Thesis for the Degree of Master of Arts

Identifying Sources of Oil Price Shocks 2008-2016

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August 2017

Identifying Sources of Oil Price Shocks 2008-2016

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Arts

June 2017

This thesis has been examined and approved.

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Abstract

Oil price shocks continue to surprise economists, policymakers, and consumers. Recent innovations in the price of oil highlight the necessity of identifying sources of oil price shocks. This paper extends Kilian's (2009) structural VAR and decomposes oil price shocks into aggregate crude oil supply, aggregate demand for industrial commodities, and oil-specific demand shocks for 2008:1-2016:12 period. Positive and negative shocks in this period stem largely from aggregate demand for industrial commodities, with smaller contributions from positive crude shocks (increased US shale production) and decreasing oil-specific demand shocks (precautionary demand for oil). Regressions of US GDP growth rates and CPI inflation exhibit opposite responses to differentiated shock sources. Identifying channels of transmission via structural VAR models has highly pertinent implications for the development of oil-sensitive macroeconomic models.

Keywords: Oil price shocks, structural VAR, oil and the macroeconomy

초록

유가 충격은 경제학자, 정책 입안자 및 소비자를 누차 놀라게 한 것이다. 본 연구는 Kilian 2009 의 구조적 벡터 자기회귀(VAR) 을 확장하고 유가 충격을 총 원유 공급, 산업재에 대한 총 수요 및 석유 관련 수요 충격으로 2008 년 1 월부터 2016 년 12 월까지 기간으로 분해한다. 이 기간의 긍정적 및 부정적 충격은 총 수요 충격으로 인해 크게 발생했고 긍정적인 공급 충격 (미국 셰일 생산량 증가) 및 오일 특정 수요의 변동(사전 예방적 수요) 모두 유가에 작은 영향을 미쳤다. 구조 VAR 모델을 통한 전달 채널을 확인하는 것은 유가 충격의 거시경제에 미치는 효과를 해석하고 오일에 민감한 거시경제 모델을 개발하는 데 매우 관련된다.

핵심어 : 유가충격, 구조적 벡터 자기회귀 모형, 유가 및 거시경제

Identifying Sources of Oil Price Shocks 2008-2016

I. Introduction

Few commodity prices are as closely watched as oil prices. Whether it is the price per barrel of crude on the international oil market or the price per gallon of gasoline at the local gas station, oil prices occupy a position of keen interest as a barometer of global and local markets. And rightly so. The dynamic relationship between oil and the economy has been the topic of extensive analysis and discussion for over four decades.

Far from exhausted, the oil field has plenty of surprises. Recent movements in the crude oil price series suggest a greater level of complexity and correlation in the dynamics governing the effects of oil prices on the macroeconomy than previously estimated (see figure 1). These unanticipated movements in the price of oil are referred to as *oil price shocks* and *innovations*. Oil prices surged through 2007 to an unprecedented high of 145.16 USD in July 2008 before falling 30.28 USD in late December 2008. The "recovery" of 100USD per barrel price levels after 2010 appear to have reflected positive expectations of global economic growth following the financial crisis and led even the most venerable energy economists to conclude such prices were "here to stay" (Hamilton, 2014).

A gradual decline in oil prices starting mid-2014 heralded a period of sustained low prices not seen since the 1990s. Between June 2014 and December 2014, the monthly average price of Brent crude oil fell by 49USD, which amounts to 44% of its original value. Sustained declines in the price of oil are rare events. The 2014 oil price decline is only surpassed in magnitude by the 56% cumulative decline in the price of oil in early 1986 after Saudi Arabia abandoned its policy of stabilizing the price of crude oil, and the 67% cumulative decline during the financial crisis of late 2008 (Baumeister and Kilian, 2016b). In the absence of an obvious oil event such as these, the source of the current decline in oil prices remains an open question.

This paper investigates how explicit structural shocks that characterize oil prices contributed to fluctuations in the oil price series from 2008:1-2016:12. The structural vector autoregression (VAR) methodology proposed by Kilian (2009) and vetted by Kilian and Murphy (2012) is extended through the end of 2016 to decompose oil price innovations into three driving forces: global crude oil supply, aggregate demand for industrial commodities, and oil-specific demand shocks. Global crude oil supply shocks (*oil supply* shocks) reflect unexpected changes in global crude oil supply levels. Global aggregate demand shocks (*aggregate demand* shocks) indicate fluctuations in the global business cycle. Lastly, oil-specific demand shocks capture changes in the precautionary demand for oil. This component may also be interpreted of as the risk premium of holding oil inventories.

The value of the model lies in its sensitivity and simplicity. The VAR model allows for the differentiation of the endogenous and exogenous sources of movements in the price of oil. With the requirements of robust data sets and heightened attention to the existence of any and all plausible oil events at any given point in time, extending Kilian (2009) proves useful for understanding oil price dynamics and recent price innovations. Whereas Kilian focused on positive oil price shocks, the sharp decline in late 2008 and steady decline since mid-2014 offer episodes of negative oil price shocks. Nonlinearities and asymmetries in responses to oil price shocks are well documented (Hamilton 2011; Balke, Brown, & Yücel 2012). Thus, periods of negative oil price shocks may be categorically different from positive oil price shocks. Kilian's analysis found decompositions of historical price shocks point to aggregate demand shocks and oil-specific demand shocks as the main source of oil price innovations, rather than oil supply, as commonly held. This paper also concludes that the contribution of supply shocks to oil price innovations is generally smaller than typically thought: the steep declines in oil prices in late 2008 and steady declines beginning in mid-2014 were largely driven by aggregate demand shocks. Thus, evaluating the dynamics of oil price shocks provides valuable insight into a highly pertinent and complex sector.

Of equal importance are the implications of shocks of varying sources on macroeconomic variables, a topic that receives much scholarship (see Kilian 2008). Some of the discrepancies in economists' findings may be attributed to a lack of sensitivity of each unique shock. This paper examines the effects of varying shock sources on the U.S. GDP growth and CPI inflation and finds opposing responses of these variables to supply shocks and demand shocks. Regarding all oil price shocks as supply-driven results in unstable regressions of macroeconomic aggregates (Kilian, 2009). Thus, disentangling the source of oil price shocks is of "first-order importance for applied work" (Baumeister and Kilian, 2016a).

The paper is organized as follows. Section 2 provides a review of relevant literature. The main topics of interest are the evolution of the methodologies employed to analyze oil price shocks and the necessity of endogenizing the price of oil while allowing for various sources of oil price fluctuations. Based on these discussions, section 3 introduces the structural VAR model developed by Kilian (2009) for disentangling sources of oil price shocks into global oil supply, aggregate demand, and oil-specific demand shocks. The model is extended from the original 1974:1-2007:12 dataset to include 2008:1-2016:12. The model is identified based on bounds on the impact price elasticities of oil demand and oil supply.

Section 4 discusses the results of the model and compares these results with other explanations of oil price movements for the 2008:1-2016:12 period. The results suggest the highs and lows of 2008 were predominantly driven by strong aggregate demand and to a lesser extent unexpected changes in crude oil supply. Likewise, the period of low prices since 2014 initially stemmed from low oil-consumer expectations concerning global economic growth, and not from increases in US oil production shifting global production levels outward. As a way of application, section 5 estimates the effects of the decomposed structural shocks on US GDP and CPI inflation following an oil price shock. The results confirm Kilian (2009) and others' finding that macroeconomic aggregates exhibit varying responses to different oil price shock sources. Lastly, section 6 concludes that the price of oil is determined by time-varying compositions of supply and demand shocks that in turn impact the macroeconomy in different ways.

I. Background

The close statistical connection between positive oil price shocks and economic recessions spurred extensive research into linking oil price innovations and macroeconomic aggregates. Beginning with Hamilton (1983), who found that nearly every recession in post-war U.S. was preceded by a change in the price of oil, economists have sought the causal link and channel of transmission of an oil shock into the macroeconomy. An extensive literature (mainly empirical) has attempted to identify the effects of energy supply shocks on real output and prices, and how monetary policy may influence the response; examples include Bernanke, Gertler, and Watson (1997) Hamilton (2003), Hamilton and Herrera (2004), and Cavallo and Wu (2006).

The literature, however, is far from conclusive. The "textbook" narrative of the 1970s is called into question by the experience of the 2000s. The oil price shocks of the 1970s were viewed as the product of exogenous political events disrupting crude oil supply, the "smoking gun" behind inflation, slowed economic growth, and recessions (see Hamilton 2003; Bernanke, Gertler, and Watson 1997) While some maintain this position, there has been a shift in the theoretical and analytical framework reflecting the experience of the early 2000s, when steadily increasing prices did not coincide with recessionary pressures as expected (Schmidt and Zimmerman, 2007). Thus, in the early 2000s, the fundamentals of the theoretical framework and analytical methodologies employed to understand oil and the macroeconomy began to be reviewed and refined (see Barsky and Kilian, 2002).

The more recent research and movements in oil prices since the 2000s suggest that the mechanisms by which oil prices flow into the macroeconomy are neither direct nor singular, but rather nonlinear and endogenous (Barsky and Kilian 2004; Hamilton 2011; Bodenstein, Erceg, Guerrieri 2011). Barsky and Kilian (2002) find serious conceptual difficulties in assigning a central role to oil price shocks in explaining recessions and inflation and point to monetary policy responses as the source of the negative effects typically associated with oil price shocks. Kilian (2009, 2014) attributes the change in response to oil price shocks to a misplaced emphasis on the recessionary effects of oil price shocks and promotes demand-focused research and analyzing each oil event as unique through carefully constructed VAR models. However, Blinder and Rudd (2009), Blanchard and Galí (2009), and Blanchard and Riggi (2013) point to structural changes in the US economy over time and defend the traditional narrative of the 1970s. They employ dynamic stochastic equilibrium models that rely on strong assumptions governing the transmission of oil prices on macroeconomic aggregates. Finally, Hamilton (2009a) surveys multiple methodologies and emphasizes the import of model-free data analysis as means of accounting for the complexity and idiosyncrasies of oil price dynamics and their effects.

This lack of a unified paradigm in the literature with which to view and analyze oil price shocks appears to be due to competing theories on the endogeneity of oil prices and lack of sensitivity to the source of the shock, both of which will be discussed in the following two subsections. These discussions provide the rationale for constructing the model in section 3.2.

2.1. The endogeneity of oil prices.

Models linking oil and the macroeconomy vary widely in the way oil enters the economy (as a consumption good, as a standard productive input, as a factor linked to capital utilization, etc.) and thus find varying implications of oil price shocks (Nakov and Pescatori, 2010). The majority, however, share the assumption of oil prices as exogenous (i.e. predetermined) and unrelated to economic fundamentals. Under predetermined energy prices, there can be no feedback from U.S. macroeconomic aggregates to the fluctuation in oil prices. This assumption is traditionally coupled with the assumption that other correlated exogenous events do not exist, which lead to impulse responses suggesting the causal effects of the oil price shock by effectively "assuming out" any other possible source of causality (Kilian, 2008). These models exhibit reverse causality concerns and inappropriate ceteris paribus assumptions (Kilian, 2009). The dangers of such limiting prima facie assumptions are obvious and the value of models built on them is unclear (Kilian, 2008). Such models do not account for reverse causality from macroeconomic aggregates to oil prices (Barsky and Kilian, 2002). Oil shocks have been shown to stem from structural demand shocks as well as supply shocks. Any direct or indirect effects operating through the price of oil from different sources of shocks would be lost under such assumptions. In response to these criticisms, more recent studies, beginning with Nakov and Pescatori (2010), endogenize oil prices and oil markets, yielding more robust results based on weaker assumptions.

The argument for the endogeneity of oil prices is based on two factors. First, it is illogical to employ the ceteris paribus assumption by holding all other variables constant while adjusting the price of oil itself. The relationship between global economic activity and energy prices is well documented (e.g. Hamilton, 2011). Especially for a country with a large economy such as the US, global oil prices are indeed linked to US business cycles. If the price is a function of supply and demand, it would be contradictory to infer that the US macroeconomy was not affecting the supply and demand of oil both directly and indirectly.

Secondly, as discussed further in the following section, by allowing for greater complexity in the oil market with its wide variety of suppliers, refiners, and consumers, it is evident that historical oil price shocks cannot all be stemming from the same source of disequilibrium (Kilian, 2009). For example, the effect of a cut in oil production in one country due to exogenous political events depends on how other oil suppliers respond to the shortfall, the overall macroeconomic environment as reflected in the demand for oil, and the current degree of "anxiety" about future oil supplies (*precautionary demand for oil*). Though as Mabro (1998) found, in the absence of "taut" demand conditions in the oil market, political events are unlikely to cause dramatic shifts in the price of oil. Thus, any model based on oil as an exogenous variable yields questionable results with little practical application.

2.2. Each oil price shock is unique.

Model construction requires assuming a distinct set of possible channels of transmission based on perceived oil events and the dynamics of the macroeconomy. By assuming a possible channel, models tend to substantiate the existence and/or importance of the channel. Thus, distinguishing the idiosyncratic features of each oil price shock from systemic effects prior to model construction is imperative for identifying the key channels of transmission for each oil event and the appropriate monetary policy response. Disentangling the sources of oil price shocks aids in understanding the wide variety of responses of macroeconomic aggregates to fluctuations in the price of oil documented over the past four decades (see Kilian, 2008).

The richer case study of the twenty-first century proves this point. The oil-shock-as-exogenous models following the "Shocking 70s" viewed disruption in crude oil supply due to exogenous political events as the source of volatility (Barsky and Kilian, 2002). However, Kilian (2009) decomposes the price of oil into time-varying combinations of supply and demand shocks. Furthermore, actual disruptions to crude oil production were marginal and fail to account for at least 80% of the price innovations in both 1973-74 and 1979-80

(Lütkepohl and Netšunajev, 2013). Thus, the textbook narrative of oil supply disruptions as the sole or dominant source of the oil price shocks finds little empirical support.

In contrast, by allowing for differing sources of shocks that in turn affect the price of oil, oil price innovations affect the evolution of macroeconomic variables through different channels (Nakov and Pescatori, 2010). Kilian (2009) proposes a structural VAR model to decompose the source of oil price shock into supply, aggregate demand, and oil-specific demand shocks. Viewed in light of these shock sources, each oil event presents clearer methods of transmission and the possibility of constructing models based on weaker assumptions. Cashin et al. (2012) construct a global VAR model based on Kilian (2009) and find supply and demand shocks produce "very different" results for oil importers and exporters. Baumeister and Peersman (2013) utilize Kilian's strategy for identifying unanticipated movements in the price of oil due to exogenous supply shocks with robust results. Thus, The literature highlights the necessity of understanding the underlying cause of each oil price shock before seeking the channel of transmission into the macroeconomy and estimating its effects.

III. Methodology

Selection of the structural VAR model to decompose the real price of oil is based on the following. First, the availability of robust data sets allows for VAR model implementation. Second, the model allows for the real price of oil to influence and be influenced by crude oil production levels and global economic activity and vice versa. The model allows each of the three model variables to linearly depend on its own lags as well as lags of the other model variables up to 24 months, allowing unrestricted feedback across the model variables. This point proves to be critical: by allowing the real price of oil to be endogenous, the model avoids breaking the ceteris paribus assumption and does not produce spurious results (see Kilian and Lütkepohl, 2017).

3.1. Data description

The model focuses on the case of the US economy within the context of the global oil market and global economy. The following data sets were chosen accordingly.

Global crude oil production. Global crude oil production is presented in millions of barrels per day and averaged over the month to create a monthly series.[1] The change in global crude oil production reflects the percent change between the observed value at month *t* and month *t-1*. Thus, these percentages reflect unanticipated movements in global production levels.

Global real economic activity. The global economic activity index employed in this paper is taken from Kilian (2009) and maintained by Professor Kilian.[2] The index, based on dry cargo single voyage ocean freight rates, reflects "shifts in the demand for industrial commodities driven by the global business cycle" (Kilian, 2009). Well-studied international freight rates have long been used as economic indicators and the index automatically aggregates the economic activity, variations in outputs, imports, and exchanges rates of all countries. Important for this paper, the index is available at the monthly frequencies required to identify the structural VAR model in the following section.

Since 2009, this indicator has become a popular choice to represent global real economic activity, in particular for oil price studies. The next best available index is the OECD industrial production data, but it is not a truly global measure of real activity; for example, it fails to reflect outpacing of OECD by growth in Asian demand for industrial commodities since 2002. The Kilian index is preferable because there is no need for exchange rate weighting (as with other indices of industrial demand) or to account for technological changes affecting the link from rising production to the global demand for

[1] Data set available at https://www.jodidata.org/oil/.
[2] Index available on Professor Kilian's homepage: http://www-personal.umich.edu/~lkilian/reaupdate.txt.

industrial commodities.

Among others, Apergis and Miller (2009) model the effect of oil shocks on different country stock prices using this index. Ratti and Vespignani (2013) build a structural VAR model to describe the influence of global liquidity on oil prices using Kilian's index as a proxy for global economic activity. Baumeister and Kilian (2015) use this index, in conjunction with other variables, to forecast real oil prices. In their discussion of the robustness of various global economic activity indicators, Ravazzolo and Vespignani (2015) find the Kilian index of global real economic activity accurately predicts world GDP growth rates.

Real price of oil. The real price of oil is based on U.S. refiner acquisition costs of imported crude oil, as available on the EIA website.[3] This price set provides an aggregated price of all foreign-produced oil, including OPEC and Brent oil prices, as well as non-major producers. Many studies base their analysis on the price of West Texas Intermediate (WTI), the price of sweet crude oil produced in the US. This paper follows Kilian (2009) in seeking out an alternative data set. Refiner acquisition costs reflect the prices importers actually face, rather than the market spot price. Thus, this source provides an accurate picture of the "real" price of oil. The prices reported by the EIA are deflated by the CPI to achieve the real price of oil.

3.2. Structural VAR model

The VAR model outlined by Kilian (2009) structurally decomposes the real price of crude oil into mutually orthogonal parts. Consider a VAR model based on monthly data for $z_t = (\Delta prod_t, rea_t, rpo_t)'$ where $\Delta prod_t$ is the percent change in global crude oil production; rea_t denotes the index of real economic activity; and rpo_t denotes the real price of oil. The variables rea_t and rpo_t are expressed in logs. Following Kilian (2009), the vector process

[3] Current and historical prices available at U.S. Energy Information Administration: https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=pet&s=r1300____3&f=m

follows a structural VAR representation [eq. 1]

$$\mathrm{A_0 z_t} = \alpha + \sum_{\mathrm{i}=1}^{24} \mathrm{A_i z_{t-i}} + \varepsilon_{\mathrm{t}}$$

where the structural error term, ε_{it} has the following distributions.

$$\begin{pmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \end{pmatrix} \sim iid \left(\begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \right)$$

Corresponding to this inestimable representation, constructing the following reduced form representation allows for solving the model.

$$\mathrm{z_t} = \mathrm{A_0^{-1}}\alpha + \sum_{i=1}^{24} \mathrm{A_0^{-1} A}_i \mathrm{z}_{t-i} + \mathrm{A_0^{-1}}\varepsilon_{\mathrm{t}}$$

This representation can be rewritten as the reduced-form VAR representation [eq. 2]:

$$\mathrm{z_t} = \gamma_0 + \sum_{\mathrm{i}=1}^{24} \gamma_i \mathrm{z_{t-i}} + u_t$$

where $\gamma_0 = \mathrm{A_0^{-1}}\alpha$; $\gamma_i = \mathrm{A_0^{-1}A}_i$; and $u_t = \mathrm{A_0^{-1}}\varepsilon_{\mathrm{t}}$. The model is then estimated by the least-squares method to construct the original structural VAR representation [eq. 1] by identifying the impact multiplier matrix $\mathrm{A_0^{-1}}$. To accomplish this, the following impact restrictions are imposed.

1. Aggregate demand and oil-specific demand shocks do not immediately affect crude oil production levels. In this model, crude oil production has a vertical short-run supply curve; production levels typically do not change within the same month as demand shocks, whether aggregate or oil-specific. This assumption is well-proven as crude oil production levels do not respond quickly to shifts in the demand curve.[4]
2. Oil-specific demand shocks may only have a delayed effect on real economic activity, as indicated by the data.

[4] Hamilton (2009) and Kilian (2009) observe that "in the absence of significant excess production capacity, the short-run price elasticity of oil supply is very low."

3. Any innovation not accounted for by changes in supply or aggregate demand will be considered as stemming from oil-specific demand shocks. The rationale lies in the absence of an alternative; indeed, any alternative would be orthogonal to an oil-specific demand shock and the issue becomes semantic, not substantive.

Consistent with these arguments of the impact price elasticities of oil supply and demand, the matrix A_0^{-1} may be postulated to take the following form:

$$A_0^{-1} = \begin{pmatrix} a_{11} & 0 & 0 \\ a_{21} & a_{22} & 0 \\ a_{31} & a_{32} & a_{33} \end{pmatrix}$$

The reduced-form errors u_t can be decomposed according to

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

Note that the covariance matrix of u_t is $E[u_t u_t'] = E[\varepsilon_t \varepsilon_t'] = \Omega$. Given the estimated covariance matrix $\widehat{\Omega}$ of the reduced-form error vector u_t, the estimates of A_0^{-1} are recoverable

IV. Results

The results of the structural VAR constructed in Section 3 successfully replicated the results reported in Kilian (2009) for the 1973:1-2007:12 data set. Furthermore, the results of the extended data set are consistent with models for the 2014 oil price series that employ endogenous oil price shocks. Models that assume exogenous supply shocks yield conflicting results. The results suggest aggregate demand shocks comprise the majority of volatility in the real price oil with smaller contributions from oil supply shocks for the period 2008:1-2016:12. Possible explanations largely echo the findings of the model proposed in section 4.2.

4.1. Model results

Evolution of structural shocks. Figure 2 reports the evolution of the various structural shocks contributing to oil price innovations. Oil supply shocks historically have a marked, low magnitude effect on the real price of oil. Oil supply failed to meet strong global demand in 2007-mid-2008 (as seen in the center graph), positively contributing to the strong upward swing in oil prices. The center graph of figure 2 highlights the uncertainty over the global economy from the initial signs of financial crisis and prospects for recovery. These aggregate demand shocks provided the largest sources of shock for the period 2008:1-2016:12. Oil-specific demand shocks, which reflect the precautionary demand for oil among other factors, positively contributed to oil price fluctuations from 2011-2016, with a short break in 2015.

Impulse response. Figure 3 reports the impulse responses of oil supply, aggregate demand, and oil-specific demand shocks to one-standard deviation structural shock in oil production, real economic activity, and the real price of oil. An oil supply shock produces a pronounced decline in oil production that is largely recovered within 6 months. This observation points to the documented pattern of oil supply disruptions in one region spurring increased production in another, essentially offsetting the original loss in output levels. Oil supply shocks initially negatively impact real global economic activity, and while real activity periodically recovers, the shock is persistent past one year. Aggregate demand shocks negatively affect oil production after one year. Oil production responds negligibly to oil-specific demand shocks. However, real activity exhibits a positive response highest after one year before recovering and the real price of oil exhibits sustained, positive impacts to oil-specific demand shocks. Examining the effects on the real price of oil (third column), oil supply shocks have a small, transitory, positive impact whereas aggregate demand shocks have slightly larger, sustained, positive impact.

Decomposition of the real price of oil. Figure 4 decomposes the real price of oil from 1973:1-2016:12. The peak cumulative effect of aggregate demand shocks on the real price of oil in 2010 suggests the current decrease in oil prices since mid-2014 may be a correction of the strong economic forecasts from 2005-2008. As global economic growth rates normalize, the time series indicate that the cumulative effect of aggregate demand shocks will also revert to its historically negligible levels.

4.2 Possible explanations for varying sources of price fluctuations

The structural VAR model in section 3.2 identifies the source of the structural shocks affecting the real price of oil. This section seeks to identify why the structural shock occurred, especially in relation to the US economy, in order to form a cohesive narrative of oil price movements and the macroeconomy.

2007-2008. Strong aggregate demand in developing countries increased the price of oil in 2007 through mid-2008. Demand for industrial commodities in China, though strong for nearly three decades, came to constitute a significant portion of global aggregate demand, especially as demand in the US, Europe, and Japan waned from 2005.

For vast and varied reasons, oil producers responded to the demand-driven boom in oil prices by increasing production only marginally (Hamilton, 2009a). Given the historical and current elasticity of demand for oil, consumers continued to demand oil products even at unprecedented prices. The economic outlook in the first half of 2008 appeared bearish and industry experts failed to anticipate the highs and subsequent rapid decline in the price of oil. The effect of unanticipated changes in crude oil supply declined after peaking in mid-2008. This result is consistent with the observations that the failure of oil suppliers to increase supply amid strong demand in 2007 and the first half of 2008 accounted for significant portion in the sharp increases in oil prices in that period (Hamilton, 2009a). As consumer and industrial demand waned, oil prices fell and supply was no longer the driving force of subsequent innovations. Rather, figure 2 shows the increasing effects of aggregate demand shocks for this period. Thus, the model in section 3 accurately accounts for the timing and magnitude of supply and aggregate demand shocks in determining the price of oil.

For the US, this extended period of increases in the real price of produced marked effects in consumer spending and the automotive industry. As analyzed in-depth by Hamilton (2009a), an increase in oil prices tends to depresses purchases of energy-using goods such as automobiles. The value of such purchases could be quite large relative to the cost of gasoline; thus, the value of postponed purchases may be larger than any decrease in oil profits due to higher oil prices, resulting in possible costly reallocation of labor across sectors due to demand shifts. Such mechanisms, however, are not symmetric: negative oil price shocks have not been shown to exhibit opposite demand shifts (Hamilton, 2011). Consumption of gasoline-using durables (such as automobiles) is likely to drop following an oil event if consumers are uncertain about oil prices in the immediate and distant future. These relatively large purchases may be postponed or shifted to more energy-efficient products. Using oil volatility as a proxy for level of uncertainty about future prices, Barsky and Kilian (2004) find drops in consumption following a major oil price innovation to be "small by historical standards." However, the compounding effect of such shocks on consumer expectations were marked between 2005-2008 when the US economy showed signs of slowdown while strong global demand pushed oil prices higher. Likewise, the drop in oil prices in late 2008 was not met with increased consumption of gasoline-using durables, further exacerbating the decline in aggregate demand for industrial commodities and expectations of future demand.

Mid-2014-2016. Unlike in 2008, the decline in oil prices has been gradual, not sharp. This fact points to the existence of multiple contributing factors culminating in a downward trend, rather than a singular event. These factors include changes in the makeup of crude oil supply (which countries producing how much); announcements concerning willingness (or lack thereof) to coordinate supply levels to drive up prices; and uncertainty over the severity and recovery from the financial crisis.

Baumeister and Kilian (2016b) attribute the price innovations of 2014 to the predictable decline in the slowing global economy and decreased demand for oil products. Whereas some observers have conjectured that the steep decline in the price of oil between June and December 2014 resulted from positive oil supply shocks in the second half of 2014, others have suggested that a major shock to oil price expectations occurred when in late November 2014 OPEC announced that it would maintain current production levels despite the steady increase in non-OPEC oil production (e.g. Arezki and Blanchard, 2014). Baumeister and Kilian (2016b) claim both conjectures are perfectly reasonable ex ante, yet provide quantitative evidence that neither explanation appears supported by the data. Kilian (2016) finds that the increase in U.S. oil production since 2010 has been small relative to the size of the global oil market. Likewise, the data does not support the influence of production level announcements on oil price fluctuations for this period.

The data produced here (see Figure 2) supports the explanation postulated by Baumeister and Kilian (2016b). Changes in production levels, announcements concerning production levels, and changes in source of crude oil production affected the real price of oil via the precautionary demand for oil channel, rather than actual shifts in production levels. For this period, supply disruptions were few and statistically insignificant. Of more interest are shifts in expectations of global supply levels (positive) and global economic growth (negative). Thus, this paper finds little support for the conclusions of Arezki and Blanchard (2014), who seek the source of falling oil prices in changes to supply levels and announcements by Saudi Arabia declaring its intentions to not curb production to raise the price of oil. The results in Figure 2 point to positive contributions of the supply starting in 2015, but the timing does not place supply as the culprit for declining prices in mid-2014.

V. Application

5.1. Oil shocks and the macroeconomy

Oil price shocks directly influence decisions of economic agents. The consequences of these shifts in consumption, production, and investment may be tracked through various and debated mechanisms of transmission into the macroeconomy (see Hamilton 2009a; Herrera, Lagalo, Wada 2001; and Bernanke 1983, respectively). The array of proposed channels is matched by an extensive literature that often reaches differing conclusions as to the channel and sign of response to historical and modeled oil price shocks (Kilian, 2008). These differences stem from the key results of the model in section 3: oil price shocks result from a time varying composition of supply and demand shocks.

5.2 Model

Real GDP growth rate data are available at quarterly frequencies. Thus, quarterly structural shocks and CPI inflation are computed by averaging the monthly structural innovations for each quarter. Assuming the absence of feedback from the structural shocks $j = 1,2,3$, structural shocks may be treated as predetermined with respect to US real GDP growth Δy_t and US CPI inflation π_t (Kilian, 2009). The impact of these structural shocks on Δy_t and π_t may be estimated by computing

$$\Delta y_t = \alpha_j + \sum_{i=0}^{12} \varphi_{ji} \hat{\eta}_{jt-i} + u_{jt}, \qquad j = 1,2,3$$

$$\pi_t = \alpha_j + \sum_{i=0}^{12} \psi_{ji} \hat{\eta}_{jt-i} + v_{jt}, \qquad j = 1,2,3$$

where $\hat{\eta}_{jt-i}$ represents the *j*th quarterly structural shock and u_{jt} and v_{jt} represent the potentially serially correlated errors. The coefficients φ_{ji} and ψ_{ji} represent the impulse response coefficients at horizon *i*, which is set to 12 quarters.

5.3 Model results

Figure 5 depicts the responses of US GDP growth and CPI inflation to oil price shocks of varying sources. Supply and demand shocks induce opposite effects. The response of GDP growth to a supply shock is negligible and indeterminate. Aggregate demand shocks initially have a positive effect on GDP growth, followed by a larger, negative effect. Oil-specific demand shocks also produce sustained, negative effects. After six quarters CPI inflation is negatively affected by a supply shock, while demand shocks produce persistent positive pressures on CPI inflation. In accordance with these results, it is critical to allow for various supply and demand shocks in models incorporating oil price shocks.

VI. Conclusions

The oil price series continually surprises economists, policymakers, and industry experts alike. Recent movements in oil prices are no different. This paper replicates and extends the structural VAR model postulated by Kilian (2009) to decompose the sources of oil price shocks for the period of 2008-2016. The structural VAR model simultaneously avoids the complications of holding oil price as exogenous and/or ignoring the differences between oil supply and demand shocks. The model proves robust in terms underlying assumptions, means of identification, and explanatory power.

The sharp increases from 2007 to mid-2008 can be traced to a combination of strong aggregate demand for industrial commodities from developing countries and the marginal increases in quantity supplied. The subsequent steep decline by year's end stemmed from alterations to global economic forecasts in the wake of the 2008 financial crisis. As expectations of economic growth normalized, prices returned to approximately 100USD from 2010-2014. From mid-2014 this price level was no longer sustainable. Lowered aggregate demand for industrial commodities triggered the decline in oil prices from mid-2014 and continued through 2016 from an increased contribution of the precautionary demand for oil.

Identifying channels of transmission via structural VAR models has highly pertinent implications for the development of oil-sensitive macroeconomic models. The results of the model used in this paper stress the importance of endogenizing the price of oil and differentiating between various sources of oil price shocks. The paradigms governing the interpretation of the experiences of the twentieth century do not hold in describing the twenty-first; and continued research suggests they may no longer hold for the former either. As explored in section 5, identification of the shock sources provides crucial insight into the channel of transmission of price fluctuations to the macroeconomy, whether through positive or negative pressure on output or inflation.

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Figure 1. Log price of West Texas Intermediate crude oil for 1970-2016; US recessions shown.

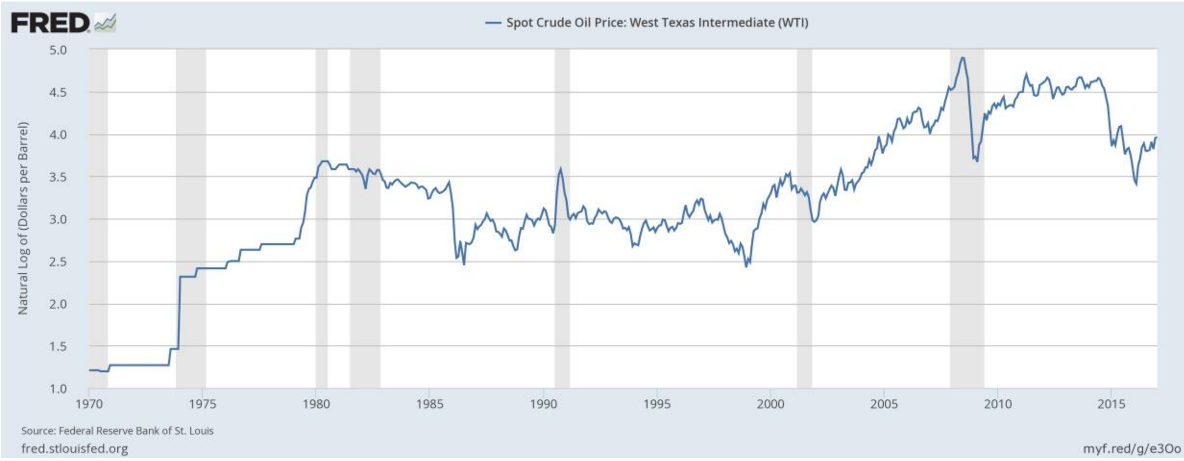

Figure 2. Evolution of structural shocks 1975-2016.

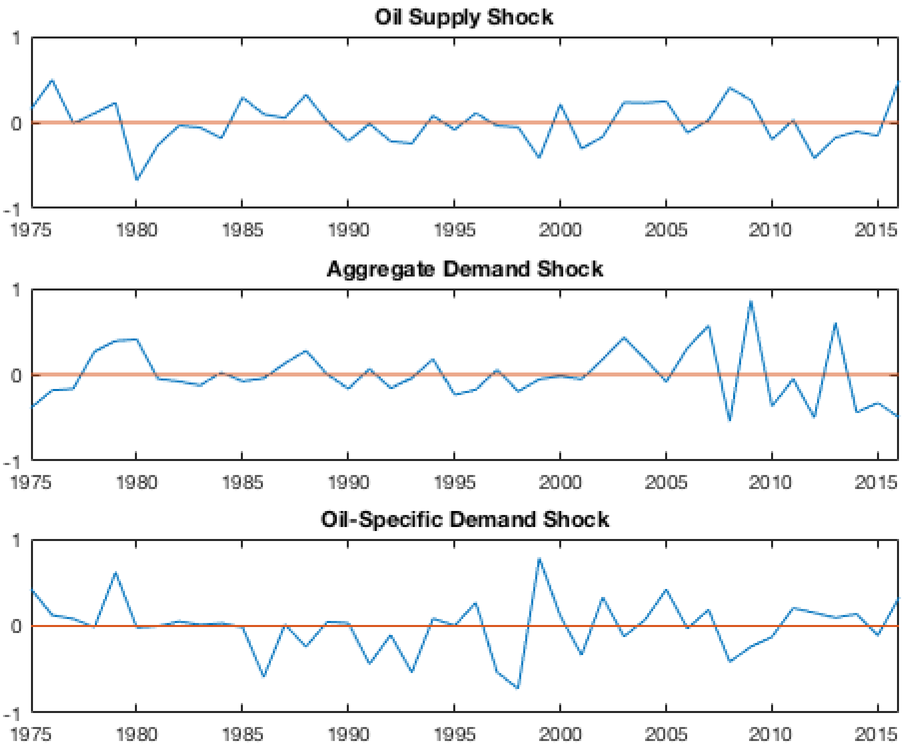

Figure 3. Impulse responses of oil supply, aggregate demand, and oil-specific demand shocks on oil production, real economic activity, and the real price of oil. Estimates include one- and two-standard error bands.

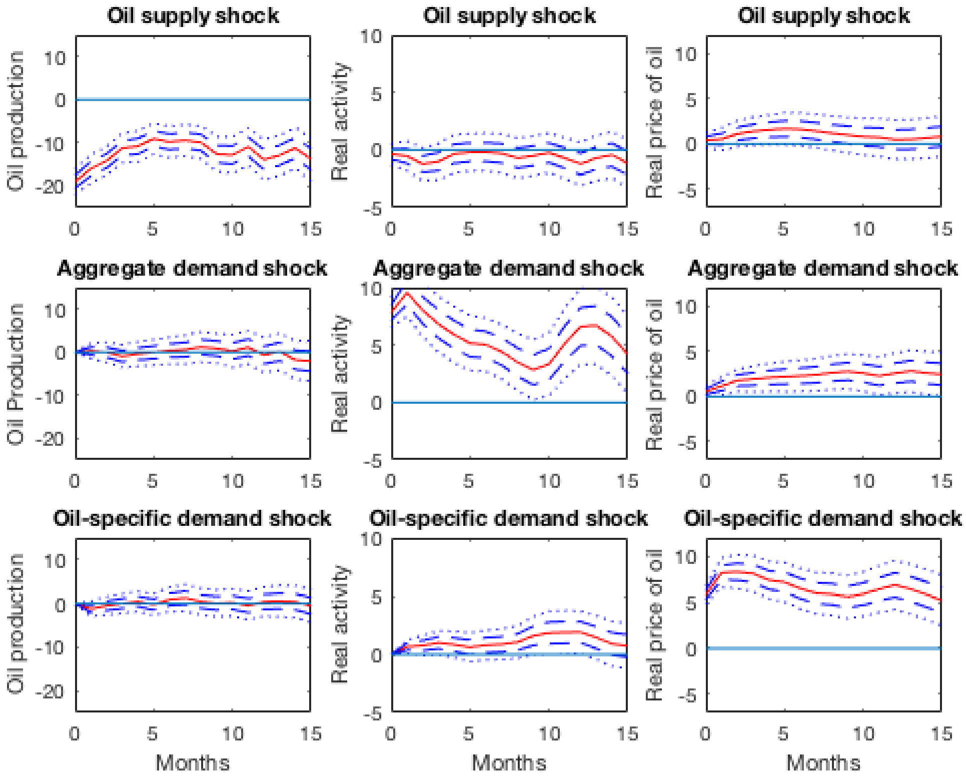

Figure 4. Decomposition of the real price of oil 1975-2016.

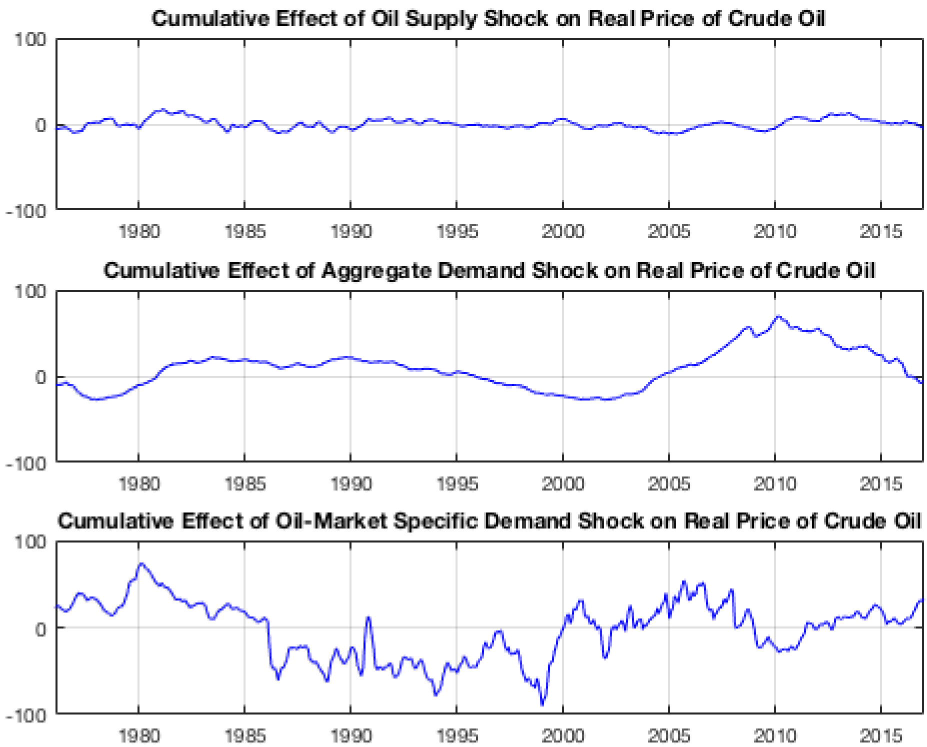

Figure 5. Responses of US real GDP growth and CPI inflation to differentiated oil price shocks. Estimates include one- and two-standard error bands.