DECODING STRUCTURAL SHOCKS IN THE GLOBAL OIL MARKET

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Abstract

In this paper, we present a straightforward structural model of the oil market designed to disentangle demand and supply shocks. This model is regularly employed and updated in the Banco de España to enhance the understanding of oil market dynamics. Building on the work of Kilian and Murphy (2014), we introduce a novel business cycle measure based on the co-movement of real commodity prices to capture global demand shocks, and also include an oil-specific demand shock. Our impulse response functions and historical decomposition align with previous studies and effectively capture significant historical milestones.

Keywords: oil structural model, supply, demand, global real activity, oil-specific demand, VAR, sign restrictions.

JEL classification: Q41, Q43.

Resumen

En este trabajo se presenta un modelo estructural del mercado del petróleo, cuyo objetivo es identificar los *shocks* de oferta y demanda. Este modelo se utiliza y actualiza de forma regular en el Banco de España para el análisis y seguimiento de la evolución del mercado de petróleo. Siguiendo la metodología propuesta por Kilian y Murphy (2014), se incorpora una nueva medida del ciclo económico global, basada en el comovimiento de los precios reales de las materias primas, que permite captar de forma más precisa los *shocks* de demanda global. Además, se incluye un *shock* específico de demanda de petróleo, diferenciado del anterior. Los resultados del modelo propuesto —tanto las funciones impulso respuesta como la descomposición histórica— son consistentes con la evidencia existente y permiten interpretar adecuadamente episodios relevantes del mercado del crudo.

Palabras clave: modelo estructural del petróleo, oferta, demanda, actividad económica global, demanda específica de petróleo, VAR, restricciones de signo.

Códigos JEL: Q41, Q43.

1 Introduction

From a central bank perspective, modeling global oil market is crucial not only for forecasting purposes but also, and maybe more importantly, for disentangling the contribution on price formation of different structural supply and demand determinants. Demand-driven oil shocks move oil output and inflation in the same direction whereas supply oil shocks tend to affect them in opposite ways.

In this regard, the economic implications of demand and supply shocks differ and, thus, the potential policy implications are also different depending on the type of shock. For instance, higher oil prices bring negative macroeconomic effects for importing countries (they entail a transfer of income to producers and reduce the purchasing power of households and increase firms' costs). These adverse effects are typically more severe when the oil price rise is due to a supply reduction rather than an increase in global demand. In the latter case, the negative impact on domestic expenditure is partially offset by increased external demand. Disentangling correctly the drivers of oil price dynamics is fundamental for calibrating the policy response.

In practice, any analysis of the respective contributions of supply and demand factors to oil price dynamics is subject to great uncertainty. Models used by policymakers and central banks often yield different and sometimes conflicting results. For example, Hamilton (2003) emphasizes the importance of supply shocks in driving oil prices since the 1970s, whereas Kilian & Murphy (2014) underscores the role of demand factors in comparable samples. Recent work by Känzig (2021), using a high-frequency specification to identify news shocks related to future oil supply by analyzing variations in oil prices around OPEC announcements, concludes that oil supply expectations significantly affect oil prices. This underscores the high uncertainty surrounding the identification of shocks in oil market models, as suggested by a long-standing academic debate (see Baumeister & Hamilton (2019)).

This work reviews the main strands of the global oil market modeling and introduces a straightforward oil model designed to enhance the understanding of oil price dynamics for policy purposes. We adopt a SVAR (structural vector autoregressive) approach, inspired by Kilian & Murphy (2014), but diverge from it by providing a more nuanced characterization of oil consumers. In our framework, an oil demand innovation can arise from either a global real activity shock or an unexpected shift in oil consumption patterns. Such shifts may result from geopolitical events (such as wars and sanctions), technological advancements, or unforeseen weather conditions. Therefore, to gain a comprehensive understanding of oil consumers, we slightly modify the identification strategy to distinguish between a global demand shock and an oil-specific shock. Furthermore, we employ an alternative business cycle indicator to gauge real global to the one proposed by Kilian & Zhou (2018). We suggest extracting a "global demand factor" from the co-movements among sixteen commodity prices. Our approach provides a comprehensive understanding of the factors influencing oil price fluctuations, facilitates the evaluation of alternative model outcomes, and allows for the consideration of potential risk scenarios.

The rest of the paper is structured as follows. Section 2 reviews the literature. Section 3 explains the data employed, the novelties of the empirical model and the identification strategy followed. Impulse response functions and historical decompositions are discussed in Section 4. Finally, Section 5 concludes.

2 Literature review

The determination of oil prices hinges on the interplay between supply and demand conditions. Policymakers aim to discern the relevance of these factors, as the effects of oil prices on macroeconomic variables depend on the source of the shock. Early literature, produced in the aftermath of the two oil crises of the 1970s, identified supply factors as the major driver of oil prices (Hamilton (2013), Nakov & Pescatori (2010)). This view persisted until the late 2000s, when an increasing consensus recognized global demand conditions as the key factor in explaining oil price movements during certain episodes, such as the run-up to the 2008 crisis, driven by strong demand from emerging economies (Kilian (2008), Baumeister & Peersman (2013)).

In this context, Kilian & Murphy (2014) developed a VAR model that became the workhorse model of the global oil market, allowing for forward-looking behavior in oil markets. They demonstrated that oil prices are largely explained by both current and forward-looking demand for oil, the latter being driven by expectations about future activity and the tightness of the oil market (precautionary or speculative demand).

Since then, significant advancements in econometric methodology and novel substantive insights have prompted refinements to the benchmark model proposed by Kilian & Murphy (2014). Scholars have examined specific aspects of the model, including the selection of elasticity bounds and the choice of a measure for the global business cycle. [1] Kilian & Murphy (2014) proposed a nearly vertical short-run oil supply curve, suggesting demand factors are crucial in explaining prices. However, recent research challenges this view. Caldara et al. (2019) argue that small changes in oil price elasticities significantly impact the drivers of oil prices and production. Incorporating their higher supply elasticity estimates into a structural VAR shows that supply and demand shocks are equally important. Baumeister & Hamilton (2019), using a less restrictive formulation for elasticity bounds, demonstrate that supply disruptions have a greater impact on historical oil price movements than previously thought, while inventory accumulation has a smaller effect. Kilian (2022) reaffirms that short-term oil supply elasticity remains close to zero and argues that the U.S. shale oil revolution has not affected the global one-month price elasticity of oil supply, as shale producers typically take more than one month to react.[2] Given the ongoing debate regarding elasticity bounds, we have decided not to include them.

Consensus remains elusive regarding the measurement of cyclical fluctuations in global real economic activity. A widely used approach involves the so-called "Kilian index", which relies on bulk dry cargo ocean shipping freight rates. However, as noted by Kilian (2022), this index has become increasingly sensitive to iron ore supply disruptions. Recently, some scholars have questioned whether the COVID-19 shock has broken the historical relationship between global economic activity and freight rates. In response, alternative measures have emerged. For instance, the global factor extracted from a diverse range of commodity prices (Delle Chiaie et al. (2022)) and the utilization of global industrial production (Baumeister & Hamilton (2019), Caldara et al. (2019)) offer viable alternatives. However, industrial production is a coincident indicator, which limits its ability to identify shifts in aggregate demand for industrial commodities. Additionally, industrial production data for emerging economies typically begins after 2000, significantly reducing the sample spam. [3] Based on this new evidence, we opt to rely on extracting a "demand factor" from the co-movement of various commodity prices.

Considering these factors, we propose a simple and easily updatable oil model (a SVAR) to distinguish between oil demand and supply shocks. Our approach uses a business cycle indicator

[1] Zhou (2020) argues that incorporating new features into Kilian & Murphy (2014)'s model, such as an improved real economic activity indicator or relaxing the upper bound on the impact price elasticity of oil supply, does not substantially change the results.

[2] This aligns with Golding (2019), who shows that "the average horizontal well pad in the Permian Basin takes 4–6 months from the commencement of drilling to production coming online." Moreover, even a "drilled-but-uncompleted well may take 1–3 months to go into production" due to frictions in setting up well completions.

[3] In addition, quarterly global real GDP indicators are not used because monthly indicators are preferred

derived from factor analysis on weekly commodity data to estimate the underlying factor driving commodity price movements. By imposing sign restrictions, we differentiate between specific oil demand shocks, aggregate demand shocks, oil supply shocks, and precautionary/inventory demand shocks, following a similar framework as Baumeister & Hamilton (2019).

3 Methodology

3.1 Data

We jointly model a vector of four endogenous variables $Y_t = [Q, REA, P_{oil}, Inv]$, where Q represents global crude production, REA a measure of global real economic activity, P_{oil} the real price of crude oil, and Inv is oil inventories above the ground. We use monthly data from 1980 to mid-2024.

The real price of crude is defined as the average Brent crude prices deflated by the US personal consumption expenditure price index. Brent price enters the model in log levels. Global crude production is derived from the US Energy Information Administration (EIA) and is expressed in million barrels per day (mbd). World crude oil inventories are approximated based on the methodologies proposed by Hamilton (2009) and Kilian & Murphy (2014). Our approach involves rescaling total US crude oil inventories by the ratio of OECD to US petroleum stocks, as reported by the US EIA also in mbd. This scaling factor varies within our sample, ranging from 2.16 to 2.78. Finally, we proxy real economic activity using a common latent factor derived from the co-movement of various real commodity prices, as explained in subsection 3.1.1. In our model, we consider monthly changes in global production, inventories, and real economic activity, all of which are seasonally adjusted. These transformations have been tested and confirmed to satisfy stationarity requirements.

3.1.1 A business cycle measure

Our proxy for real business economic activity relies on a global factor extracted from a wide range of real commodity prices. This approach assumes that commodity-specific shocks, such as supply shocks in individual commodity markets, are typically idiosyncratic and therefore tend to average out when analysing a broad cross-section of commodity prices. In contrast, sustained changes in the common component, which is referred to as the global factor, are more likely to signal demand shifts driven by the global business cycle. Consequently, persistent fluctuations in broad-based indices of real commodity prices reflect aggregate demand pressure.

This approach offers several advantages, as highlighted by Kilian & Zhou (2018). First, the index is available in real time on a monthly basis. Second, it serves as a leading indicator of real economic activity or, at the very least, an instantaneous gauge of aggregate demand. Third, its global coverage encompasses both advanced and emerging economies. Fourth, the time series data are sufficiently long to facilitate the estimation of structural models [4]. However, similar to the Kilian indicator, this index lacks a direct quantitative interpretation. Instead, it should be understood as proportionate to the underlying fluctuations in the business cycle.

Since we use a very simple model, a factor analysis, the critical consideration lies in selecting the appropriate commodities to construct the global factors. In line with Kilian & Zhou (2018) and Alquist et al. (2020), we choose to incorporate constituents from the Bloomberg commodity index that adhere to the four criteria outlined by Alquist et al. (2020). Specifically, we exclude commodities that exhibit safe asset or financial asset characteristics, such as gold and silver, as well as derivative oil products such as diesel or petroleum. This exclusion ensures that idiosyncratic shocks unrelated to demand conditions do not distort our analysis. Therefore we include sixteen commodities[5]. In order to avoid capturing the inflation component in commodities denominated in US dollars, we deflate the series by the US personal consumption expenditure price index. Finally, we use a factor analysis, which is more simple than the model proposed by Delle Chiaie et al. (2022)[6]. The latent common factor captures around 65% of the variance of commodity price fluctuations [7].

3.2 Identification strategy

We model the variables Y_t in a Bayesian Structural Vector. The resulting SVAR with 24 lags using monthly data has the following reduced form representation:

$$Y_t = c + A(L)Y_{t-1} + u_t$$

[4] Indeed, the proposed global factor meets the six criteria recommended by Kilian & Zhou (2018), which are: 1) The index is global; 2) it accounts for the increased weight of the service sector at the expense of the industrial sector; 3) it is a leading indicator; 4) it is long enough to facilitate the estimation of the structural model; 5) it is available at a monthly frequency; and 6) it is available in real time.

[5] Namely crude oil, live cattle, wheat, corn, soy, sugar, cotton, coffee, cocoa, hogs, aluminum, copper, zinc, tin, nickel and lead.

[6] Factor analysis searches for joint variations in response to unobserved latent variables. The observed variables are modelled as linear combinations of the potential factors, plus "error" terms. Factor analysis aims to find independent latent variables.

[7] As a robustness we also consider the 53 commodities included in the IMF commodity database, which is discontinued, with similar results.

Y_t is the vector of four endogenous variables, comprising (1) the monthly change of global oil production, (2) the monthly change of the global factor embedded in the comovement of 16 real commodity prices, (3) the log-real price of oil derived from Brent crude prices deflated by the US consumer price index, (4) the monthly change of the proxy for world inventories. The vector c contains the intercepts, $A(L)$ is a matrix polynomial in the lag operator and u_t is a vector of reduced form error terms. The reduced form residuals have a full rank covariance matrix, $\Sigma = A_0^{-1} A_0^{-1\prime} = DD'$.

To identify structural shocks, we follow the standard approach popularized by Arias et al. (2018) by imposing sign restrictions on the columns of the structural impact matrix D. These restrictions allow us to discern the underlying structural shocks and analyze their effects on oil prices.

We follow Kilian & Murphy (2014) who propose to identify three shocks as key determinants of oil price movements: global demand, oil supply, and precautionary demand shocks. We diverge from this work by providing a more comprehensive characterization of oil consumers. Kilian & Murphy (2014) justify that fluctuations of the price of oil in the global oil market can be attributed to oil supply, precautionary demand and demand shocks. However, oil demand innovations can be due either to an aggregate global real activity shock or to a specific oil-demand shock. The global real activity innovation refers to an unexpected change in overall economic activity worldwide that will affect positively consumer spending and industrial production globally, and as a result, demand for oil. By contrast, the oil-specific shock captures an unexpected change in the demand for oil due to factors related directly to oil consumption, which can be due to geopolitical events (wars, sanctions), technological changes (development of the electric vehicle or renewable deployment) and weather conditions, among others. Identifying the specific oil-demand shock also allows us to more accurately capture the aggregate demand shock.

The key identifying assumptions are sign restrictions imposed on the contemporaneous responses of the four variables to the structural shocks, grounded in economic theory. An unexpected reduction of oil production (a negative supply shock) will lead to a decline in global oil inventories, a rise of oil prices and, therefore, to a drop in real economic activity. A positive global real activity shock increases oil prices and boosts, as a result, global oil production on impact (i.e., a shift of the oil demand curve). In the case of a precautionary demand shock, market participants anticipate future oil shortages. Consequently, they purchase oil ahead of time. This behavior results in higher real oil prices, increased inventories, elevated oil production, and a decrease in aggregate demand. Finally, the oil-specific demand shock is explained by an increase in oil consumption, unrelated to global real activity. This increase in oil consumption leads to higher oil prices and production. However, it also reduces oil inventories and dampens overall economic activity due to the impact of elevated prices. The following table summarizes the set of sign restrictions imposed to identify the model [8].

Table 1: Identification restriction

	Structural shocks			
	Oil Supply	World Demand	Precautionary Demand	Oil specific demand
Supply	-	+	+	+
Real Activity	-	+	-	-
Real Price of Oil	+	+	+	+
Inventories	-		+	-

Note: Sign restrictions are only imposed on impact. As commonly done in the literature, all responses have been normalized such as structural shocks have a positive impact on oil prices.

4 Results

To justify that the proposed model yields reasonable results in line with existing empirical evidence, we first check that impulse response functions behave as one would expect. Second, we examine the contributions of different structural shocks across key historical periods. Additionally, this model has been employed for unconditional forecasting [9].

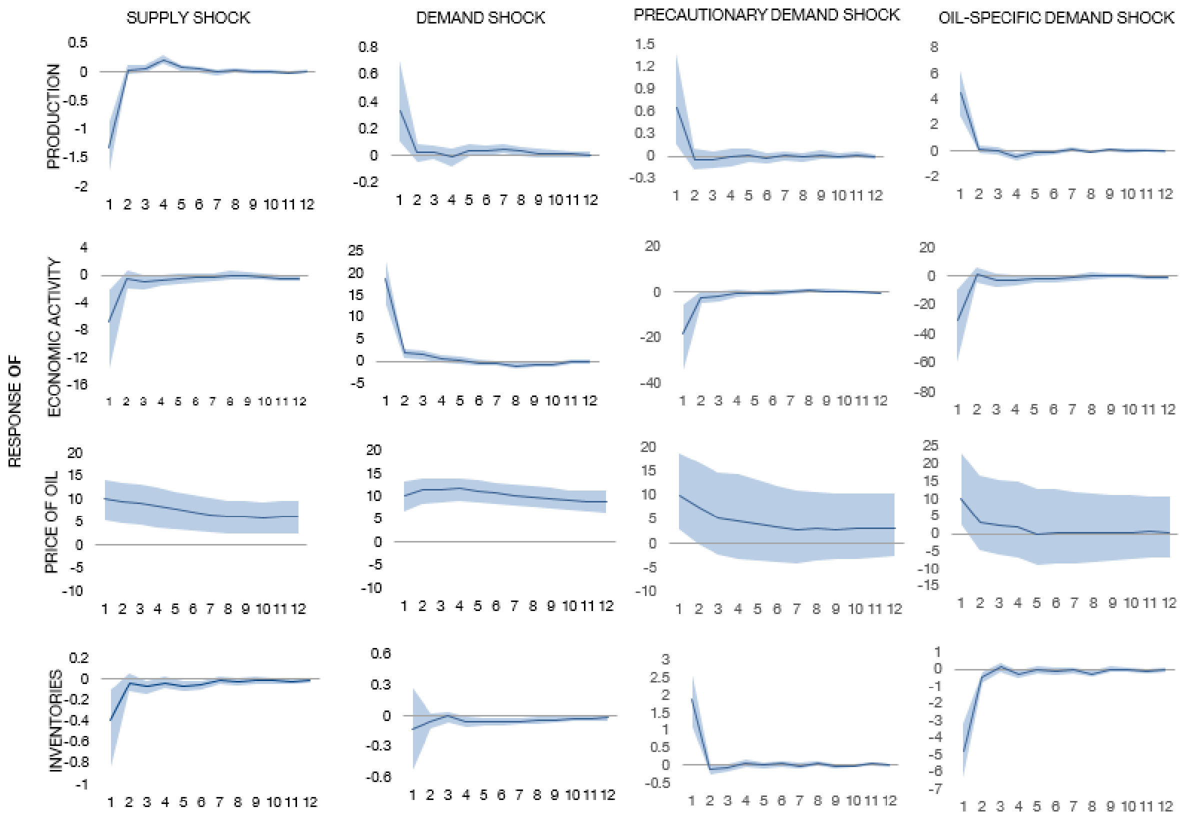
4.1 Impulse response functions

The impulse response functions (IRFs) behave as expected. To compare different shocks, we normalize the IRFs to represent the effect of a 10 percent increase in oil prices at impact. As shown in Figure 1, a supply shock results in a 10 percent increase in oil prices, a reduction in economic activity, and a decrease in inventories. A positive demand shock causes oil prices to rise, prompting oil producers to increase their production. A precautionary demand shock indicates that oil consumers anticipate higher future oil prices and decide to purchase and store oil. Consequently, oil prices rise, producers boost production, and economic activity is negatively impacted by the higher oil prices. Finally, an oil-specific demand shock signifies an increase in

[8] In accordance with Alonso-Alvarez et al. (2022), we refrain from incorporating elasticity bounds due to the lack of consensus, as discussed in Section (2). Alonso-Alvarez et al. (2022) find supply and demand elasticities that align with the existing literature.

[9] For example, see exercises related to the impact of geopolitical (supply) shocks on oil prices in Banco España (2019) and Banco de España (2020).

Figure 1: Impulse response functions



Note: Each subplot represents the impulse response function of the corresponding shock to the specific variable. Impulse response functions have been normalized to represent the effect of a 10 percent increase in oil prices.

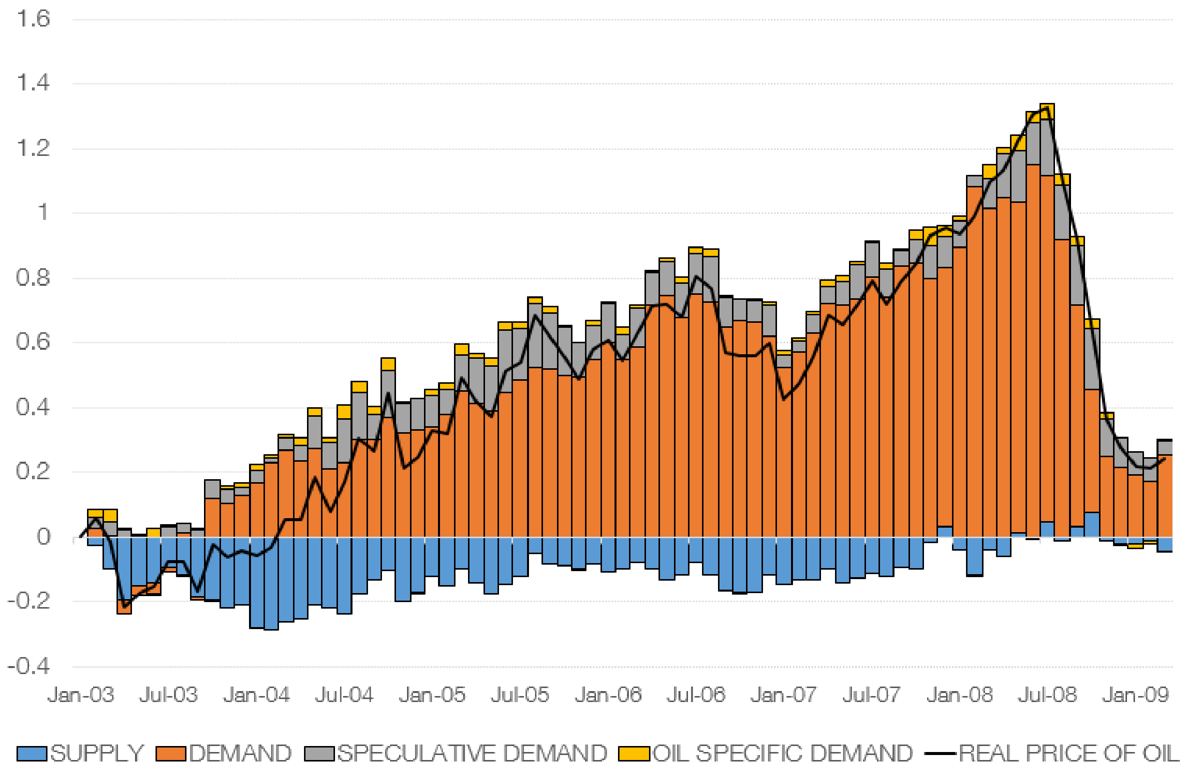
oil consumption unrelated to global economic activity. This leads to higher oil prices, increased oil production, and a reduction in oil inventories and economic activity.

In addition, the impulse response functions of the proposed model suggest that supply and demand shocks have a more permanent impact on oil prices compared to precautionary or oil-specific demand shocks. In the case of supply and demand shocks, the impact on oil prices lasts around 12 months, whereas for precautionary or oil-specific demand shocks, the effect only lasts two to three months.

4.2 Historical Decomposition

The historical decomposition of oil prices also appears to behave reasonably and effectively captures oil price dynamics. To illustrate this, Figures 2, 3, 4 and 5 show the contribution of each shock to fluctuations in the price of oil between 2004 to 2022.

Figure 2: The emerging markets momentum



4.2.1 The emerging market momentum (2003-2008)

From 2003 to 2008, the commodities super-cycle led to a surge in oil prices from $30 per barrel in 2003 to a peak of $147 per barrel in July 2008. There is a broad consensus that robust growth from emerging economies, particularly China, drove prices to this record high in mid-2008, just before the global financial crisis.

In our historical decomposition, we observe that global demand was the primary factor driving oil prices, while supply struggled to keep pace. Hamilton (2013) referred to this period as one of "growing demand and stagnant supply," as illustrated in Figure 2.

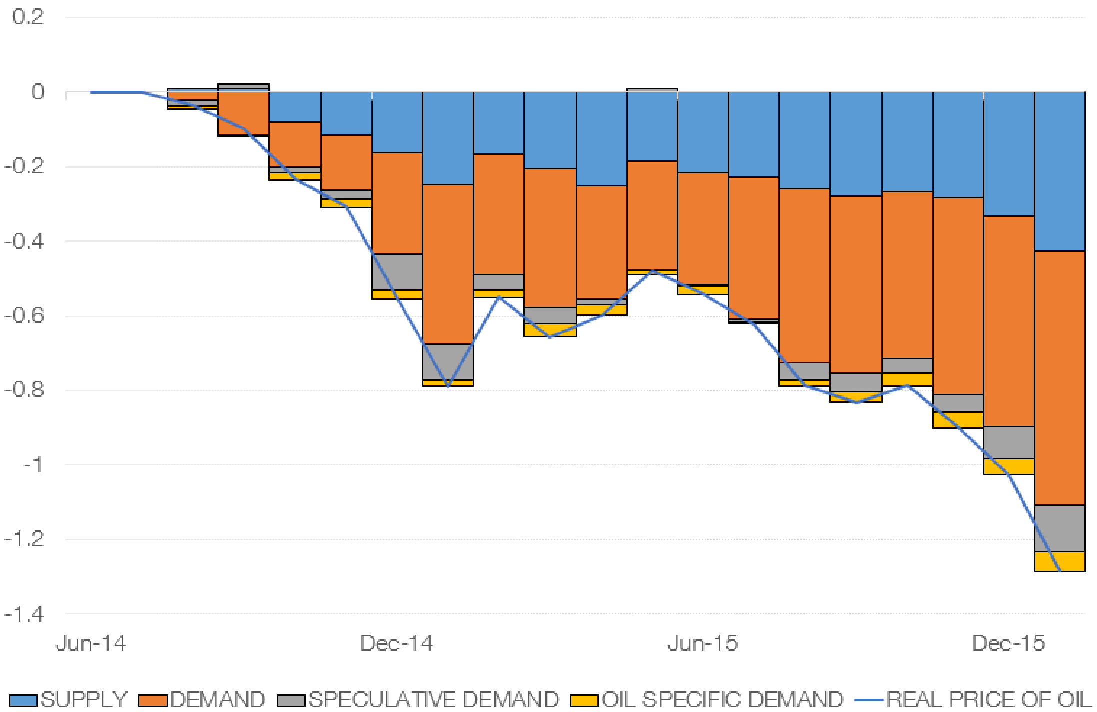
4.2.2 The shale oil era (2014-2018)

The second and third episodes we consider are related to the period when shale oil was a key driver of oil prices. For instance, Brent nominal prices dropped by around 70% between mid-2014 and January 2016 as a result of the strategic decision by OPEC countries to flood the oil market, aiming to squeeze competitors, mainly shale oil producers, by abandoning production quotas. Simultaneously, there were signs of a slowdown in energy consumption on the demand side, particularly in major emerging economies. Figure 3a reveals that the significant drop in oil prices was primarily due to demand factors, followed by supply drivers, with precautionary and oil-specific demand shocks being residual.

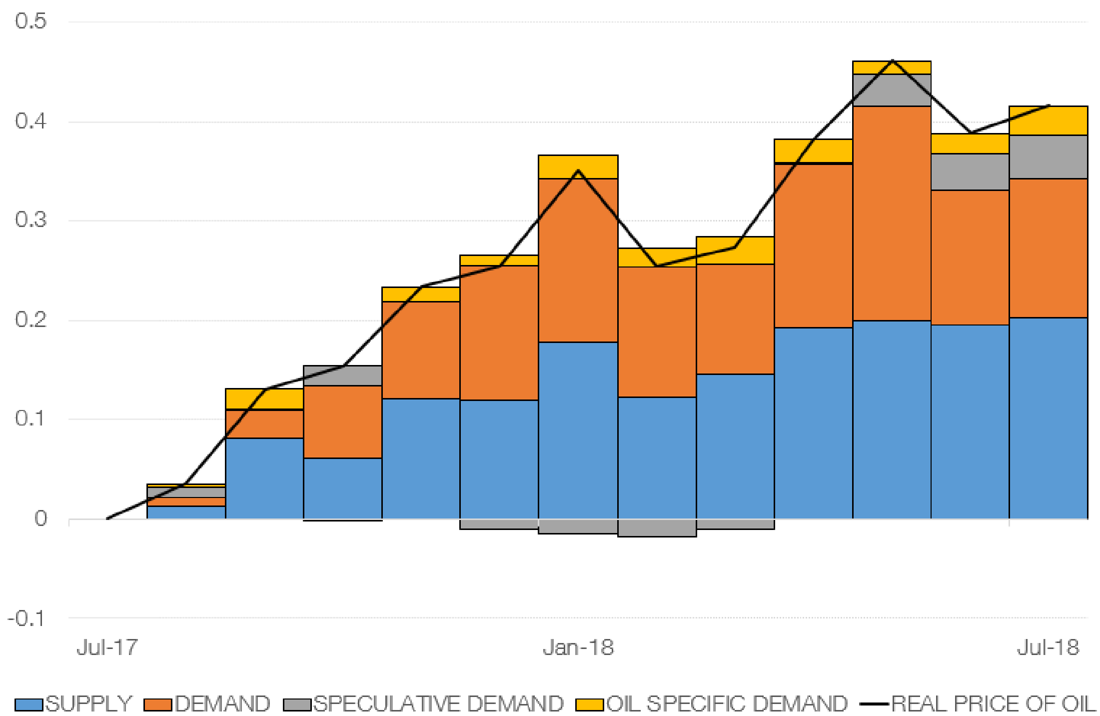
From July 2017 to May 2018, oil prices increased from around $50 to nearly $80 per barrel. The main drivers of this increase were stronger-than-expected growth in global demand, the effectiveness of the strategy adopted by OPEC and some non-OPEC countries to curb their production due to high compliance rates, and geopolitical events. The model captures this dynamic well, suggesting that both supply and demand factors equally contributed to the increase in oil prices (see figure 3b).

Figure 3: The shale oil era

(a) The age shale emergence

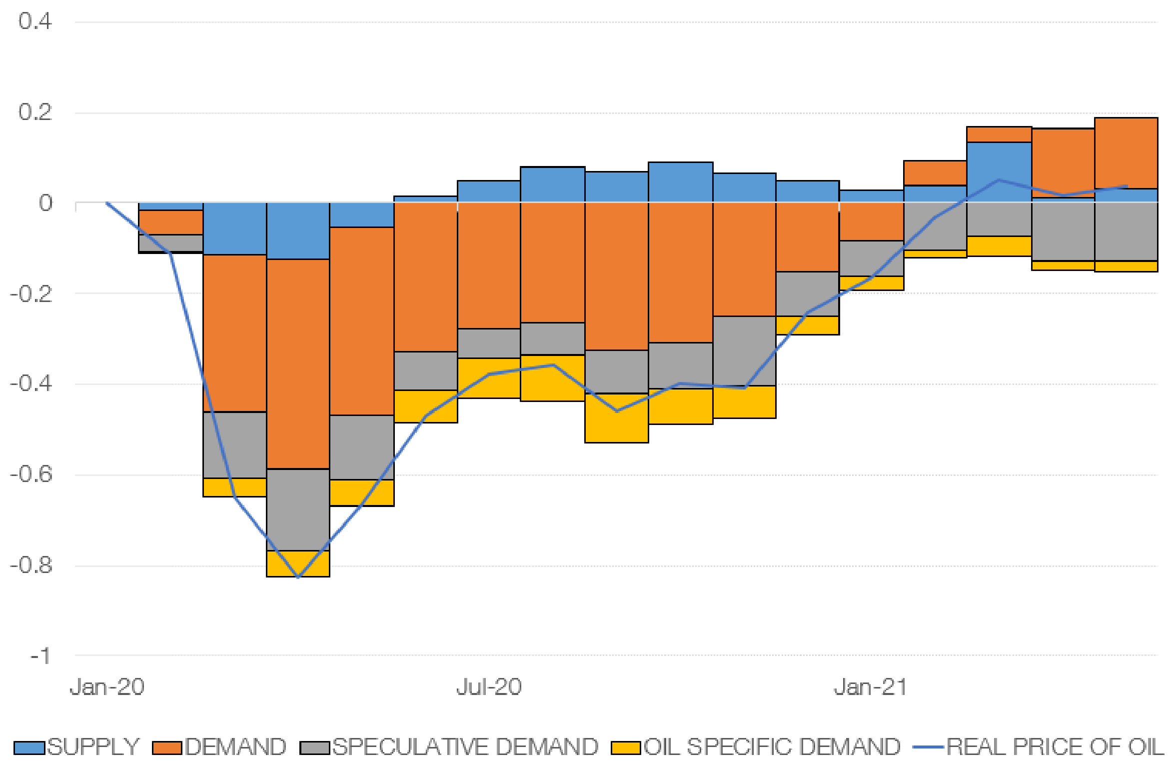


(b) Growing demand and OPEC+ strategy



4.2.3 The covid crisis

Figure 4: The covid crisis (2020)



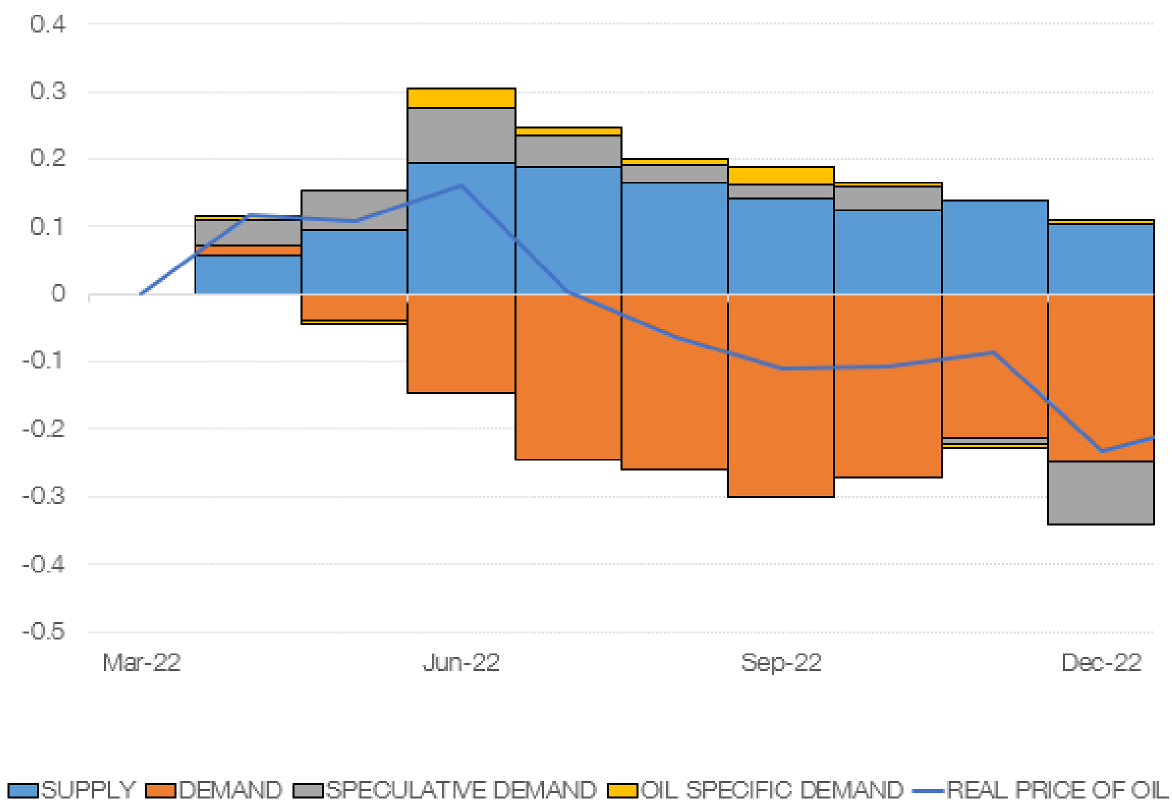
The COVID-19 pandemic profoundly affected the oil market, leading to unprecedented disruptions in both supply and demand. Between mid-January and mid-April, the price of Brent crude oil plummeted by approximately 75%. This dramatic collapse was unique due to the simultaneous sharp decline in demand and a temporary surge in production, resulting in a rapid accumulation of inventories globally.

The historical decomposition shown in Figure 4 indicates that the primary driver of the decline was the collapse in demand. The pandemic caused a dramatic reduction in global oil demand due to lockdowns, decreased travel, and a shift to remote work. This led to significantly lower consumption of oil products, particularly impacting the transport sector, which accounts for nearly 65% of the OECD's oil demand.

Supply factors also contributed to the situation. Disagreements between Saudi Arabia and Russia over the OPEC+ strategy resulted in the removal of production quotas in April. This led to an unexpected increase in OPEC+ production by 2.4 million barrels per day and substantial price discounts by Saudi Arabia. However, this shock was temporary, as OPEC+ agreed on a program of production cuts in mid-April to stabilize the market in the medium term.

4.2.4 The invasion of Ukraine (2022)

Figure 5: The Ukraine war



The final episode refers to the impact of the Russian invasion of Ukraine on oil prices, which led to a surge in oil prices, reaching 127 US dollar per barrel in March 2022, due to fears of supply disruptions. This spike was driven by concerns over the availability of Russian oil, the world's third-largest oil producer, accounting for about 13% of global crude oil production. Potential sanctions on Russia exacerbated these fears.

Since June 2022, oil prices began to decline due to weakening demand, influenced by the global economic slowdown and lockdowns in China, as indicated by continuous downward revisions from the International Energy Agency (IEA). These demand concerns more than offset the largest cut in oil production targets implemented by OPEC+ since the onset of the crisis. OPEC+ reduced its oil production starting in November 2022. Additionally, the release of strategic oil reserves by OECD countries, including the United States, aimed to alleviate price pressure. However, such releases typically have only a short-lived impact on prices, as the released oil needs to be replenished later.

Figure 5 illustrates that supply-side factors, such as fears of supply disruptions, the impact of the embargo on Russian oil, and the announcement of OPEC's strategic decisions, exerted upward pressure on oil prices. In contrast, since July 2022 demand-side factors explain the decline in oil prices as a result of lower demand due to global economic slowdown and China's zero-COVID policy in 2022.

5 Conclusions

In this paper, we present a straightforward structural model of the oil market to disentangle demand and supply shocks. Building on the work of Kilian & Murphy (2014), we incorporate a nuanced characterization of oil consumers by distinguishing between global demand shocks and oil-specific shocks. By extracting a "demand factor" from the co-movements among sixteen commodity prices, we offer a comprehensive tool for evaluating the factors influencing oil price fluctuations. The historical decomposition and impulse response functions generated by this model provide a reasonable and accurate representation of historical episodes, validating the model's robustness. This model is primarily aimed at policy purposes, either for risk scenario analysis or conditional and unconditional forecasting.

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