OPEC SUPPLY AND OIL PRICE VOLATILITY

EC681: Major Research Paper

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Abstract

Extending the theoretical SVAR framework reported by Kilian (2009), this paper reconsiders the role of OPEC in the global oil market. Particularly, this paper's methodological contribution lies in the revised identification restrictions wherein OPEC production is assumed to not be inelastic in the short run, but instead assumed to respond to both supply demand and supply shocks within the month given its excess capacity. The results of the analysis suggest that OPEC exhibits behavior complimenting a partial market-sharing cartel that's consistent with the literature. While oil supply shocks are found to influence prices, the importance of demand and unimportance of demand shocks for determining real oil prices are consistent with Kilian (2009). Specifically, the price response elasticity to OPEC production shocks is found to be 0.4, suggesting that OPEC needs to increase production by 2.5 percent to decrease production by a percentage point. However, the lack of OPEC production shock incidences from the estimated in the historical variance decomposition leads to the conclusion that OPEC has not been inducing oil price volatility in aggregate.

1. Introduction

Since the mid 20th century, crude oil and its derivatives have underpinned modern societies across the globe as the main source of fuel for transportation and electricity generation. Crude oil is heavily relied on as a global commodity and its prices have significant influence on economic aggregates such as inflation and GDP[1]. For example, a large chunk of the volatility in headline inflation can be attributed to crude oil prices. In addition, crude oil is a tradeable commodity par excellence. Being a homogeneous good, conventional economic theory explains the movement of global oil prices as derived from shifts in global demand and global supply. Supply consists of oil production and changes in inventories, while demand is derived from direct consumption and production as oil is often an intermediate good.

One of the most important players in the global supply market is the organization of petroleum exporting countries (OPEC). OPEC describes itself as an intergovernmental organization between 13 countries with a unifying goal to coordinate petroleum production policies to ensure the stability of oil markets, hence reducing oil price volatility. Altogether OPEC produces about 40% of the world's crude oil, and its members meet several times annually to strategically set production quotas to manipulate oil prices. However, there have been numerous political events in the middle east that have caused major oil flow supply disruptions, for instance the Oil Embargo in the 1970s, Iran-Iraq war in the 1980s, and the Gulf War of 1990s. Moreover, OPEC members often disband quotas and have inconsistent strategic behavior[2]. These events made significant impacts on oil prices, contributing to global oil price volatility, hence contradicting

[1] See for example Hamilton (1983, 1996), Cuñado and Gracia (2003, 2005), Jiménez-Rodríguez and Sánchez (2005), Bodenstein et al. (2012), and Nyangarika et al. (2018) among many others.

[2] For example, OPEC switched to a market share targeting strategy in 2014 before switching back to a price targeting strategy in 2016.

the organization's mandate. This leads to the question: Has OPEC been fulfilling its mandate on reducing oil price volatility? This paper hypothesizes that, on net, OPEC has not been fulfilling its mandate, but has instead contributed positively to oil price volatility.

In order to evaluate the hypothesis, this paper employs a structural decomposition of a vector autoregressive (VAR) model that disaggregates structural oil price shocks into oil supply shocks, global aggregate demand shocks and oil-specific demand shocks as used by Kilian (2009). Many subsequent studies have built upon Kilian's (2009) theoretical framework, differentiating OPEC and non-OPEC production shocks with the assumption that OPEC can respond to non-OPEC production within the same month. Upon revaluation of the identification restrictions commonly used in the literature, this paper motivates for an alternative set of economic assumptions; OPEC can respond to both demand and supply shocks within a month due to its excess production capacity. After estimating a structural VAR (SVAR) with theses assumptions in consideration, impulse responses indicate that OPEC dampens oil price movements in response to demand shocks and has a negligible effect on oil prices when responding to foreign supply shocks. While oil prices do respond to OPEC production shocks with a response elasticity of 0.4, a historical variance decomposition suggests that OPEC production shock incidences are few and inconsequential, hence rejecting the hypothesis. As a complementary result, OPEC is found to exacerbate production effects in response to foreign supply shocks which is consistent with the partial market-sharing cartel behavior often identified in literature.

These results and the methods used to obtain them are described in the remainder of the paper as follows. Section 2 provides a brief overview of long spanning studies on the behavior of OPEC and how oil prices have been modeled in the literature. Section 3 discusses the empirical framework for the SVAR, motivating for a different set of economic assumptions than what's commonly found in the literature. Section 4 explores the data used to model the analysis. Section 5 presents the empirical results and a sensitivity analysis. Section 6 concludes with a rejection to the hypothesis.

2. Literature Review

2.1 OPEC Behavior

OPEC is often described as a cartel; OPEC holds considerable power in the oil market with near 80% of crude oil reserves and has the power to influence both worldwide supply and the price of oil. In an earlier paper, Griffin (1985) models the strategic behavior of OPEC, fitting cartel and four other models to find one that best explain the production levels among OPEC members[3]. The study employs ordinary least squares (OLS) regressions over quarterly oil price data and production data from the Petroleum Intelligence Weekly and the U.S. Monthly Energy Review over 1973Q1 through 1983Q3 to perform hypothesis tests. In the analysis, the regression results failed to reject the cartel model, indicating that OPEC's strategic behavior fits that of a market share targeting cartel. However, if OPEC targets to maintain or increase market share, OPEC production would have to respond in the same direction of non-OPEC production, hence exacerbating production shocks on global oil prices and contradicting its mandate on stabilizing oil prices.

On the other hand, there is no clear consensus in the literature on a single model that can capture OPEC's behavior[4]. Smith (2005) discusses this inscrutable view of OPEC, suggesting that conflicting interpretations have been due to a combination of varying assumption and framework

[3] There are various empirical specifications to what a cartel model means. In Griffins (1985) version, cartel models assume a market share targeting strategy that allow for market shares to change over time.
[4] For example, Geroski et al. (1987) and Griffin and Neilson (1994). Alhjji and Heuttner (2000) reviews 13 studies of which only 2 have statistical support for the cartel hypothesis.

choices across literature. Smith (2005) aims to rectify these conflicting hypotheses by analyzing production responses to distinguish between models. In doing so, several testable hypotheses arise to analyze if OPEC members exhibit behavior of a perfectly managed cartel. The rationale being that if OPEC acts as a cartel, members will increase output to offset the decline of another member such that marginal costs of each producer will equate marginal revenue. Data employed by Smith (2005) consists of monthly crude oil production of OPEC and major non-OPEC producers from the US Energy Information Administration. Applying logistic regression to crude oil production data of selected OPEC and non-OPEC countries between 1973M1 to 2001M12 to discern the hypotheses, Smith (2005) rejects the traditional cartel model. Instead, Smith's (2005) regression results provide evidence in favor of a less than frictionless cartel model that's impaired by the enforcement of quotas between members[5]. The lack of a coherent behavior suggests that OPEC has not been able to perform as an effective cartel that is able to stabilize prices.

One notable example of OPEC's inconsistent behavior is OPEC's regime switch to improving its market share in November 2014, before switching back to a price stabilization strategy announced November 2016. Behar and Ritz (2017) interprets this strategic behavior as an attempt to squeeze out high-cost producers such as US shale oil out of the market and explains the market factors that rationalized the regime switch. They assume that if OPEC can choose between two strategies upon the arrival of a new competitor: to accommodate and keep prices high or squeeze out its higher cost competitors by driving down prices. If this is the case, then OPEC should choose the strategic behavior that maximizes its profits. By employing a dynamic

[5] This variant of the cartel model suggests that OPEC is consistent with a cartel model that incurs high transaction costs whenever market shares shift due to the quota system. The quota system makes it difficult for OPEC producers to freely produce and therefore less likely to offset production changes as that of a frictionless cartel.

model and using empirical calibrations of 2012 and 2014 data[6], Behar and Ritz's model (2017) finds market conditions such as lower demand and non-OPEC supply growth can rationalize a regime switch by OPEC to maximize profits. However, this is inconsistent with OPEC's mandate because it is exacerbating production shocks by employing a market share targeting strategy in response to foreign competition.

Another avenue for influencing oil price volatility comes from OPEC meetings scheduled a few times a year since 1986, where members collude on production quotas to manipulate oil prices. The wide consensus in the literature is that these decisions to change production quotas have significant impact on oil price levels[7]. For example, Schmidbauer and Rösch (2012) investigate the impact of these OPEC announcements on production adjustments and the volatility of oil prices using daily data of West Texas Intermediate (WTI) prices from 1986M1 to 2009M9, and the 88 production quota announcements made by OPEC over the sample period. To search for a central theme, Schmidbauer and Rösch (2012) uses five types of regressions with dummy variables to indicate the OPEC production announcement[8], of which 3 regression are conducted with GARCH residuals to analyze both pre- and post-announcement effects[9]. Results of the model reveal that aftereffects of OPEC announcements have a significant effect on oil price volatility in all three cases, giving evidence to the notion of which OPEC announcements act as a channel through which can induce oil price volatility.

[6] Behar and Ritz (2017) uses comprehensive data sources on production, prices, capacity and costs for related OPEC and non-OPEC members.
[7] See for example, Deaves and Krinsky (1992), Horan et al. (2004), Wang et al. (2008), Lin and Tamvakis (2010) and Loutia et al. (2016).
[8] Increase, no change, or decrease.
[9] The GARCH model is particularly useful in time series analysis where it is suspected that variance is clustered.

2.2 Modeling Oil Prices

Traditionally, the literature attributed oil price fluctuations to be exogenous with respect to the U.S. economy and a product of oil production shocks caused by political events in the Middle East related to OPEC members[10]. For example, Hamilton (2003) evaluates the appropriateness of using exogenous oil price changes as a measure to forecasting GDP growth. Hamilton (2003) applies an instrumental variable regression on growth rates of real GDP from 1949Q1 to 1999Q4 using real oil prices changes attributed to exogenous production short-falls as instruments. Specifically, the war between Israel and its neighbors in 1973, the Iranian revolution in 1978, the Iran-Iraq war in 1980 and the invasion of Iraq to Kuwait in 1990 are treated as exogenous events as world production drops by at least 7 percent during these events. Having comparable regression and results state-of-the-art non-linear specifications using the same data, Hamilton's (2003) results validates using exogenous supply disruptions in the middle east as an instrument for oil prices.

However, this explanation often fails to fit the data and subsequent studies have since shown that major oil price increases have an important endogenous component. In one example, Kilian (2008) debunks the role of supply in his investigation. Using OLS regression and creating counterfactuals[11] for oil production from 1973M1-2005M10, Kilian (2008) re-estimates the explanatory power of exogenous supply disruptions on real oil prices and finds that only 20 percent of changes in real oil prices can be attributed to these exogenous oil production shocks. These results then raise a need to further investigate the determinants of crude oil prices.

[10] Exogeneity in this sense indicate that these events are unrelated to the current and past state of the U.S. economy. See for example, Hamilton (1983, 1985), and Jones and Kaul (1996)
[11] The counterfactuals are what the estimated production levels would have been if it there weren't any exogenous events such as wars.

Rectifying long-standing beliefs on the causes and consequences of oil price shocks, Kilian (2009) postulates that real oil prices are instead determined endogenously in the global market. His seminal paper employs a structural vector autoregression model (SVAR)[12] which allows him to disentangle the effects of oil price determinants and 3 identified shocks: oil supply, aggregate demand, and oil-specific demand[13]. Data consists of global crude oil production, an index of real economic activity, and the real price of crude oil[14] between 1973:M1-2007M12. In the analysis, Kilian (2009) distinguishes the contemporaneous effects of supply and demand shocks on real oil prices and real economic activity. Specifically, a one standard deviation shock to aggregate demand shock permanently increases real activity and has a persistent and significant positive effect on real oil prices. On the other hand, oil supply shocks are found to be insignificant, having no effect on oil prices nor demand[15]. Kilian's (2009) seminal paper initiated a shift in the literature, transitioning from an outlook where oil prices are determined exogenously by political events to currently an endogenous outlook. By doing so, he also provides a foundational framework through the SVAR model for the analysis of oil price, one that will be used in this paper. However, Kilian (2009) does not disaggregate oil production to identify the isolated effect OPEC production has on oil prices.

2.3 Extensions of Kilian (2009)

Many literatures have since adopted Kilian's (2009) framework to re-examine the effects of OPEC and non-OPEC production in the global market, criticizing Kilian (2009) for grossly

[12] See methodology section for a more detailed explanation of SVARs.
[13] Aggregate demand shocks are defined as innovations to real economic activity that cannot be explained by oil supply shocks. Oil-specific demand shocks are defined as innovations to the real price of oil that cannot be explained by oil supply or aggregate demand shocks. For more details see Kilian (2009).
[14] Real price of oil is measured by the refiner's acquisition cost.
[15] Kilian (2009) does not quantify these results.

underestimating the role of supply in the global market. Evaluating the degree of robustness Kilian's (2009) paper, Kodozeij and Kaufmann (2014) tests the appropriateness of using an index of dry bulk maritime freight costs as a proxy for global real economic activity. Moreover, Kodozeij and Kaufmann (2014) revaluate the effects that supply has on global real oil prices through a split lens OPEC and non-OPEC production, commenting OPEC has historically followed strategic behavior while non-OPEC nations set production primarily based on economic considerations. The analysis is done by employing a cointegrated vector autogestion model to account for the non-stationary time series used[16]. Sample data from 1973M1 to 2007M11, consists of Kilian's (2009) index for real economic activity, OPEC and non-OPEC oil production, and the real price of crude oil. The results provide evidence that is consistent with the large literature on supply shocks; reductions in OPEC production have a significant positive effect on oil prices, while non-OPEC production does not have short or long run effects on oil prices. However, the study lacks an analysis to study the cumulative contribution of OPEC supply shocks on real oil prices.

Ratti and Vespignani (2015) further enriches the study on the role of supply in the global market of crude oil by extending the SVAR model of Kilian (2009). Ratti and Vespignani (2015) evaluate the use of structural breaks and disaggregate global oil supply to split OPEC and non-OPEC production. The model consists of data from 1974Q1 to 2012Q4 of OPEC and non-OPEC oil production, global GDP, and the real price of oil. In the analysis, one structural break was identified[17] in the fourth quarter of 1996. Prior to 1996, various political events such as the Iran-

[16] Kilian's variables are in logged levels, integration order one I(1), except for aggregated oil production which is first differenced without justification in the paper. Kodozeij and Kaufmann (2014) performs the analysis using logged levels of OPEC and non-OPEC production for consistency, motivating for the employment of a cointegrated vector autoregressive model.

[17] Structural breaks are when a time series show an unexpected permanent change in its trend, mean values or change in other parameters of the processes that produces the series.

Iraq war and the first Gulf War caused significant oil production disruptions before stabilizing in the late 1990s. Post 1996, countries began recovering from the Asian Financial Crisis, leading to rapid economic growth and world petroleum consumption up until the Global Financial Crisis of 2008. Ratti and Vespignani (2015) accounts for the structural break and evaluates two SVARs following the assumptions made in Kilian (2009)[18]. Their findings suggest that prior to 1996, OPEC demonstrated price stabilization behavior by reducing oil production in response to positive shocks to non-OPEC production, but exhibits no such behavior post 1996. Moreover, OPEC oil production shocks are found to have significant contributions to changes in the real oil prices throughout the entire sample, further providing evidence against Kilian's (2009) underestimation of supply. Moreover, the findings also motivate to include a structural break analysis when investigating the effects of supply and demand shocks on oil price.

Further disentangling the role of OPEC, Álvarez and Venditti (2020) study the interactions of OPEC and non-OPEC production and evaluates the extent of which OPEC's regimes can explain oil price dynamics. Particularly, the strategies of OPEC are closely examined, studying supply shock effects when members produce in order to keep market shares stable compared to when members produce to stabilize prices. Álvarez and Venditti (2020) extends the SVAR of Kilian (2009) using 1973M1-2017M1 data on percentage changes of OPEC and non-OPEC production, world GDP growth, Brent oil prices and world crude inventories. In addition, the behavior of oil suppliers is characterized in the model so that OPEC producers can strategically respond to non-OPEC producers in time-varying fashion, given OPEC's excess spare capacity. Model results find that price targeting supply shocks have a small contribution to the rise of oil prices from

[18] Contemporaneous restrictions are applied of which both OPEC and non-OPEC production are assumed to not respond to the other's structural shocks within the same quarter.

2004-2014, but market-sharing strategic behavior explain two-thirds of the price drop between 2014-2016. Moreover, Álvarez and Venditti (2020) finds that price elasticity of OPEC supply is significantly larger than that of non-OPEC supply due to OPEC's spare capacity, which OPEC members to readily adjust production following strategic considerations. This motivates for the consideration of OPEC's behavior and spare capacity when modeling its effects on oil price volatility.

3. Methodology

VARs are multivariate time series models that evaluate the dynamic relationship of quantities as they change over time through ordinary least squares or maximum likelihood regressions. Reduced-form VARs express dependent variables in the model as a linear function of its past values and the past values of other related variables in evaluation. SVARs are an extension of VAR models where economic assumptions, often referred to as the identification restrictions, are imposed to identify structural shocks within the framework of a reduced-form VAR model[19], hence transforming it into a causal model with causal economic shocks. These causal models are often used in the literature to study the cause and consequences of oil price shocks. If the identifying restrictions are sound, then the estimated SVAR provides two tools that will be used to answer the hypothesis on if OPEC contributes to global oil price volatility. First, impulse response functions analyze the average response of model variables resulting from one standard

[19] See Stock and Watson (2001).

deviation shocks. Second, historical variance decompositions evaluate the contribution of each shock on a dependent variable's evolution.

Particularly, there are four global economic shocks identified in this paper, consistent with ones commonly seen in the literature. First, there are unpredictable innovations to global oil production, disentangled as OPEC and non-OPEC production shocks. Second, are innovations to global aggregate demands, primarily driven by the global business cycle including economic booms and recessions. Lastly, there are oil specific-demand shocks which reflect the substitution of demand effect from oil and industrial commodities. To that end, innovations to the demand for oil can change without being reflected in aggregate demand due to this substitution effect.

As such, consider a SVAR based on monthly data of non-OPEC (*NOPEC*) and OPEC (*OPEC*) production, real brent oil prices (*POIL*) and world industrial production (*WIP*). Specifically, the model employs $\boldsymbol{z_t} = (NOPEC_t, WIP_t, OPEC_t, POIL_t)$ with the representation:

$$(\mathbf{1})\ \boldsymbol{A_0 z_t} = \boldsymbol{\alpha} + \sum_{i=1}^{12} \boldsymbol{A_i z_{t-i}} + \boldsymbol{\varepsilon_t}$$

where $\boldsymbol{\varepsilon_t}$ is the vector of structural innovations and the reduced form errors $\boldsymbol{e_t}$ can be decomposed as $\boldsymbol{e_t} = \boldsymbol{A_0^{-1} \varepsilon_t}$[20]:

[20] Statistical innovations are transformed into structural shocks by imposing structural identification restrictions on $\boldsymbol{A_0^{-1}}$. Particularly, this SVAR is identified through short-run restrictions within the month and structural innovations are disentangled by orthogonalizing the reduce form errors, making the errors uncorrelated, by using a lower-triangular matrix. This is referred to as a recursively identified model. See Kilian (2011).

$$\boldsymbol{e_t} \equiv \begin{pmatrix} e_t^{NOPEC} \\ e_t^{WIP} \\ e_t^{OPEC} \\ e_t^{POIL} \end{pmatrix} = \begin{bmatrix} a_{11} & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \begin{pmatrix} \varepsilon_t^{non-OPEC\ supply\ shock} \\ \varepsilon_t^{aggregate\ demand\ shock} \\ \varepsilon_t^{OPEC\ supply\ shock} \\ \varepsilon_t^{oil\ specific-demand\ shock} \end{pmatrix}$$

Kilian (2009) has strong motivations for his identifying assumptions for $\boldsymbol{A_0^{-1}}$. He assumes supply is inelastic in the short run due to a lack of excess capacity and high costs associated to changing production and orders it first. Following, aggregate demand is ordered second because it can respond to production as part of its calculation, but reacts to oil specific-demand shocks with a delay of at least a month because both corporate and consumer consumption behavior does not significantly change in the short run with a low price elasticity of demand for oil[21]. Finally, oil prices are ordered last because the literature finds that it can respond to new information quickly as a weak form efficient market, of which oil future contracts[22] can respond to all available information within the month[23]. Both Kodozeij and Kaufman (2014) and Álvarez and Venditti (2020) extends these identifying restrictions by disaggregating OPEC and non-OPEC production and assume that OPEC's excess capacity allow its members to respond to supply shocks within the month. However, if the literature assumes that OPEC can respond to supply shocks within the month, then all things considered, OPEC should also be able to respond to demand. There is

[21] For example, Cooper (2003) surveys the demand for crude oil between 23 countries and finds it to be highly insensitive to changes in prices.
[22] An agreement to purchase or sell the commodity asset at a predetermined price on a specific date in the future.
[23] See for example Tabak and Cajueiro (2007), Alvarez-Ramirez et al. (2008), and Maslyuk and Smyth (2009) which finds support for the weak form efficient market hypothesis, meaning prices reflect all current information.

no justification to why it can only respond to supply within the month and not demand. Hence lies the methodological contribution of this paper. The SVAR model employed is an extension of these three papers that includes the disentanglement of OPEC and non-OPEC production and allows for OPEC production to respond to demand shocks through its excess spare capacity.

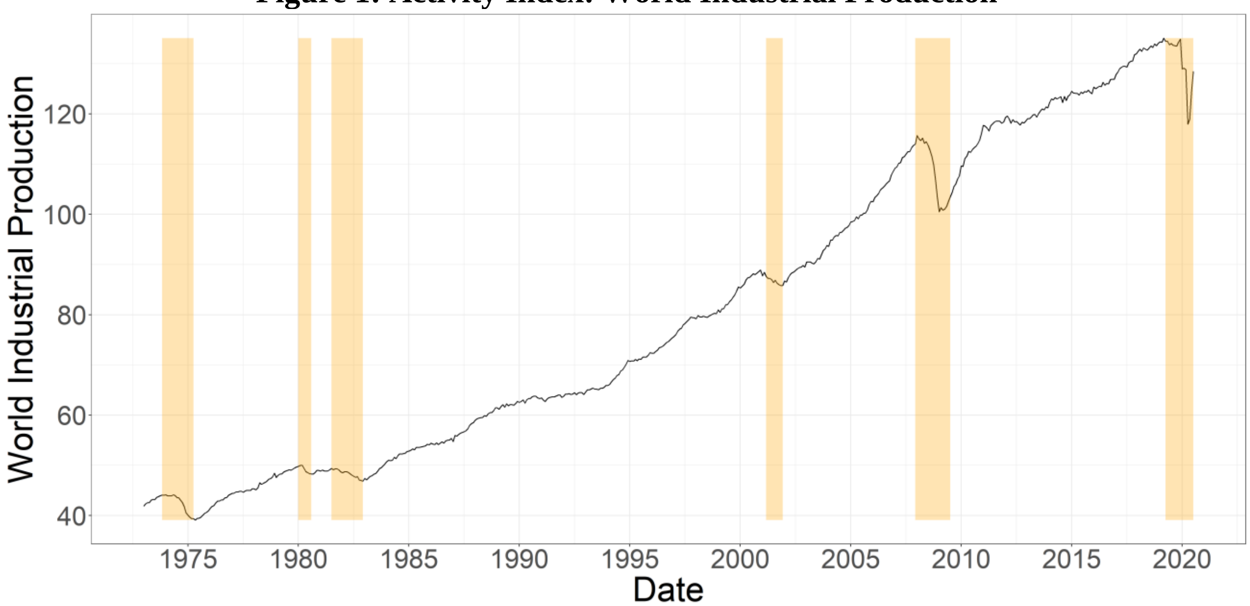
4. Data

Considering the SVAR model is a global one, measures of global proxies will be required for global demand, global prices, and global supply. First, global aggregate demand can be proxied by world industrial production, which is obtained from Baumeister and Hamilton (2019) as the aggregate industrial production of the Organisation for Economic Co-operation and Development[24] (OECD) members and 6 non-OECD major countries: Brazil, China, India Indonesia, the Russian Federation and South Africa. Altogether, the 37 countries of OECD and 6 non-OECD major countries make up over 70% of the world's estimated global GDP and petroleum product consumption. Hamilton (2019) and Baumeister et al. (2020) evaluate indicators for global aggregate demand, including Kilian's (2009) real activity index of freight rates, and have found world industrial production to be the most coherent with the global business cycle. This coherency is visualized in Figure 1, plotting world industrial production in conjunction with U.S. recession dates highlighted in yellow blocks. Notably, contractions in the world industrial production series are all consistent with recession dates, hence making it the standard proxy in the literature.

[24] The OECD is an intergovernmental organization founded in 1961 to provide a platform for stimulating international economic development between members. See oecd.org.

While using global real GDP data to measure global aggregate demand is a more intuitive and direct method to measure aggregate demand, there are several drawbacks prevalent in the literature. For example, Hamilton (2019) finds that global real GDP data is only available in annual or quarterly data. The consequences of evaluating time series in lower frequencies is that it can potentially mis-specify co-movements and the analysis impulse response functions[25]. Moreover, Kilian and Zhou (2018) studies the composition of global GDP and finds that it does not account for structural changes in the service sector. As the service sector has become more prominent in the calculation of global real GDP, it has reduced the weight of the industrial sector of which raw materials such as crude oil has a more significant role in.

Figure 1: Activity Index: World Industrial Production

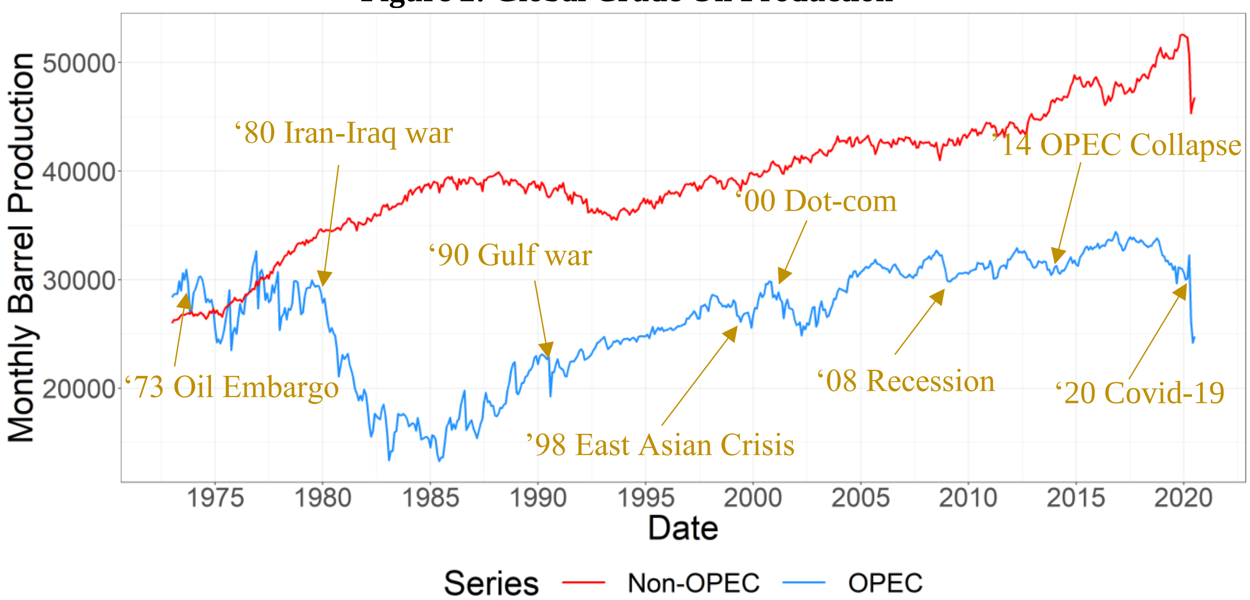


Note: Plot of monthly world industrial production from January 1973 to July 2020 constructed by Baumeister and Hamilton (2019) and sourced from Baumeister's web page. Yellow shaded regions represent US recession dates over the sample in accordance with the National Bureau of Economic Research.

[25] See Ghysels (2016) for more details.

Next, disaggregated global oil production values from OPEC and non-OPEC[26] members are taken from the U.S. Energy Information Administration (EIA) with both series plotted in Figure 2. Focusing on the first half of the sample, OPEC production has many swing episodes associated to large-scale supply disruptions from political events in the Middle East[27]. In the second half of the sample, OPEC becomes much less volatile and production swings are associated with recession episodes instead. Throughout the sample, non-OPEC production isn't as responsive as OPEC supply, moving with little fluctuation, suggesting that OPEC's higher volatility indicates that they are contributing more to supply shocks.

Figure 2: Global Crude Oil Production



Note: OPEC and world crude oil barrel production variable are downloaded from the EIA to construct non-OPEC production as the difference. Both series in the figure report monthly barrel production from January 1973 to July 2020. Several exogenous oil supply shocks due to political events or global contractions over the sample period are labeled in the figure.

[26] The EIA does not provide a stand-alone non-OPEC oil production series. Non-OPEC production is calculated as the difference of OPEC oil production from world oil production

[27] For example, OPEC's drop in oil production between 1981 to 1985 due to the Iran-Iraq war. Saudi Arabia's shutdown of about ¾ of its over the duration. Another example is the Gulf war in 1990 where Iran and Kuwait, which made up 9% of the world's oil production, went to war and caused respective oil productions to collapse.

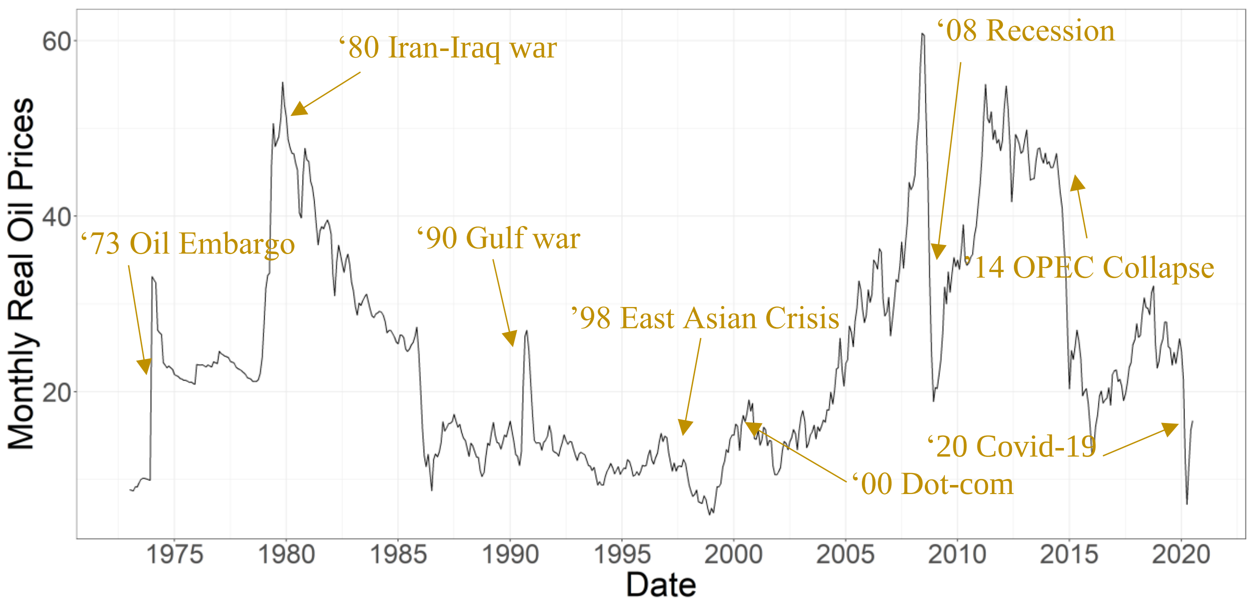
Finally, demand and supply come the Brent crude oil prices, which is also retrieved from the EIA. Brent crude oil prices are based on the index of Brent futures contract and is currently the global benchmark for petroleum products, acting as the price barometer for over two-thirds of the world's physical oil prices[28]. A CPI series is used as-is with the index centered in August 1983 to deflate the nominal Brent series and obtain a measure of real Brent oil prices. Figure 3 plots the series along with the same political events and global contractions as seen in Figure 2. Notably there are large contemporaneous spikes in both data series for all major events, hence motivating a connection between OPEC supply shocks and real oil prices but requires further investigation for a definitive answer.

Kilian's (2009) seminal paper evaluates his SVAR model using percentage change of global crude oil production but uses a logged real oil price and an index of real economic activity in levels without justification. To keep the data consistent, all data series in this paper are evaluated as monthly logged first differences and scaled by 100 from 1973M1 – 2020M7[29], totaling 570 observations after differencing. First differences transform the data series into stationary processes to have a constant mean and variance, hence avoiding spurious regressions.

[28] Source: Theice.com/brent-crude

[29] The starting date is based on the earliest available data from the EIA.

Figure 3: Real Brent Oil Price



Note: Nominal brent oil prices are retrieved from the EIA in USD/Barrel and CPI deflated using US CPI index centered around 1983 to obtain real oil prices. The same exogenous oil supply shocks labeled in Figure 2 are labeled in the Figure 3.

Table 1: Logged First Differenced Summary Statistics

VARIABLE	MIN.	1ST QUART.	MEDIAN	MEAN	3RD QUART.	MAX.	S.D.
WIP	-8.84	-0.12	0.29	0.20	0.57	4.47	0.77
NOPEC	-11.07	-0.45	0.12	0.11	0.73	2.85	1.01
OPEC	-21.09	-0.92	0.22	-0.02	1.15	11.42	3.53
PRICE	-54.90	-3.92	-0.38	0.11	4.82	120.40	10.39

Note: Summary statistics of monthly logged first differenced variables from the period February 1973 to July 2020, totaling 570 observations. Statistics include values for minimum (MIN), first quartile (1st QUART.), median, mean third quartile (3rd QUART.), maximum (MAX) and standard deviation (S.D.). World industrial production (WIP) is retrieved from Baumeister and Hamilton (2019). Non-OPEC (NOPEC) production is retrieved from the EIA. OPEC production (OPEC) is retrieved from the EIA. The real price of Brent (BRENT) is retrieved from the EIA. First differences are also scaled by 100.

Summary statistics of all variables can be found in Table 1. Means of all variables are within a 10% deviation from the median, suggesting that the dataset is rather evenly distributed when comparing its highest and lowest values. OPEC supply is the only variable with a median higher than its mean, suggesting its distribution is slightly skewed to the left and every other variable to be slightly skewed to the right. Particularly, OPEC supply's skewness is largely in part due to the large drop in production during the 1980s, for a duration over a fifth of the entire sample period. Most importantly, standard deviations of the logged first differences further show that OPEC production is more volatile than non-OPEC production. This suggests OPEC may be able to capture more of the large volatility in real oil prices than world industrial production or non-OPEC production.

5. Empirical Results

The resulting VAR model is consistently estimated using ordinary least squares before transformed into the SVAR representation using maximum likelihood via the Newton-Raphson method[30]. Impulse response functions are constructed using an orthogonal transformation from structural factorization matrices derived from the SVAR with asymptotic 95% confidence intervals[31], before responses are accumulated to transform the series from growth rates to levels. Finally, historical variance decompositions are computed using Burbridge and Harrison's (1985) method to decompose the observed real oil price series into each structural shock component over the sample.

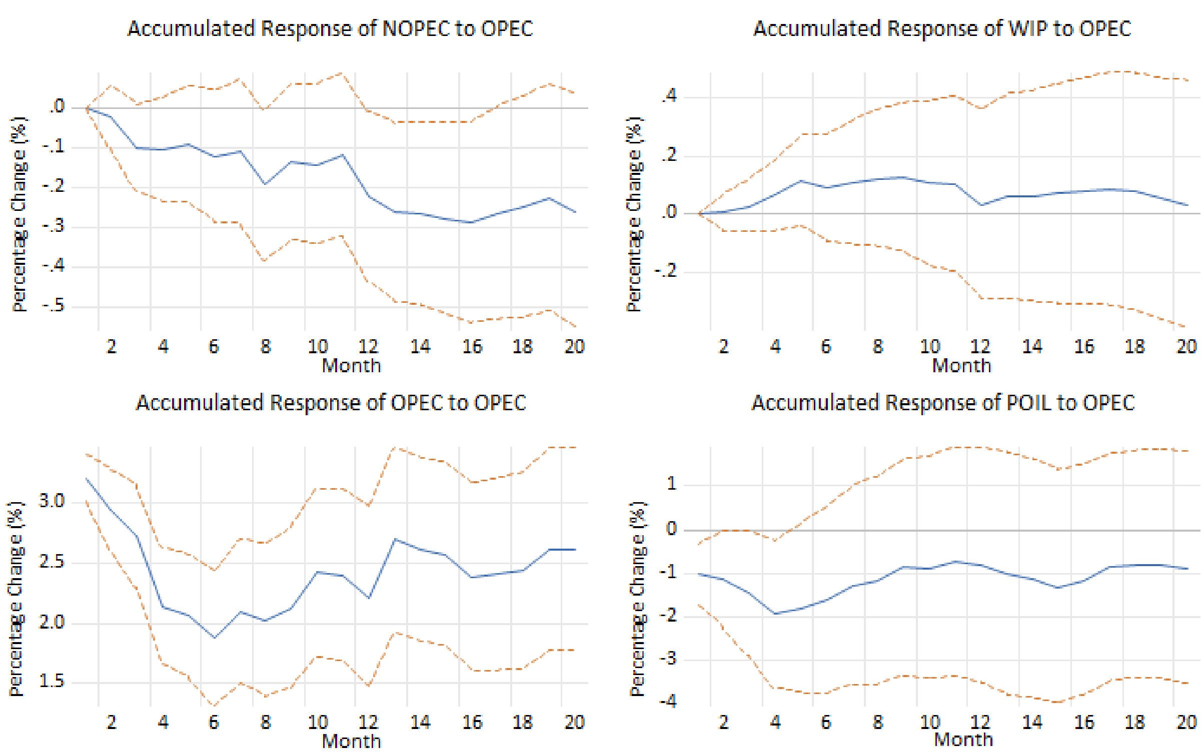
5.1 Impulse Response Functions

Figures 4 plots the responses of model variables to one-standard deviation structural innovations to OPEC supply. This unanticipated OPEC supply shock has a permanent and positive effect on

[30] Twelve lags are selected, corresponding to a one-year period. Hamilton and Herrera (2004) and Güntner and Linsbauer (2018) recommends long lag lengths to account for seasonality and the often-slow response of macroeconomic variables to real oil prices.

OPEC oil production, persistently increasing it by 2.5 percent after a year. The real price of oil responds with a decrease, matching priors and providing evidence against the lack of response found in Kilian (2009). Particularly, the real price of oil persistently decreases by a percentage point, having an elasticity of 0.4. Furthermore, non-OPEC producers also respond with a drop in production after a 12-month lag. OPEC has often exhibited such behavior in recent years when disbanding quotas, in favor of retaining or increasing market share. The organization's consistent high output is often criticized as a conscious effort by the cartel to squeeze out high-cost producers such as North American supply of shale and oil sands from the market by lowing prices[32].

Figure 4. Responses to One-Standard Deviation OPEC Supply Shocks



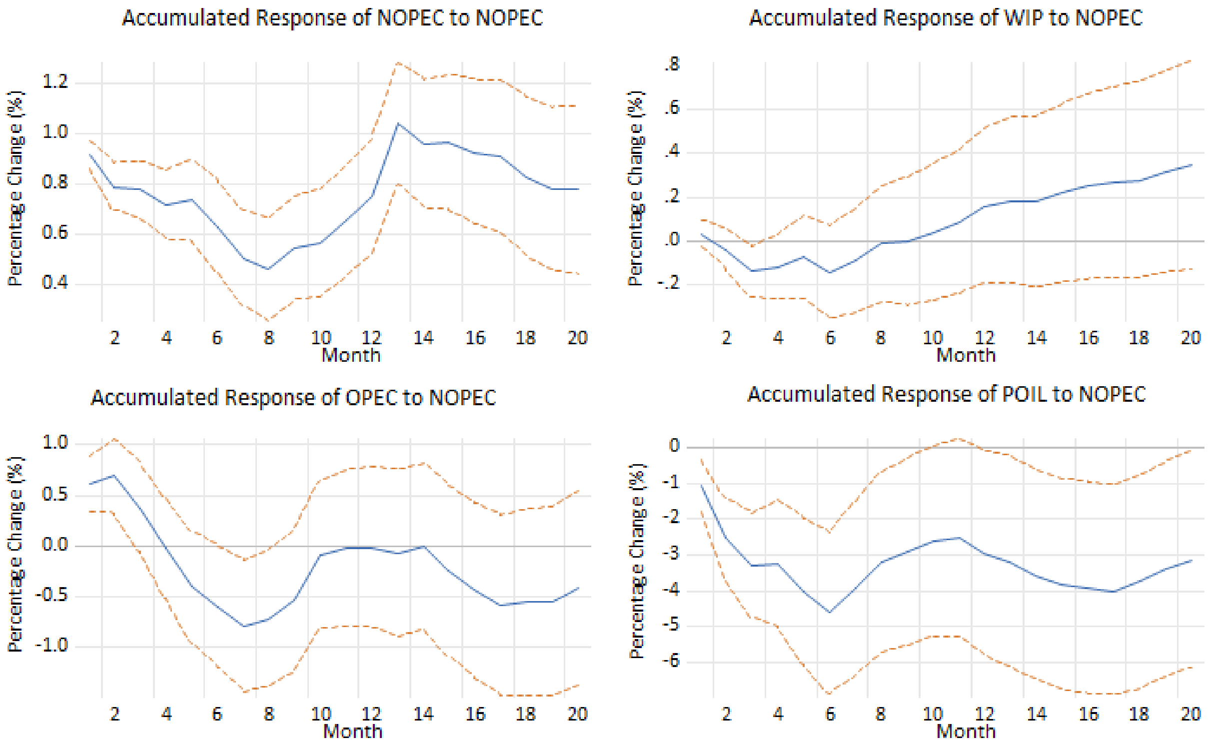
[32] During the 2014-2016 period, Rubin (2016), and Toews and Naumov (2016) finds that many non-OPEC producers are found to sustain production but reduce investment in future capacity, making them susceptible to be squeezed over a longer time horizon.

Note: Impulse response functions from a one standard-deviation shock of OPEC production estimated based on equation (1). The red lines indicate the asymptotic 95 percent confidence intervals.

Figure 5 depicts the responses to one standard deviation shock to non-OPEC supply. An unanticipated innovation to non-OPEC production has a permanent and positive effect on non-OPEC production, permanently increasing it by about 0.9 percent. Again, consistent with priors and unlike Kilian's (2009) results, real oil prices respond with a decrease. Specifically, prices decrease persistently by a 3 percent after half a year. OPEC production also responds with some short-run exacerbation, significantly increasing production for a few months by 0.5 percent. This consistent with OPEC's cartel behavior to market share targeting strategy since the introduction of U.S. shale oil in the market in 2014 when OPEC responds by increasing production to lower oil prices and thereby reducing competitor revenues. Notably, there is an indication that the real price of oil reacts positively to declines in OPEC production after 6 months as efforts made to stabilize oil prices[33]. However, considering the elasticity of response from the price of oil to OPEC supply indicated previously, OPEC production of a 0.5% increase has a negligible and economically insignificant effect on real oil prices.

[33] OPEC has been shown to exhibit inconsistent strategic behavior, sometimes adopting a stern price stabilization strategy such as from 2004-2014 and other times exhibiting episodes of maintain market share targeting such as from 2014-2016. Impulse response functions capture the average response of OPEC to structural shocks over the sample, therefore capturing these conflicting behaviors.

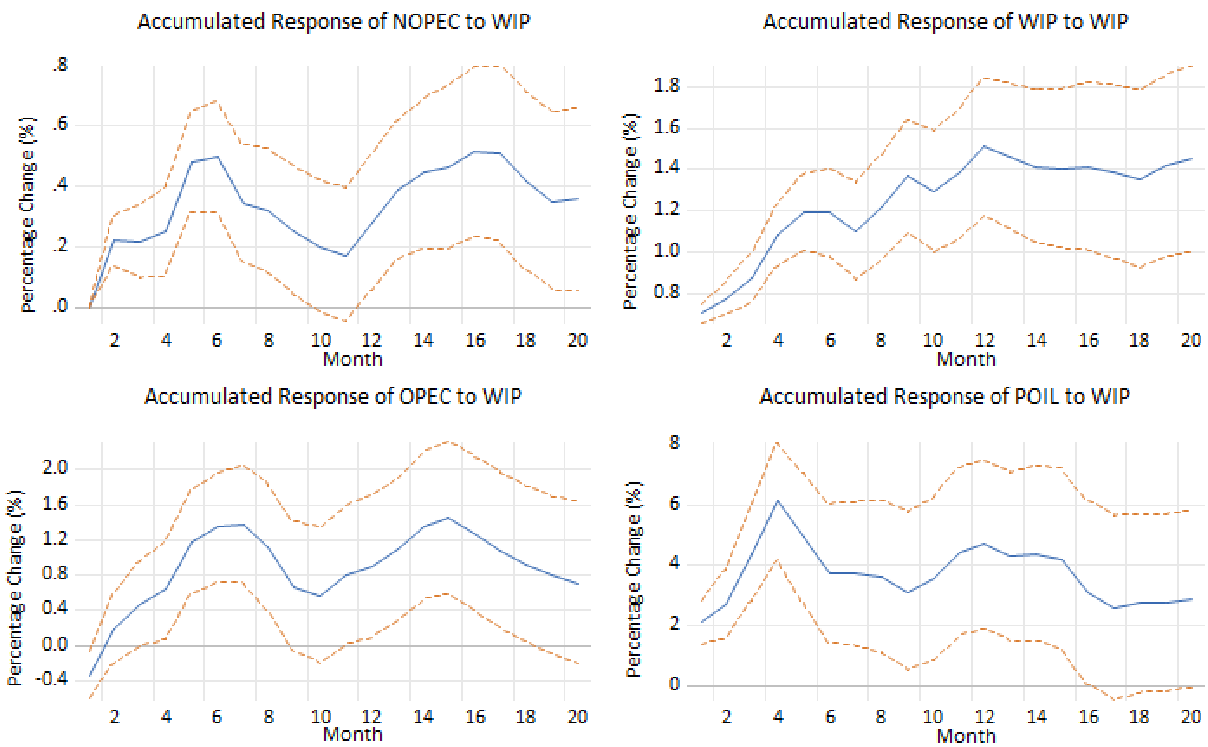
Figure 5. Responses to One-Standard Deviation Non-OPEC Supply Shocks



Note: Impulse response functions from a one standard-deviation shock of non-OPEC production estimated based on equation (1). The red lines indicate the asymptotic 95 percent confidence intervals.

Lastly, Figure 6 shows that the effect an aggregate demand shock. Particularly, a one standard deviation aggregate demand shock persistently increases world industrial production by 1.5 percent after a year and remains high. On average, such a shock induced a price response elasticity of supply that is more than twice as large in OPEC than non-OPEC regions, and caused a permanent response in the price of oil with over a year and a half of significance. This is consistent with Álvarez and Venditti (2020) where OPEC is found to be more elastic due to its excess capacity. Moreover, real oil prices increase persistently by 4 percent with small overshooting in the run which is again consistent with priors. If OPEC is to exhibit price stabilization behavior, then OPEC should respond with increases to production, and this is exactly the case here. In fact, both production regions and their response dynamics track the growth rate of world industrial production, dampening price movement. An example of such a behavior is during the emergence of China in the oil market, accounting for one-fourth of world incremental oil demand between 1995-2006 and exhibiting upward pressure prices on oil prices. Hamilton (2009) explains that both regions tried to increase production in order to capture the profits and dampen price movements but was slow to do so due to geological limitations.

Figure 6. Responses to One-Standard Deviation WIP Shocks



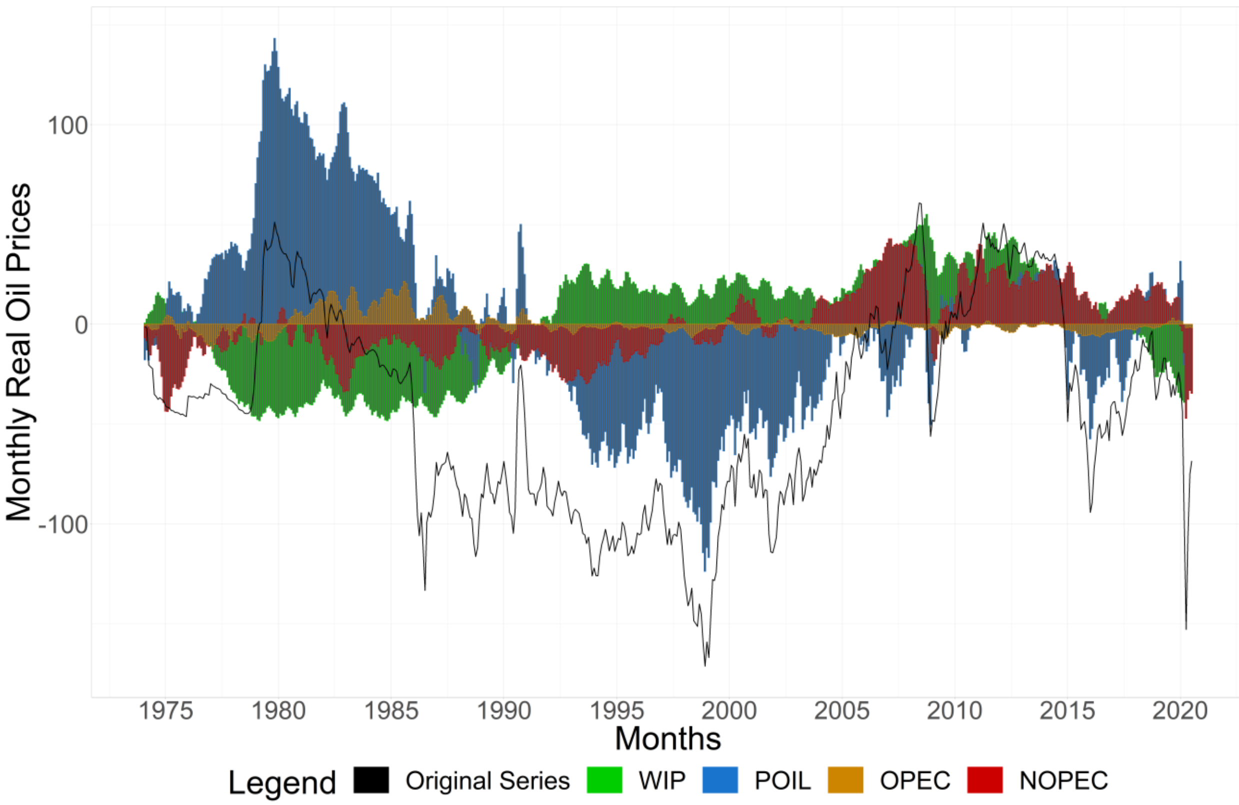
Note: Impulse response function from a one standard-deviation shock of world industrial production estimated based on equation (1). The red lines indicate the asymptotic 95 percent confidence intervals.

5.2 Historical Variance Decomposition

Based on the impulse response functions, OPEC dampens price volatility in response to demand shocks and has a minimal effect on prices when responding to non-OPEC supply shocks. However, it can still be a significant source of shock if OPEC productions shocks are prevalent in the data, motivating the importance of evaluating its own incidence. Figure 7 plots the cumulative contribution of each structural shock on the evolution of real oil prices. For example, the historical variance decomposition indicates that the main drivers of oil prices in the few years leading up to 2008 are demand and then non-OPEC supply shocks. This is consistent with findings in the literature that have pointed at China's demand to be the main cause of price increases during that time period, amid struggling production from other regions[34]. During the 2008 recession afterwards, demand is seen to be the biggest contributor driving down oil prices which is also consistent with priors on the effects of the global recession. This historical variance decomposition echoes the results of Kilian (2009), that the biggest contributions to real oil price come from demand, while supply, including OPEC production, has historically made negligible contributions to the real price of oil. This is consistent with numerous studies show that major oil price fluctuations are, for the most part, endogenously demand driven with the global business cycle[35]. In fact, a variance decomposition analysis[36] indicates that OPEC has only contributed to 2 percent of the variation in the data. Surprisingly, non-OPEC production has played a bigger role in determining oil prices than what has been previously suggested, perhaps confounding the effects of OPEC production responses. Notwithstanding, the minimal incidences of OPEC production shocks and the miniscule variance contribution is evidence to reject the hypothesis set out in the beginning of the paper: that there is sufficient evidence against the net positive contribution of OPEC on oil price volatility.

[34] See for example Hamilton (2009, 2011).
[35] Kilian (2014) surveys the literature and finds strong empirical evidence for endogeneity in determining oil price fluctuations.
[36] Evaluated as the variance of the sum of shocks less OPEC supply shock, divided by the variance of the sum of shocks, before normalizing to one. These results are comparable to the adjusted R^2 values from fitting a regression on the shocks.

Figure 7. Historical Decomposition of POIL



Note: Historical variance decomposition showing the contribution each identified shock on the evolution of POIL as estimated based on equation (1). The POIL series is also overlayed to the plot.

5.3 Sensitivity Analysis

In contrast to the 12 lags employed in the SVAR model above, Kilian (2009) employs a SVAR model with 24 lags, corresponding to two years. On the other hand, the Akaike Information Criterion estimates an optimal lag selection of 6 to fit the model. To assess the differences between these specifications, the SVAR model is re-estimated in both 6 and 24 lags. However, both specifications had only minor deviations in the impulse responses and a variance decompositions analysis still result in OPEC contributing to less than 3 percent of the variation in the price of oil.

The approach used in this paper to identify structural shocks in the real price of oil studies the sample in aggregate. Hamilton (2013) and Ratti and Vespignani (2015) identifies two main periods associated with significant changes in oil prices as 1973-1996 and 1997-present and finds a structural break at the end of 1996. Re-estimating the SVAR by accounting for these two periods, an interesting result is that the variance decomposition analysis now indicates OPEC contributes to over 6 percent of the variation but is still economically inconsequential. One caveat to the estimation using structural breaks is that lower sample sizes significantly reduce the power of the model, leading to more biased estimates.

6. Conclusion

This paper explores the extent to which OPEC has been fulfilling its mandate stabilizing oil prices and contributing to oil price volatility from 1973M1-2020M7. To perform the analysis, this paper revisits the structural drivers of oil prices through the lens of a SVAR model that is motivated to allow OPEC to respond to both supply and demand shocks within the same month. The model finds that OPEC is consistent to a partial market-sharing cartel model found in the literature as OPEC responds to unexpected positive innovations to non-OPEC production by increasing its own production. However, these OPEC production responses to innovations to non-OPEC production shocks have economically insignificant effect on the real oil prices as the price response elasticity to OPEC production is 0.4. Lacking sufficient OPEC production shock incidences in the data, the findings suggest that OPEC has not been contributing positively to oil price volatility and inadvertently fulfilling its mandate.

Of considerable note, this paper uses a recursively identified model in the analysis. These models are often criticized about their strong identifying assumptions on the error terms of the underlying VAR model. Future studies should instead revisit this model through the framework of a Bayesian SVAR which can be used to relax the strict assumptions made in the identification strategy in this paper[37].

[37] See Baumeister and Hamilton (2019).

7. References

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