The Macroeconomic Effects of Supply-driven and Demand-driven Oil Price Shocks in Oil-exporting Countries, a Time-Varying Approach

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Abstract

This study investigates the effects of different oil price shocks on macroeconomic variables in selected oil-exporting countries. For this purpose, by imposing two different types of restrictions on the parameters of the model, I distinguish between supply-driven and demand-driven shocks to the oil price. Employing a structural VAR model, I impose bounds on the elasticity of oil supply and also use sign restrictions on the responses generated by the model to identify oil price shocks. Moreover, the model uses time-varying coefficients which allow the slopes of short-run oil supply and demand curves to change over time. I then examine the effects of the identified oil price shocks on key macroeconomic variables of selected oil-exporting countries (namely Iran, Saudi Arabia, Qatar and United Arab Emirates). The results suggest that the increase in GDP growth and inflation after the oil price shock in oil-exporting countries could be mainly attributed to the component that reflects the increase in the aggregate demand.

Keywords: Oil Price Shocks, Time Variation, Sign Restrictions
1 Introduction

Oil price shocks have been seen as one of the main factors affecting economic performance during the past decades. The relationship between the macroeconomic situation and the crude oil price has been documented in the literature (e.g. Hamilton [1983], Mork [1989]). Oil-exporting countries, especially OPEC members with less diversified economies, are particularly vulnerable to such shocks, as the revenue from oil exports is the main driver of their whole economy. In Iran and Saudi Arabia, for example, it accounts for approximately 50 and 90 percent respectively of total government revenue. The price of crude oil has shown large variations in recent years, changing from values of around $25 per barrel in August 2003 to over $130 in mid-2008, before collapsing dramatically during the Great Recession of 2008. These fluctuations create uncertainty and result in economic instability for both oil-importing and oil-exporting countries. OPEC members in particular have experienced high volatility of exports and hence of government revenues. Considering the structure of these economies, oil price fluctuations can have strong effects on government budgets as well as on other macroeconomic and financial variables. Given the high degree of dependence on oil revenues, understanding the macroeconomic implications of oil price shocks is of great importance for policy makers in such countries.

While the oil price shocks of the 1970s and 1980s had severe effects on the global economy, the impact of oil price shocks become milder afterwards. Two major oil shocks have hit the world economy since the late 1990s, but GDP growth and inflation have remained fairly stable in the majority of developed countries. As Kilian [2009] argues, “not all oil price shocks are alike” and the implication of oil price increases may be quite different on real GDP and CPI inflation, depending on the underlying cause of the price change. This could be the case for oil-exporting countries as well. So, distinguishing different oil shocks (e.g. supply, aggregate demand and oil-specific demand) and analyzing their effects on key macro variables can be a step forward in understanding the consequences of oil price fluctuations in oil-exporting economies. Moreover, even the response of macroeconomic variables to a specific type of oil price shock may not be constant over time. Some studies provide evidence suggesting that the economy’s structure has changed and thus the
dynamic effects of oil price shocks are now different from what we have seen in the past (Blanchard and Gali [2007], Baumeister and Peersman [2009]).

This study conducts an empirical investigation on the effects of oil shocks. I will use a time varying VAR model that includes the amount of oil supply, a proxy for the aggregate demand and the real oil price. I impose sign restrictions to identify different types of oil shock. Then I employ these identified shocks as regressors in a finite order distributed lag model to examine their effects on macroeconomic aggregates of selected oil-exporting countries.

The rest of the paper is organized as follows. Section 2 briefly reviews the literature on the effects of oil price fluctuations on macroeconomic variables. Section 3 explains the econometric approach used to obtain historical time series of the different oil shocks, and introduces the distributed lag model for analyzing the effects of the identified shocks on output growth and inflation in selected countries. Section 4 provides the results and Section 5 brings a conclusion.

2 Literature Review

The study of the effect of oil price shocks on macroeconomic performance has been a central issue in energy economics literature for a few decades. In a seminal contribution Hamilton [1983] asserts that, prior to 1972, oil shocks have been a significant contributing factor of recessions in the US. Some studies consider the existence of structural break in the effects of oil prices on GDP during the 1980s (McConnell and Perez-Quiros [2000], Blanchard and Gali [2007], Baumeister and Peersman [2009]). Blanchard and Gali [2007] indicate a substantial decrease in the effects of a given change in the price of oil over time, and conclude that the effects of the price of oil on either output or the price level after 1984 were roughly one-third of those for the period before it. Looking at the origins of different oil price surges, Kilian [2009] differentiates between supply and demand shocks in oil price given that they might have different dynamic effects on the economy, and uses the Cholesky identification scheme to recover structural shocks. Baumeister and Peersman [2009] impose sign restrictions on the implied responses of different shocks and observed that, over time, the volatility of oil production decreased while the volatility of price increased.
They explain these facts based on the declines in the supply and demand elasticities. Kilian and Murphy [2010] show that imposing sign restrictions are not sufficient to determine the relative importance of different supply and demand shocks, as they illustrate different shocks satisfying sign restrictions whilst having contradictory implications. They argue that one still needs to impose a bound on the magnitude of the price elasticity of oil supply in order to narrow down the range of admissible models. In their work, the underlying VAR structure is assumed to be time invariant, implying that the slope of supply and demand for oil is fixed over time.

While most papers studying the relationship between oil price shocks and macroeconomic variables in the literature have focused on oil importing countries (Hooker [1996], Mork et al [1994], Blanchard and Gali [2007], Holmes and Wang [2003], Kilian [2009], Baumeister and Peersman [2009]), very few of them have explored oil exporting developing countries.

Eltony and Al-Awadi [2001] provide evidence on the importance of oil price shocks in explaining fluctuations of macroeconomic variables in Kuwait. Their results reveal that oil price shocks significantly affect government expenditures, which are the major determinant of the level of economic activity in that country.

Berumet and Ceylan [2005] study the effects of symmetric oil price shocks on industrial production for a group of Middle East and North African countries. Their results suggest that the effects of oil price shocks on output are positive and statistically significant in Algeria, Iran, Iraq, Jordan, Kuwait, Oman, Qatar, Syria, Tunisia, and UAE. On the contrary, for Bahrain, Egypt, Lebanon, Morocco and Yemen no significant impact is found.

Farzanegan and Markwardt [2009] investigate the dynamic relationship between oil price shocks and macroeconomic variables in the Iranian economy using the VAR approach and find a positive relation between positive oil price changes and both output growth and inflation.

My analysis aims at investigating the effects of different types of oil shocks on output growth and inflation in selected oil exporting countries in a time varying setting.
3 Empirical Methodology

3.1 A time-varying VAR with stochastic volatility

To account for change in oil price volatility, I use a VAR framework with time-varying coefficients and stochastic volatility following Primiceri [2005], Cogley and Sargent [2005], and Benati and Mumtaz [2007].

Consider a structural VAR model of the form

$$Y_t = C_t + \sum_{i=1}^{p} B_{i,t} Y_{t-1} + u_t$$

In which $Y_t$ is a vector containing the global crude oil production, a measure of the global economic activity and the real price of oil. The matrices $B_{i,t}$ are 3 by 3 matrices of the time varying coefficients of the lagged endogenous variables. $u_t$ are reduced form innovations that are assumed to have time varying covariance matrix $\Omega_t$ and zero mean. This time varying covariance matrix allows the shocks to have time variation in their magnitude as well as in their contemporaneous impacts. Having time varying coefficients will also enable the propagation mechanism of the shocks to change over time. The model is estimated using Gibbs sampling algorithm presented in Primiceri [2005]. More details regarding the model setup are provided in the Appendix.

3.2 Data

World crude oil production levels are taken from the U.S. Energy Information Administration (EIA) and I use the percentage change of it. For the second variable, I use Kilian’s [2009] index of global real economic activity that is based on a global index of dry cargo single voyage freight rates. This index is measured at monthly frequency and has some advantages over an index of industrial production in the OECD, the closest available proxy for world industrial production. The OECD index excludes emerging economies in Asia such as China and India and it requires exchange rate weighting.

The last variable is the log of the real oil price constructed by deflating the nominal oil price by the U.S. CPI. The data are collected for the sample period
starting from January 1974 to December 2007.

3.3 Identification

Sign restrictions have been employed mainly to identify different shocks within the crude oil market in recent years (Baumeister and Peersman [2009], Kilian and Murphy [2010]). This approach represents an identification strategy that avoids restricting the magnitude of the contemporaneous impacts of shocks and can be considered a clear advantage over recursive identification schemes.

Through the use of sign restrictions I identify three underlying structural shocks which are shocks to the world production of crude oil (“oil supply shock”), shocks to the demand for crude oil and other industrial commodities as a result of the global business cycle (“aggregate demand shock”), and oil-specific demand shocks which can also be considered as shocks to crude oil demand, albeit orthogonal to the previous shock (see Kilian [2009] for more details). The latter type of shock particularly reflects any fluctuations in oil demand that can be considered as sector-specific, such as fears about future supply shortages. This shock is also known as “precautionary demand” or “speculative” shock.

An oil supply shock reflects unexpected shifts in the oil supply curve along the oil demand curve, given the history of the endogenous variables. It includes unexpected disruptions to the physical supply of oil due to, for example, political events in oil-producing countries or a strategic decision by OPEC member states to change the amount of production. As a result of this shock, crude oil production and global economic activity are assumed to decrease, while the real price of oil is assumed to increase.

The aggregate demand shock relates to unexpected changes in the overall demand for industrial commodities associated with fluctuations in the global business cycle. It can be thought of as a shift in the oil demand curve along the supply curve. Moreover, it is assumed to raise global economic activity and the real price of oil, as well as increase the production of crude oil.

The oil-specific demand shock includes precautionary demand shocks or pure uncertainty shocks, which do not shift the expected levels of future supply or demand as well as expectation about demand surplus of oil in the future. An example of this
shock could be the expectations of political unrest in oil producing countries such as Iraq or Libya. This shock is assumed to raise both the production and real price of oil, while global real economic activity is assumed to decrease after the shock.

Table (1) below summarizes the identification restrictions.

<table>
<thead>
<tr>
<th></th>
<th>$Q_{oil}$</th>
<th>$P_{oil}$</th>
<th>$Y_{world}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil supply shock</td>
<td>$\leq 0$</td>
<td>$\geq 0$</td>
<td>$\leq 0$</td>
</tr>
<tr>
<td>Global demand shock</td>
<td>$\geq 0$</td>
<td>$\geq 0$</td>
<td>$&gt; 0$</td>
</tr>
<tr>
<td>Oil-specific demand shock</td>
<td></td>
<td>$\geq 0$</td>
<td>$\geq 0$</td>
</tr>
</tbody>
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Table 1. Identification Restrictions

In addition to these restrictions, I also limit the price elasticity of oil supply in order to restrict the model from replicating dynamics which are unlikely to happen, as in Kilian and Murphy [2010]. The logic behind the imposition of this restriction is as follows.

In the VAR model, by construction, the relation between reduced form and structural shocks are

$$
\begin{bmatrix}
    \varepsilon_{t}^{prod} \\
    \varepsilon_{t}^{worldIP} \\
    \varepsilon_{t}^{Oil price}
\end{bmatrix} =
\begin{bmatrix}
    a_{11} & a_{12} & a_{13} \\
    a_{21} & a_{22} & a_{23} \\
    a_{31} & a_{32} & a_{33}
\end{bmatrix}
\begin{bmatrix}
    \varepsilon_{Oil supply shock} \\
    \varepsilon_{Aggregate demand shock} \\
    \varepsilon_{Oil-specific demand shock}
\end{bmatrix}
$$

The ratio of $\frac{a_{13}}{a_{33}}$ is the short run elasticity of oil supply and we knew from the literature that it should be close to zero. Therefore I abandon all models that have a large value for this ratio. The upper bound that I put on this ratio has been obtained by considering the period of Persian Gulf War on August 1990 as a well-defined exogenous oil price shock. At the time, the price of oil increased by 44 percent while the production of crude oil from all producers except Iraq and Kuwait increased by just 1.17 percent, suggesting a ratio of .025 ($\frac{1.17}{44}$) that can be regarded as an upper bound for this elasticity following Kilian and Murphy [2010].
3.4 Alternative Measures of Oil Shocks

While this paper distinguishes between different types of oil shock regarding their origins, most of the studies in the literature concentrate on a single measure for oil shock. This section briefly describes these measures. In order to identify the unexpected changes to oil price, Mork [1989], Lee et al. [1995] and Hamilton [2003] have used different methodologies that are summarized as follows:

1. Mork [1989] observed that rising oil prices have negative and significant effects on economic activities, while the effects of falling oil prices on stimulating the economy are small and insignificant. Thus he modeled the oil shock as below:

$$ o_t^+ = \begin{cases} 0 & \text{if } o_t \leq 0 \\ o_t & \text{if } o_t > 0 \end{cases} $$

where $o_t$ represents the percentage change in the nominal price of oil.

2. Lee et al. [1995] argue that the volatility of the oil price has to be taken into account in modeling the relationship between GDP growth and oil price changes. They showed that the scaling oil price increases by the standard deviation of the volatility would improve the explanatory power of the model. Their proposed measure is as follows:

$$ o_t^+ = \begin{cases} 0 & \text{if } \frac{o_t^R}{\sqrt{h_t}} \leq 0 \\ \frac{o_t^R}{\sqrt{h_t}} & \text{if } \frac{o_t^R}{\sqrt{h_t}} > 0 \end{cases} $$

where $o_t^R$ is the real oil price and $\sqrt{h_t}$ is the conditional volatility of oil price changes estimated from a GARCH(1,1) model.

3. Hamilton [2003] suggested that the difference between the oil price increase in current period and the highest increase over the previous 1-year (or 3-years) period could be a more accurate measure of oil shock. This specification would filter out price increases that correct recent decreases and captures the unexpected shocks. Hamilton’s measure of the net nominal price increase can be calculated as:

$$ \text{noil}_{it}^+ = \max\{0, o_t - \max\{o_{t-1}, o_{t-2}, ..., o_{t-12}\}\} $$

where $o_t$ is the nominal price of oil.
Although all of these measures could help the researcher to identify the shock in the oil price, differentiating between various oil shocks regarding their origins would result in better understanding of the effect of oil shock on the economy.

3.5 Regression model for understanding the effects of oil price shocks on oil-exporting economies

Having identified different types of shocks, an interesting question is how these structural shocks affect macroeconomic aggregates such as inflation and real GDP growth in oil-exporting countries. Assuming that there is no feedback from inflation and output growth of these countries to oil shocks within a quarter, I can treat these structural shocks as predetermined regressors and examine their effects on inflation and GDP growth of these countries. This assumption could be justified considering the following argument. None of these countries is large enough to affect either aggregate demand or oil specific demand. The share of crude oil production of these countries is not large enough (the highest share is for Saudi Arabia with about 10 percent of global oil production), moreover, oil supply cannot significantly change within a quarter due to technical restrictions.

One of the main challenges in dealing with this regression model is the frequency mismatch, as I have the shocks at monthly frequency but GDP growth becomes available quarterly. By averaging structural shocks in each quarter, a measure of quarterly shock has been constructed as below:

\[
\hat{\mu}_{jt} = \frac{1}{3} \sum_{i=1}^{3} \hat{\varepsilon}_{j,t,i} \quad \text{for } j=1,2,3
\]

where subscript \( t \) represents the quarter and subscript \( i \) represents the month in each quarter.

Then I regress output growth and inflation on these new measures of oil shocks as follows:

\[
\Delta Y_t = \alpha_j + \sum \psi_{ji} \hat{\mu}_{j,t-1} + u_{jt}
\]

\[
\pi_t = \gamma_j + \sum \phi_{ji} \hat{\mu}_{j,t-1} + \nu_{jt}
\]
In which $\psi_{ji}$ and $\phi_{ji}$ can be interpreted as impulse response functions of GDP growth and inflation, respectively. In the above regressions, as $u_{jt}$ and $v_{jt}$ potentially have serial correlation, block bootstrapping should be used to provide reliable inferences.

### 4 Empirical Result

In the first step, I estimate a time-varying VAR with stochastic volatility based on monthly data for the vector $Y$. In order to calibrate the priors for estimation, I used the first six years of data as a training sample.

Figure 1 displays the annual average of different oil shocks as implied by the model. It indicates for each period of time, which component of oil shock was the main driver of price change. For example, if we look at the top panel which shows the crude oil supply shock, there is a negative shock to crude oil supply in the early eighties. This disruption in the supply of oil is likely related to the decrease in the production capacity of Iran and Iraq, which engaged in a war started in September 1980 and lasting for eight years. Another notable drop in the supply of crude oil is in August 1990, when Iraq invaded Kuwait and disturbed the oil extraction of this small country. In the middle panel which depicts aggregate demand shock, we can observe a significant decline in aggregate demand of the global economy during the early 1980s. In particular, the United States experienced a severe recession as the unemployment rate was more than 10% in December 1982, the highest since the great depression. In 1997, the Asian crisis happened and decreased the aggregate demand from these growing economies. In the bottom panel, the shock to specific demand for oil has been shown. This will suggest that during the Asian crisis, the speculative demand for oil has also experienced a negative shock. Considering the price of oil, one could conclude that a big drop in oil price between 1985 and 1986 might be related to the shock in the aggregate demand, while the price increase in 1990 can be driven by the negative supply shock related to Persian Gulf War.

The elasticity of oil demand has been shown in Figure 2. It can be seen that from the early 1990s, this elasticity no longer exceeds -0.5, implying the demand has become less sensitive to recent price changes. This result is in line with Baumeister
and Peersman’s finding of substantial decline of both demand and supply elasticities over time.

Figure 3 depicts the median response of GDP growth and inflation in Iran to different types of shocks, together with the 16th and 84th percentile error band. Iran is the biggest country in the sample, with a population of 77 million as of 2014. Its crude oil production is 3.5 million barrel per day (MBD), of which 1.2 MBD is exported. Iran’s oil export has decreased significantly in recent years due to international sanctions. Looking at the response of output to oil shocks, it becomes clear that supply shock and oil-specific demand shock have no significant effect on output growth in Iran. Aggregate demand shock, however, has a positive significant effect in the short run, and its effect declines after a several quarters. Regarding its impact on inflation, oil supply shock increases inflation in the long run, although its effect is mainly insignificant. The other two shocks induce a statistically significant decrease in inflation. The explanation for this difference is that the oil supply shock would increase the price of goods and services in developed economies, causing an increase in the price level of imported goods. The other two shocks do not necessarily increase the price level in developed economies, hence the extra government revenues from selling oil at higher prices result in providing cheaper services for nationals and decreasing inflation.

Figures 4-6 represent the same graphs for Saudi Arabia, Qatar and UAE. Saudi Arabia’s oil export is 7.5 million barrels per day (a quarter of the total 30 MBD of OPEC supply, which itself provides around 40 percent of the world supply), while Qatar and UAE export 0.60 and 0.65 MBD of oil respectively. The economies of these countries are similar to each other as they all share a high level of dependence on revenues from oil exports. Moreover, the local currencies of these countries are pegged to US dollar, so they do not have independent monetary policies. As can be seen, the response of GDP growth and inflation to each type of oil shock is similar across these economies. The only type of oil shock that boosts output growth is the aggregate demand shock, and it is the only oil shock that causes inflation to increase. This result has an interesting implication for these economies. It suggests that the increase in the oil price induced by decrease in the oil supply or increase in oil-specific demand, while having a negative effect on inflation, will not increase
the output growth of these countries. Moreover, considering the fact that almost all episodes of supply fall occurred during political unrest in the region, and the theory of investment under uncertainty (Henry [1974]), would explain this decrease, since uncertainty about the future causes investment as a part of aggregate output to fall.

To summarize, the shock to aggregate demand results in what we would have expected from an oil shock in oil-exporting countries, as it increases real GDP growth and also inflation. This makes more sense given the earlier evidence documented by Kilian [2009], that much of the recent increase in crude oil prices has been driven by global aggregate demand shocks.

5 Conclusions

This study aims at disentangling different oil shocks in a time-varying setting, and analyzing their effects on output growth and inflation in selected oil-exporting countries. In this regards, I firstly run a VAR on global oil production, world industrial production and real oil prices allowing the coefficients and variance-covariance matrix of the shocks to be time varying. Three types of oil shocks have been identified with the use of sign restrictions and limiting the price elasticity of supply (as in Kilian and Murphy [2010]). I observed substantial declines in the price elasticity of demand for crude oil which confirms the previous results on volatility puzzle.

Then, assuming no feedback from GDP growth and inflation to oil shocks within a quarter, I find the aggregate demand components of the oil shocks as the most relevant factor influencing GDP growth and inflation of oil-exporting countries. These findings are in line with the evidences documented in the literature.
References


L. Kilian and D.P. Murphy. Why agnostic sign restrictions are not enough: understanding the dynamics of oil market VAR models. CEPR Discussion Paper, 2010.


6 Appendix

6.1 A. Model setup.

This model is a time varying VAR model, so we can write it in the state space representation. the measurement equation can be written as

\[ Y_t = B_t X_{t-1} + u_t \]

Where \( X_t \) is a vector of lags \( (p = 2) \) of all dependent variables as well as a constant term and \( B_t \) includes time-varying coefficients. As we also have stochastic volatility in the model, \( u_t \) are heteroskedastic error terms with variance-covariance matrix \( \Omega_t \) that can be decomposed as \( \Omega_t = A_t^{-1} H_t (A_t^{-1})' \).

\( H_t \) is a diagonal matrix that contains stochastic volatilities and \( A_t \) is a lower triangular matrix of the contemporaneous interactions among variables:

\[
H_t = \begin{bmatrix}
    h_{1,t} & 0 & 0 \\
    0 & h_{2,t} & 0 \\
    0 & 0 & h_{3,t}
\end{bmatrix}
\]

\[
A_t = \begin{bmatrix}
    1 & 0 & 0 \\
    a_{21,t} & 1 & 0 \\
    a_{31,t} & a_{32,t} & 1
\end{bmatrix}
\]

For the evolution of these parameters, I assume the following processes inline with Primiceri [2005]:

\[
B_t = B_{t-1} + \tau_t \\
\log(h_t) = \log(h_{t-1}) + \eta_t \\
a_t = a_{t-1} + \vartheta_t
\]

And error components are assumed to be normally distributed and uncorrelated with each others.

\[
\begin{bmatrix}
    u_t \\
    \tau_t \\
    \eta_t \\
    \vartheta_t
\end{bmatrix} \sim N(0, V), \text{ where } V = \begin{bmatrix}
    R & 0 & 0 & 0 \\
    0 & Q & 0 & 0 \\
    0 & 0 & S & 0 \\
    0 & 0 & 0 & G
\end{bmatrix}
\]
6.2 B. Figures

Figure 1: Evolution of different oil shocks

Notes: Structural innovations implied by the model, averaged to annual frequency.
Figure 2: Price Elasticity of demand for oil
Figure 3: Response of GDP growth and inflation to different oil shocks in Iran
Figure 4: Response of GDP growth and inflation to different oil shocks in Saudi Arabia
Figure 5: Response of GDP growth and inflation to different oil shocks in Qatar
Figure 6: Response of GDP growth and inflation to different oil shocks in UAE