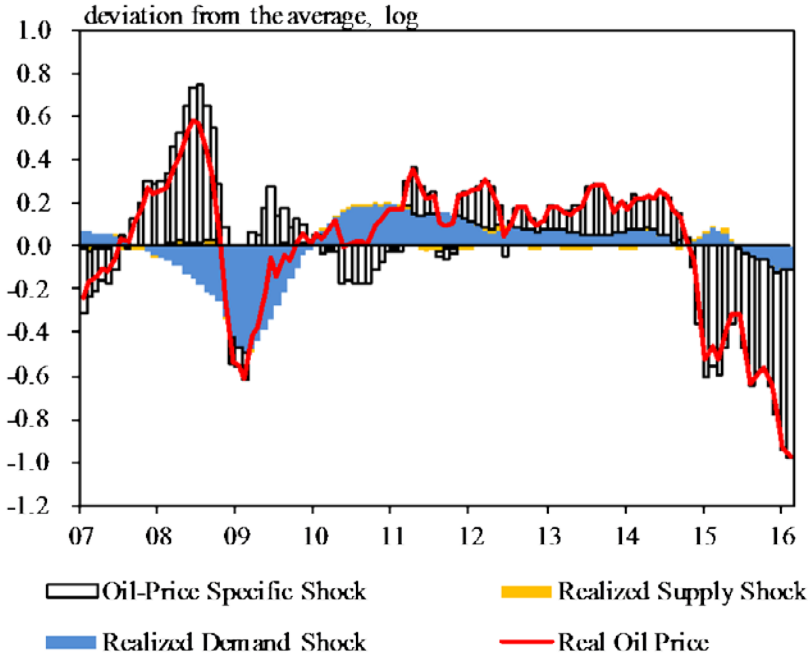

Figure 2. Historical decomposition of the real oil price with 3 variables.

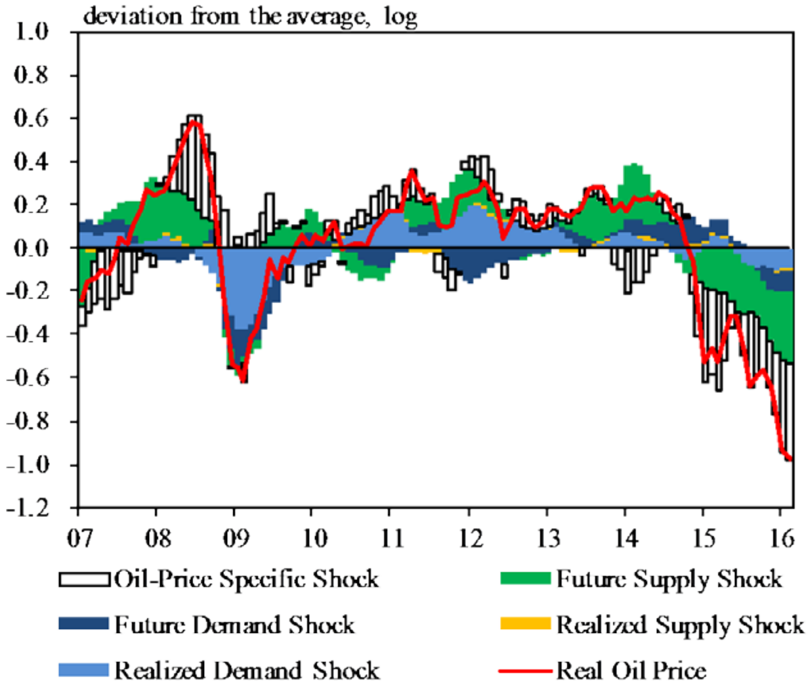

Figure 3. Historical decomposition of the real oil price with 5 variables.

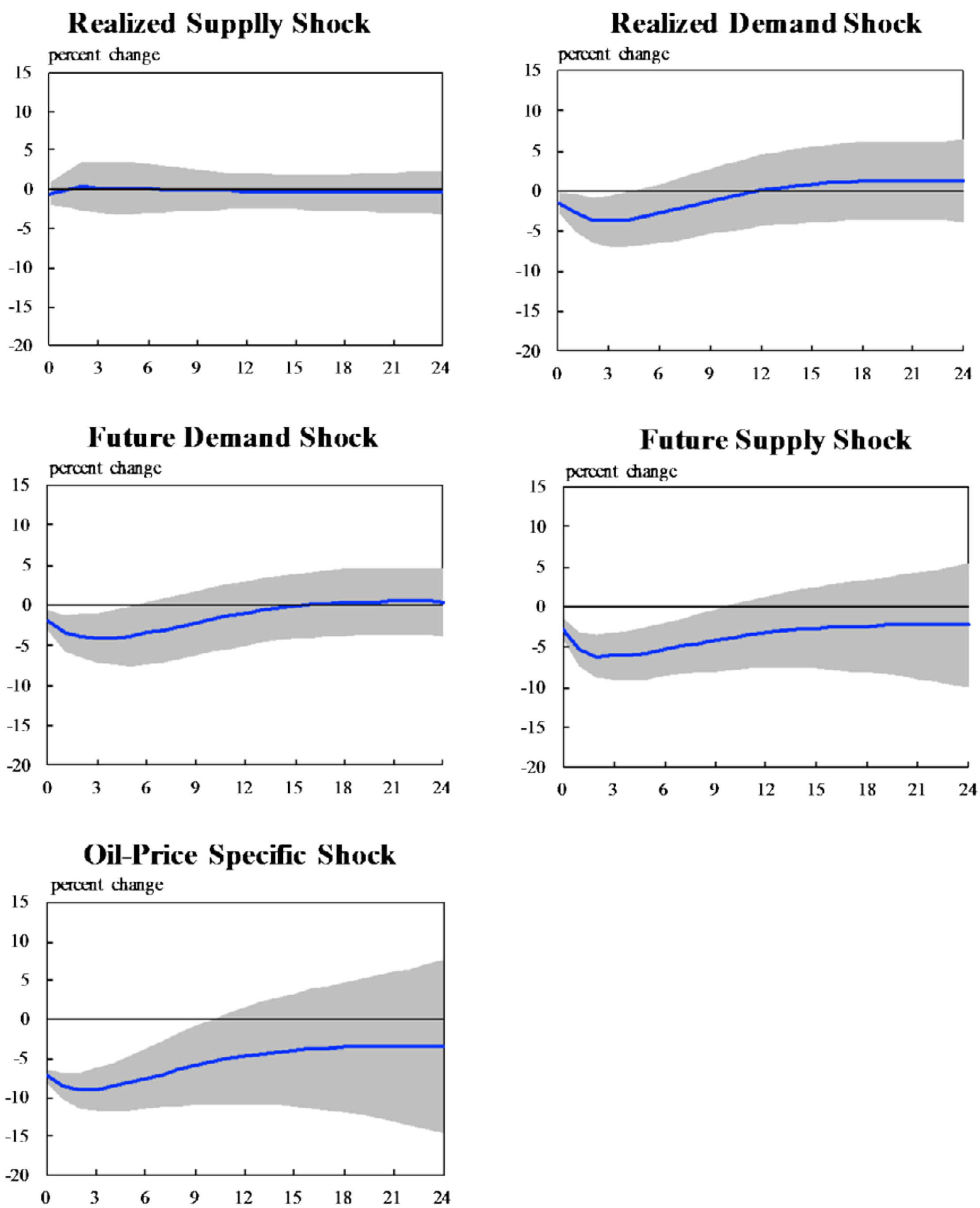

Figure 4. Impulse responses of the real oil price in the 5-variable VAR. The shaded area refers to 95 percent credible intervals. The horizontal axis refers to months from the shock. The sign of shock is set to lower the real oil price.

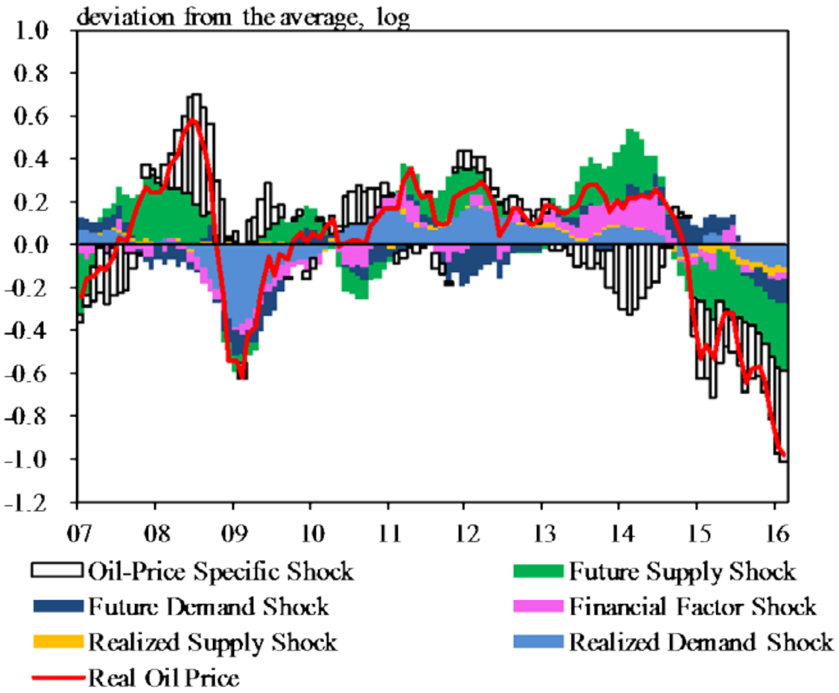

Figure 5. Historical decomposition of the real oil price with 6 variables including the financial factor.

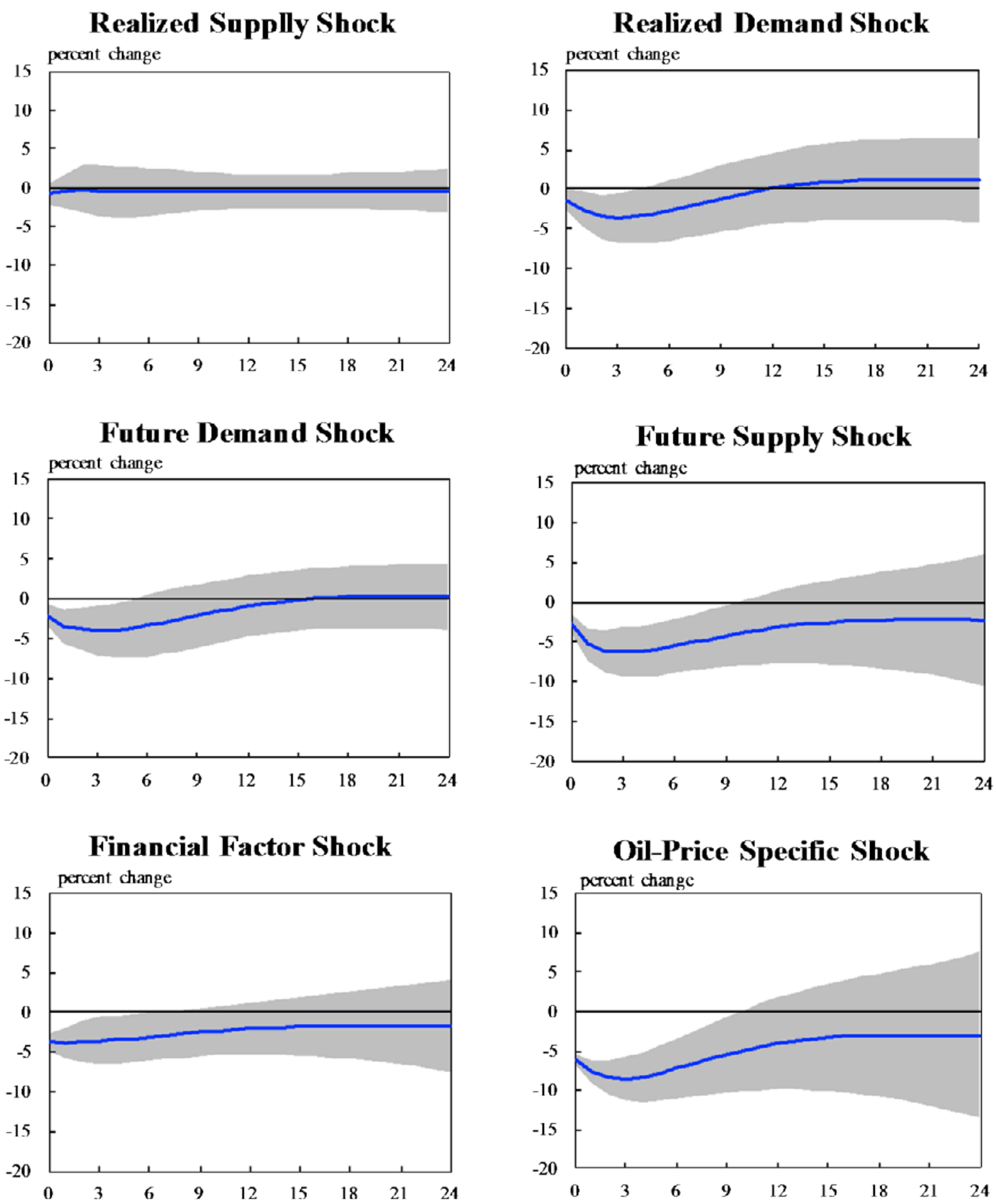

Figure 6. Impulse responses of the real oil price in the 6-variable VAR including the financial factor. The shaded area refers to 95 percent credible intervals. The horizontal axis refers to months from the shock. The sign of shock is set to lower the real oil price.

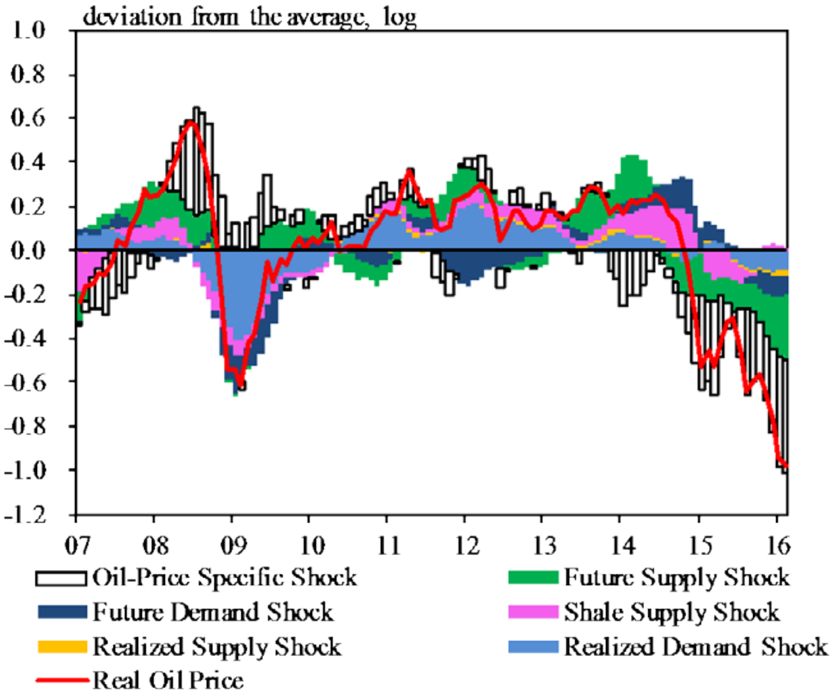

Figure 7. Historical decomposition of the real oil price with 6 variables including the shale news index.

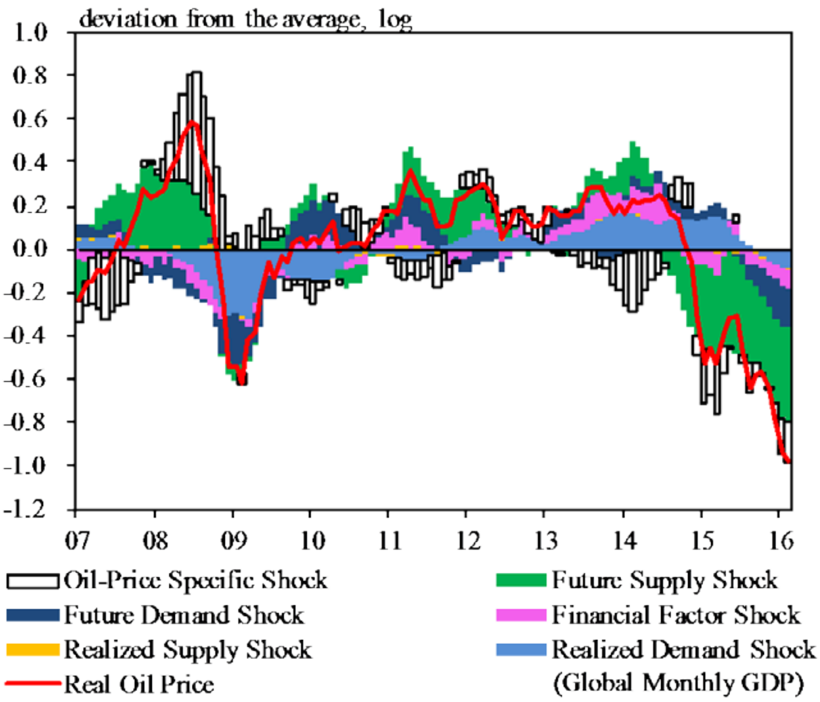

Figure 8. Historical decomposition of the real oil price with 6 variables including global monthly GDP.

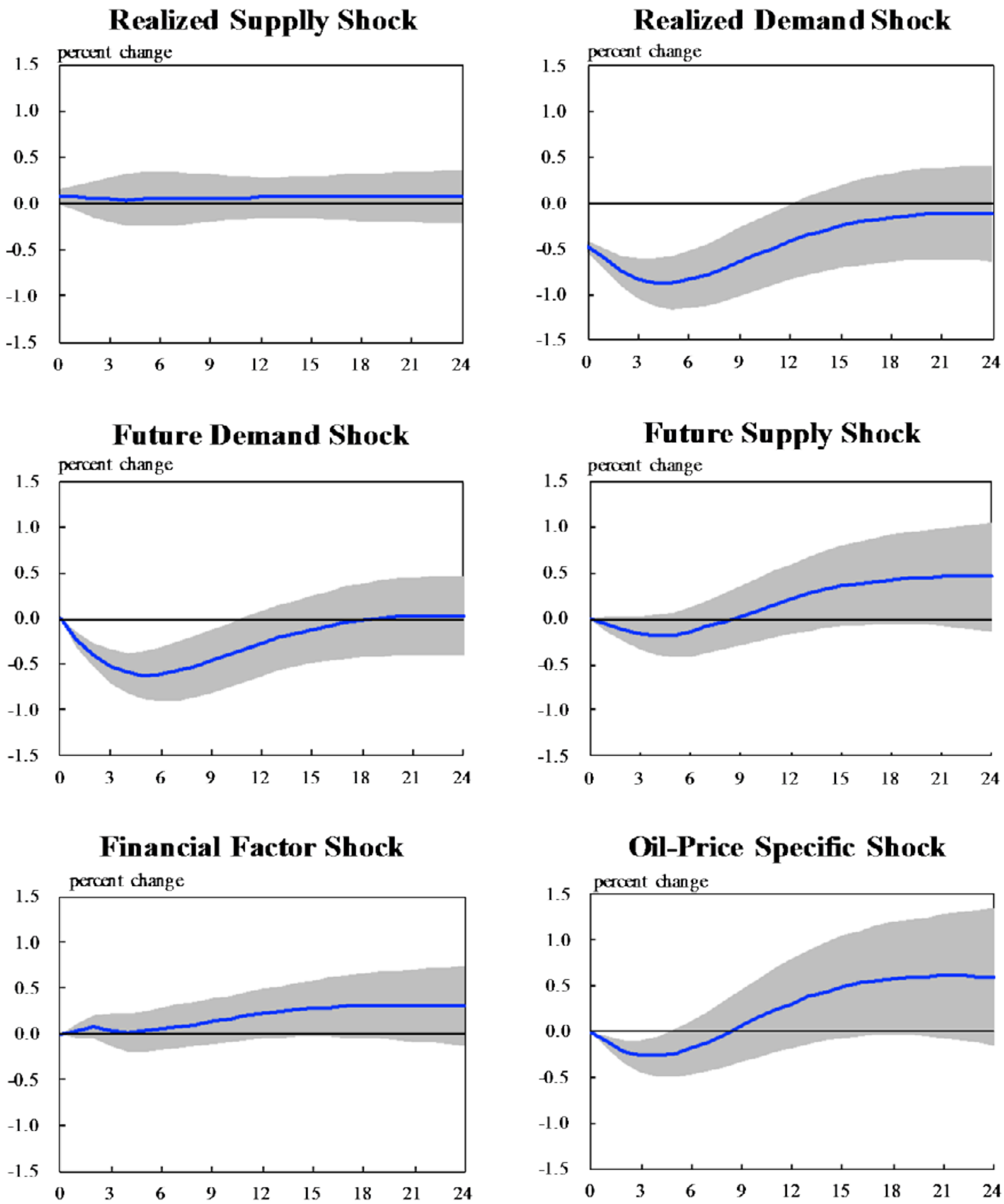

Figure 9. Impulse responses of the global output in the 6-variable VAR including the financial factor. The shaded area refers to 95 percent credible intervals. The horizontal axis refers to months from the shock. The sign of shock is set to lower the real oil price.

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