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A Structural Model of the World Oil Market: The Role of Investment Dynamics and Capacity Constraints in Explaining the Evolution of the Real Price of Oil

1. Introduction

Just a few years ago, it was commonly believed that all major oil price shocks could be attributed to oil supply disruptions triggered by exogenous geopolitical events in oil-producing countries, such as wars and revolutions, and/or by some other disruptive supply-based factors, such as a shift in OPEC's oil policy (Hamilton, 1983, 1985, 2003).[1] Today, this view has little empirical support. Not only do direct measures of exogenous oil supply disruptions have little explanatory power (see, for example, Kilian, 2006, 2008b), but also structural vector autoregressive (VAR) models of the world oil market that focus on the supply-demand determinants of the oil price show that oil supply shocks overall have had little impact on the real price of oil since 1973 (Baumeister & Peersman, 2013a, 2013b; Kilian, 2009a; 2009b; Kilian & Murphy, 2014; Kilian & Hicks, 2013; Peersman & Van Robays, 2009). In contrast, there is now widespread recognition that changes in crude oil demand best explain most major oil price fluctuations since the 1970s. Demand shocks driven by shifts in the global business cycle are now seen as the primary driver of oil prices, with shocks to physical speculative (or inventory) demand arising from shifts in market participants about future supply-demand tightness playing a much lesser part (see also Baumeister & Hamilton, 2015; Baumeister & Kilian, 2016b; Kilian & Lee, 2014; Lippi & Nobili, 2012; Melolinna, 2012).

Although traditional supply-side explanations of the real price of oil have come under close scrutiny during the past decade, there is still good reason to be sceptical about the assertion that supply shocks are not as important as originally thought. The classical notion of an oil supply shock as discussed in the literature (also referred to as *flow supply shock*), corresponds to an exogenous disturbance to oil production that shifts the upward-sloping oil supply curve along the downward-sloping oil demand curve, and hence, results in an opposite movement in global oil production and in the real price of oil (see, for example, Baumeister & Peersman, 2013b; Kilian, 2009a; Kilian & Murphy, 2014).

However, the oil price collapse in the second half of 2014, which saw the monthly average real price of oil plunge by 44%,[2] showed that oil supply shocks can generate abrupt changes in the real oil price without large changes, if any at all, in observed global oil production. For example, Baumeister & Kilian (2016b) argue that to the extent that oil supply shocks mattered for the 2014 oil price collapse, the question of interest is not whether there was a large shift in oil production or not, but whether it moved relative to what was expected. The authors go further and suggest (p. 135): "If oil production was expected to decline, for example, but did not because of a positive oil supply shock, then this shock

[1] Exogeneity here means that these events did not occur in response to the current or past state of the crude oil market and the global economy.
[2] The real price of oil in this paper refers to the Brent price deflated by the US consumer price index in August 2016 USD, unless otherwise stated.

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would trigger an additional [downward] adjustment of the price of oil without a change in observed oil production".

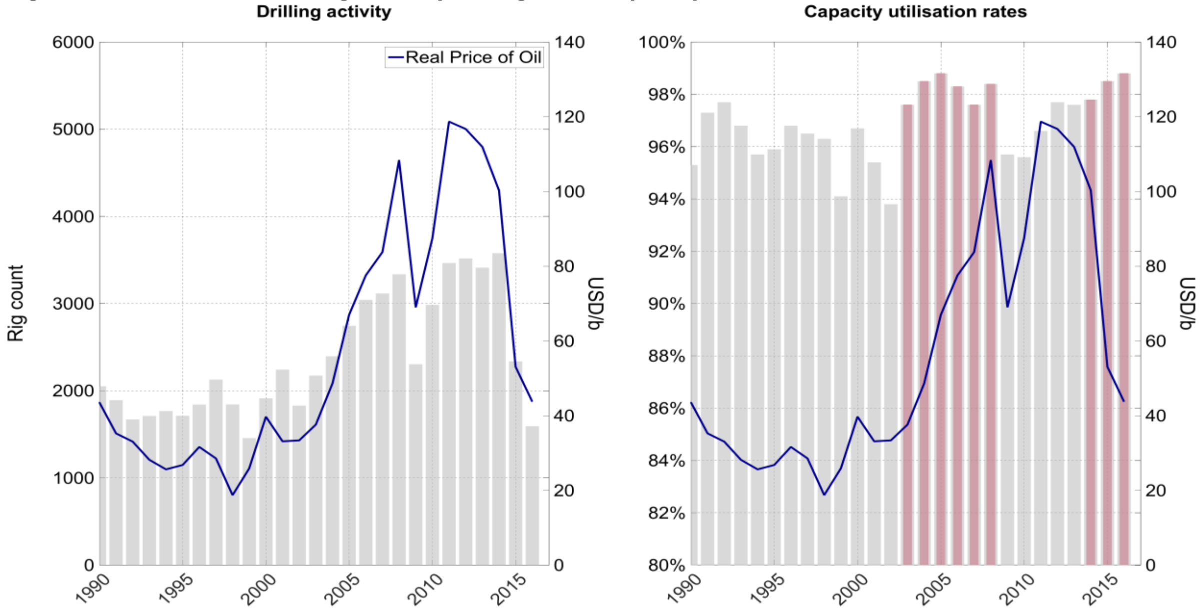
In a falling market characterised by relative oil abundance, such expectations could arise from the belief that OPEC oil producers will put a floor under the price by curbing their output and/or non-OPEC oil producers whose long-run marginal costs exceed the current price of oil will exit the market. An opposite situation arises in tight market conditions. If oil production is expected to increase, but does not because of a negative oil supply shock, then this shock would trigger an additional *upward* adjustment of the price of oil without a change in observed oil production (see, for example, Hamilton, 2009a). This phenomenon was seen during the 2003 to mid-2008 surge in the monthly average real oil price from $41/b to $147/b. That price move was driven by a series of stronger-than-expected flow demand shocks *in conjunction* with stagnate global oil production from 2004 onwards (Hamilton, 2009b, 2013a, 2013b; Kilian, 2009b, 2010a, 2010b; Lombardi & Van Robays, 2011; Nakov & Pescatori, 2010). In both cases, the heart of the problem is the limited ability of oil producers to adjust supplies in response to demand-driven shocks to the real price of oil due to capacity constraints in crude oil production (see Baumeister & Kilian, 2016a; Kilian, 2008b; Mabro, 1998, 2006; Smith, 2009). Indeed, there is a consensus in the literature that relatively low surplus production capacity since the early-1990s may have contributed to more dramatic oil price fluctuations, albeit quantifying the extent of these changes has proven hard to empirically pin down (see, for example, Baumeister & Peersman, 2013a).

Traditional oil market VAR models implicitly assume that existing production capacity in oil producing countries is fixed over time, while the ability or willingness of oil producers to adjust production to smooth out price changes is observationally equivalent to a shock to the flow supply of crude oil, as measured by global crude oil production (see, for example, Kilian & Murphy, 2014).[3] Capacity constraints however are not fixed over time. On the one hand, considering the long lead times and long gestation periods from the point at which a Final Investment Decision (FID) is made and the start of first production, underinvestment in upstream oil can generate large price spikes due to the inability of producers to maintain and expand production in the face of an upward oil demand shock. On the other hand, overinvestment in the upstream can depress the price of oil due to the unwillingness of producers to defer output. Once costs have been sunk into a project, producers are unlikely to reverse an investment decision, while shutting-in operating capacity is costly and rarely done, especially outside of OPEC.

Most importantly capacity constraint due to inefficiencies in investment dynamics are not linearly related to the price of oil. For example, while either under- or over-investment can induce capacity constraints in crude oil production, their effect on the real price of oil would be markedly different. This point is displayed in Figure 1, which shows the annual worldwide active rig count (i.e. drilling activity) as one of the primary indicators for investment in the oil sector, and global capacity utilisation rates for the period 1990-2016. As is evident from both graphs, the presence of capacity constraints due to underinvestment refers to a situation where the current or future production capacity is unable to meet the current or expected increases in global oil demand (as observed by the large year-on-year increases in drilling activity during 2003-2008), generating abrupt and persistent increases in the real price of oil. In contrast, the presence of capacity constraints due to overinvestment refers to a situation where the current and future operating capacity runs ahead of the current and expected increases in oil demand. This severely depresses the real price of oil and results in low investment that affects the supply conditions in the next cycle (as observed by the more-than-half displacement of drilling rigs during 2014-2016). Such asymmetric responses are not allowed for in the existing VAR models of the world oil market, which implies that this type of oil supply shock cannot be identified from traditional observables of flow supply.

[3] Production capacity is the sum of operating and spare (or surplus) capacity. Operating capacity is defined as the maximum sustainable amount of capacity that is in operation at the beginning of a period. Spare capacity is defined as the component of production capacity that is not in operation but can be brought online within one month; or not in operation but under active repair that can be completed within three months.

Figure 1: Worldwide drilling activity and global capacity utilisation rates, 1975-2016



Notes: The real price of oil refers to the West Texas Intermediate price deflated by the US consumer price index in 2016 USD. The red shaded bars indicate the periods 2003-2008 and 2014-2016. Data source: Federal Reserve Bank of St. Louis; Baker Hughes GE Database; US Energy Information Administration.

In a new paper, we quantify the role of investment dynamics and capacity constraints in determining the real price of oil by redefining oil supply shocks in terms of, (i) exogenous geopolitical disruptions in crude oil production (henceforth referred to as *exogenous supply shocks*), and (ii) the presence of capacity constraints due to investment dynamics (henceforth referred to as *endogenous supply shocks*). Accordingly, the analysis in this paper builds on a fully specified structural vector autoregressive (VAR) model of the world oil market, in the tradition of Kilian and Murphy (2014), that decomposes the real price of oil as follows:

- Shocks to oil supply that are caused by exogenous geopolitical events in OPEC countries (*exogenous supply shocks*);
- Shocks to oil supply that arise within the crude oil market due to either under-investment or over-investment in upstream oil that lead to capacity constraints (*endogenous supply shocks*);
- Shocks to oil demand associated with the global business cycle (*flow demand shocks*);
- Shocks to crude stocks demand arising from forward-looking behaviour (*speculative demand shocks*); and
- Other idiosyncratic oil demand shocks not otherwise captured by the preceding structural shocks (*other demand shocks*).

Our analysis provides estimates of the dynamic effects of supply and demand shocks on the real price of oil and by how many dollars each structural shock contributed to the evolution of the real oil price from February 1992 to August 2016. The central message of the paper is that while there is overwhelming empirical evidence that most large and persistent fluctuations in the real oil price have been driven by the cumulative effects of oil demand, the robustness of this evidence crucially depends on the rigorous identification of oil supply shocks.

2. A Review of the Supply Shock Measures of Crude Oil

Considering the rich history of geopolitical episodes in oil-producing countries since the 1970s oil crises, numerous studies concerned with the effects of exogenous supply shocks on the price of oil and other macroeconomic aggregates introduce measures that control explicitly for these shocks (Dotsey & Reid, 1992; Hamilton, 2003; Hoover & Perez, 1994; Kilian, 2008). Historical examples of such exogenous geopolitical events in the modern OPEC period that began in the early 1970s, include: the Arab oil embargo of 1973, the Iranian Revolution of 1978, the Iran-Iraq War of 1980, the Gulf War of 1990, the Venezuelan oil crisis of 2002, the Iraq War of 2003 and the Libyan Civil War of 2011, among other episodes.

Recent empirical evidence demonstrates that commonly used measures of exogenous supply disruptions explain little about major oil price fluctuations post-1974 (Kilian, 2008b). In fact, subsequent empirical studies on the causes of oil price shocks drop these explicit oil supply shock measures and instead rely on the observed monthly changes in global oil production to identify shocks to the flow supply of oil collectively (see, for example, Kilian & Murphy, 2014). This approach, however, points to a potential limitation of modelling the supply side of the oil market, which does not differentiate between supply shocks originating from outside and within the crude oil market, or recognise the differences associated with the responses of oil production, real economic activity, inventories, and hence the real price of oil to these shocks over time.

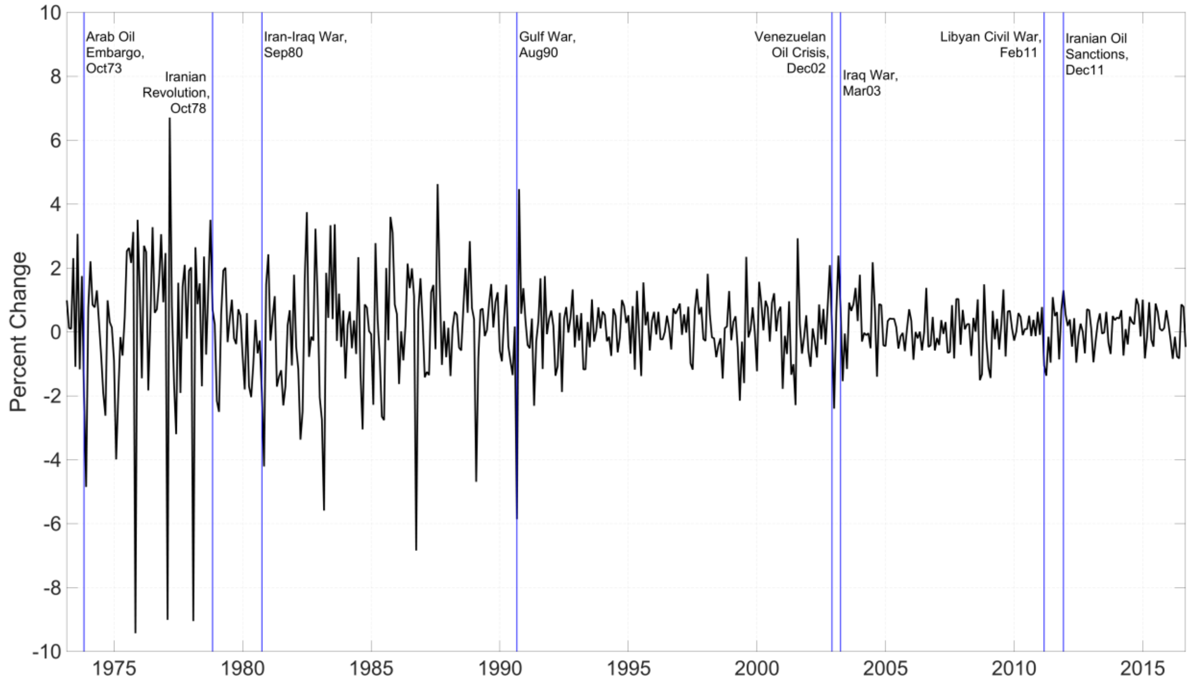
In addressing these problems, recent empirical work by Economou (2016) introduces a new set of oil supply shock measures that distinguish between changes in crude oil production that arise due to exogenous geopolitical events in OPEC, such as wars and civil unrest, and constraints in production capacity that arise due to market-specific innovations associated with the investment dynamics in upstream oil.

2.1. Measure of flow supply shocks to global crude oil production

Figure 2 plots the monthly percent changes in global crude oil production from February 1973 to August 2016, using data compiled by the US Energy Information Administration (EIA). As can be seen from this figure, major historical movements in crude oil production mostly result from key exogenous geopolitical events in OPEC countries (indicated by the vertical lines in the plot), such as wars and political unrest, politically motivated supply decisions, and internal OPEC power struggles observed during periods of high volatility such as in the mid-1980s (see Gately, Adelman & Griffin, 1986). It can also be seen that, by historical standards, there have been no substantial fluctuations in global oil production since 1990, with the largest changes corresponding to the Gulf War of 1990, the Venezuelan Oil Crisis of 2002, and the Iraq War of 2003. From January 1990 to August 2016, shocks to the flow supply of oil accounted for 0.8% of the variability in global oil production changes, compared to 4.8% in the previous period of the sample (February 1973 to December 1989).

A visual examination of the series also seems to belie any obvious relationship to endogenous shocks in crude oil production after 2003. Yet a large body of the recent literature postulates that major oil price developments after 2003 were driven, at least in part, by capacity constraints in crude oil production associated with the long-run challenges of depletion, the erosion of spare capacity, the economic viability of new sources of supply such as US shale oil and Canadian oil sands, as well as shifts in OPEC oil output policy (Alquist & Guenétte, 2014; Arezki, 2016; Fattouh & Sen, 2015; Hamilton, 2013a, 2014; Sandrea, 2014).

Figure 2: World crude oil production in monthly percent changes, 1973.2-2016.8



Source: EIA

A case in point is the 2003-2008 episode, during which strong demand growth from non-OECD economies had caught up with the decade-long structural underinvestment in the upstream sector of the 1990s, the maturity of legacy oil fields, and the long lead times associated with the development of new production capacity. Between 2004 and 2007, oil consumption in emerging economies grew by an annual average of 4.3%, whereas global oil production growth between 2005 and 2007 unexpectedly stalled.[4] Although there have been other episodes when global oil production stagnated over a two-year period, these were inevitably either responses to falling demand during recessions or to exogenous supply disruptions (Hamilton, 2013b). During this episode, however, the strength of global demand growth caught oil producers by surprise. By 2007, crude oil production outside OPEC was 0.73 mb/d lower from its levels in 2004, as important contributors to the growth of non-OPEC oil supply (e.g. the US, the North Sea and Mexico) failed to maintain and expand production. Fattouh & Mabro (2006) attribute this stagnation of crude oil production to a number of economic, political and geological factors, as well as corporate behaviour, that predominated in the oil industry since the 1980s. Taken together, these factors produced a long-lasting environment conducive to low investment rates in the upstream sector at the expense of maintaining and developing new crude capacity. Most importantly, generalised structural underinvestment in the upstream sector over the previous two decades was felt in the erosion of spare capacity, which between 2002 and 2005 collapsed by 4.15 mb/d, to just 1.02 mb/d (Fattouh, 2006).

The unprecedented growth of US shale oil production and its importance to recent price dynamics which shifted market perceptions from oil scarcity to oil abundance is another case of interest. Between 2009 and 2015, US oil production grew on average at an annual rate of 9.6%, while US shale oil production alone grew on average by a remarkable annual rate of 22.3%. The immense growth of US production had no obvious impact to the growth of global oil production, at least not until 2014. Many observers have suggested that this paradox can be explained by the fact that from December 2010 to March 2014, the 3.2 mb/d of new production originating from the US were exactly matched by exogenous disruptions

[4] Calculations in this section are based on publicly available data from the US Energy Information Administration, unless stated otherwise. Available at: https://www.eia.gov/petroleum/data.php

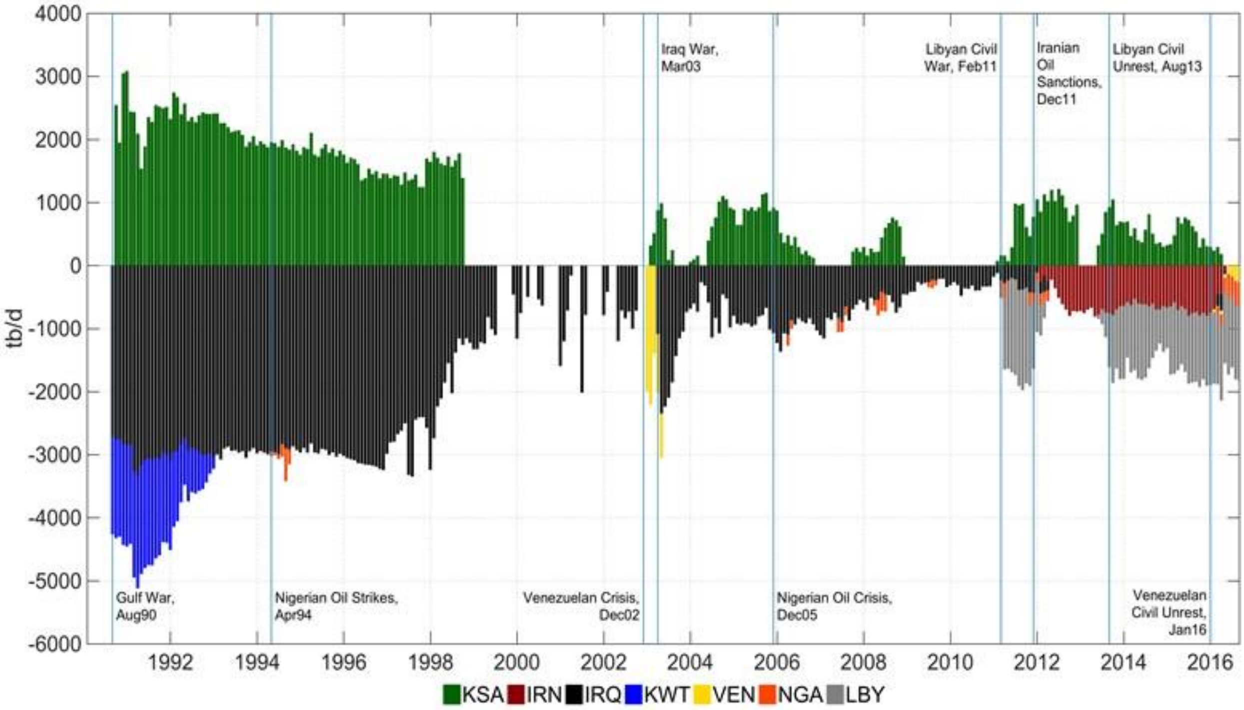
in oil production in the Middle East and North Africa (Stevens, 2015, p. 6). Only in the second half of 2014, when the earlier geopolitically induced production shortfalls unexpectedly receded and OPEC decided not to cut output to counter the excess supply, did the supply-demand imbalance materialise, generating a very significant price response to the downside (Baffes et al. 2015). By 2015, the annual average real price of oil halved from $100/b to $53/b, as global oil production continued to grow at an annual average rate of 2.8%, driven by an increase in OPEC and US crude oil production of 4% and 7.4% respectively, while global oil consumption grew by a comparably weaker annual average rate of 1.6%.

Modelling shocks to the flow supply of oil collectively, based on changes in global oil production per se, implies that critical information about the underlying supply conditions of the crude oil market are not contained in the shock measure of flow supply available to the econometrician (e.g. oil production might be subject to capacity constraints). An additional implication is that exogenous shocks in crude oil production would be expected to have a markedly different effect on the real price of oil, as on the rest of the model's variables, compared to shocks to crude oil production within the confines of the world oil market. To the extent that this assumption is valid, estimates of the dynamic effects of flow supply shocks on the real oil price are potentially misleading, especially at increasingly distant horizons. The reason is that, on the one hand, geopolitically driven shortfalls in crude oil production tend to be resolved in the short-run by spare capacity releases when excess production is available, which explains why recent empirical studies find that exogenous supply shocks have little systematic impact on the real price of oil (see, for example, Kilian, 2008). On the other hand, unless oil demand deteriorates, capacity constraints due to underinvestment can only be resolved in the long-run by adding new capacity in the oil market, which is a process associated with long gestation periods and lead times of investment decisions and planning (Fattouh & Mabro, 2006). Similarly, unless oil demand recovers or OPEC collectively decides to balance the market, the only way to resolve capacity constraints due to overinvestment hitting the market, is for oil producers whose long-run marginal cost exceeds the current price of oil to exit the market (Baumeister & Kilian, 2016), which can take time. This line of reasoning suggests that while exogenous oil supply shocks are non-negligible, capacity constraints in crude oil production may have generated larger and more persistent price responses in recent years than previously thought.

2.2. Measures of exogenous and endogenous supply shocks

Many studies have proposed measures of exogenous oil production shortfalls (see Dotsey & Reid, 1992; Hamilton, 2003; Kilian, 2008). More recently, Economou (2016) proposes a monthly measure of exogenous shocks to OPEC crude oil production that takes full account of the timing and the actual duration of the shock, as well as of variations over time in its magnitude and sign. Figure 3 shows the OPEC-wide exogenous shortfalls and offsets in crude oil production driven by major geopolitical events for the period January 1990 to August 2016. The negative production levels at each point in time may be viewed as the true shortfalls in crude oil production from a given country as a response to a major exogenous event, indicated by the vertical lines in the plot; namely from Iran (IRN), Iraq (IRQ), Kuwait (KWT), Venezuela (VEN), Nigeria (NGA) and Libya (LBY). The positive production levels at each point in time may be viewed as the oil production responses from Saudi Arabia (KSA) that are triggered in response to an exogenous event elsewhere in OPEC.

Figure 3. Exogenous disruptions and offsets in OPEC crude oil production in thousand barrels per day, 1990.1-2016.8

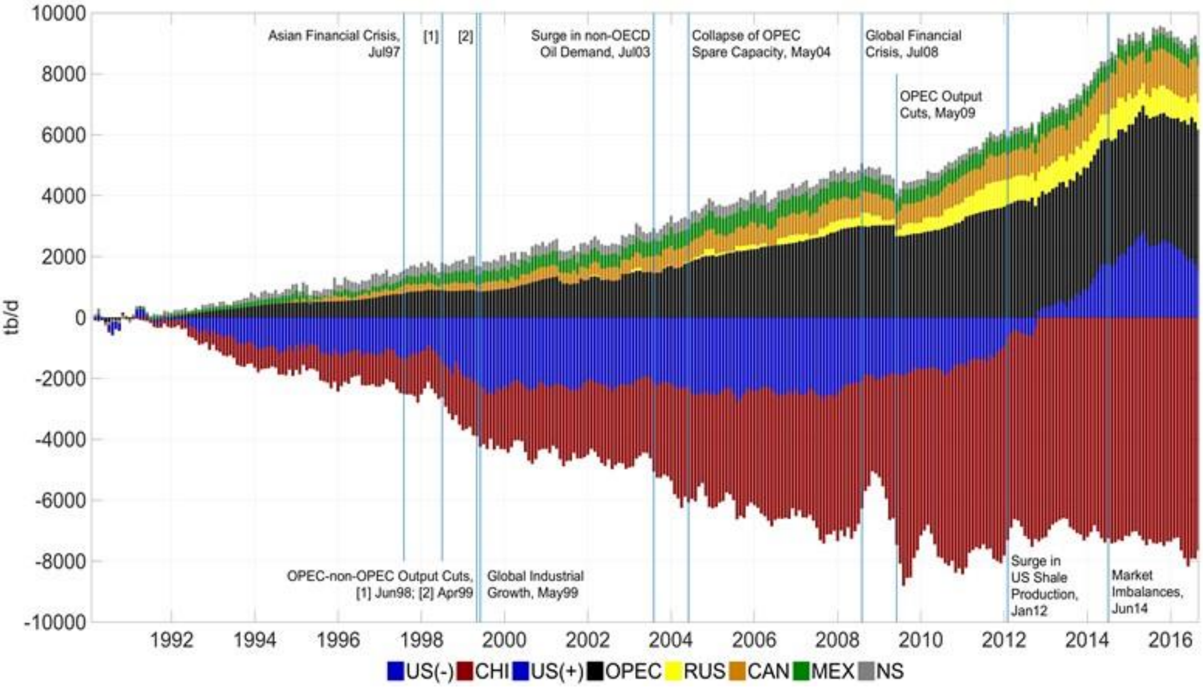


Source: Authors' Calculations

Exogenous shocks to global crude oil production constitute only one type of supply shock. As discussed above, there may also be shocks to global production capacity due to a number of uncertainties affecting the investment decisions of oil producers and hence affecting the oil supply. This type of oil supply shock (referred to as *endogenous oil supply shocks*) arises within the crude oil market, and implicitly reflects the rate of investment in new production capacity, conditional to the expectations of oil producers regarding future market conditions and the oil price (Adelman, 1993; Mabro, 2006). Accordingly, recent empirical work by Economou (2016) introduces a novel methodology for constructing a monthly measure of endogenous oil supply shocks that takes full account of the timing, the magnitude and the sign of any supply-related deviations from the equilibrium production path driven by oil market-specific factors.

Figure 4 shows the vertical differences between actual and counterfactual production levels by country for selected oil producers that are net importers, namely the US and China (CHI), and those that are net exporters, namely for aggregate OPEC, Russia (RUS), Canada (CAN), Mexico (MEX) and the North Sea (NS; i.e. the UK and Norway combined), along with key oil market-specific events in the period January 1990 to August 2016. The negative production levels at each point in time may be viewed as that amount of oil supply that the net importers need to cover by imports drawn and not met from domestic production. The positive production levels at each point in time may be viewed as that surplus amount of oil supply that is available to be exported by the net exporters, given that they cover in principle their own domestic needs. The change over time in the series is driven explicitly by endogenous factors conditional to the current and past state of the crude oil market. For example, increasing production could be driven either by a significant oil discovery or by a past period of high investment rates in the upstream sector, or both. On the other hand, declining production could be driven by natural decline rates or by a past period of structural underinvestment in the upstream sector, or both. In addition, these changes reflect collective OPEC and non-OPEC output adjustment decisions based on expectations about future market conditions and price. By summing all country-specific endogenous shortages and surpluses in oil production, it is possible to construct an aggregate time series of imbalances in global production capacity caused explicitly by oil market-specific factors.

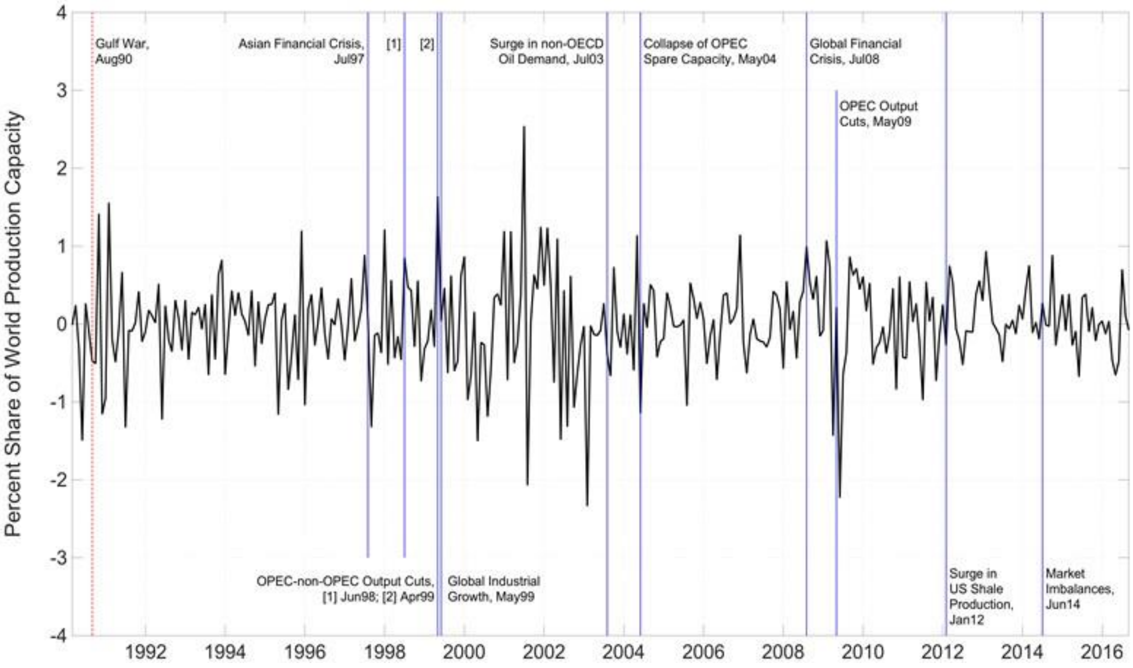
Figure 4: Endogenous cover/exposed levels of crude oil production in thousand barrels per day, 1990.1-2016.8



Source: Authors' Calculations

The change over time in the series provides a natural measure of the endogenous oil supply shocks at monthly frequency as shown in Figure 5, expressed as a percentage share of global production capacity. Endogenous oil supply shocks from February 1990 to August 2016 range from around +2.5% to -2.5% of global production capacity and account for 3.1% of the variability in the changes of the time series, compared to only 1.2% of the variability due to exogenous oil supply shocks.

Figure 5: Measure of endogenous oil supply shocks to global production capacity in first-difference, 1990.2-2016.8



Source: Authors' Calculations

The movements in the baseline endogenous oil supply shocks measure can be reconciled with key market-specific oil dates, indicated by the blue vertical lines in the plot. For example, the initially negative and then positive swings exhibited in the shocks seen in 1998, 1999, 2008 and 2009 are consistent with the collective OPEC-non-OPEC output adjustment decisions related to the market uncertainty in the aftermath of the Asian Financial Crisis of 1997 and the Global Financial Crisis of 2008. In addition, the negative spikes between 2002-2004 reflect the erosion of spare capacity amid the unexpected surge in non-OECD oil demand that followed the generalised underinvestment in the oil sector in the 1990s (Fattouh and Mabro, 2006). Finally, there are two periods of gradual fluctuations in the endogenous oil supply shock series that denote persistence: the 2005-2008 and the 2012-2015 timespans. The former reflects the global production stagnation associated with persistent declines in the series followed by temporary increases, while the latter reflects the US capacity expansions in unconventional oil production associated with persistent increases in the series followed by temporary declines. Overall, endogenous oil supply shocks from February 1990 to December 2003 account for 1.9% of the variability in global production capacity changes, compared to 4.2% from January 2004 onwards.

3. A Structural Model of the World Oil Market and Empirical Results

The analysis in this paper builds on a dynamic simultaneous equation model in the form of a structural VAR that generalises the structural oil market model introduced by Kilian and Murphy (2014). The sample period covers February 1990 to August 2016. The model is specified based on a monthly dataset that includes: (1) a measure of exogenous oil supply shocks; (2) a measure of endogenous oil supply shocks; (3) a measure of global real economic activity; (4) the real price of oil; and (5) a proxy of global crude oil inventories. The structural VAR model is set-identified based on a combination of sign restrictions, as well as bounds on the impact price elasticities of oil supply and oil demand. These identification restrictions constitute an essential component for the economic interpretation and causal meaning of the model estimates and they are motivated by economic theory, institutional knowledge and other extraneous information. Our structural VAR model is identified based on a combination of static sign restrictions on the impact responses of the five observables to each structural shock, dynamic sign restrictions on the responses to an unexpected exogenous oil supply shock and bounds on the impact price elasticities of oil supply and oil demand. The structural VAR model is consistently estimated by the least-squares method (for full details, see the link to the full paper).

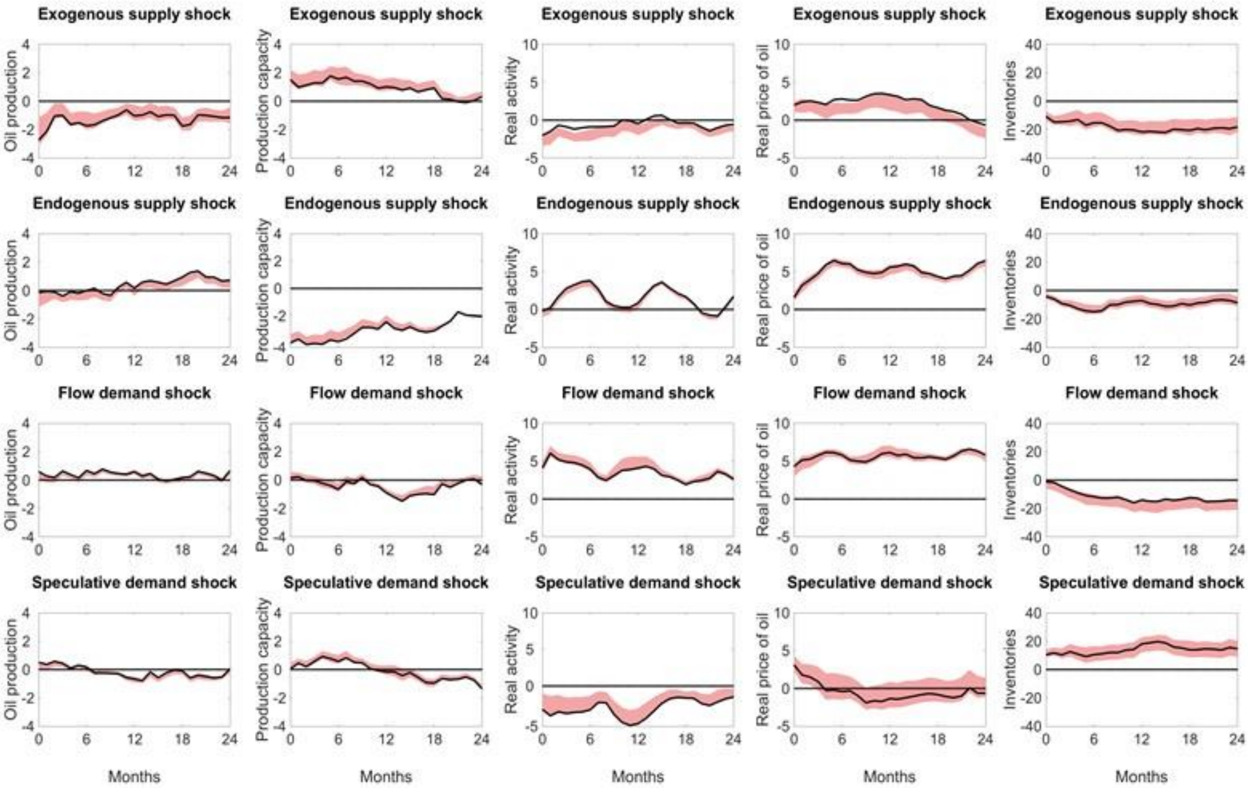
Figure 6 plots the responses of oil production, production capacity, real economic activity, the real price of oil and oil inventories to each structural shock. All shocks have been normalised such that they imply an increase in the real price of oil. The most striking result in Figure 6 is the fact that the relative importance of oil supply shocks for the real price of oil differs greatly, depending on the nature of the shock. On the one hand, a negative exogenous oil supply shock causes a sharp decline in crude oil production on impact, followed by the partial reversal of that decline within three months. The real price of oil temporarily rises on impact and after one year it gradually starts to decline towards its starting value, as oil production recovers to near pre-shock levels. The price increase triggers endogenous expansions in production capacity that are proportional in magnitude to the exogenous shortfalls in oil production but peaks after half a year. Real economic activity drops slightly for less than a year, while oil inventories are persistently drawn down.

On the other hand, an unanticipated negative endogenous oil supply shock is associated with a significant contraction in production capacity on impact (through its effect on investment) that persists at all horizons and relates to year-long stagnation periods. Notably, in the two-year horizon, the gains in production capacity reach only half the level of the initial shortage, consistent with the long lead times associated with the development of new capacity. This shock causes a steep and very persistent increase in the real price of oil that is twice as large in magnitude and duration compared with that caused by an exogenous supply disruption. Real economic activity is associated with large positive loops that progressively become more persistent to the downside. Oil inventories are temporarily drawn down and reverse back to near starting levels within one year. These estimates imply a larger role for shocks to oil supply that originate within the crude oil market than those driven by exogenous events, underscoring the importance of modelling explicitly each oil supply shock, as well as the central role of endogenous capacity pressures in determining the real price of oil.

At the same time, Figure 6 illustrates that a positive shock to the flow demand for oil is associated with a persistent and hump-shaped increase in real economic activity that causes an immediate jump in the real price of oil. The price increase remains large and persistent at all horizons. By contrast, the effect on oil production is insignificant, while production capacity remains largely negative owing to the shortages in excess capacity. Oil inventories are persistently and significantly drawn down in an effort to smooth out consumption.

Finally, a positive speculative demand shock causes a persistent increase in oil inventories. The real price of oil temporarily rises on impact and reverts to its starting value after three months, before marginally declining further within one year. Production capacity slightly rises while real economic activity remains largely in decline at all horizons. These estimates support some of the core insights provided by earlier studies, suggesting that flow demand shocks have large predictive power for changes in the real price of oil as opposed to speculative demand shocks that are largely negligible (see Kilian, 2014).

Figure 6. Structural impulse responses and corresponding pointwise 68% posterior error bands, 1990.2-2016.8

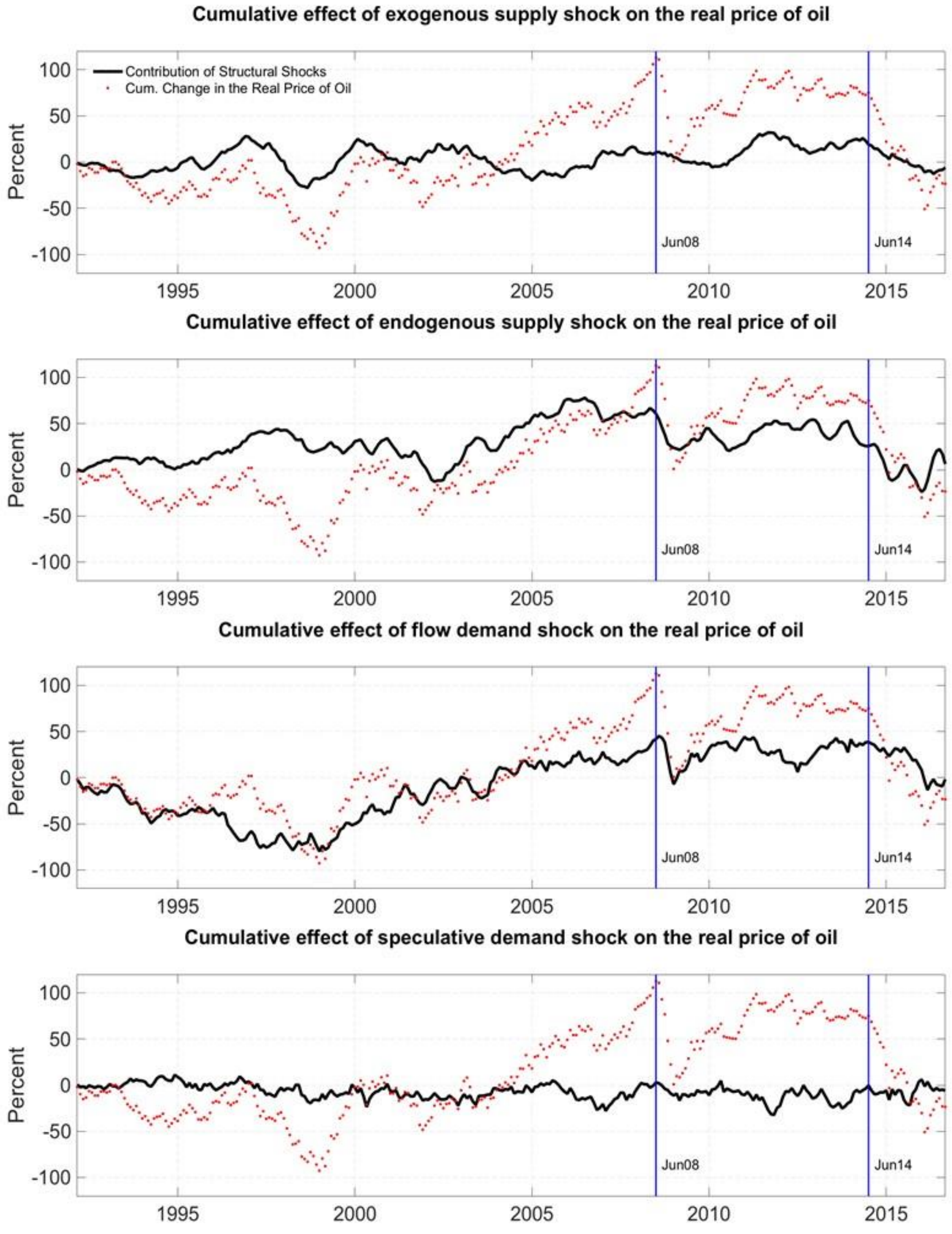


Notes: All responses but the inventory responses are expressed in percentages. The inventory responses are in million barrels.

Figure 7 shows the historical decomposition of the real price of oil from February 1992 to August 2016. Each panel in the figure plots the respective cumulative contribution of each structural shock to the real price of oil over time. The solid lines show how the real price of oil would have evolved if all structural shocks but the shock in question had been turned off. The dashed lines show the cumulative change in the real price of oil caused by all structural shocks.

The first panel indicates that exogenous oil supply shocks overall made little contribution to the real price of oil, especially after 2000. By far the biggest contribution is due to the endogenous oil supply shock and the flow demand shock. Endogenous oil supply shocks exerted significant upward pressure on the real price of oil between 2004 and mid-2007, while their increasing importance to the market imbalance, which led to the June 2014 price collapse, appears as early as mid-2012. Flow demand shocks are responsible for the bulk of the oil price decline in 1997-1999 and largely for the price surge that preceded June 2008's price peak, but there is little evidence to suggest that the 2014 oil price collapse was demand driven. To the extent that flow demand shocks mattered for the oil price slump of 2014-2016, they appear to be responsible for a sharp defined decrease in the real price of oil only after mid-2015. The final panel indicates that speculative demand shocks make no large systematic contribution to the evolution of the real price of oil.

Figure 7: Historical decomposition of the real price of oil by structural shock in percent changes, 1992.2-2016.8



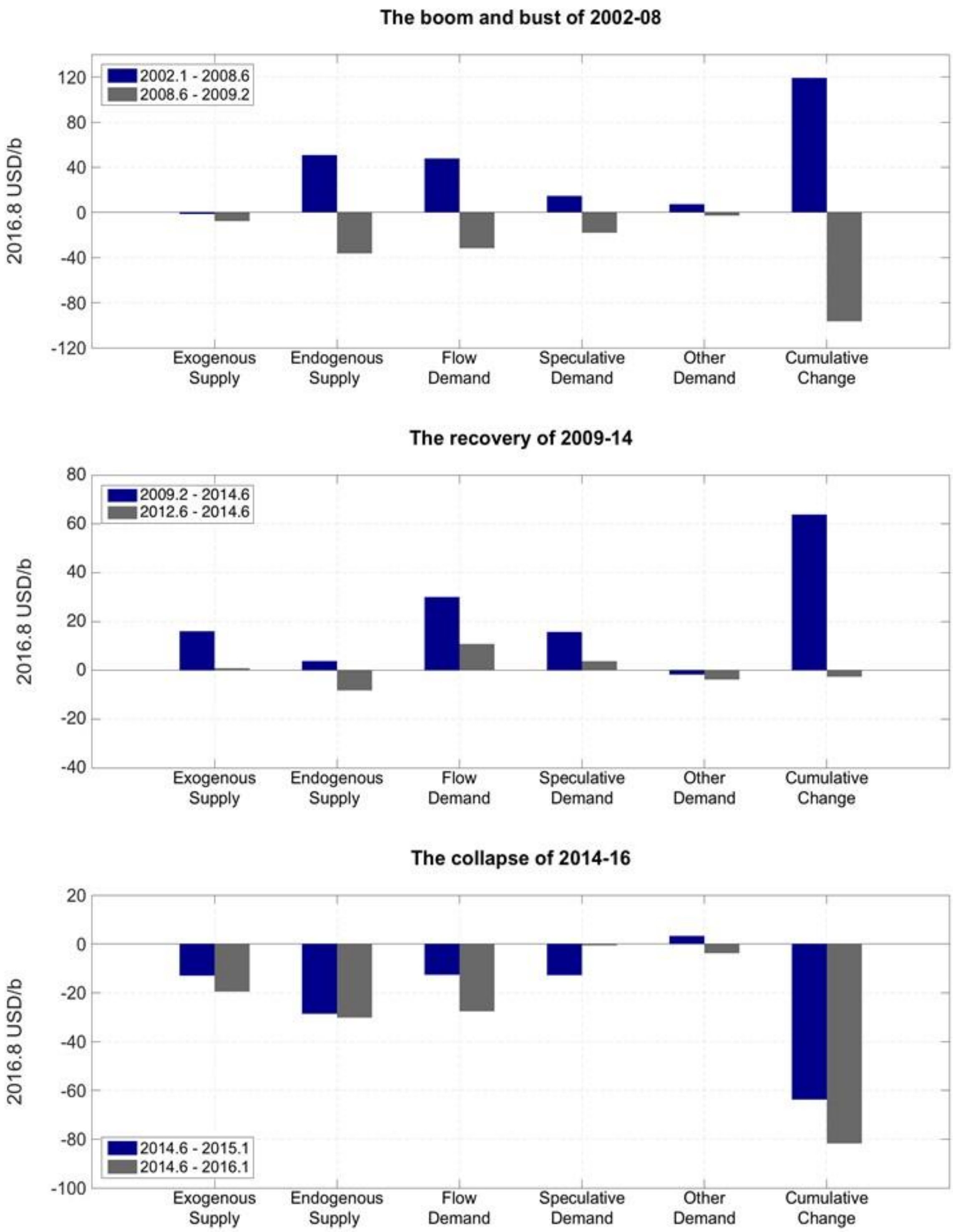
Notwithstanding these historical decompositions, it is instructive to focus on specific episodes since the early 2000s. Figure 8 shows by how many dollars per barrel each oil supply and oil demand shock contributed to the cumulative change in the real price of oil over some period of interest. The results are broken down into three periods, representing: (a) the boom and bust of 2002-2009 (panel 1); (b) the oil price recovery of 2009-2014 (panel 2); and (c) the oil price collapse of 2014-2016 (panel 3). The real price of oil is inflation-adjusted in 2016.8 US dollars. The first five bars in each panel show the cumulative contribution of each structural shock to the cumulative change in the real price of oil over the period in question. The last bar indicates the actual cumulative change in the real price of oil observed in the data.

Starting with the results from January 2002 to June 2008 in the first panel of Figure 8 (indicated by the blue bars), we observe that out of the cumulative $119/b increase in the real price of oil over this period, $50/b are attributed to the cumulative effect of the endogenous oil supply shocks and $48/b to flow demand shocks. An additional $22/b is attributed to speculative and other demand shocks combined. The cumulative effect of exogenous oil supply shocks is negative but negligible, lowering the price of oil by $1/b. What these results suggest is that despite the popular belief that positive shifts in the flow demand for oil produced the bulk of the oil price surge between 2002-2008 (see Kilian, 2014, p. 6), if available production capacity was sufficient to cover the unexpected rise in flow demand, the real price of oil would have been lower by at least $50/b. In other words, the oil price would have risen to around $75/b (from $26/b) if driven solely by the growth of flow demand for oil, but endogenous capacity constraints in oil-producing countries amplified the effect of flow demand shocks on the real price of oil by roughly 104%.

The same can be said for the subsequent plunge of the real price of oil by $96/b between June 2008 and February 2009 (indicated by the grey bars in the first panel). Endogenous supply shocks in conjunction with flow demand shocks accounted in total for 70% of the observed cumulative oil price decline, that is for $36/b and $32/b respectively. The difference in this episode is that OPEC oil producers were able (and willing) to adjust production to counterbalance the fall in flow demand and hence to smooth out the price collapse, which proved to be short lived.

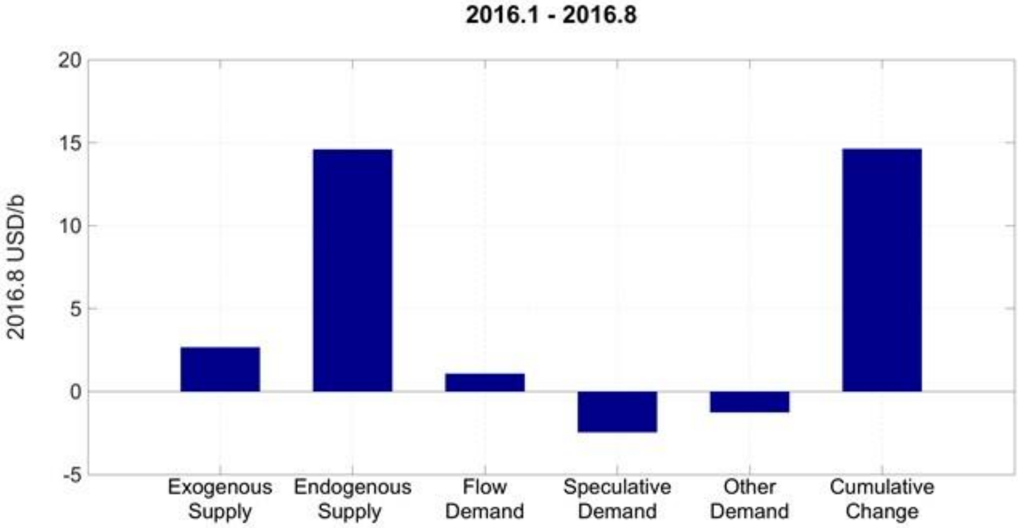
The second panel in Figure 8 focuses on the oil price recovery between February 2009 and June 2014 (indicated by the blue bars). We observe that out of the cumulative $64/b increase in the real price of oil over this period, $30/b is attributed to the cumulative effect of flow demand shocks and $16/b are due to exogenous oil supply shocks following the outbreak of the 2011 Arab Uprisings. Speculative demand shocks accounted for an additional $15/b, while endogenous supply shocks accounted for just $4/b. It is useful to explore further the price dynamics over this period, especially between June 2012 and June 2014 (indicated by the grey bars in the second panel). A closer examination shows that even though the real price of oil was fairly steady, with a minor cumulative decline of $2/b, the underlying shocks in the oil market had been far more important. For example, we observe that endogenous oil supply shocks in the form of unanticipated capacity expansions exerted significant downward pressure on the real price of oil by $11/b. However, the real price of oil response to these shocks was small, as the excess supply was largely matched by positive shifts in the flow demand for oil that accounted for $10/b of the cumulative price change. These estimates contradict earlier assertions in the literature suggesting that the market oversupply at the time had been offset by unexpected exogenous shortfalls in crude oil production (see, for example, Stevens & Hulbert, 2012). This explanation is not supported by our results. On the contrary, out of the observed $16/b cumulative contribution of exogenous oil supply shocks to the price increase between February 2009 to June 2014, these shocks account for at most $1/b after June 2012.

Figure 8: Contribution to the cumulative change in the real price of oil by structural shock, in 2016.8 USD per barrel



Finally, the third panel in Figure 8 shows that of the $64/b cumulative decline in the real price of oil from June 2014 to January 2015 (indicated by the blue bars), $29/b is due to endogenous oil supply shocks, $13/b is due to exogenous oil supply shocks and $12/b is attributed to flow demand shocks. An additional $12/b of the price collapse is attributed to speculative demand shocks. These estimates suggest that endogenous oil supply shocks alone accounted for roughly twice as much as any other supply or demand shock in explaining the oil price plunge during this episode, indicating that the persistence of the earlier capacity expansions were the dominant factor. In contrast, an unexpected slowdown in global real economic activity affecting the flow demand for oil was the major contributor to a renewed price decline by $22/b between January 2015 to January 2016 (observed by the grey bars in the third panel). Over this period, flow demand shocks accounted for an additional cumulative decline in the real price of oil by $15/b, while endogenous oil supply shocks accounted for just $1/b. The other $6/b of additional price decline was due to receding exogenous supply disruptions. Thereafter, between January and August 2016, the real price of oil recovered from its earlier drop by a cumulative increase of $14/b, of which over 95% is attributed to negative endogenous oil supply shocks driven primarily by a contraction in US shale oil production (see Figure 9).

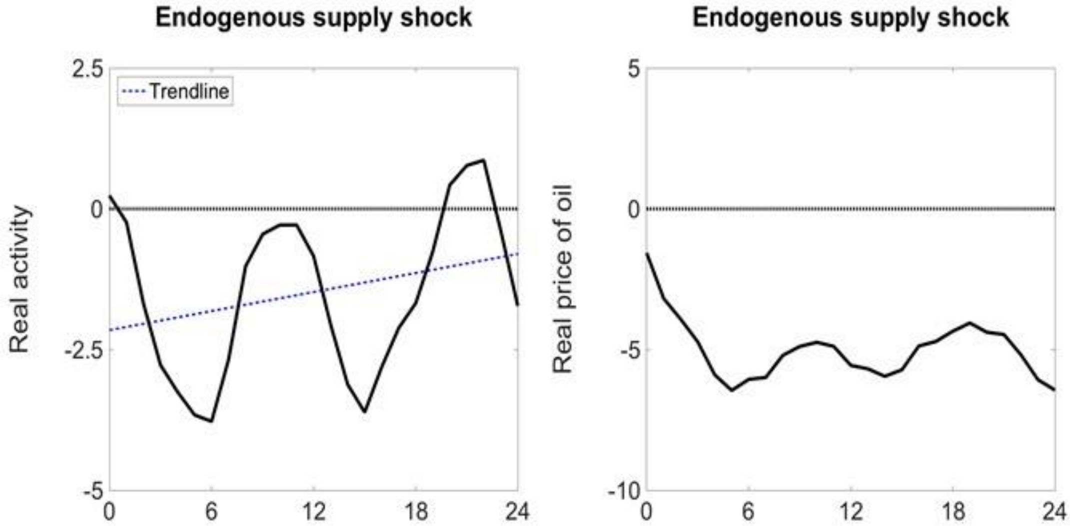
Figure 9: Contribution to the cumulative change in the real price of oil by structural shock from January to August 2016, in 2016.8 USD per barrel



4. Why did not the 2014 oil price shock stimulate stronger demand response?

An obvious question that arises fom these results is why did flow demand for oil unexpectedly fail to grow after June 2014, amid a persistent decline in the real price of oil. Figure 10 illustrates how our response estimates of real economic activity and the real price of oil to a positive endogenous oil supply shock could help explain this paradox. Whereas a positive endogenous oil supply shock causes a persistent decline in the real oil price, this shock causes almost no change in real economic activity on impact, followed by negative loops that progressively shift upwards (shown by the trend line in the plot). These findings suggest that despite the belief that an oil price fall has a net positive effect on the global economy, the expected economic boost due to a market oversupply is far from smooth (through its effect on price). This view is consistent with recent empirical evidence in the literature suggesting that there were no signs of economic growth picking up in the first year following the price collapses in either 2014 or 1986 (see IMF, 2015). Both these episodes share two common and interrelated characteristics. First, a large persistent component to the oil price declines. Second, a large drop in oil revenues for oil exporters. Oil exporting economies' heavy dependence on oil revenues creates many fiscal and external vulnerabilities, so falling oil prices lead to adverse shocks to the economic growth of the oil exporters that pass through to the global economy (IMF, 2016).

Figure 10: Responses of global real economic activity and the real price of oil to a positive endogenous oil supply shock



Notes: Both responses are expressed in percentages.

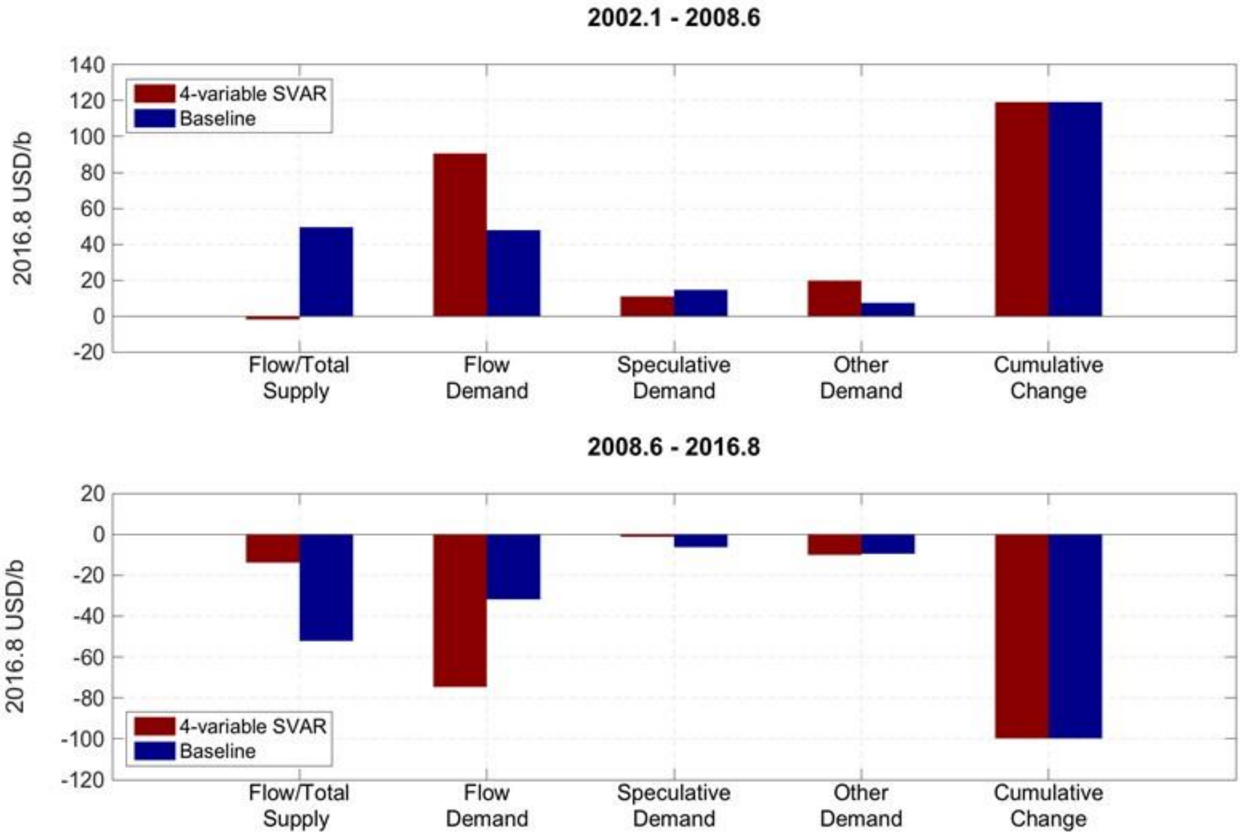
For example, Obstfeld, Arezki and Milesi-Ferretti (2016) argue that oil exporting countries were the largest contributors to the slowdown of global economic growth during 2015-2016, despite their relatively small share of global GDP (about 15% based on purchasing power parity). The European Central Bank (2016) found that oil exporting economies experienced substantial fiscal deficits and financial strains. These negative economic effects in exporting countries outweighed the marginal consumption gains in oil importing countries, resulting in a net negative effect on the global economy. Furthermore, the absence of a balancing mechanism in the oil market (i.e. the unwillingness of OPEC producers to cut output) has led to a prolonged environment of higher price uncertainty, which prompted oil producers to curtail capital investment in the upstream sector, weighing heavily on global economic activity and trade. For example, Baumeister and Kilian (2017) show that because of the increased share of oil-related investment in US real GDP growth due to the shale oil boom, the sharp decline in capital expenditure in the shale oil sector dampened the aggregate growth of the US economy. These examples highlight the fact that the timing of the boost to global economic activity amid a market oversupply (through its effect on price), depends on whether the latter is temporary or persistent. If temporary, oil exporters can draw on their financial reserves or increase borrowing to buffer their losses in oil rents, while upstream investment will remain robust as the oil price would be expected to recover. If persistent, the spending patterns of the oil exporters need time to adjust, while upstream investment will decline.

5. Empirical comparison with a structural VAR model of flow supply, flow demand and speculative demand shocks

A central objective in this paper is to explore how the use of endogenous and exogenous supply shock measures potentially affects the conventional estimates of the effects of supply and demand shocks to the real price of oil obtained from structural oil market models that identify shocks to the flow supply of oil collectively. This section compares our *baseline* results to those obtained by re-estimating a structural VAR model of flow supply, flow demand and speculative demand in the tradition of Kilian and Murphy (2014). The *4-variable SVAR* model includes four monthly variables: (1) the percent change in global oil production; (2) the measure of global real economic activity due to Kilian (2009a); (3) the real price of crude oil; (4) and the proxy for changes in global oil inventories.

Figure 11 plots the cumulative change in the real price of oil caused by each structural shock from January 2002 to August 2016, obtained from the 4-variable SVAR model (red bars) and our baseline model (blue bars). The first bar in each panel compares the cumulative contribution of flow supply shocks against that of total supply shocks, as specified in the previous section. It can be shown that regardless of the period in question, the 4-variable SVAR model attributes the bulk of the cumulative changes in the real price of oil to flow demand shocks, whereas the differences between the two models regarding the speculative demand shock are quite small. For example, of the $119/b cumulative increase in the real price of oil from January 2002 to June 2008 (first panel), this model assigns $90/b to the cumulative effect of flow demand shocks compared to $48/b attributed by the baseline model. Likewise, of the $99/b cumulative decline in the real price of oil from June 2008 to August 2016 (second panel), the 4-variable SVAR model assigns $75/b to the cumulative effect of flow demand shocks, compared to the baseline model that assigns only $32/b to this shock. Evidently, these differences operate at the expense of the explanatory ability of the supply determinant. Flow supply shocks in the 4-variable SVAR model play a limited role in explaining the evolution of the real price, compared to the more significant role assigned to total supply shocks in the baseline model. The former assigns -$1/b and -$14/b to the cumulative contribution of flow supply shocks to the price changes over the two periods, against $49/b and $52/b assigned by the baseline model to total supply shocks respectively.

Figure 11. Contribution to the cumulative change in the real price of oil by structural shock, by model specification, in 2016.8 USD per barrel



It is worth emphasising that the cumulative contribution of flow supply shocks is strikingly similar to that of exogenous supply shocks, that is of -$1/b and -$12/b. These results underscore that the traditional emphasis on changes in global oil production, per se, for modelling the supply side of the world oil market collectively is misplaced. Moreover, the claim that economic fundamentals in the form of flow demand and to a lesser extent speculative demand have been the main determinants of the real price of oil must be rethought. Whereas exogenous shocks to crude oil production are not negligible, endogenous shocks in global production capacity have been a far more important determinant for major oil price fluctuations in recent years.

6. Real-time forecasts of the Brent price

Recent studies have shown that suitably chosen reduced-form VAR models that include the key variables relevant to the determination of the real price of oil exhibit superior out-of-sample forecast accuracy than alternative forecasting models (see Baumeister & Kilian, 2012). The question of interest is whether the inclusion of the proposed decomposition of oil supply shocks in a forecasting model of the price of oil potentially improves the real-time predictive accuracy of conventional VAR forecasts that model shocks to the flow supply of oil collectively. This question may be addressed by generating real-time forecasts of the Brent price using the reduced-form representation of each structural VAR model (Baumeister & Kilian, 2014). The objective is to assess the real-time forecasting performance of each model in predicting the June 2014 oil price collapse and the subsequent evolution of the Brent price up to December 2016, converted to nominal US dollars.

Figure 12 shows the evolution of the nominal Brent price from January 2014 to January 2015, along with the real-time forecasts obtained by the 4-variable SVAR model and the baseline model as of June 2014 (marked by the vertical line in the plot). For expository purposes, we focus on the one-step ahead forecasts. Each forecast is generated in real-time using only information as of the previous month (denoted by the black markers). As can be seen from Figure 12, the 4-variable SVAR model forecast performs relatively poorly in predicting the one-step ahead directional change of the Brent price, with a success ratio of 43% (i.e. the fraction of times that the model correctly predicts the directional change of the oil price). Even though the forecasts in July and August are very close to the actual Brent price, the model systematically overshoots the price of oil from the September forecast onwards by about $13/b. On the contrary, the baseline model forecasts are much closer to the realisations of the Brent price, with a success ratio of 86%. Only the September 2014 and January 2015 baseline forecasts exceed the Brent price, by $7/b and $10/b respectively. The consistency of this pattern, regardless of the model specification, raises the question of what are the causes of the competing forecast errors after August 2014, in the related context of supply and demand shocks to the price of oil.

Figure 12: One-step ahead forecasts of the Brent price for July 2014 to January 2015, in nominal USD per barrel, 2014.1-2015.1

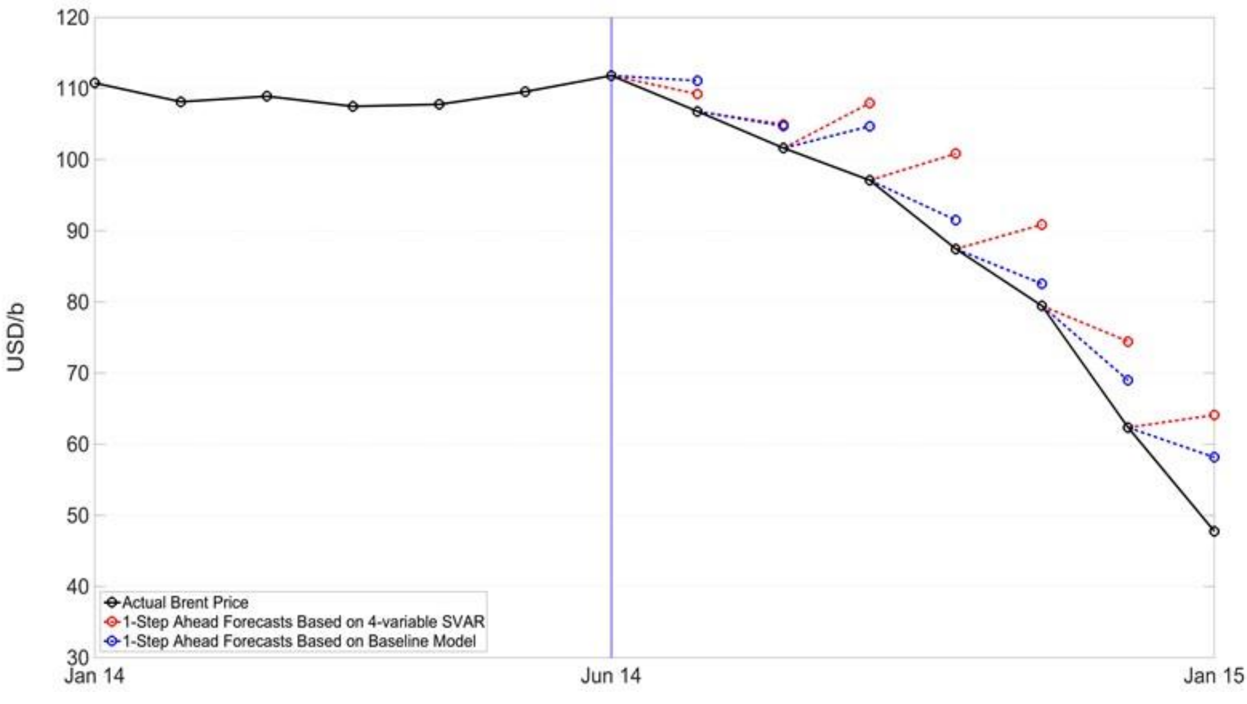


Figure 13 shows the evolution of the Brent price from December 2013 to December 2016 together with the real-time forecasts of the Brent price by model specification as of December 2014 (marked by the vertical line in the plot). Very similar results hold for both models regarding the directional accuracy of the December forecasts 24-months ahead, with a success ratio of 54% due to the 4-variable SVAR forecast and 50% due to the baseline forecast. However, by comparison, the baseline model forecast produced systematically lower real-time mean squared prediction errors (MSPEs), denoting higher predictive accuracy (Table 1). In most cases, MSPE reductions are higher than 40% relative to the 4-variable SVAR model forecast even at longer horizons.

Figure 13: Real-time forecasts of the Brent price as of December 2014, in nominal USD per barrel, 2013.12-2016.12

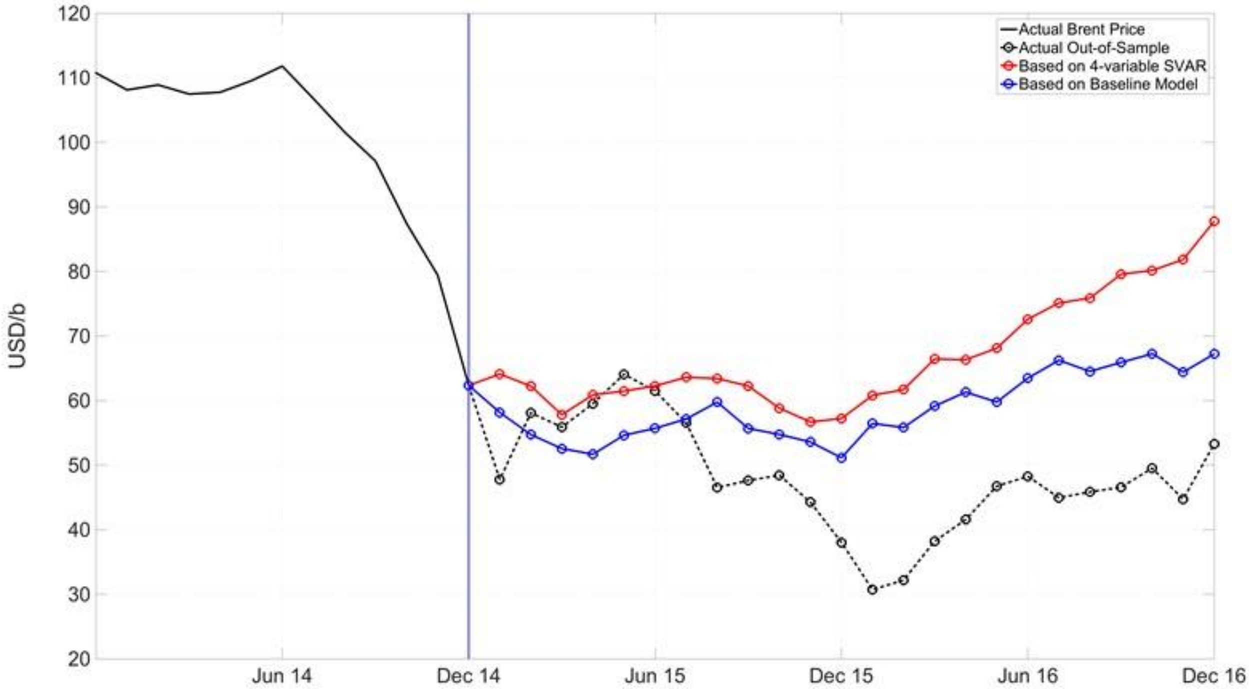


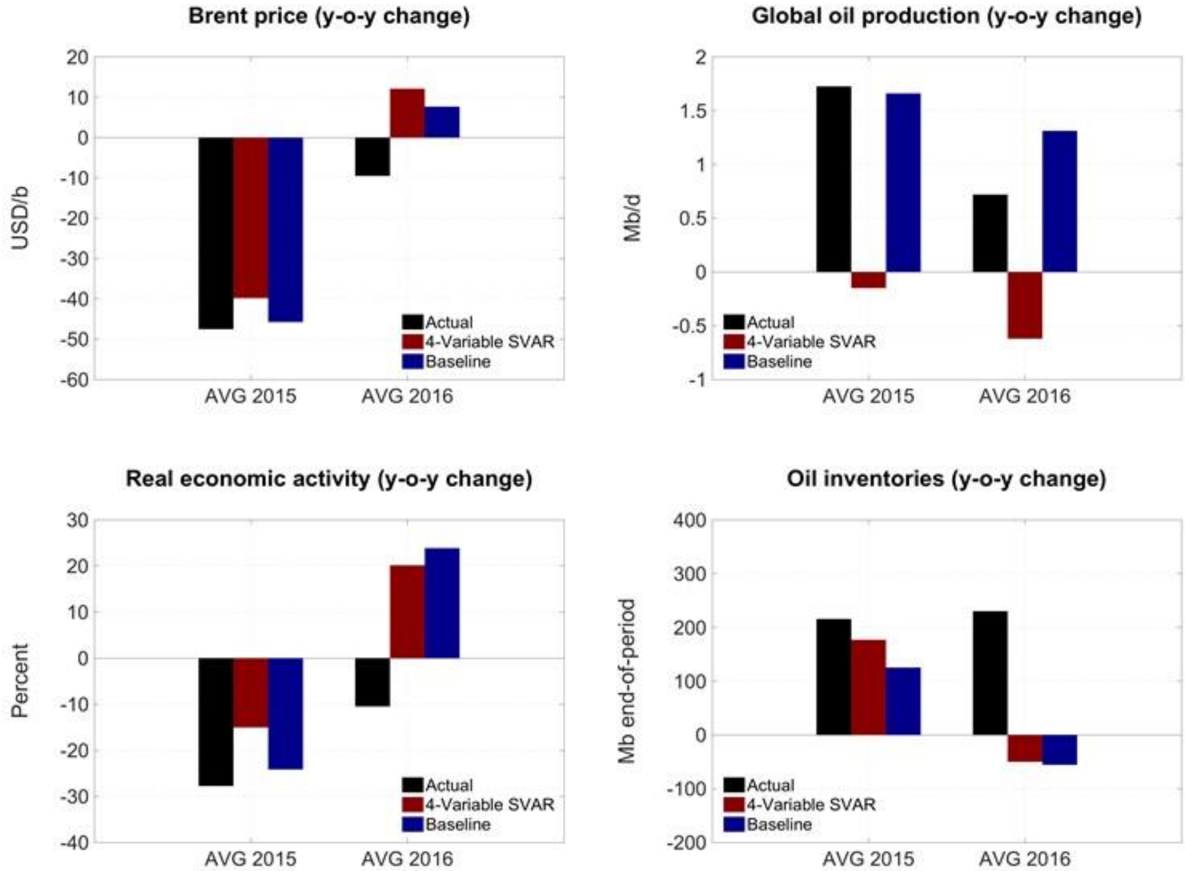
Table 1. Recursive MSPE ratio of the baseline model forecast relative to the 4-variable SVAR model forecast

Month	Jan 15	Mar 15	Jun 15	Sep 15	Dec 15	Jun 16	Dec 16
[Horizon]	[1]	[3]	[6]	[9]	[12]	[18]	[24]
MSPE	**0.4043**	**0.4535**	1.0587	**0.6560**	**0.5781**	**0.5785**	**0.4437**

Notes: Boldface indicates improvements relative to the 4-variable SVAR model forecast.

An intuitive way to put these results into perspective is to observe the bar charts in Figure 14 that compare the actual and predicted annual change of the key oil market indicators in 2015 and 2016, based on the real-time forecasts as of December 2014. The main disagreement between the competing real-time forecasts is associated with the predicted annual growth of global oil production. The real-time 4-variable SVAR forecast predicted that global oil production in 2015 would marginally turn negative by -0.15 mb/d, before declining further in 2016 by -0.62 mb/d year-on-year (y-o-y). On the other hand, the real-time baseline forecast correctly predicted that the annual growth of global oil production would persist well into 2015 and 2016, by 1.6 mb/d and 1.3 mb/d y-o-y, missing the average 2016 realisation by just 0.59 mb/d. As a result, in 2016, the 4-variable SVAR forecast predicted that the Brent price would rise to $88/b by year-end, compared to the actual December price of $53/b. The baseline forecast predicted a price ceiling at $66/b by the second half of the year (see Figure 14). These results are particularly informative given that the ability of the baseline forecasting model to distinguish between oil supply shocks that are different in nature has led to the much closer realisations of global oil production and hence of the Brent price over time. The fact that both forecasts detected an unexpected weakening of global economy and a stronger than expected growth of storage demand for oil is further support for the robustness of the baseline forecasting model.

Figure 14: Actual and predicted annual change of the key oil market indicators for 2015 and 2016, year-over-year



7. Conclusion

There is a recurring question in the crude oil market about the importance of oil supply and oil demand shocks in explaining major oil price fluctuations. Advancements in theoretical and empirical work during the past decade made considerable strides addressing this question, enhancing our understanding of the determinants of oil price shocks. The conventional view today in the literature is that most major oil price fluctuations are explained by oil demand shocks collectively, rather than flow supply shocks, with a central role played by shifts in the global business cycle affecting the flow demand for oil.

Traditionally, flow supply shocks were thought to reflect disruptions in crude oil production triggered by geopolitical events in oil producing countries and politically motivated OPEC decisions, both of which occurred outside the confines of the crude oil market. However, such exogenous shocks to global crude oil production constitute just one type of oil supply shock. There also may be shocks to global production capacity due to a number of uncertainties affecting the investment decisions of oil producers and hence affecting the oil supply. This type of oil supply shock arises endogenously with respect to the crude oil market and reflects the rate of investment in new production capacity and the lead times in adding new capacity, conditional on the expectations of oil producers about future market conditions and prices. This means that oil price shocks can only be understood with the help of structural models of the world oil market that jointly identify and estimate the exogenous and endogenous supply components of the real price of oil, along with the components affected by flow demand and speculative demand. In this paper, we augmented the standard structural VAR model of flow supply, flow demand and speculative demand pioneered by Kilian and Murphy (2014) to allow for the structural decomposition of the supply determinant and for the simultaneous identification of all the supply and demand components of the real oil price, conditional on all past data.

Our findings suggest that the traditional focus on flow supply shocks per se is misplaced, as evidence suggests that they largely reflect disruptions in crude oil production that are brought about by exogenous events, neglecting important information about endogenous innovations to flow supply that arise within the crude oil market. This missing information is instead transmitted to the real price of oil through demand-related channels at the expense of the explanatory power of the supply determinant. In this regard, we show that the relative importance of oil supply shocks for the real price of oil differs greatly, depending on the nature of the shock. For example, endogenous oil supply shocks appear to be associated with a markedly larger and more persistent impact on the real price of oil than exogenous disruptions in crude oil production. Furthermore, these shocks are also associated with important indirect effects on the real price of oil through other demand-related channels, such as their asymmetric effect on the global economy.

The central message of the paper is that while there is overwhelming empirical evidence in the literature that most large and persistent fluctuations in the real price of oil have been driven by the cumulative effects of oil demand, the robustness of this evidence crucially depends on the rigorous identification of oil supply shocks. In general, our analysis showed that most large and persistent fluctuations in the real price of oil since the early-1990s can be explained either by large positive shifts in flow demand in conjunction with negative endogenous oil supply shocks or by persistent positive endogenous oil supply shocks at the same time as unexpected negative shifts in the flow demand for oil. For example, our results suggest that despite the popular belief in the literature that the sustained run-up in the real price of oil between 2002-2008 was caused primarily by positive shifts in the global business cycle affecting oil demand, endogenous capacity constraints in oil producing countries more than doubled the effect of flow demand shocks to the real price of oil. Likewise, while the 2014 oil price collapse was primarily triggered by the persistence of positive endogenous oil supply shocks, an unexpected downshift of the global business cycle in mid-2015 aggravated the recent price downturn both in terms of magnitude and duration. On the contrary, there is little evidence to suggest that exogenous supply disruptions and shifts in speculative demand for oil contributed much to the evolution of the real price of oil over the sample period, confirming some of the core conclusions of earlier studies. Still, both of these types of shocks remain important components for the structural decomposition of the real price of oil.

Finally, we demonstrated that forecasting models able to distinguish between oil supply shocks that are different in nature, produce more realistic out-of-sample estimates of the sequences of supply and demand shocks, thus enjoying higher real-time predictive accuracy than forecasting models that incorporate shocks to the flow supply of oil collectively. These findings underscore the importance of explicitly modelling endogenous supply shocks in structural models of the world oil market and the central role of production capacity pressures in understanding the evolution of the real price of oil.

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References

Adelman, M. A. 1993. Modelling World Oil Supply. *The Energy Journal* 14(1): 1-32.

Adelman, M. A. 2002. World Oil Production and Prices: 1947–2000. *The Quarterly Review of Economics and Finance*, 42(2): 169-191.

Adelman, M. A. and Watkins, G. C. 2008. Reserve Prices and Mineral Resource Theory. *The Energy Journal*, 29(2008): 1-16.

Alquist, R. and Guenétte, J. D. 2014. A Blessing in Disguise: The Implications of High Global Oil Prices for the North American Market. *Energy Policy*, 64(C): 49-57.

Alquist, R. and Kilian, L. 2010. What Do We Learn from the Price of Crude Oil Futures? *Journal of Applied Econometrics*, 25(4): 539-573.

Alquist, R., Kilian, L. and Vigfusson, R. J. 2013. Forecasting the Price of Oil. In G. Elliot and A. Timmersmann (ed.) *Handbook of Economic Forecasting*, 2: 427-507. Amsterdam: North Holland.

Arezki, R. 2016. Seven Questions on Rethinking the Oil Market in the Aftermath of the 2014-16 Price Slump. *IMF Research Bulletin*, 17(3): 9-12.

Arezki, R. and Blanchard, O. 2015. The 2014 Oil Price Slump: Seven Key Questions. *IMF Direct*, International Monetary Fund: December 22.

Babel, A. and McGillicuddy, J. 2015. Oil Prices: Is Supply or Demand Behind the Slump? Federal Reserve Bank of St. Louis.

Baffes, J., Kose, M. A., Ohnsorge, F. and Stocker, M. 2015. The Great Plunge in Oil Prices: Causes, Consequences and Policy Responses. *Policy Research Note*, No. 1 World Bank.

Barsky, R. B. and Kilian, L. 2002. Do We Really Know that Oil Caused the Great Stagflation? A Monetary Alternative. In B.S. Bernanke and K. Rogoff (ed.) *NBER Macroeconomics Annual 2001*, 16: 137-183. Cambridge: MIT Press.

Barsky, R. B. and Kilian, L. 2004. Oil and the Macroeconomy since the 1970s. *Journal of Economic Perspectives*, 18(4): 115-134.

Baumeister, C. and Hamilton, J. D. 2015. Structural Interpretation of Vector Autoregressions with Incomplete Identification: Revisiting the Role of Oil Supply and Oil Demand Shocks. Manuscript University of Notre Dame and UCSD.

Baumeister, C. and Kilian, L. 2012. Real-Time Forecasts of the Real Price of Oil. *Journal of Business and Economic Statistics*, 30: 326-336.

Baumeister, C. and Kilian, L. 2014. Real-Time Analysis of Oil Price Risks using Forecast Scenarios. *IMF Economic Review*, 62: 119-145.

Baumeister, C. and Kilian, L. 2016a. Forty Years of Oil Price Fluctuations: Why the Price of Oil May Still Surprise Us. *Journal of Economic Perspectives*, 30(1): 139-160.

Baumeister, C. and Kilian, L. 2016b. Understanding the Decline in the Price of Oil since June 2014. *Journal of the Association of Environmental and Resource Economics*, 3(1): 131-158.

Baumeister, C. and Kilian, L. 2017. Lower Oil Prices and the U.S. Economy: Is This Time Different? *Brookings Papers on Economic Activity*, Fall 2016: 287-336.

Baumeister, C. and Peersman, G. 2013a. The Role of Time-Varying Price Elasticities in Accounting for Volatility Changes in the Crude Oil Market. *Journal of Applied Econometrics*, 28(7): 1087-1109.

Baumeister, C. and Peersman, G. 2013b. Time-Varying Effects of Oil Supply Shocks on the US Economy. *American Economic Journal: Macroeconomics*, 5(4): 1-28.

Bodenstein, M., Erceg, C. J. and Guerrieri, L. 2007. Oil Shocks and External Adjustment. *International Finance Discussion*, No. 897.

Caldara, D., Cavallo, M. and Iacoviello M. M. 2016. Oil Price Elasticities and Oil Price Fluctuations. *FRB International Finance Discussion Paper*, No. 1173.

Canova, F. and De Nicolo, G. 2002. Monetary Disturbances Matter for Business Cycle Fluctuations in the G-7. *Journal of Monetary Economics*, 49: 1131-1159.

Dotsey, M. and Reid, M. 1992. Oil Shocks, Monetary Policy, and Economic Activity. *FRB Richmond Economic Review*, 78(4): 14-27.

Economou, A. 2016. Oil Price Shocks: A Measure of the Exogenous and Endogenous Supply Shocks of Crude Oil. Oxford Institute for Energy Studies WPM 68.

European Central Bank. 2016. Economic and Monetary Developments. *Economic Bulletin Issue*, No. 4/2016: June.

Fattouh, B. 2006. Spare Capacity and Oil Price Dynamics. *Middle East Economic Survey* XLIX(5).

Fattouh, B. 2007a. The Drivers of Oil Prices: The Usefulness and Limitations of Non-Structural Models, Supply-Demand Frameworks, and Informal Approaches. *EIB papers*, 12(1): 128-156.

Fattouh, B. 2007b. OPEC Pricing Power: The Need for a New Perspective. Oxford Institute for Energy Studies WPM 31.

Fattouh, B. and Mabro, R. 2006. The Investment Challenge. In R. Mabro (ed.) *Oil in the 21st Century: Issues, Challenges and Opportunities*, 101-127. Oxford: Oxford University Press.

Fattouh, B. and Mahadeva, L. 2013. OPEC: What Difference Has It Made? Oxford Institute for Energy Studies MEP 3.

Fattouh, B. and Sen, A. 2015. Saudi Arabia Oil Policy: More than Meets the Eye? Oxford Institute for Energy Studies MEP 13.

Fattouh, B., Kilian, L. and Mahadeva, L. 2012. The Role of Speculation in Oil Markets: What Have We Learned So Far? Oxford Institute for Energy Studies WPM 45.

Faust, J. 1998. On the Robustness of Identified VAR Conclusions about Money. *Carnegie-Rochester Conference Series on Public Policy*, 49: 207-244.

Favero, C. A. and Perasan M. H. 1991. Oil Investment in the North Sea. Oxford Institute for Energy Studies WP EE15.

Gately, D. 2011. OPEC at 50: Looking Back and Looking Ahead. In conference at the National Energy Policy Institute: April 18.

Gately, D., Adelman, M. A. and Griffin, J. M. 1986. Lessons from the 1986 Oil Price Collapse. *Brookings Papers on Economic Activity*, 2(1986): 237-284.

Hamilton, J. D. 1983. Oil and the macroeconomy since World War II. *Journal of Political Economy*, 91:228-248.

Hamilton, J. D. 1985. Historical causes of postwar oil shocks and recessions. *Energy Journal*, 6: 97-116.

Hamilton, J. D. 2003. What Is an Oil Shock? *Journal of Econometrics*, (113): 363-398.

Hamilton, J. D. 2009a. Understanding Crude Oil Prices. *The Energy Journal*, 30(2): 179-206.

Hamilton, J. D. 2009b. Causes and Consequences of the Oil Shock of 2007-08. *Brooking Papers on Economic Activity*, Spring: 215-259.

Hamilton, J. D. 2013a. *Historical Oil Shocks*. In Routledge Handbook of Major Events in Economic History: 239-265. edited by Randall E. Parker and Robert Whaples. New York: Routledge Taylor and Francis Group.

Hamilton, J. D. 2013b. *Oil Prices, Exhaustible Resources, and Economic Growth*. In Handbook of Energy and Climate Change: 29-57. edited by Roger Fouquet. Cheltenham: Edward Elgar Publishing.

Hamilton, J. D. 2014. The Changing Face of Crude Oil Markets. *IAEE Energy Forum*, 4th Quarter: 7-13.

Hamilton, J. D. and Herrera, A. M. 2004. Oil Shocks and Aggregate Macroeconomic Behavior: The Role of Monetary Policy. *Journal of Money, Credit, and Banking*, 36: 265-286.

Hoover, K. D. and Perez, S. J. 1994. Post Hoc Ergo Propter Hoc Once More: An Evaluation of 'Does Monetary Policy Matter?' in the Spirit of James Tobin. *Journal of Monetary Economics*, 34(1994): 89-99.

Inoue, A. and Kilian, L. 2013. Inference on Impulse Response Functions in Structural VAR Models. *Journal of Econometrics*, 177: 1-13.

International Monetary Fund. 2015. Global Implications of Lower Oil Prices, IMF Staff Discussion SDN/15/15.

International Monetary Fund. 2016. Economic Diversification in Oil-Exporting Arab Countries. In Annual Meeting of Arab Ministers of Finance: April.

Katzman, K. 2003. Iraq: Oil-For-Food Program, International Sanctions, and Illicit Trade. *Congressional Research Service*: April 16.

Kaufmann, R. K. 2011. The Role of Market Fundamentals and Speculation in Recent Price Changes for Crude Oil. *Energy Policy*, 39(1): 105-115.

Kilian, L. 2006. Not All Oil Price Shocks Are Alike: Disentangling Demand and Supply Shocks in the Crude Oil Market. CEPR Discussion Paper No. 5994.

Kilian, L. 2008a. The Economic Effects of Energy Price Shocks. *Journal of Economic Literature*, 46(4): 871-909.

Kilian, L. 2008b. Exogenous Oil Supply Shocks: How Big Are They and How Much Do They Matter for The U.S. Economy? *Review of Economics and Statistics*, 90(2): 216-240.

Kilian, L. 2009a. Not All Oil Price Shocks Are Alike: Disentangling Demand and Supply Shocks in the Crude Oil Market. *American Economic Review*, 99(3): 1053-1069.

Kilian, L. 2009b. Comment on "Causes and Consequences of the Oil Shock of 2007-08" by James D. Hamilton. *Brookings Papers on Economic Activity*, 1(2009): 267-278.

Kilian, L. 2014. Oil Price Shocks: Causes and Consequences. *Annual Review of Resource Economics*, 6(2014): 133-154.

Kilian, L. and Hicks, B. 2013. Did Unexpectedly Strong Economic Growth Cause the Oil Price Shock of 2003-2008? *Journal of Forecasting*, 32(5): 385-394.

Kilian, L. and Lee, T. 2014. Quantifying the Speculative Component in the Real Price of Oil: The Role of Global Oil Inventories. *Journal of International Money and Finance*, 42: 71-87.

Kilian, L. and Lütkepohl, H. 2017. *Structural Vector Autoregressive Analysis*. Forthcoming: Cambridge University Press.

Kilian, L. and Murphy, D. 2012. Why Agnostic Sign Restrictions Are Not Enough: Understanding the Dynamics of Oil Market VAR Models. *Journal of the European Economic Association*, 10(5): 1166-1188.

Kilian, L. and Murphy, D. 2014. The Role of Inventories and Speculative Trading in the Global Market for Crude Oil. *Journal of Applied Econometrics*, 29(3): 454-478.

Knittel, R. C. and Pindyck, R. S. 2013. The Simple Economics of Commodity Price Speculation. *NBER Working Paper* 18951.

Lippi, F. and Nobili, A. 2009. Oil and the Macroeconomy: A Quantitative Structural Analysis. *Bank of Italy: Discussion Paper*: 704.

Lombardi, M. and Van-Robays, I. 2011. Do Financial Investors Destabilise the Oil Price? *ECB Working Paper Series*, No. 1253/October 2010.

Mabro, R. 1992. OPEC and the Price of Oil. *The Energy Journal*, 13(2): 1-17.

Mabro, R. 1998. The Oil Price Crisis of 1998. Oxford Institute for Energy Studies SP 10.

Mabro, R. 2006. *Oil in the 21st Century: Issues, Challenges and Opportunities*. Oxford: Oxford University Press.

McNally, R. 2012. Managing Oil Market Disruption in a Confrontation with Iran. *Council on Foreign Relations* Energy Brief January.

Melolinna, M. 2012. Macroeconomic Shocks in an Oil Market VAR. *ECB Working Paper Series*, No. 1432/May 2012.

Naimi, A. 2005. Shaping the Energy Future: The Role of Saudi Arabia. *Middle East Economic Survey* XLVIII(40).

Nakov, A. and Pescatori, A. 2010. Monetary Policy Trade-Offs with a Dominant Oil Producer. *Journal of Money, Credit and Banking*, 42(1).

Obstfeld, M., Arezki, R. and Milesi-Ferretti G. M. 2016. Oil Prices and the Global Economy: It's Complicated. VoxEU: April 13.

Pindyck, R. S. 1991. Irreversibility, Uncertainty and Investment. *Journal of Economic Literature*, 29(3): 1110-1148.

Sandrea, I. 2014. US Shale Gas and Tight Oil Industry Performance: Challenges and Opportunities. Oxford Institute for Energy Studies: Energy Comment.

Smith, J. L. 2009. World Oil: Market or Mayhem. *Journal of Economic Perspectives*, 23(3): 145-164.

Smith, J. L. 2012. On the Portents of Peak Oil (And Other Indicators of Resource Scarcity). *Energy Policy* 44: 68-78.

Stevens, P. 2015. The Shale Technology Revolution and the Implications for the GCC. Arab Center for Research and Policy Studies: January.

Stevens, P. and Hulbert, M. 2012. Oil Prices: Energy Investment, Political Stability in the Exporting Countries and OPEC's Dilemma. *EEDP Programme Paper*, No. 2012/03.

Uhlig, H. 2005. What Are the Effects of Monetary Policy on Output? Results from an Agnostic Identification Problem. *Journal of Monetary Economics*, 52: 381-419.