EUROPEAN CENTRAL BANK

EUROSYSTEM

Working Paper Series

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Strategic interactions and price dynamics in the global oil market

No 2368 / January 2020

Abstract

In a simplified theoretical framework we model the strategic interactions between OPEC and non-OPEC producers and the implications for the global oil market. Depending on market conditions, OPEC may find it optimal to act either as a monopolist on the residual demand curve, to move supply in-tandem with non-OPEC, or to offset changes in non-OPEC supply. We evaluate the implications of the model through a Structural Vector Auto Regression (VAR) that separates non-OPEC and OPEC production and allows OPEC to respond to supply increases in non-OPEC countries. This is done by either increasing production (Market Share Targeting) or by reducing it (Price Targeting). We find that Price Targeting shocks absorb half of the fluctuations in oil prices, which have left unexplained by a simpler model (where strategic interactions are not taken into account). Price Targeting shocks, ignored by previous studies, explain around 10 percent of oil price fluctuations and are particularly relevant in the commodity price boom of the 2000s. We confirm that the fall in oil prices at the end of 2014 was triggered by an attempt of OPEC to re-gain market shares. We also find the OPEC elasticity of supply three times as high as that of non-OPEC producers.

Non-technical Summary

Academics have long debated about the competitive structure of the global oil market and on the consequences for oil price formation. Existing studies have discussed whether OPEC is a cartel or a form of internal Stackelberg competition, to what extent members cooperate-coordinate their production strategies and the role of Saudi Arabia as the swing producer. More recently theoretical frameworks have considered the possibility that OPEC pursues different production strategies, depending on competitors' efficiency, production capacity and aggregate demand, in addition to internal OPEC cohesion.

We find the macro-empirical literature has somewhat disconnected from the debate, remaining anchored to the question of whether oil price fluctuations are dominated by unexpected changes in the supply of oil, or by shifts in global demand. In these studies, differences in the competitive environment of the global oil market play a limited role in guiding the identification of structural shocks. This is despite the acknowledgement that OPEC has the possibility and incentive (given the large market share and the production spare capacity) to act as a monopolist on the residual part of the demand curve. In recent years, the unprecedented surge in US shale oil production has radically changed market conditions, raising the question on whether this had an influence on oil price dynamics.

In this work we bridge the gap between theory and empirics, drawing a direct link between market structure and implications for structural empirical models of the global oil market. We show, in a simplified theoretical framework, how strategic interactions between a dominant player and fringe competitive firms can affect the oil market equilibrium. In particular the dominant player (OPEC) can operate alternative strategies, whereas fringe firms take as given market conditions and produce as much as their capacity allows. Specifically OPEC can act as a monopolist on the residual demand curve, and move its production in *tandem* with the production of the fringe firms (thereby following Market Share targeting). This is an attempt to keep market shares stable. Another option is to move production in the *opposite direction* to non-OPEC producers, thus attempting to stabilize prices around a target (Price Targeting). Next we ask to what extent these results can help our understanding of oil price dynamics in recent decades.

Following Kilian and Murphy (2014), we set up a Structural Vector Autoregressive Model (SVAR) of the global oil market in which we jointly model oil production, global economic activity, oil inventories and the price of oil. We modify the model in two directions to take into account the implications of our theoretical setup. First, we model OPEC and non-OPEC production separately. Second, we allow for distinct reactions from OPEC following a supply shock from non-OPEC countries. In the first case

we let OPEC production move in the same direction as that of non-OPEC production. This identification restriction coincides with the one employed by Kilian and Murphy (2014), Baumeister and Peersman (2013) and Baumeister and Hamilton (2019) to identify an *oil supply shock*. Consistently with our theoretical model, we define such shock a *Market Share Targeting* shock. In the second case we let OPEC production move in the opposite direction with respect to that of non-OPEC production, therefore stabilizing prices. We call this second shock a *Price Targeting* shock.

The main results of our empirical analysis are the following. First, *Price Targeting* shocks account for around 10 percent of the overall oil price forecast error variance on all horizons. They absorb around half of the forecast error variance that is left unexplained in a smaller model in which OPEC and non-OPEC production are not distinguished and only aggregate supply shocks are considered. Second, OPEC targeted prices, rather than market shares, in the early 2000s, somewhat contributed to booming oil prices in the run-up to the crisis. Third, we can characterize the supply elasticity for OPEC (0.20) to be notably higher than non-OPEC supply elasticity (0.06), on account of the OPEC's option to rapidly resort to spare capacity. Demand elasticity (-0.28) is quantitatively in line with those obtained in recent studies (see Caldara, Cavallo, and Iacoviello (2019) and Baumeister and Hamilton (2019)).

1   Introduction

Theoretical papers have long debated on the competitive structure of the global oil market and on the consequences for oil price formation. Existing studies have discussed whether OPEC is a cartel or a form of internal Stackelberg competition (Dahl (2004) and Berg, Kverndokk, and Rosendahl (1997)), to what extent members cooperate-coordinate their production strategies (Geroski, Ulph, and Ulph, 1987) and the role of Saudi Arabia as the swing producer (Nakov and Nuno, 2013). A more sophisticated approach is taken by Behar and Ritz (2017), who set up a model where OPEC can pursue alternative production strategies, depending on competitors' efficiency, production capacity and aggregate demand, in addition to internal OPEC cohesion. Some authors have also looked at how the market structure has evolved over time; Huppmann and Holz (2012b), for instance, argue that it has shifted from an oligopoly to a more competitive environment following the Great Recession.

The macro-empirical literature has remained somewhat disconnected from these studies and has focused on a relatively top-down question, i.e. whether oil price fluctuations are dominated by unexpected changes in the supply of oil or by shifts in global demand. In the early literature, supply factors were typically assumed to be the major drivers of oil prices. Little attention was paid to the underlying nature of oil price shocks and to their different macroeconomic effects. This view persisted until the end of the 2000s, when an increasing consensus identified global demand conditions as the key factor explaining oil price movements, especially in specific episodes like the run-up to the 2008 crisis, (see Kilian (2008), Kilian (2009), Kilian and Murphy (2014), Baumeister and Peersman (2013) and Baumeister and Hamilton (2015)). It is worth noticing that, in these studies, differences in the competitive environment of the global oil market play a limited role in guiding the identification of structural shocks. This is despite the acknowledgement that OPEC has the incentive and the ability (given their production spare capacity and their relatively large market share) to act as a monopolist on the residual part of the demand curve (Caldara, Cavallo, and Iacoviello, 2019). A loose relationship between market conditions and structural oil price drivers is implicitly drawn by Kilian and Murphy (2014), who assume oil supply elasticity to be relatively low. In recent years, the unprecedented surge in US shale oil production has radically changed market conditions, raising the question on whether this has had a influence on oil price dynamics (Foroni and Stracca (2019)), and its potential impact on Arab oil producers' economic policies (Kilian (2017)).[1]

While the focus in this work lies on an improved assessment of the contribution of OPECs strategy, and therefore of the contribution of supply shocks, to oil price fluctuations, a number of studies have

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[1] The shale oil revolution has attracted significant interest because it has marked a historical and unexpected turning point in US energy production trends. After three decades of steady decline, US oil production provided the largest contribution to global supply growth in the period from 2012 to 2014 and today rivals Saudi Arabia and Russia in terms of its share in global oil production.

instead investigated to what extent the activity of speculators in oil financial markets influences crude prices. Results are not univocal. Juvenal and Petrella (2015) encompass speculative shocks identified through a standard scheme of sign restrictions in a VAR model using factors extracted from a dynamic factor model. They find that speculative shocks start driving oil price upward in 2004, which is consistent with the timing when oil financial markets begun experiencing brisk investment inflows. They however confirm demand remains the dominant driver behind the oil price spike of 2008. On the contrary Chari and Christiano (2017) using a large panel dataset containing information on multiple commodities find no significant empirical link between price behaviour and futures market trading. In the same vein, Fattouh and Mahadeva (2013) argue that there is no enough evidence to support a relevant role of speculation in driving oil prices in the run up to the global financial crisis.[2]

In this paper we contribute to the literature by drawing a direct link between strategic interactions in the oil market and its implications for structural empirical models of the global oil market. We start by presenting a simple theoretical framework that shows how strategic interactions can affect the oil market equilibrium. We consider a standard dominant firm-competitive fringe model for the crude oil market (see Golombek, Irarrazabal, and Ma (2018) among others). This environment is populated by fringe firms (shale producers for instance) that are atomistic, and one large player/producer (namely OPEC) that can exert market power and willingly influence the oil market equilibrium. In our setup, fringe firms take as given market conditions and supply as much as their capacity allows them to produce. OPEC, on the other hand, takes as given the production of the fringe firms and acts as a monopolist on the residual demand, strategically adjusting its production. However we depart from standard frameworks since in our model, depending on market conditions, OPEC can follow three strategies. Specifically it can operate as a monopolist on the residual demand curve, it can move its production in *tandem* with the production of the fringe firms, in an attempt to keep market shares stable. Alternatively it can modify the production in the *opposite direction* to non-OPEC producers, this time in an attempt to stabilize prices. Next we ask to what extent these results can help our understanding of oil price dynamics in recent decades.

This empirical strategy seems to be underpinned by the time-varying correlation between OPEC and non-OPEC supply. The developments of the correlation of OPEC and non-OPEC supply across time may reflect changes in the *modus operandi* of OPEC. In particular, Figure 1 shows the two strategies pursued by OPEC in the aftermath of the emergence of US shale production: its Price Targeting strategy and the switch from Price to Market Share Targeting in September 2014. Both policies are indicated by the red dotted vertical bars. We interpret the chart through the lenses of our theoretical underpinnings.

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[2]Another question is the relation between oil prices and stock markets. For an extensive and interesting survey on this topic, see Degiannakis, Filis, and Arora (2018)

Figure 1: Time varying correlation between OPEC and non OPEC supply
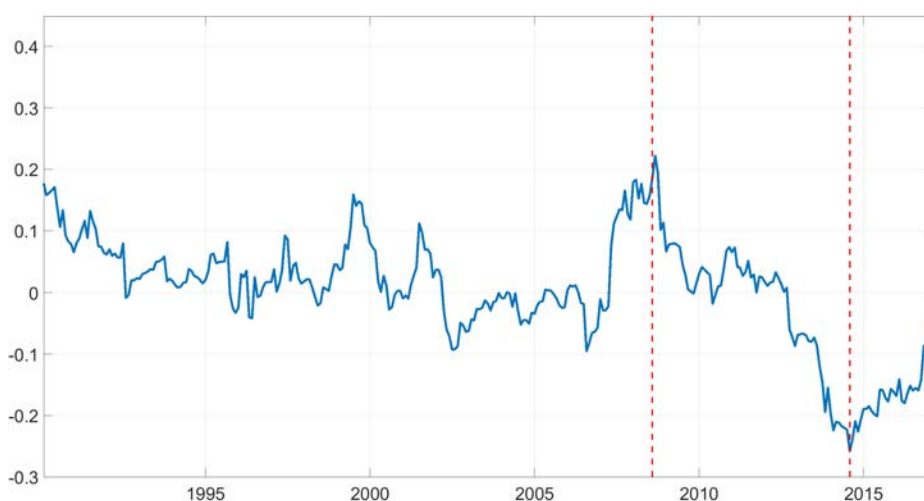
Notes: 60-month moving windows correlation between OPEC and non OPEC supply.

Until the start of the commodity super-cycle in early 2000, OPEC appears to have acted mainly as a monopolist on the residual demand. A modest positive correlation between OPEC and non-OPEC production suggests that higher global consumption was met gradually at increasing crude oil prices. But, the price spiral during the super-cycle period was also the result of OPEC manipulating global supply to maintain quotations rather high (since the correlation falls below zero). If we exclude the peak of the global financial crisis (when this correlation was mainly driven by demand forces), the Price Targeting strategy was pursued until 2014. Indeed in the first stage of the shale age (from 2010 until the third quarter of 2014) OPEC kept restraining its own production as shale supply kept expanding unabated.[3] Over this period, the correlation between OPEC and non OPEC supply remained below zero, exactly as predicted by the Price Targeting strategy in our model. Since then, OPEC has been mainly worried about defending its market share. In a world of declining production costs, as we explain in details in section 2, the attempt of the dominant player to fix a price is doomed to fail. Indeed we believe a trigger of the switch in OPEC's production strategy was the persistent upward revision of the medium and long-term profile of shale production and reserves in mid-2014. From the end of 2014 the correlation reverts to a positive trend.

Following Kilian and Murphy (2014), we set up a Structural Vector Autoregressive Model (SVAR) of the global oil market in which we jointly model oil production, global economic activity, oil inventories and the price of oil. We modify the model in two directions to take into account the implications of our theoretical setup. First, we model OPEC and non-OPEC production separately. Second, we

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[3]This is documented in monthly oil bulletins by the increasing spare capacity of the cartel joint with a reduced supply

allow for distinct reactions of OPEC following a supply shock from non-OPEC countries. In the first case, we let OPEC production move in the same direction as that of non-OPEC production. This identification restriction coincides with the one employed by Kilian and Murphy (2014), Baumeister and Peersman (2013) and Baumeister and Hamilton (2019) to identify an *oil supply shock*. Consistently with our theoretical model, we define this shock as a *Market Share Targeting* shock. In the second case, we let OPEC production move in the opposite direction to that of non-OPEC production, therefore stabilizing prices. We call this second shock a *Price Targeting* shock. To the best of our knowledge, no previous work has so far quantified the implications for price developments of different OPEC's production strategies. In particular the literature has so far only considered one type of supply shock, overlooking the fact that in oligopolistic markets major producers can decide to compete over quantities or over prices.

The main results of our empirical analysis are the following. First, *Price Targeting* shocks account for around 10 percent of the overall oil price forecast error variance on all horizons. They absorb around half of the forecast error variance that is left unexplained in a smaller model in which OPEC and non-OPEC production are not distinguished and only aggregate supply shocks are considered. Second, OPEC targeted prices, rather than market shares, in the 2000s, somewhat contributed to booming oil prices in the run-up to the crisis. Third, we can characterize different supply elasticities for OPEC and non-OPEC producers. We estimate aggregate price elasticities of supply (0.10) and demand (-0.28) that are quantitatively in line with those obtained in recent studies, see Caldara, Cavallo, and Iacoviello (2019) and Baumeister and Hamilton (2019). We estimate the price elasticity of OPEC supply to be around 0.2, similarly to (Caldara, Cavallo, and Iacoviello, 2019), and to be notably higher than that of non-OPEC suppliers (0.06). This difference is related to the OPEC's option to rapidly adapt production by resorting to spare capacity.

The remainder of the paper is organized as follows. In section 2, we provide a brief overview of the theoretical underpinnings behind the empirical identification strategy. Section 3 discusses the empirical strategy developed, highlighting the differences with previous known models. Section 4 presents the empirical results. Section 5 concludes.

2 Theoretical framework

In this section, we present a simple theoretical framework that accounts for strategic interactions of oil producers. This model will be used to assess under which conditions it is optimal for OPEC to switch from one strategy to another.

The oil market has traditionally been modeled as a special case of an imperfectly competitive

market. While previous works suggest that oil players compete a la Cournot, or OPEC acts as a Stackelberg leader, Huppmann and Holz (2012a) show that the oil market structure has evolved over time, changing from an oligopoly to a more competitive framework after the Great Recession. Moreover, Hansen and Lindholt (2008) suggest that the characteristics of a dominant producer model can fit well the behaviour of OPEC after 1994.

As in Golombek, Irarrazabal, and Ma (2018), we consider a dominant firm-competitive fringe model for the crude oil market. We assume the existence of one large player/producer, namely OPEC, that can exert market power and influence the equilibrium. Nonetheless our theoretical framework departs from their model in a series of key features. Foremost our model encompasses three possible different types of behaviour of the dominant player. OPEC can play monopolist on the residual demand or act strategically adjusting its production in response to changes in the production of the fringe firms in order to either steer the equilibrium price or to make room for greater production. Unlike OPEC, the rest of producers, called fringe firms, (shale producers for instance) are atomistic, meaning that they take as given market conditions and stay ready to supply as much as their capacity allows them to produce. Therefore, non-OPEC producers are assumed to be price-takers. The different competitive behaviour between the dominant and the fringe firms is determined by the lower cost of production of the former, in this case OPEC. Furthermore the possibility for OPEC to pursue alternative strategies in our model depends on the assumption we hold about marginal costs of the two different types of players. Our model assumes constant marginal costs for OPEC and increasing marginal costs for non-OPEC.

In this framework, OPEC can act strategically since its production has an impact on the price of oil: if OPEC increases (decreases) its production, the price of oil will decrease (increase), caeteris paribus. Specifically OPEC can follow two different strategies as the marginal revenue has two sections in this model: it can charge a high price so both the dominant and the fringe firms make profits or break-even or it can set a low price such as the fringe firms are obliged to shut down to avoid making losses and the dominant firms becomes a monopoly. The decision will depend on OPEC's inter-temporal profit maximization problem, given by the following function:

$$\Pi = \sum_{t=0}^{t=T} \beta^t [(p_t - c)Q_O] \tag{1}$$

where Q_O is OPEC's production, p_t is the price of oil, c is the constant marginal production cost and β is the time discount factor. To keep the model as streamlined as possible, the demand schedule

is assumed linear, a hypothesis that implies that the price elasticity of demand varies with p and Q.

$$p_t = a - bQ_t \tag{2}$$

where a and b are parameters representing respectively market size and price sensitivity to change in quantities. Q is the sum of OPEC and non-OPEC supply (Q_O and Q_{NO} respectively). Non-OPEC operates at a unit production cost equal to $c_{NO} = \alpha c$ with α measuring the inefficiency relative to OPEC, which we assume to be strictly greater than 1.

Let's assume that OPEC sets a price higher than the marginal cost of the fringe firms ($p \geq \alpha c$), so that all the firms make profits. From the maximization of OPEC's profit, subject to the residual demand constraint, we know that Q_O can be expressed as a function of Q_{NO}:

$$Q_O = \frac{a-c}{2b} - \frac{Q_{NO}}{2} \tag{3}$$

and plugging back Q_O in (2) also the price becomes a sole function of Q_{NO} and parameters:[4]

$$p = \frac{a+c}{2} - b\frac{Q_{NO}}{2} \tag{4}$$

For a given demand, equation (3) shows that OPEC will restrain its supply following an increase in non-OPEC production, counteracting the initial shock in the attempt to stabilize the price. However it will accommodate only half of the variation ($\frac{\Delta Q_{NO}}{2}$). As a result, total supply will increase and the price will fall but by less than in the case in which OPEC had not adjusted (by $\frac{b}{2}\Delta Q_{NO}$ in equation (4)).

Because non-OPEC producers are price-takers and cannot act strategically, they will produce as long as the oil market price remains above their production costs: $p \geq \alpha c$. In this case Q_{NO} can be derived by imposing $p = \alpha c$ in 4. The equilibrium supply of non-OPEC will be:

$$Q_{NO} = \frac{a + (1 - 2\alpha)c}{b} \tag{5}$$

OPEC production is $Q_O = \frac{c(\alpha - 1)}{b}$, a positive function of the profit margin. Notice however that, under a linear demand assumption, while non-OPEC increases its production in response to a positive demand innovation (i.e. a increases), OPEC will only do it if α is not constant. Total supply on the market is given by:

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[4]Notice that Q_{NO} is constrained by the capacity of the fringe firms, and therefore $Q_{NO} \leq K$, where K stands for the fringe firms capacity.

$$Q_T = \frac{a - \alpha c}{b} \tag{6}$$

Substituting equations 5, 3 and 4 in 1, it is immediate to show that, without structural changes, the discounted value of OPEC future profits can be expressed as:

$$\Pi = \frac{1}{1 - \beta} \frac{(\alpha - 1)^2 c^2}{b} \tag{7}$$

As T is finite, the game repeats over time unchanged but exogenous factors may intervene to alter market conditions, for instance an improvement in the production efficiency of non-OPEC producers. Technology progress can decrease α and the dominant player will revise its production accordingly. OPEC's profits will be negatively affected via two channels: 1) the profit margin is compressed and 2) the residual demand is reduced. However, does this provide an incentive to OPEC to revise its production strategy?

2.1 When are strategic deviations from the equilibrium preferable?

So far, we have defined the equilibrium of the oil market under a dominant firm-competitive fringe model based on the assumption that OPEC will set a price higher than the marginal cost of the fringe firms, so all the firms can compete in this market. However, is it always optimal for OPEC to act like a monopolist on the residual demand? Or would it be better to act strategically? In this subsection, we analyze two new strategies that OPEC can follow and determine under which conditions OPEC has incentives to deviate from the "equilibrium" of acting as a monopolist on the residual demand.

In the spirit of Behar and Ritz (2017), we imagine two possible strategies that can be enforced by the dominant player: in the former OPEC can decide to regain market share by pushing some fringe firms out of the market, in the latter OPEC decides to target the oil market price to stabilize it around a desired value.[5]

We therefore assume these two strategies to be possible objectives of OPEC and investigate under which conditions OPEC has incentives to deviate from the equilibrium. As T is finite, the game repeats over time unchanged but following any change in market conditions, OPEC will reconsider its strategy and evaluate whether deviating from the equilibrium is preferable.

Specifically, defining Π_{PT} the profits obtained under Price Targeting and Π_o the status quo profits, OPEC will follow a Price Targeting Strategy when $\Pi_{PT} > \Pi_o$. In this case OPEC will cut production by a ΔQ_O to support oil prices, given new market conditions. This means that as non-OPEC pro-

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[5]This can be driven by idiosyncratic reasons, such as maintaining their internal fiscal balance, which are not explicitly modeled in our framework.

duction expands for exogenous reasons, OPEC will reply by cutting production, and hence the two productions will move in an opposite direction under a Price Targeting Strategy in the same period . This strategy is preferable when[6]:

$$
\begin{aligned}
p_{PT} - p_0 = \Delta p_{PT} &> (p_0 - c)\frac{\Delta Q_O}{Q_O - \Delta Q_O} \\
\Delta p_{PT} &> (\alpha - 1)c\frac{\Delta Q_O}{Q_O - \Delta Q_O}
\end{aligned}
\tag{8}
$$

where p_0 and Q_O are the equilibrium values of price and OPEC production when OPEC acts as a monopolist on the residual demand. Similarly, a deviation from the status quo, consisting in increasing production above the equilibrium level by ΔQ_O, is preferred by OPEC in order to regain market shares when $\Pi_{MST} > \Pi_o$. Differently from the previous strategy, in this situation both oil productions for OPEC and non-OPEC move in the same direction at the same time; a condition verified when:

$$
\begin{aligned}
p_{MST} - p_0 = \Delta p_{MST} &> (p_0 - c)\frac{\Delta Q_O}{Q_O + \Delta Q_O} \\
\Delta p_{MST} &> (\alpha - 1)c\frac{\Delta Q_O}{Q_O + \Delta Q_O}
\end{aligned}
\tag{9}
$$

Both conditions state that profits gains from deviation must be larger than profits losses. The conditions under which equation 8 and 9 are satisfied depend fundamentally on the assumptions made about demand schedule and the functional form of non-OPEC production costs.

Focusing on the functional form of non-OPEC production costs, when α is constant, Market Share Targeting is always the preferred strategy. This is intuitive because if the marginal production cost of non-OPEC does not vary with Q_{NO}, every effort made by OPEC to raise the price will only result in non-OPEC expanding its share as the equilibrium price remains determined by non-OPEC production costs. Under such conditions, Price Targeting is clearly sub-optimal but Market Share Targeting is instead preferred to the situation of OPEC playing monopolistic on the residual demand. By the same token if OPEC increases, even marginally, its production, the price will decrease below αc, resulting in non-OPEC producers leaving the market and OPEC earning the monopoly profits shaved by a tiny value; therefore Market Share Targeting results the winning strategy. Less trivial is the situation when α increases with total non-OPEC production.[7]

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[6]See Appendix 6.1.1 for derivation details.

[7]The case of unit costs decreasing in total production, that is increasing return to scale is not considered as it will always lead, in the absence of maximum production capacity, to the entire market concentrated in the hands of a single producer.

In the case of a linear demand schedule, imposing equation 2, it is immediate to obtain that OPEC will adopt a Price Targeting Strategy when:

$$\frac{\Delta Q_{NO}^{PT}}{\Delta Q_O^{PT}} < 1 - \frac{(\alpha_0 - 1)c}{b} \frac{1}{Q_O - \Delta Q_O^{PT}}$$

and it will pursue a Market Share Targeting strategy provided:

$$\frac{\Delta Q_{NO}^{MST}}{\Delta Q_O^{MST}} > 1 + \frac{(\alpha_0 - 1)c}{b} \frac{1}{Q_O + \Delta Q_O^{MST}}$$

Ultimately whether one of the two strategies is preferred to the status quo and which of the two strategies is pursued depends on the reaction of non-OPEC production to OPEC moves, determined by the functional form of the fringe firms costs.[8]

When non-OPEC production costs are increasing in Q_{NO}, if OPEC attempts to raise the price above the equilibrium by cutting its production (Price Targeting strategy), the possibility of non-OPEC expanding its own production by the same amount will be limited by the increase in marginal production costs. It must therefore exist a range of α for which Price Targeting is feasible and optimal.

Similarly in order to regain market shares, OPEC will expand production pushing down the oil market price, non-OPEC then cuts back on its production but less than OPEC's initial expansion, as unit production costs decrease. In conclusion, when α increases with total non-OPEC production, it is not obvious any longer that Market Share Targeting is preferred to the status quo and to Price Targeting.

Although it is not necessary for the sign restrictions imposed in the empirical model, we can determine the range of parameters under which it is optimal for OPEC to deviate from the equilibrium. In particular, it can be proved that under the linear demand schedule hypothesis, assuming that non-OPEC production costs also increase with production linearly ($\alpha = \delta Q_{NO}$), we have that:

$$\frac{\Delta Q_{NO}}{\Delta Q_O} = -\frac{b}{\delta c + b} \tag{10}$$

The ratio of non-OPEC to OPEC production decreases with demand sensitivity to prices ($\frac{1}{b}$) and relative to inefficiency of non-OPEC. More importantly, exogenous shocks to δ can induce OPEC to start or cease a strategy. Finally, replacing equation 10 in 8, we obtain the optimal OPEC deviation

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[8]It is immediate to verify that as long as OPEC production is positive, it never happens that both conditions 2.1 and 2.1 are satisfied at the same time.

from status quo under Price Targeting:[9]

$$\frac{\Delta Q_O}{Q_O} < \frac{-b}{\delta c} \tag{11}$$

and the optimal OPEC deviation from the status quo under Market Share Targeting is found by replacing 10 into 9:[10]

$$\frac{\Delta Q_O}{Q_O} > \frac{b}{\delta c} \tag{12}$$

Therefore for $\frac{-b}{\delta c} < \frac{\Delta Q_O}{Q_O} < \frac{b}{\delta c}$, the status quo (acting as a monopolist on the residual demand) is preferred by OPEC. Small perturbations in quantities will not be sufficient to deviate from the optimal equilibrium, but relevant changes in production can trigger a switch in the optimal strategy. Moreover whatever strategy is followed, it has to become more aggressive as δ decreases, which is when non-OPEC producers become relatively more efficient, or when oil prices are more sensitive to a change in quantities.

Last, like in other theoretical frameworks, following positive demand shocks total supply increases. In particular, maintaining the assumption of increasing non-OPEC marginal production costs, demand shocks originate shifts in the same direction of both OPEC and non-OPEC productions, regardless of whether the pursued strategy is the status quo, Price or Market Share targeting. Moreover, demand shocks consisting in Δa do not generate switches of OPEC strategy since they do not enter the two conditions 12 and 11.

2.2 Price Targeting vs Market Share targeting

We have identified a range of parameters under which deviating from the status quo of playing monopolistic on the residual demand curve seems to be optimal. However, it is also relevant to know when OPEC prefers to follow a Market Share Strategy or a Price-Targeting Strategy.

OPEC decides its optimal strategy based on its inter-temporal profit maximization problem given the information set available at each time t. OPEC will follow a Price Targeting Strategy whenever:

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[9]See appendix 6.1 for derivation details.
[10]see appendix 6.1 for derivation details.

$$
\begin{aligned}
\Pi_{PT} &> \Pi_{MST} \\
(p_0 + \frac{\delta bc \Delta Q_O}{b + \delta c} - c)[Q_O - \Delta Q_O] &> (p_0 - \frac{\delta bc \Delta Q_O}{b + \delta c} - c)[Q_O + \Delta Q_O] \\
Q_O &> (p_0 - c)\frac{b + \delta c}{\delta bc} \\
\frac{Q_O}{Q_{NO}} &> (\delta - \frac{a + c}{b + \delta bc})\frac{b + \delta c}{\delta bc}
\end{aligned}
$$

Price Targeting is preferred to Market Share Targeting as long as OPEC production remains above a precise threshold (δ), and therefore a certain market share seems to be guaranteed by OPEC. However, whenever OPEC's production is largely and negatively affected, for instance by a fierce competition from the fringe firms, OPEC might find optimal to switch from one strategy to another in order to defend its production, even at the cost of accepting a drop in oil prices.

This simple framework provides a better understanding of strategic interactions in the oil market in order to assess the impact of OPEC's strategies on oil price dynamics. It also provides underpinnings to bridge theoretical considerations with the empirical identification of the oil market. It highlights the three possible strategies that OPEC can pursue and provides precise conditions under which one strategy prevails on the other: 1) act as a monopolist on the residual demand, 2) target oil prices to keep them around a desired target, by cutting down its own production in some cases, 3) regain market shares if competitors are expanding.

More importantly, this simple theoretical model shows that following an exogenous shock to non-OPEC production, OPEC can decide to switch from one to another strategy. When OPEC finds optimal to pursue a Price Targeting Strategy, it will cut on its original production following a non-OPEC positive supply shock, therefore the two productions changes will have opposite signs. When Market Share Targeting is found to be optimal, OPEC will increase beyond its initial status quo level its production. Notice that the framework encompasses the possibility of uncertainty around which strategy is optimal to play as non-OPEC efficiency can change exogenously. It also exists a range of market conditions (demand and competitor efficiency) that accommodates a period of inertia during which no active strategy is pursued. This can explain OPEC's behaviour during the initial stages of the shale revolution.

Based on the policy reaction function of OPEC to non-OPEC supply shocks depending on the strategy pursued, in section 3 we present an empirical model that aims at formalizing the theoretical considerations presented in this section. Our ultimate goal is to better understand oil price dynamics

in recent decades, and specifically to assess in which episodes OPEC was acting strategically.

3   Empirical strategy

3.1   Data

We jointly model a vector of five time series $Y_t = [Q_{Opec}, Q_{Non-Opec}, REA, P_{oil}, Inv]$, where Q_{Opec} and $Q_{Non-Opec}$ are, respectively, oil production from OPEC and Non-OPEC, REA is a measure of global real economic activity, P_{oil} is the real price of oil, and Inv are oil inventories. All time series are transformed to achieve stationarity.

OPEC and non-OPEC production are obtained from the *Monthly Energy Review* published by the US Energy Information Administration (EIA), and they are expressed in monthly percentage changes. In order to measure global economic activity we use a monthly series of world GDP obtained by interpolating quarterly world GDP growth.[11] The measure of real oil prices is derived from the average Brent crude prices, obtained from the International Financial Statistics (IFS), and deflated by the US consumer price index. Brent prices enter the model in log-levels. Finally, owing to the lack of available data and following Kilian and Murphy (2014), world crude inventories are proxied by monthly changes in total US crude oil inventories, rescaled by the ratio of OECD to US petroleum stocks, which are taken from the EIA.[12]

3.2   A SVAR model

We model the vector of variables Y_t in a Structural Vector Auto Regression (SVAR). We follow the previous literature including 24 lags (Kilian and Murphy, 2014) and employ monthly data. The structural form representation of the model is as follows:

$$A_0 Y_t = B(L)Y_{t-1} + \epsilon_t \tag{13}$$

Y_t is a vector of five endogenous variables, including (1) the monthly percentage change in OPEC crude oil production, (2) the monthly percentage change in non-OPEC crude oil production, (3) the monthly growth rate of the interpolated global GDP, (4) the log-real price of oil, (5) the monthly

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[11]Results do not change fundamentally when using Kilian's measure for global economic activity, which is based on dry cargo single voyage ocean freight rates, see Kilian (2009). Notice, however, that the performance of this indicator, as pointed out by **?**, has deteriorated in recent years. During the slowdown in economic activity in early 2016, for instance, the negative spike in Kilian's indicator would have predicted a more severe crisis than the Global Financial Crisis, casting doubts about its suitability as a leading indicator.

[12]As OECD petroleum series is only available from 1987, the series is backcasted from 1973 using the growth rate of US petroleum inventories, closely correlated to overall OECD changes especially in the early years of the sample (see Kilian and Murphy (2014)).

changes in global oil inventories. The matrix A_0 shapes the contemporaneous interaction among the endogenous variables, while B(L) is a matrix polynomial and ϵ_t is a vector of structural disturbances.[13] The *reduced form* representation of the model is the following:

$$Y_t = C(L)Y_{t-1} + u_t \tag{14}$$

where $u_t = A_0^{-1}B(L)$ and $C(L) = A_0^{-1}B(L)$. The reduced form residuals have a full rank covariance matrix, $\Sigma = A_0^{-1}A_0^{-1\prime} = DD'$. Identification of the structural shocks is achieved via sign restrictions on the columns of D following the standard method popularized by Arias, Rubio-Ramirez, and Waggoner (2018).

In order to identify structural shocks and to study their effects on the price of oil we need to place restrictions on the structural impact matrix D. A number of papers have shown that fluctuations of the price of oil in the global oil market can be mostly attributed to three fundamental shocks, namely oil supply, oil demand and precautionary demand shocks, see for instance Kilian and Murphy (2014) and Baumeister and Hamilton (2015). We deviate from these analyses by allowing for a richer characterization of the behaviour of *oil suppliers*, given the focus of our analysis on the strategic interaction of oil producers. The existent empirical literature has typically bundled together the behaviour of OPEC and non-OPEC producers and considered a single aggregate global supply shock. To see how such an aggregate shock is identified in a SVAR model of the type hereby employed, let us suppose that such oil supply shock is identified as the first shock in the system. This would be obtained by imposing restrictions on the signs of the first column of D, let us call it d_1. In particular, an exogenous tightening of oil supply would lead to a fall in oil production, an increase in prices and a contraction of global economic activity. Therefore, the first three elements of d_1, corresponding to the response of (1) OPEC production, (2) non-OPEC production and (3) real economic activity are supposed to be negative, while the fourth one, corresponding to the response of the real price of oil, is supposed to be positive. However, the theoretical model derived in section 2 suggests that OPEC and non-OPEC producers interact strategically. Such strategic interaction, in turn, implies that OPEC producers would likely adjust their response to non-OPEC producers in a time-varying fashion, depending both on market conditions and on domestic economic considerations.[14]

One would be tempted to address this issue by making the coefficients in d_1 time-varying, but this by itself would not solve the problem. What one needs, in fact, is to allow for the second element of d_1 (corresponding to the behaviour of OPEC suppliers) to *switch* sign over time so as to give OPEC the

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[13] An intercept and seasonal dummies are also included in the model.

[14] For instance, domestic fiscal balance considerations could shape the decision by OPEC members to react one way or another to a supply shock originating in non-OPEC countries.

possibility to follow non-OPEC production (so as to target market shares) or to partially/completely offset it (so as to target prices). In order to strike a sensible balance between flexibility and simplicity, our solution consists of identifying an additional structural shock, which imposes *opposite* signs on the response of OPEC and non-OPEC production. In other words, we identify two independent structural shocks— a "Market Share Targeting" shock and a "Price Targeting" supply shock, related to the strategic interactions of OPEC and non-OPEC supply decisions. The former is the typical global oil supply shock identified as in Kilian and Murphy (2014) and Baumeister and Hamilton (2015), where OPEC and non-OPEC production moves in the same direction. The latter is identified by allowing OPEC to move its production in the opposite direction to that of non-OPEC, in order to partially stabilize prices. Besides these shocks, we also identify a global demand and a precautionary demand for oil shock, as in Kilian and Murphy (2014). Table 1 reports a summary of the sign restrictions imposed on the first four columns of D in order to recover the structural shocks.

Table 1: Identification Restrictions

Variables	Market share targeting supply	Price targeting supply	Aggregate demand	Speculative demand
OPEC production	-	-	+	+
Non-OPEC production	-	+	+	+
Real activity	-		+	-
Real price of oil	+		+	+
Inventories				+

Notes: As commonly done in the literature, all responses have been normalized such as structural shocks have a positive impact on oil prices. Moreover, a fifth shock, not represented in the table, captures the linear combination of all unidentified shocks accounting for the unexplained part of variables' dynamics.

The key identifying assumptions are sign restrictions imposed on the responses at time 0 of the five variables to the structural shocks, as well as dynamic restrictions on some of the variables. The novelty of this set-up is that it exploits specific conditions derived within a simple theoretical framework to identify the two types of supply shocks. If OPEC seeks to maintain its market share (MST strategy), it reacts to expansions (declines) in non-OPEC production by also increasing (decreasing) its supply. In this case, both productions move in the same direction at the same time, and therefore the contemporaneous responses have the same sign, leading to an amplification of the decrease (increase) in oil prices.[15] On the contrary the "Price Targeting supply shock", considers opposite movements in OPEC and non-OPEC production. If OPEC aims at stabilizing oil prices around a target (for given global demand conditions), it must drain the eventual excess supply by reducing its own supply to support prices. In this case, no sign restrictions are imposed on price and global activity since there are two forces operating in opposite directions and the overall effect on prices and activity is

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[15]To select only supply shocks with some persistent effect, we further impose that the oil price reaction persists for at least 12 months.

ambiguous, depending on the net impact on production (see Table 1). Notice that, at any point in time, the model will assign some of the changes in the price of oil to *both* the Market share and to the Price targeting strategies. This simply implies that following an exogenous increase in production from non-OPEC producers, the overall *net* reaction of OPEC producers will be determined by the sum of the two shocks. Despite being a crude shortcut for allowing OPEC to react differently at each point in time, this identification strategy allows us to capture the main qualitative implications of the theoretical model. Furthermore it allows for an endogenous optimal selection of the strategy pursued within a single econometric workhorse. This compares with other works (see Golombek, Irarrazabal, and Ma (2018)) where the dominant OPEC and the competitive OPEC paradigms lead to alternative estimation methodologies (a non linear instrumental variable and a 3 stage least square method respectively) and econometric models carried out on different time frames.

Similarly to previous works, positive aggregate demand shocks in the oil market (i.e. a shift in the demand curve) are identified by simultaneous increases in oil prices and production in both OPEC and non-OPEC countries. A positive speculative demand shock gives origin to a situation when market players purchase oil inventories ahead of expected future shortages in the oil market and as a result the current level of inventories and the real price of oil rise. At the same time, higher oil price boosts oil production in OPEC and non-OPEC countries while aggregate economic activity decreases.[16]

4 Results

We name 3-shocks and 4-shocks models, respectively, a standard model which identifies, demand, supply and precautionary demand shocks and our model which distinguishes two types of supply shocks in addition to demand and precautionary demand shocks. In order to highlight the main contribution of the novel framework accommodating for producers strategic interactions, we rely first on the comparison of the forecast error variance decomposition of oil prices between the 3-s and the 4-s model.[17] We then move to compute oil supply and oil demand elasticities, and finally comment on the historical decomposition.

4.1 Forecast Error Variance Decomposition

We start by comparing how the 3-s and the 4-s models decompose the oil prices' forecast error variance, see Figure 2. The plot is organized in four panels. The top-left panel reports the share of forecast

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[16]Notice that we do not impose any particular elasticities bounds on oil supply and demand. The main reason is that there is no consensus on what the correct values of elasticities that should be imposed are. A recent paper by Caldara, Cavallo, and Iacoviello (2019), for instance, finds that the short-run oil supply elasticity might be as high as 0.077, three times higher than the supply bound (0.0258) imposed in Kilian and Murphy (2012).

[17]Impulse response functions are shown to be well behaved in the appendix.

error variance that is explained by the typical supply shock in the 3-s model and by the Market Share targeting shock in the 4-s model. The top-right and bottom-left panels report the shares of, respectively, the demand and the speculative demand shocks for both models. Finally, the bottom-right panel compares the share of variance that in the 3-s model is attributed to the residual shock, to the share that in our setup is captured by the Price Targeting shock.

We draw attention to three results. First, the supply shock in the 3-s model and the Market Share Targeting shock in the 4-s model explain by large the same share of oil price fluctuations (around 40 percent at short horizons and about half as much at longer horizons). This, by itself, suggests that our newly identified shock is not subtracting explanatory power from the traditional supply shock. Second, in our model global demand is slightly less relevant than in the 3-s model, especially at longer horizons, while the relevance of shocks that originate from precautionary demand for inventories is somewhat lower. Last and most importantly, the Price Targeting shock explains almost an additional 10% of the FEVD, which in the 3-s is left non-identified and therefore attributed to the residual shock. Indeed the part of the variance of the forecast errors explained by the residual.[18] is substantially reduced in the 4-shocks framework (to about half of what is in the 3-s model), suggesting that the added model flexibility captures indeed some relevant heterogeneity in the behaviour of OPEC supply over the considered sample.

4.2 Elasticities

Based on the structural shocks identified in our specification, we can estimate implied short-run price elasticities for oil demand and oil supply. Furthermore, having split oil production in OPEC and non-OPEC countries, we allow for heterogeneous oil supply elasticities in these two economic areas, by looking at how their production react in the face of a structural demand shock.[19]

Table 2 summarizes the median short-run price elasticities derived in our model. They turn out to be consistent with those recently estimated of the recent literature. Indeed, the median of the aggregate oil supply elasticity is 0.10, qualitatively close to the elasticity obtained in Caldara, Cavallo, and Iacoviello (2019) and in Baumeister and Hamilton (2019). More specifically, Baumeister and Hamilton (2019) derive a short-run oil supply elasticity of 0.15 using Bayesian inference with relaxed prior information on the size of elasticities, while Caldara, Cavallo, and Iacoviello (2019) estimate a 0.077 short-run supply elasticity using country-level instrumental variable regressions.

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[18]Not shown in the graph.

[19]Given that we model two different producers that can adopt different strategies we need to make some assumptions when estimating elasticities. The global oil price supply elasticity is obtained by considering the overall percentage increase in global oil production determined by OPEC and non-OPEC (conditional on a demand shock) and dividing the resulting percentage change by the percentage increase in global oil prices. The price elasticity of demand is obtained conditioning on the Market Share targeting shock.

Figure 2: Forecast Error Variance Decomposition of oil prices: comparing the 3-s and 4-s models
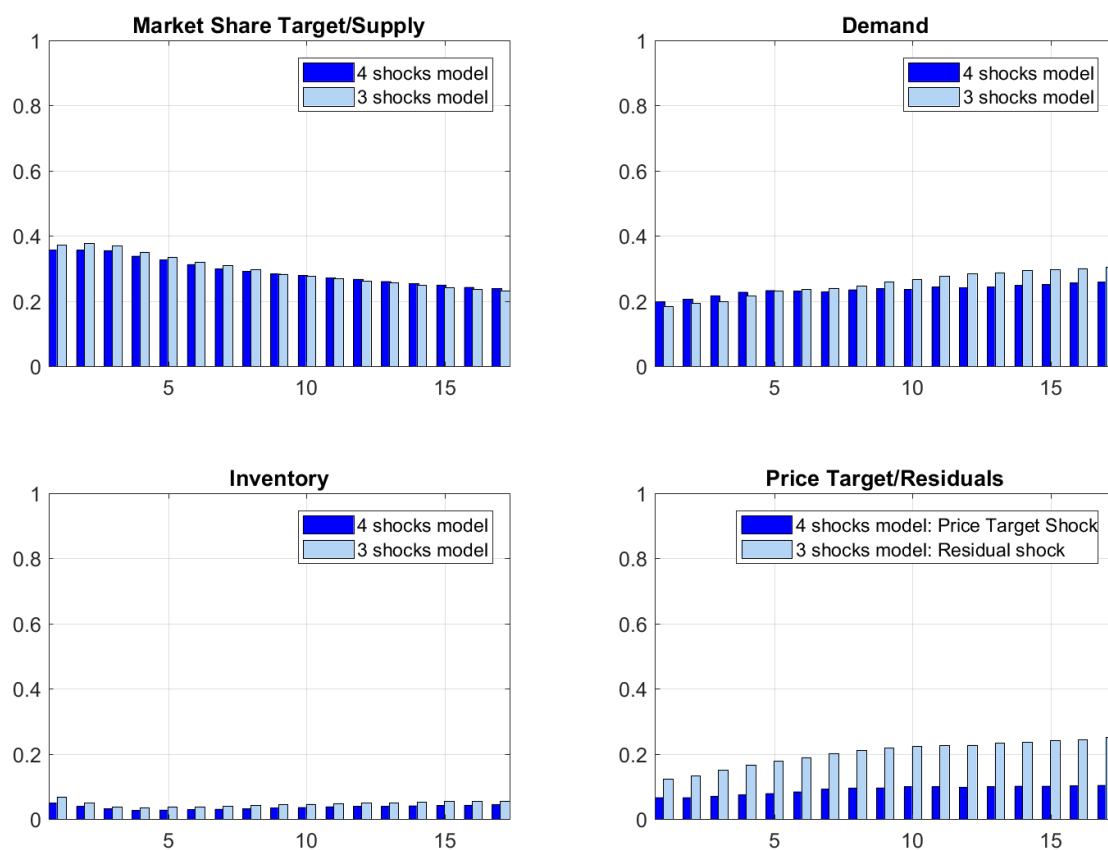
Notes: The 4-shock model refers to the new model that distinguishes between two types of supply shocks, while the 3-shock model focuses on a standard model which identifies, demand, supply and precautionary demand shocks.

Turning to the difference between OPEC and non-OPEC supply elasticity, unsurprisingly we find that the elasticity of OPEC supply is higher than that of non-OPEC supply. A similar result, albeit with very different techniques, is obtained by Caldara, Cavallo, and Iacoviello (2019), who estimated an elasticity of 0.22 for Saudi Arabia, 0.19 for the rest of OPEC members and non significantly different from zero for non-OPEC countries. While our results are qualitatively similar for OPEC countries with a supply elasticity of 0.2, we also derive a small positive supply elasticity for non-OPEC countries, of around 0.06. OPEC adjust production in response to price changes more easily due to available spare capacity, but also to optimally decided production policies.

Table 2: Median price elasticities of crude oil supply and demand

Elasticities	Our model	KM14	CCI19	BH19
Price elasticity of crude oil demand	-0.28	-0.08	-0.07	-0.35
Price elasticity of crude oil supply				
- Global	0.10	0.03	0.08	0.15
- OPEC	0.20		0.19	
- non-OPEC	0.06		-0.01	

Notes: Estimates Km14 refers to Kilian and Murphy (2014), CCI19 refers to Caldara, Cavallo, and Iacoviello (2019) and BH19 refers to Baumeister and Hamilton (2019). Notice that in the case of KM14, elasticities refer to the upper bound for supply and to lower bound for demand.

The short-run demand elasticity (-0.28) is also closer to the estimates retrieved in the recent literature. Indeed, there is an extensive literature on oil demand elasticities, with heterogeneous results as elasticities range from -0.81 for the long-run price elasticity of gasoline demand (Hausman and Newey (1995) to -0.07 of short-run oil elasticity of Caldara, Cavallo, and Iacoviello (2019).[20] However, the recent literature challenges previous estimates and points to lower elasticities. Caldara, Cavallo, and Iacoviello (2019) find a demand elasticity around -0.07 using data from 1985 to 2007. Gelman, Gorodnichenko, Kariv, Koustas, Shapiro, Silverman, and Tadelis (2016) retrieve a short-run elasticity for gasoline of -0.22. Therefore, a short-run elasticity around -0.285 is reasonable for an average estimation using a larger sample period, from 1973 to 2017, as there is a persistent decline in elasticities over time.

Since we model OPEC and non-OPEC supply separately, we also look at possible breaks over time in the oil supply elasticity of these two producers. In particular, we obtain a time-varying version of our VAR model using the non-parametric estimator by Giraitis, Kapetanios, and Yates (2018) and identify at each point in time structural shocks. This allows us to have an estimate of time-varying supply and demand elasticities. The elasticity of OPEC and non-OPEC supply are obtained as price

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[20]Of course, one needs to differentiate between crude oil and gasoline elasticities and between short and long run elasticities. While it is reasonable to argue that short-run elasticity is smaller than long-run elasticities, Hamilton (2009) makes the case that crude oil demand elasticity should be around half the gasoline demand elasticity since crude oil accounts for half the retail cost of gasoline.

percentage changes following demand shocks, that is the response of production to oil price when an exogenous expansion or contraction of world demand occurs (e.g. shifts of the demand curve along the supply curve). Therefore, as explained in section 2, and irrespective of the strategy OPEC is pursuing, both OPEC and non-OPEC, to a different degree, will adjust their supply in the same direction to accommodate demand at least partially.[21] The evolution of supply elasticities is shown in Figure 3 . As two different demand shocks have been identified in our model, the global aggregate demand shock and the speculative demand shock, we can derive different OPEC and non-OPEC supply elasticities conditional on each of these shocks. While the dynamics of supply elasticities are quite similar, oil supply seems to be slightly more elastic in the case of a speculative shock, pointing to a different reaction depending on the source of the shock.

Figure 3: Time varying supply elasticity
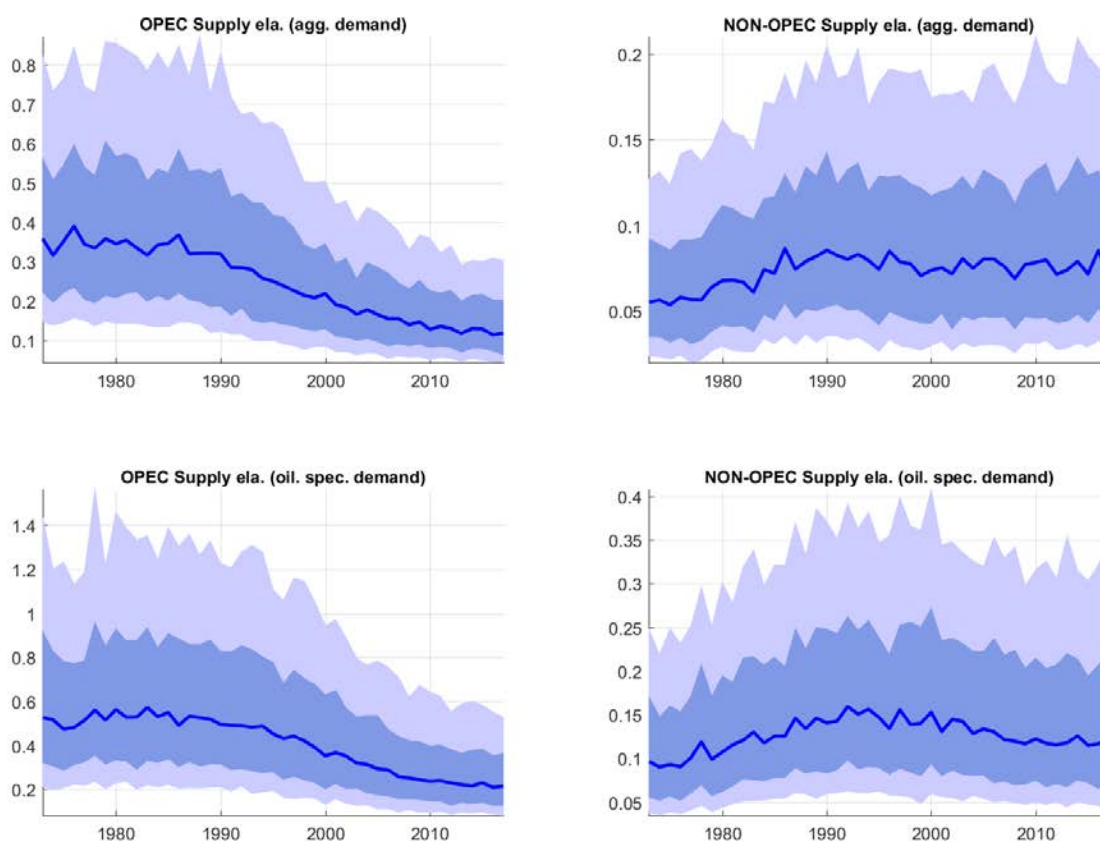
In addition, these time-varying supply elasticities confirm that OPEC elasticities are higher than

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[21]In section 2 we clarify that it is for a given demand level that, depending on the strategy pursued, OPEC may restrain its supply when non-OPEC expands its own, while the elasticity of OPEC and non-OPEC supply are computed over different demand schedules

non-OPEC elasticities for both demand shocks. Nevertheless, while OPEC supply elasticity seems to decline, for non-OPEC countries it slightly increases over time. OPEC supply elasticities are relatively more elastic in the seventies and eighties with median elasticities between 0.3 and 0.4 when computed as shifts along the aggregate demand and around 0.5 when computed from shifts along the speculative demand, while currently they are around 0.15 and 0.2, respectively. Focusing on non-OPEC time-varying supply elasticities, there is no evidence so far of a recent structural break in elasticities due to the surge in shale oil production in the US. Elasticities remained rather constant over the past two decades despite the fact that shale producers are able to stop and restart production more easily than conventional non-OPEC producers, see also Foroni and Stracca (2019). Two factors can be behind this result: the phenomenon is too recent for a structural break to be properly identified in a time series analysis which has to be performed including many lags (up to 24) and the share of shale oil in total production is still only around 6.5% of world oil and 11% of non-OPEC production.

Figure 4: Time varying overall demand elasticity
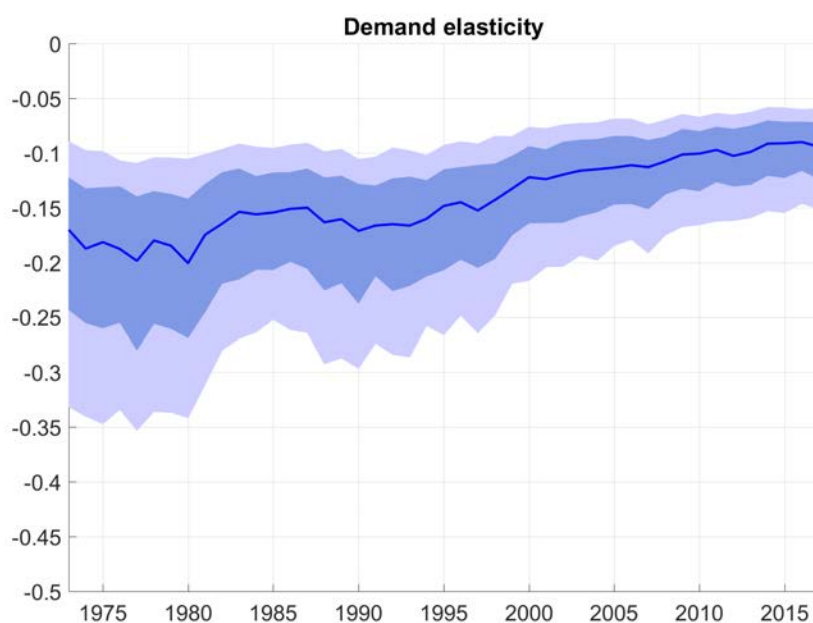
Estimates of oil demand time-varying elasticities, reported in Figure 4, indicate that this has declined quite markedly over time. In the seventies, oil demand median estimate was close to -0.2 until 1980, period in which they started their downward trend, in absolute value, until reaching a current level close to -0.1. The lower elasticity may result from economies having become more resilient to oil price shocks over time, chiefly owing to lower energy intensity. Its decline by a third since the early nineties is a consequence of the improved energy efficiency and the declining share of the energy intensive manufacture in global production.[22]

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[22]A similar pattern is also shown in Baumeister and Peersman (2013). However, our estimates display a smaller

4.3 Historical Decomposition

The historical decomposition of oil prices obtained from the 4-shocks model confirms some of the major findings of the previous literature but it also contains relevant innovations. To illustrate this point, in Figure 5 we show the contribution of each shock to fluctuations in the price of oil between 2000 and 2017 in the 3-s and in the 4-s models.

Supply shocks in the two models behave similarly. In Figure 5, top-left panel, the contribution of the Market Share Targeting shock of the 4-shocks model and that of the supply shock in the 3-s model overlap to a great extent over the entire period. It is worth remarking that the 4-shocks model imposes productions of OPEC and non-OPEC to comove, that is both must change at the same time in the same direction, for a Market Share Target shock to occur, while the 3-s only requires a positive innovation in the *sum* of the two. Therefore, despite the 4-s definition of Market Share Target is more restrictive, we find that its contribution to price dynamics is comparable to that of the supply shock identified in the 3-s model.

Demand shocks continue to play a relevant role; in particular, they remain the most important factor explaining the pre-crisis spike. Nonetheless their contribution in our 4-s model is smaller both during the post-crisis fall as well as during the recovery phase of oil quotations in the aftermath of the global crisis, when also OPEC production strategy supported prices.

The importance of speculative demand shocks in explaining oil price evolution remains marginal (Kilian and Murphy (2014), Peersman, Baumeister, et al. (2009)).[23]

The Price Targeting strategy turns out to explain a relevant fraction of price variation in a few specific historical episodes. This can be seen in the bottom-right panel of Figure 5, which plots side by side the contribution of the unidentified shocks in the 3-s model (blue dashed line) and of the Price Targeting shock in our 4-s model (red solid line). It is clear that part of the unidentified shock the 3-s model is picked up in our richer set-up by the Price Targeting behaviour of OPEC countries. We take this as the validity of the 4-shocks model comes from the much smaller contribution to oil price dynamics of unidentified shocks. In particular, the Price Targeting strategy seems to have played a significant role in explaining oil price changes in the five years before the crisis, picking up part of the run-up in the price of oil that in the simpler 3-s model is attributed partly to demand, and partly left unexplained.

In a nutshell, this new model seems to provide a better understanding of key episodes with large

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volatility and their magnitudes are considerably smaller in the seventies and early eighties.

[23]We noticed that this result seems to be rather sensitive to the indicator of global activity adopted. In particular, using the freight bulk dry rates used in Kilian (2009), seems to inflate the role of precautionary demand for inventories shocks

Figure 5: The historical oil price decomposition
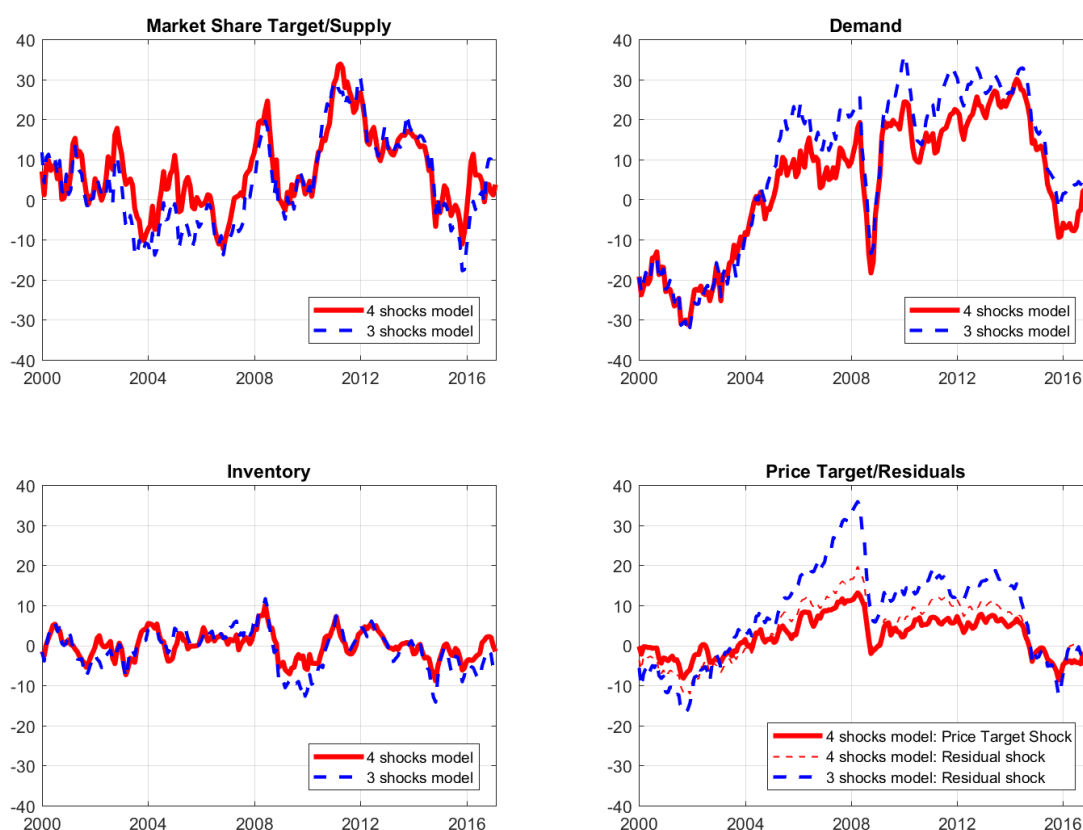
changes in oil prices as explained in the following subsections.

4.3.1 The Great Price collapse and Saudi's ability to play as a swing producer

Between 1981 and until 1985, OPEC, namely Saudi Arabia, tried to counteract the drop in the oil price by restricting its production. The period is generally regarded as one of limited demand growth, increasing non-OPEC production and declining prices. Hamilton names it the Great Price collapse and we follow here his labeling. Judging from declining prices, Saudis attempt has been considered ineffective by the previous literature, however our analysis helps reestablishing the role that supply played in this period. Figure 6 shows that supply shocks were offsetting, at least partially, the downward pushes due to weakening demand dynamics, hence revealing that Saudi Arabia strategy of curbing supply supported, indeed, oil quotations. Supply shocks between 1981 and early 1984 have constantly contributed positively to oil dynamics. Remarkably our analysis highlights with some precision the timing of Saudis decisions to give up the production restraint; in the chart the contribution

Figure 6: The Great Price Collapse. 1981-1985
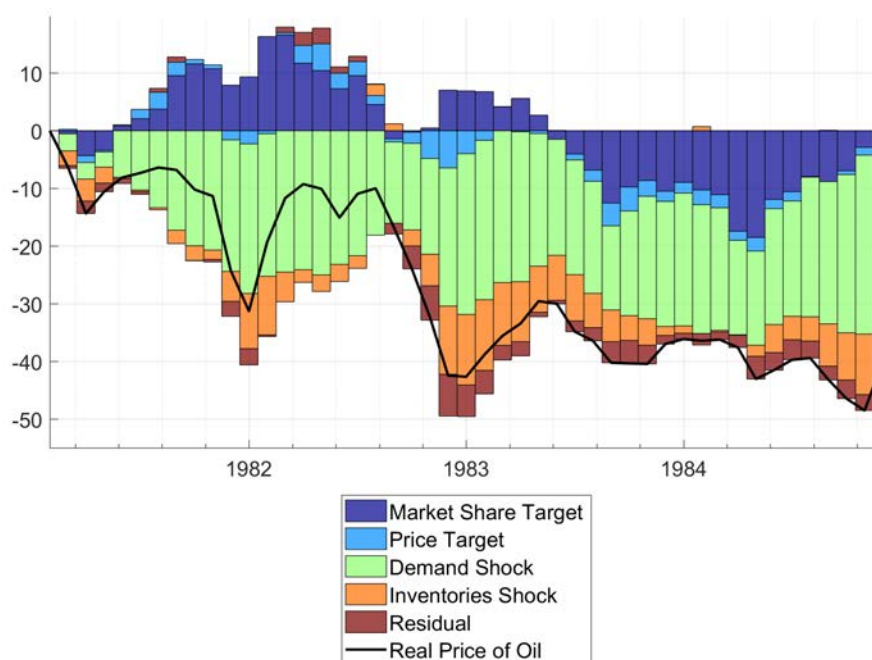
of supply shocks turns negative around the second quarter of 1984 shortly ahead of the Saudis public announcement.

4.3.2 The emerging momentum

The second episode we consider concerns the years around the global crisis from early 2003 to 2009, what the literature named the commodities super-cycle. There is a large consensus suggesting that a buoyant growth from emerging economies, China above all, amid supply struggling to keep up the pace, drove prices to a new record in mid-2008, just before the global crisis (see for instance Hamilton (2011), Kilian (2009)). While the steadily rising oil demand from emerging economies was a key factor, we uncover also an active role of OPEC, which strove to keep the market tight and price elevated. The policy of Price Targeting was constantly sought over the entire period. Our empirical findings show this strategy enacted even during and right after the great oil price collapse (see Figure 7), an analysis indirectly confirmed by the particularly reduced level of oil inventories in this span of time. While Hamilton (2011) named it a period of *Growing demand and Stagnant supply*, we rather refer to this period as *Growing demand and restrained supply* since the strong demand was not fully accommodated by OPEC additional production which purposely did not want to bite into its spare capacity any further. Strikingly but not unexpected by practitioners, Figure 7 also shows the positive contribution of supply shocks to price dynamics while prices were free falling at the end of 2008

Figure 7: The emerging momentum
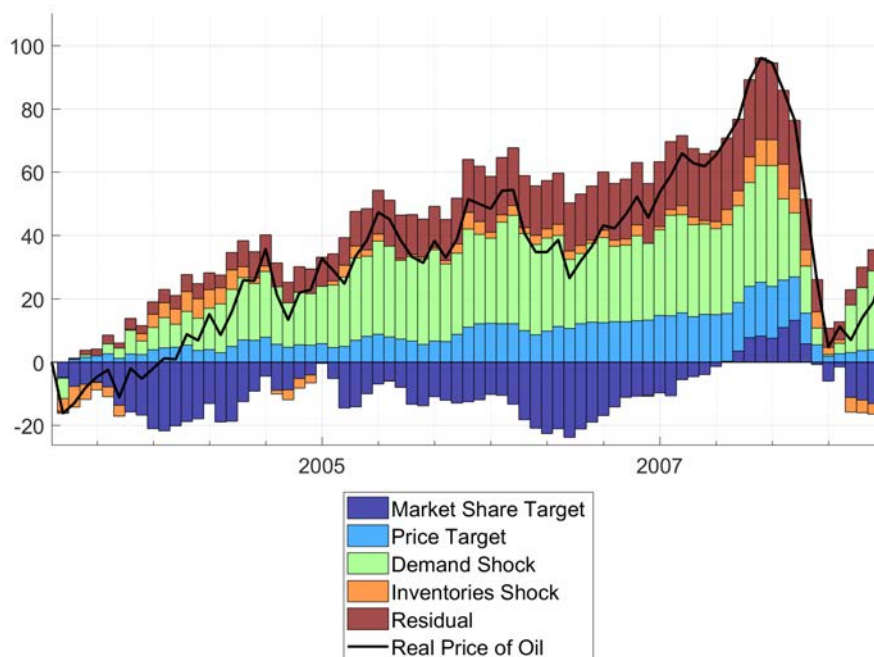
and early-2009. Indeed production statistics prove that OPEC withdrew within 6 months around 3 millions barrels a day over a semester and brought the market from a condition of excess supply into one of excess demand amid the global crisis.

4.3.3 The age of shale

More recently, during the shale age, demand factors were the major driver of oil prices until mid-2014. However the strategic interactions between OPEC and non-OPEC producers can explain a great deal of later developments. For instance, different strategies were pursued in the wake of the surge in shale oil production. In November 2014, OPEC announced that in order to regain market space, lost to shale producers, they were to abandon production targets. Our estimations suggest that starting from the second half of 2014, oil prices have been primarily driven by supply shocks (See Figure 8). Most of the drop experienced in the second half of 2014 was indeed due to supply factors, while demand factors started playing a role only later in 2015.

4.3.4 The coordinated supply restraint

However, as this strategy turned out to be more costly than expected in terms of fiscal revenues and shale oil producers were able to become more competitive in a low price environment, OPEC

Figure 8: Supply factors explain most of the price fall, demand dynamics were instead supporting prices in the second half of 2014
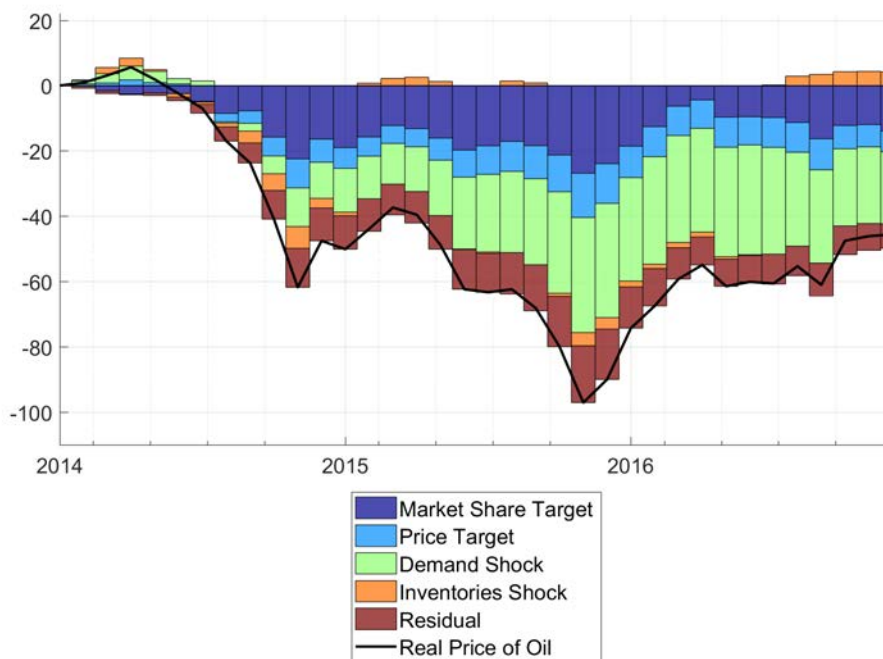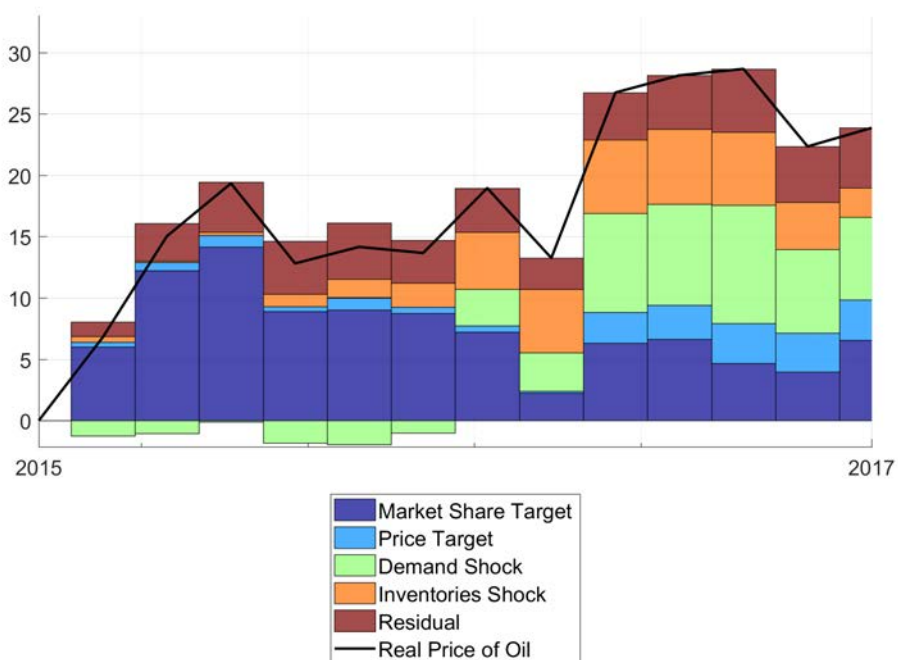

Figure 9: The announcement triggered the recovery of oil prices ahead of the coordinated supply restraint

switched backed to a price stabilization strategy in order to re-balance the oil market. The price recovery, which started in mid-2016 and continued over 2017, was also triggered by this policy switch (See Figure 9). Our model results are consistent with the OPEC announcement (in November 2016), on the reinstatement of production quotas and a concerted production restraint. Both the supply policies Market Share Target and Price Targeting contributed to support the oil price recovery. Indeed, given US shale production had resumed growth, in order to have a pure Price Targeting policies, OPEC must have cut more the price for a pure Price Targeting to materialize. The relevance of Price Targeting over Market Share Target has grown over time.

5   Conclusions

In this paper we have explored the implications of strategic interplays among large oil producers for the determination of the price of oil in global oil markets. The model sheds light on how OPEC might decide either to follow non-OPEC production (in an attempt to defend market shares) or to counteract it in order to stabilize prices.

We then revisit the evidence on the structural drivers of oil prices in the light of a structural model where we separately identify Market Share Targeting from Price Targeting shocks. We find that OPEC's Price Targeting behaviour explains around 10 percent of the FEVD of the price of oil. Furthermore, although global demand shocks remain the major driver of oil price increases in the last commodity super-cycle (from 2004 onward), Price Targeting shocks contribute non negligibly to the rise in oil prices in the run-up to the crisis. Looking at specific episodes, the model highlights the contribution of OPEC's policy (namely Saudi Arabia) in preventing quotations from free falling during *the great price collapse* between 1981 and 1985, generally characterized by less buoyant demand, increasing non-OPEC supply and declining prices. OPEC also pursued a price-targeting policy in the decade 2004-2014, to maintain a relatively tight market balance and quotations elevated, while after the crisis it acted to push up quotations ahead of the economic recovery. Two thirds of the price drop between the end of 2014 and early 2016 is attributed to OPEC's market-share targeting strategy and in the first six months the drop is fully explained by supply factors. The opposite move, tightening up global supply to trigger the de-stocking of oil inventories overhung, contributed to the recovery since the end of 2016.

As a complementary result, we obtain separate estimates for OPEC and non-OPEC supply elasticities. In line with Caldara, Cavallo, and Iacoviello (2019), we find that the price elasticity of the OPEC supply curve is larger than that of the non-OPEC supply curve, an indirect confirmation of the fact that large spare capacity gives OPEC a greater ability to adjust production also following

strategic considerations.

6 Appendices

6.1 Step by step model derivation

We hold two assumptions in the following derivation: linearity of the demand schedule (see equation 2) and increasing marginal cost of production for non-OPEC $\alpha = \delta Q_{NO} c$. From section 2 we can compute non-OPEC equilibrium production under the status quo $\frac{a+c}{b+\delta bc}$ and OPEC production $\frac{c}{b} * \frac{\delta(a-c)-b}{b+2c\delta}$. As non-OPEC competitors produce as long as their cost remains below the price and they are price-takers, the equilibrium is simply pinned down as follows:

$$p^{'} = \delta c Q^{'}_{NO}$$
$$\delta c Q^{'}_{NO} = a - b[Q_O + Q_{NO} + \Delta Q_O + \Delta Q_{NO}]$$
$$\delta c[Q_{NO} + \Delta Q_{NO}] = a - b[Q_O + Q_{NO} + \Delta Q_O + \Delta Q_{NO}] \tag{15}$$
$$p^0 + \delta c \Delta Q_{NO} = p^0 - b[\Delta Q_O + \Delta Q_{NO}]$$
$$\frac{\Delta Q_{NO}}{\Delta Q_O} = \frac{-b}{b + c\delta}$$

Equation 15 holds irrespective of OPEC's strategy. Because non-OPEC faces increasing production costs, it will only partially offset changes in production coming from OPEC. This feature enables OPEC to move the equilibrium price by steering their supply.

6.1.1 Price and Market Share targeting optimality condition

Below we report step by step the derivation of optimality conditions for PT strategy to be pursued.

$$\Pi_{PT} > \Pi_0$$
$$(p_{PT} - c)[Q_O - \Delta Q_O] > (p_0 - c)Q_O$$
$$(p_{PT} - p_0)[Q_O - \Delta Q_O] > (p_0 - c)\Delta Q_O]$$
$$\Delta p_{PT} > (\alpha - 1)c\frac{\Delta Q_O}{Q_O - \Delta Q_O}$$

$$b(\Delta Q_{NO} + \Delta Q_O) > (\alpha - 1)c\frac{\Delta Q_O}{Q_O - \Delta Q_O}$$

$$\Delta Q_O \frac{\delta bc}{b + \delta c} > (\alpha - 1)c\frac{\Delta Q_O}{[Q_O - \Delta Q_O}$$

$$Q_O - \Delta Q_O > (\alpha - 1)c\frac{b + \delta c}{b\delta c}$$

$$\frac{\Delta Q_O}{Q_O} < 1 - \frac{(\delta Q_{NO} - 1)}{Q_O}\frac{b + \delta c}{b\delta}$$

$$\frac{\Delta Q_O}{Q_O} < 1 - (\frac{\delta(a + c) - 2\delta c - b}{c(\delta(a - c) - b)})\frac{b + \delta c}{\delta}$$

$$\frac{\Delta Q_O}{Q_O} < 1 - \frac{b + \delta c}{\delta c}$$

$$\frac{\Delta Q_O}{Q_O} < \frac{-b}{\delta c}$$

Similarly, a deviation from the status quo, consisting in increasing production above the equilibrium level by ΔQ_O, is preferred by OPEC in order to regain market shares when $\Pi_{MST} > \Pi_0$.

$$\Delta p_{MST} > (\alpha - 1)c\frac{\Delta Q_O}{Q_O + \Delta Q_O}$$

$$1 + \frac{\Delta Q_O}{Q_O} > \frac{\delta(a + c) - 2\delta c - b}{c(\delta(a - c) - b)})\frac{b + \delta c}{\delta}$$

$$\frac{\Delta Q_O}{Q_O} < \frac{b + \delta c}{\delta c} - 1$$

$$\frac{\Delta Q_O}{Q_O} > \frac{b}{\delta c}$$

Therefore for $\frac{-b}{\delta c} < \frac{\Delta Q_O}{Q_O} < \frac{b}{\delta c}$ the status quo (acting as monopolist on the residual demand) stay preffered by OPEC.

6.1.2 When is Price Targeting preferred to Market Share targeting ?

We have identified a range of parameters under which each strategy is preferred to the status quo of playing monopolistic on the residual demand curve. But when is one of the two preferred in term of profits?

$$\Pi_{PT} > \Pi_{MST}(p_{PT} - c)[Q_O - \Delta Q_O] > (p_{MST} - c)[Q_O + \Delta Q_O]$$

$$(p_0 + \frac{\delta bc\Delta Q_O}{b + \delta c} - c)[Q_O - \Delta Q_O] > (p_0 - \frac{\delta bc\Delta Q_O}{b + \delta c} - c)[Q_O + \Delta Q_O]$$

$$\frac{2\delta bc\Delta Q_O Q_O}{b + \delta c} + 2c\Delta Q_O > 2p_0\Delta Q_O$$

$$Q_O > (p_0 - c)\frac{b + \delta c}{\delta bc}$$

$$\frac{Q_O}{Q_{NO}} > (\delta c - \frac{c}{\frac{b + \delta bc}{a + c}})\frac{b + \delta c}{\delta bc}$$

$$\frac{Q_O}{Q_{NO}} > (\delta - \frac{a + c}{b + \delta bc})\frac{b + \delta c}{\delta bc}$$

Therefore Price Targeting is preferred to Market Share Targeting as long as OPEC production remains above a precise threshold.

6.2 Appendix B Well behaved impulse response functions

The IRF analysis is consistent with the results obtained from the historical decomposition of oil prices.

In line with sign restrictions, supply shocks, occurring when market-share is targeted, reduce total production on impact, leading to persistent higher oil prices and to a fall in economic activity for over a year. Unsurprisingly, every time a supply shock occurs when a desired price is targeted, the OPEC tends to counteract it; so doing it generates an offsetting effect on the real prices of oil and the real economic activity which therefore remain overall rather unaffected.

The response of the real price of oil to a demand shock and to precautionary demand follows similar dynamics in the 3 and the 4 shocks model. As expected, it raises production on impact and oil prices in a persistent way; however in our model price reaction to speculative shocks is shorter lived and it falls back to zero after 7 instead of the 10 months of the 3-shocks model.

Finally, to make sure that the four shocks are correctly identified in our model, we rule out the possibility that the fifth unrestricted shock is anyhow correlated to the four identified shocks or that it affects sensibly the variables in the models. From the impulse response of the real price of oil, the global demand, the inventories and both OPEC and non-OPEC production, it is evident that the residual shocks have almost no impact on the variables considered in the model; the IRFs remain flat and insignificant at any time horizon.

Figure 10: The impulse response functions
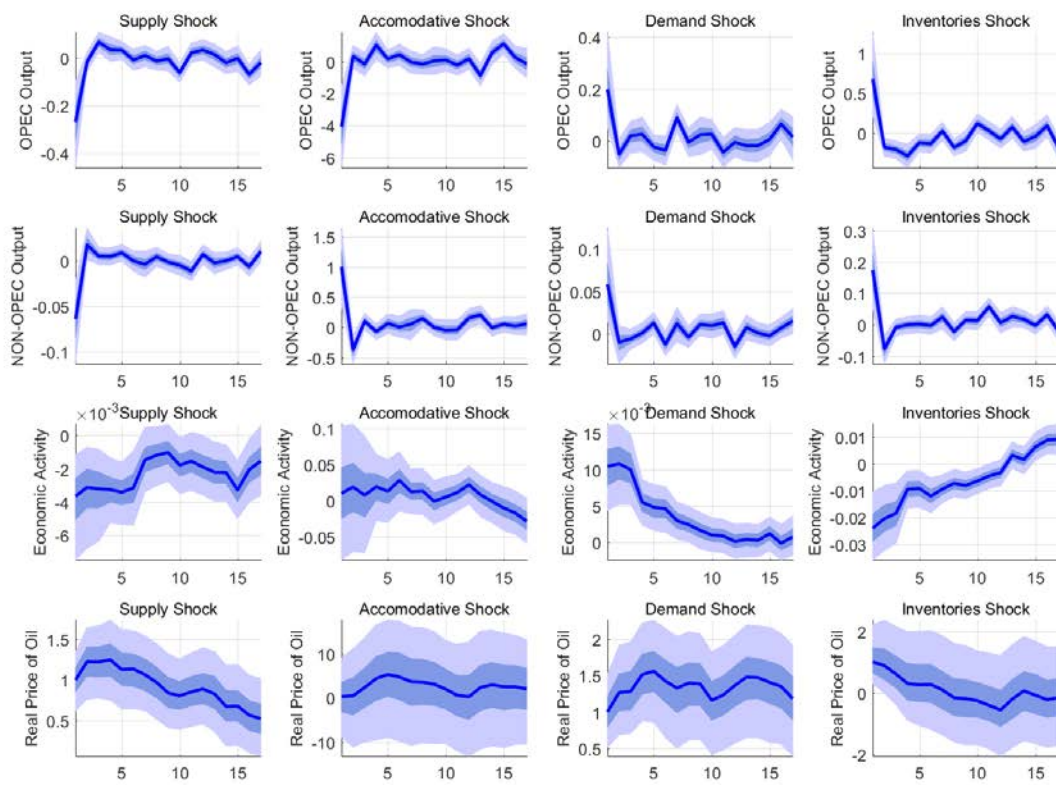
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