

OPEC vs US shale: Analyzing the shift  
to a market-share strategy

Alberto Behar  
Strategy, Policy, and Review Department  
International Monetary Fund  
abehar@imf.org

Robert A. Ritz\*  
Energy Policy Research Group  
Judge Business School  
University of Cambridge  
rar36@cam.ac.uk

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**Abstract**

In November 2014, OPEC announced a new strategy geared towards improving its market share. Oil-market analysts interpreted this as an attempt to squeeze higher-cost producers, notably US shale oil, out of the market. Over the next year, crude oil prices crashed, with large repercussions for the global economy. We present a simple equilibrium model that explains the fundamental market factors that can rationalize such a “regime switch” by OPEC: (i) the growth of US shale oil production; (ii) the slowdown of global oil demand; (iii) reduced cohesiveness of the OPEC cartel; and (iv) production ramp-ups in other non-OPEC countries; while (v) reductions in US shale costs act against these factors. We show that these qualitative predictions are broadly consistent with oil market developments during 2014-15. The model is calibrated to oil market data; it predicts accommodation up to 2014 and a market-share strategy thereafter, and explains large oil-price swings as well as realistically high levels of OPEC output.

*Keywords:* Crude oil, limit pricing, market share, OPEC, shale oil

*JEL Classifications:* L12, L71, Q41

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\*Corresponding author: Dr Robert Ritz, Assistant Director, Energy Policy Research Group (EPRG), Cambridge University. Mailing address: Judge Business School, Trumpington Street, Cambridge CB2 1AG, U.K. Telephone: +44 (0)1223 766638, Mobile: +44(0)7768 285267. E-Mail: rar36@cam.ac.uk

# 1 Introduction

In 2014, global oil supply overtook demand and the oil price started to decline from mid-2014. In its November 2014 meeting, OPEC<sup>1</sup> decided not to reduce supply and prices fell further. Many oil-market analysts interpreted this as the formal decision to squeeze higher-cost competitors, including US shale oil extracted using hydraulic fracturing (“fracking”), out of the market. The Saudi Arabian oil minister at the time (and de facto leader of OPEC) expressed intentions consistent with these interpretations: “In a situation like this, it is difficult, if not impossible, for the kingdom or for OPEC to take any action that would reduce its market share and increase the shares of others...”<sup>2</sup> This decision stood in contrast with OPEC’s coordinated cut during the Global Financial Crisis.

OPEC’s actions occurred against the backdrop of weakening global demand for crude and several years of steadily rising capacity from non-OPEC sources—most notably from unconventional sources in the US. Since mid-2014, the oil price fell from above \$100 to an average of \$50 during 2015. In its December 2015 meeting, OPEC reiterated its commitment to a “market-share” strategy. Many have opined on whether OPEC is taking a sensible perspective by driving competitors out of business or whether it is a misguided move tantamount to “hara-kiri”.<sup>3</sup>

Our goal in this paper is to understand the fundamental market factors that induced the shift in OPEC’s strategy. We present a simple economic model of the oil market: OPEC has a degree of market power and competes against a set of non-OPEC producers who act as a price-taking competitive fringe.<sup>4</sup> OPEC has a choice between two strategies. The first strategy, which we call “accommodate”, is to maximize profits via a “high” oil price which allows high-cost non-OPEC producers to remain profitable. The second strategy, “squeeze”, is to drive up production—and hence drive down price—and thereby induce high-cost producers to exit the market.

We show that either of these two strategies can be *optimal* for OPEC, depending on market fundamentals. In particular, the market-share strategy becomes relatively more attractive for OPEC in the face of: (i) slower global oil demand; (ii) greater US shale oil production; (iii) reduced cohesiveness within OPEC; (iv) higher output in other non-OPEC countries; and (v) higher costs of US shale. We show that a *regime switch* from accommodate to squeeze becomes

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<sup>1</sup>The members of The Organization of the Petroleum Exporting Countries (OPEC) for the purposes of analysis are (in descending order of crude oil capacity for 2015): Saudi Arabia, Iraq, Iran, United Arab Emirates, Kuwait, Venezuela, Nigeria, Angola, Algeria, Qatar, Ecuador, and Libya, although Libya’s capacity is highly constrained by its security situation. This amounts to cumulative production capacity of 35 mbd. OPEC’s actual crude (31½ mbd) and NGL (6½ mbd) output exceeded 40% of global demand in 2015. After the regime shift relevant for our analysis took place, Gabon and Indonesia rejoined OPEC, although Indonesia’s status is uncertain at the time of writing. These countries are excluded unless otherwise indicated.

<sup>2</sup>Saudi Arabia Oil Minister at the time Mr Al-Naimi cited by Jared Anderson, *Energy Quote of the Day: ‘We Would Lose on Both Market Share and Price’*, <http://breakingenergy.com>, 18 December, 2014

<sup>3</sup>Ise (1926) quoted in Yergin (2008).

<sup>4</sup>Although Saudi Arabia is the dominant player in OPEC, we refer to the broader group as a collective. Saudi Arabia has accounted for the bulk of OPEC adjustment when responding to moderate changes in the oil market, but large adjustments in OPEC output have included participation from multiple parties, including collective cuts during the Global Financial Crisis and some increases in output during the recovery and in response to supply outages during the Arab Spring. In addition, a lot of recent growth in OPEC capacity and output has come from Iraq, representing the choice of Iraq to produce more and of other members not to keep collective OPEC output constant.

optimal when high-cost production grows beyond a specific point. The model can rationalize OPEC’s decision to raise output in the face of weaker demand, and help explain a large drop in the oil price.<sup>5</sup>

In the empirical part of the paper, we begin with a description of oil-market developments which highlight how the model’s comparative-statics are pertinent. We give an account of OPEC’s strategy shift and the market responses of non-OPEC players. We then calibrate the model to oil<sup>6</sup> market data across a range of scenarios. First, we show how the model rationalizes the oil market in the period preceding the price collapse as a high-price accommodate scenario where OPEC *chooses* not to squeeze US shale oil—despite already substantial market-share erosion and sufficient spare capacity for a squeeze. Second, we show how some parameter changes can prompt a rational decision by OPEC to squeeze US shale out of the market. Third, we show that the model generates squeeze equilibria when calibrated to forecasts of future data that yield higher OPEC output and lower prices.

Our model exposes the fallacy of interpreting a decline in OPEC’s revenues or profit as evidence that a market-strategy is necessarily misguided. The simple point is that the relevant comparison is not how profits compare to an earlier period, but rather how they would compare to pursuing a different strategy today—for which profits could be even lower. By showing how a market-share strategy can be optimal for OPEC in a formal framework, we offer the model as a potential rational economic explanation for its 2014 strategy switch.<sup>7</sup> However, we do not wish to claim that it is the most likely of a range of possible economic or political motivators.<sup>8</sup>

Our theory makes a number of simplifying assumptions. The model is static and partial-equilibrium; it does not explicitly incorporate dynamics such as a producer’s intertemporal decision to sell today or leave the oil in the ground.<sup>9</sup> Relatedly, the model does not feature inventory behaviour—although we do account for this in the empirical part of the paper. We also do not address the potential roles of uncertainty, expectations and asymmetric information. Finally, the production of non-OPEC players is modelled as a binary decision: they produce up to capacity if price exceeds their cost and otherwise shut down.

OPEC’s market-share strategy is broadly aimed at its high-cost competitors.<sup>10</sup> OPEC has

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<sup>5</sup>Weaker demand reduces OPEC profits, all else equal, under *both* the accommodate and squeeze strategies; it is not clear *a priori* how it affects the *relative* attractiveness of two strategies. Our model demonstrates that lower demand makes the squeeze more preferable.

<sup>6</sup>Unless crude is specifically mentioned, oil refers to liquids, namely crude oil and natural gas liquids (NGLs) as these are very close substitutes. The IEA does not distinguish between the two when reporting demand or non-OPEC supply. For OPEC, these are separated out by the IEA in part because NGLs are not formally part of OPEC’s quota. Gas, whether natural gas or associated gas generated from the production of liquids, is excluded.

<sup>7</sup>Mabro (1998) suggests a market-share strategy is not sensible: since conventional oil producers traditionally have operating costs that are well below prevailing prices, it would take too large price decline to induce their exit. Our analysis revisits this issue with a more formal economic framework geared towards the distinction between conventional and unconventional oil production. Earlier, having incurred substantial losses in the early 1980s following accommodative production cuts (Westelius, 2013), the subsequent rise in output was arguably a shift to a market-share strategy.

<sup>8</sup>As argued by Fattouh, Poudine and Sen (2016) for Saudi Arabia, many OPEC countries remain undiversified and hence reliant on oil for meeting domestic spending pressures, which makes revenue the prime consideration.

<sup>9</sup>The Hotelling rule is well known to have little empirical explanatory power. Cairns and Calfucura (2012) argue it is only relevant for producers with a limited resource horizon, which is not the case for the large oil producers.

<sup>10</sup> “[The policy to defend market share] is also a defense of high efficiency producing countries, not only of market

recently disputed a common perception in the industry by stating that it is not targeting specific countries or production technologies.<sup>11</sup> Nonetheless, the market-share strategy illustrated in this paper emphasizes US shale; this is the main focus of oil-market analysts partly because its short life-cycle relative to conventional oil extraction makes the US supply response to prices quicker (Bjornland, Nordvik and Rohrer, 2016). Our static model’s marginal costs include upfront expenses for US shale but excludes the large (sunk) investment costs of other producers.

**Related literature.** Although there has been a lot of policy-related discussion since November 2014, we believe ours is at the forefront of papers beginning to offer a formal economic model of OPEC’s strategy shift and its repercussions. Fattouh, Poudineh and Sen (2016) analyze the trade-offs between a strategy of market share and one of curtailing output to generate near-term revenue. Introducing uncertainty about the nature of US shale tends to favor accommodation but, as further information reduces this uncertainty, a switch in strategy becomes more likely.<sup>12</sup>

There remains considerable debate on the extent to which OPEC members cooperate when setting output or prices (Smith, 2005; Bremond, Hache, and Mignon, 2012; Nakov and Nuño, 2013; Huppmann, 2013). Almoguera, Douglas and Herrera (2011) suggest that OPEC’s behaviour is a mix of near-collusive episodes and subsequent non-cooperative breakdowns. Pierru, Smith and Zamrik (2016) analyze how OPEC (or a subset of members) stabilizes prices through optimization of spare capacity. Huppmann and Holz (2012) find that OPEC’s degree of market power has declined, and Fattouh and Mahadeva (2013) attribute fluctuations in this power to market conditions.

Our approach is flexible in that we calibrate OPEC’s market power to fit the data across each of our scenarios. We obtain parameters that describe the level of competition in the market and are broadly in line with those from the empirical literature. Pricing regimes fall short of a perfect cartel but still allow low-cost producers (OPEC and non-OPEC) to earn rents. Our accommodate strategy also has OPEC offset other producers’ production changes, and our squeeze strategy has some similarity with Stackelberg behaviour (Huppmann, 2013). OPEC’s decision between these strategies is influenced by its time-varying ability to coordinate and its market-dependent choice means that its market power is endogenous. Complementing the longer-term views in the existing literature, we focus on market developments since 2014.

The strategy pursued by OPEC against high-cost producers in our model is a form of “limit pricing”. An advantage of our approach over classic industrial-organization theory is that it does not rely on the dynamic of a later period with again-higher prices in which OPEC can recoup “lost” profits.<sup>13</sup> Our model shows that OPEC’s profits under a low-price squeeze can be

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share. We want to tell the world that high efficiency producing countries are the ones that deserve market share. That is the operative principle in all capitalist countries.” Saudi Arabia Oil Minister at the time Mr Al-Naimi cited in *Middle East Economic Survey Interview*, 21 December 2014.

<sup>11</sup> “We have not declared war on shale or on production from any given country or company.” Saudi Arabia Oil Minister at the time Mr Al-Naimi cited in *CBS News Moneywatch*, “Saudi Arabia: We have not declared war on shale,” 23 February 2016.

<sup>12</sup> They also note that OPEC allowing for more price volatility introduces uncertainty for prospective entrants and can discourage entry as a result.

<sup>13</sup> Classic limit-pricing theory relies on the “incumbent” player raising price again following the exit of the weaker “entrant” (Tirole, 1988: Chapter 9). Under perfect information, this leads to a credibility problem: the

*permanently* higher than under accommodate. In related work, Andrade de Sá and Daubanes (2016) suggest that OPEC prices out of the market any “backstop technology” which has large potential to erode oil demand. Their main focus is on how this behaviour differs from a Hotelling rule and the implications for carbon-tax design.

Finally, there are a number of analyses of what caused the 2014-2015 oil price crash, representing different views on the relative contributions of demand, supply and speculative factors (Baffes et al., 2015; Baumeister and Kilian, 2016; Beidas-Strom and Osorio-Buitron, 2015; Hamilton, 2015; and Hussain et al., 2015). Although the precise contributions can be hard to pin down, many support the view that the drivers laid out in our model played a role. Smith (2009) demonstrates how the combination of low demand and supply elasticities can account for historical levels of oil price volatility—without any role for any volatility-enhancing financial speculation. Our model highlights how demand and supply shocks can be interlinked: an oil price decline caused by weaker demand is magnified where it also induces an endogenous shift in OPEC supply behaviour. By showing how high-cost supply can reach a “tipping point” that invokes an OPEC supply increase, it demonstrates how seemingly small rises in non-OPEC supply in the period of study can lead to large price drops. In a similar vein, Verleger (2016) emphasizes the vital role that market structure plays for oil prices.

**Outline of the paper.** Section 2 sets up the model and analyses its “accommodate” and “squeeze” equilibria. Section 3 presents the comparative statics that favour a regime switch, and a testable condition on when it occurs. Section 4 argues that the comparative-statics predictions are consistent with market experience. Section 5 presents a quantitative calibration of the model to oil-market data across a range of scenarios. Section 6 concludes.

## 2 A simple equilibrium model of the oil market

### 2.1 Setup of the model

The global demand curve for oil takes the linear form  $D(P) = (\alpha - P)/\beta$ , with parameters  $\alpha, \beta > 0$ . This is a common assumption in the literature, and will facilitate empirical calibration of the model later on. On the supply side, there are  $N + 1$  oil producers, namely OPEC, denoted as  $i$ , plus  $N$  other non-OPEC players. OPEC has production capacity  $K_i$  with a marginal cost of production of  $C_i$ . Of the other producers, player  $n \in N$  has capacity  $K_n$  and unit cost  $C_n$ ; it is a price-taker which sells up to capacity if  $P > C_n$  and zero otherwise. Let  $C_j \equiv \max_{n \in N} \{C_n\} > C_i$  denote the player  $j$  with the highest unit cost, and capacity  $K_j$ . In the present analysis, we take this to be US shale oil because it is the highest-cost producer in our chosen period of analysis, but this could generalize to any highest-cost producer. Let  $K_\ell \equiv \sum_{n \in N \setminus \{j\}} K_n$  denote the combined production capacity of all other non-OPEC players. Note that the setup implies that all non-OPEC players produce up to capacity whenever US shale oil does so (but not necessarily

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entrant realizes that price will go back up (making re-entry profitable), so cannot be induced to exit in the first place. Thus limit pricing does not work without the addition of another market imperfection such as asymmetric information (which allows the incumbent to build a “tough” reputation by pricing low).

*vice versa*).

OPEC has market power and can choose between two strategies:

1. “Accommodate”: Maximizing its profits taking as given that player  $j$  produces up to its capacity level  $K_j$ ;
2. “Squeeze”: Lowering the market price to  $C_j$ , thus squeezing player  $j$  out of the market.

The first of these corresponds to what is often called a “price” strategy whilst the second is about “market share”. Our main question is, which of these two strategies is more profitable for OPEC?

In practice, OPEC is not an efficient cartel: its internal ability to restrict output has fallen short of what monopoly pricing would require. To capture this, we use a parameter  $\lambda \in (0, 1]$  as a reduced form of OPEC’s pricing power under the accommodation strategy. The case with  $\lambda = 1$  corresponds to a fully-efficient cartel (facing a competitive fringe); lower values of  $\lambda$  represent weaker pricing power.<sup>14</sup> As will become clear, our theory does not hinge on the precise value of  $\lambda$ , but this parameter plays an important role in the calibration exercise later on.

## 2.2 Analysis of the strategies

We begin by deriving OPEC’s profits under each of the two strategies. Two assumptions on parameter values are made:

$$\mathbf{A1.} \quad (C_j - C_i) < \lambda[(\alpha - C_j) - \beta(K_j + K_\ell)]$$

$$\mathbf{A2.} \quad (\alpha - C_j) \leq \beta(K_i + K_\ell)$$

The first assumption ensures that player  $j$  (US shale oil in this paper) is viable under the “accommodation” strategy. It implies that all other non-OPEC producers are also viable, and that OPEC is too (since they all have lower costs); in particular, note that  $\lambda$  cannot be too small. The second assumption ensures that OPEC has sufficient spare capacity to be able to carry out the “squeeze”. A1 and A2 together imply  $(C_j - C_i) < \lambda[(\alpha - C_j) - \beta(K_j + K_\ell)] \leq \lambda\beta(K_i - K_j)$ , so that OPEC has significantly higher production capacity than US shale, specifically  $K_i > K_j + (C_j - C_i)/\lambda\beta$  (where  $C_j > C_i$ ). We verify that these parameter assumptions are satisfied in the empirical calibration of the model.

### 2.2.1 Strategy 1: Accommodate

Since OPEC is the only strategic player it can equivalently choose price *or* its output level to maximize its profits—given that by A2 it always has sufficient capacity  $K_i$ . (Since our model features a dominant player with a competitive fringe, rather than oligopolistic interaction, it is not sensitive to whether the choice variable is price (Bertrand) or quantity (Cournot). For expositional reasons, we let OPEC choose prices—though we stress that our results would be

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<sup>14</sup>Lower pricing may also be the result of dynamic considerations which we do not model explicitly here, or because some domestic OPEC stakeholders wish to maximize revenue rather than profits.

unchanged by instead having OPEC choose its production level.) OPEC faces residual demand  $\{D(P) - K_j - K_\ell\}$  and thus chooses price to:

$$\begin{aligned} \max_P \Pi_i(P) &\equiv \{D(P) - K_j - K_\ell\} (P - C_i) \\ &= \frac{1}{\beta} \{(\alpha - P) - \beta(K_j + K_\ell)\} (P - C_i). \end{aligned}$$

The parameter  $\lambda \in (0, 1]$  captures how effective OPEC is at raising the price. We thus write the first-order condition as  $0 = \{\lambda [(\alpha - P) - \beta(K_j + K_\ell)] - (P - C_i)\}$ . The parameter  $\lambda$  captures the weight received by the inframarginal units of production,  $[(\alpha - P) - \beta(K_j + K_\ell)]$ , relative to the marginal unit on which OPEC earns a margin of  $(P - C_i)$ . So the “optimal” price for OPEC equals

$$P^* = \frac{C_i + \lambda[\alpha - \beta(K_j + K_\ell)]}{(1 + \lambda)}. \quad (1)$$

This price declines with lower values of  $\lambda$ , and falls towards  $i$ 's marginal cost  $C_i$  as  $\lambda \rightarrow 0$ .<sup>15</sup> However, our assumption A1 is equivalent to  $\lambda$  being sufficiently high such that  $P^* > C_j$ , so that US shale is viable. (Note also that  $[\alpha - \beta(K_j + K_\ell)] > 0$  by A1.) The price  $P^*$  also falls continuously with higher non-OPEC production,  $K_j + K_\ell$ . The corresponding production level for OPEC is given by:

$$\begin{aligned} S_i^* &\equiv \{D(P^*) - K_j - K_\ell\} \\ &= \frac{1}{\beta} \{[\alpha - \beta(K_j + K_\ell)] - P^*\} = \frac{[\alpha - \beta(K_j + K_\ell) - C_i]}{(1 + \lambda)\beta}. \end{aligned} \quad (2)$$

So OPEC optimally absorbs higher production capacity of non-OPEC players,  $K_j + K_\ell$ , at a rate of  $[100/(1 + \lambda)]\%$ , that is,  $dS_i^*/d(K_j + K_\ell) = -1/(1 + \lambda)$ . Since  $\lambda \in (0, 1]$ , this rate is at least 50% and rises towards 100% as  $\lambda$  falls, that is, as OPEC becomes less effective at raising the price. In this sense, OPEC here acts as a “swing producer”: for  $\lambda = 1$ , it behaves like a textbook Stackelberg leader and accommodates 50 percent of any change in non-OPEC production; for  $\lambda \rightarrow 0$ , it almost fully accommodates changes in non-OPEC production.

It follows that OPEC's profits under this strategy are:

$$\Pi_i^* = S_i^*(P^* - C_i) = \frac{\lambda}{\beta} \left( \frac{(\alpha - C_i) - \beta(K_j + K_\ell)}{(1 + \lambda)} \right)^2. \quad (3)$$

The profits of non-OPEC player  $n \in N$ , which produces  $K_n$  by construction, are simply equal to  $K_n(P^* - C_n)$ , and are positive by A1.

## 2.2.2 Strategy 2: Squeeze

Here the price  $P^{**} = C_j$  by definition, and OPEC can again equivalently choose this price *or* the corresponding output level. This implies that US shale oil (player  $j$ ) sells zero while all other non-OPEC players still produce up to a combined capacity of  $K_\ell$  (given their individual costs

<sup>15</sup>It is easy to check that the second-order condition is satisfied for any  $\lambda > 0$ .

are each below  $C_j$ ). The corresponding total market output satisfies  $D(P^{**}) = (\alpha - C_j)/\beta$ , from which it follows that OPEC's sales are market output net of remaining non-OPEC production

$$S_i^{**} \equiv \{D(P^{**}) - K_\ell\} = \frac{(\alpha - C_j)}{\beta} - K_\ell. \quad (4)$$

By A2, OPEC has sufficient capacity for this level of sales, i.e.,  $S_i^{**} \equiv \{D(P^{**}) - K_\ell\} \leq K_i$ . Thus OPEC's profits under this strategy are:

$$\Pi_i^{**} = S_i^{**}(P^{**} - C_i) = \frac{1}{\beta} [(\alpha - C_j) - \beta K_\ell] (C_j - C_i). \quad (5)$$

Thus OPEC's profits under the squeeze do not depend on the  $\lambda$  parameter which captures its pricing power under the previous accommodate strategy. The profits of non-OPEC player  $n \in N \setminus \{j\}$  are  $K_n(P^{**} - C_n)$ , and are positive since  $C_j \equiv \max_{n \in N} \{C_n\} = P^{**} > C_n$  for all  $n \in N \setminus \{j\}$ .

### 3 Model results

We now turn to our main results on the different market factors which can lead to a “regime switch” under which OPEC finds it optimal to squeeze player  $j$ .

The preceding analysis already pins down the difference in profits between the two strategies,  $\Delta\Pi_i \equiv (\Pi_i^{**} - \Pi_i^*)$ . Here we begin with some comparative statics on which market factors lead to a rise in  $\Delta\Pi_i$ , and then obtain a quantitative result on when  $\Delta\Pi_i > 0$ , i.e., the squeeze is preferred from OPEC's viewpoint.

**Proposition 1** *The “squeeze” strategy becomes relatively more attractive compared to the “accommodate” strategy, in that it offers relatively higher profits (that is, higher  $\Delta\Pi_i$ ), for OPEC under the following conditions:*

- (i) *the production capacity of high-cost player  $j$  ( $K_j$ ) is larger;*
- (ii) *the internal cohesiveness of OPEC ( $\lambda$ ) is lower;*
- (iii) *the global demand for crude oil ( $\alpha$ ) is lower;*
- (iv) *the marginal cost of player  $j$  ( $C_j$ ) is higher;*
- (v) *the production capacity of other non-OPEC players ( $K_\ell$ ) is larger.*

The comparative statics from Proposition 1 are intuitive. First, larger production by player  $j$  (e.g., US shale) depresses price under the accommodation strategy but its production is zero by construction under the squeeze strategy, regardless of capacity. This makes squeezing more shale out of the market look relatively more attractive to OPEC.

Similarly, if OPEC is less internally cohesive, then it cannot raise price as strongly and extract as much profit under accommodation. Under the squeeze, the degree of price coordination is not a factor so this again favours the squeeze strategy.

Third, weaker global demand for crude depresses profits under *both* the accommodate and the squeeze strategies, so the comparison is less straightforward. However note that, under



accommodation, lower demand reduces both OPEC’s sales and its profit margin. By contrast, under the squeeze, lower demand only reduces sales—since the price is pinned down by the marginal cost of the squeezed-out player. Thus the model shows how lower demand relatively favours the squeeze strategy.<sup>16</sup>

Fourth, higher costs of player  $j$  have no impact on the accommodate equilibrium from OPEC’s viewpoint: since player  $j$  remains viable by A1, and produces up to capacity, higher costs simply mean less profits for player  $j$  but no change in the market equilibrium. However, the squeeze strategy becomes more attractive as less of a price decline is needed to squeeze US shale out of the market.

Finally, higher production by other non-OPEC players also makes the squeeze relatively more attractive. Similar to the demand effect, this reduces both price and OPEC sales under accommodate but solely its sales under the squeeze strategy.

Proposition 1 delivers a clean set of qualitative “all-else-equal” results which can be taken to the data. In practice, many of these market factors—global demand patterns, oil production capacities and costs, OPEC’s internal dynamics—change simultaneously. Our empirical analysis in Sections 4 and 5 therefore considers the evolution of all of these market factors together.

The comparison of profits between the two strategies leads to the following quantitative prediction:

**Proposition 2** *OPEC prefers the squeeze strategy (that is,  $\Delta\Pi_i > 0$ ) whenever the production capacity of high-cost player  $j$  is sufficiently large,*

$$K_j > \left[ \frac{1}{\beta} \left( (\alpha - C_i) - (1 + \lambda) \sqrt{\frac{1}{\lambda} [(\alpha - C_j) - \beta K_\ell] (C_j - C_i)} \right) - K_\ell \right] \equiv \bar{K}_j$$

*and otherwise accommodates if  $K_j \leq \bar{K}_j$ . At this “regime switch”, the oil price falls discontinuously from  $P^*(\bar{K}_j) = C_i + \sqrt{(1/\lambda) [(\alpha - C_j) - \beta K_\ell] (C_j - C_i)}$  to  $P^{**} = C_j$ .*

Put simply, it is a profitable strategy for OPEC to squeeze out a rival selling  $K_j$  units at cost  $C_j$  whenever “the prize” is sufficiently large in that  $K_j > \bar{K}_j$ . Under this condition, the subsequent gain in market share outweighs the fall in price.

Proposition 2 thus delivers a critical value  $\bar{K}_j$  which determines which of the two strategies is optimal for OPEC. This critical value depends on demand and cost conditions as well as other non-OPEC players’ production capacities. It lends itself to quantitative empirical testing, which we pursue in Section 5.

We stress that the optimality of the market-share strategy does *not* rely on a subsequent “harvesting” period with again-higher prices after the high-cost players have been squeezed out of the market.

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<sup>16</sup>The industrial-organization literature on collusion comes to conflicting views on how the cycle affects the stability of price coordination (Tirole, 1988: Chapter 6). On the one hand, there is a greater short-term temptation to cheat when demand is high; *equilibrium* prices are thus lower in booms in order to limit this incentive to cheat. On the other hand, with imperfect observability of actions, firms cannot perfectly distinguish between rivals cheating and low demand; thus price wars are more likely during busts. Similarly, the incentive to deviate is typically stronger when future demand is falling. Our model results are consistent with the latter perspective.

We thus obtain a further result on OPEC supply following a regime switch:

**Proposition 3** (i) Suppose that an increase in capacity of player  $j$ , from  $K_j' \leq \bar{K}_j$  to  $K_j' > \bar{K}_j$ , induces a regime switch from accommodate to squeeze. This leads to an increase in OPEC's production,  $S_i^{**} > S_i^*$ .

(ii) Suppose that a decline in global oil demand, from  $\alpha'$  to  $\alpha''$ , induces a regime switch from accommodate to squeeze, that is,  $K_j \leq \bar{K}_j(\alpha')$  but  $K_j > \bar{K}_j(\alpha'')$ . This leads to an increase in OPEC's production,  $S_i^{**} > S_i^*$ , as long as the demand decline  $\Delta\alpha \equiv (\alpha' - \alpha'')$  is not too large.

Proposition 3 shows how OPEC's *optimal* supply responses can take an unexpected form. Standard intuition from economic theory, as well as the usual logic of a “swing producer”, suggest that higher rival output and lower demand should prompt a “soft” response in the form of lower OPEC supply. While this is true within an accommodate strategy, the situation is different if these market factors induce a regime switch. Then higher US shale production can induce a “fighting response” from OPEC, and lower demand can make it optimal to produce *more*.

We next illustrate the workings of the model using two simple examples which, respectively, highlight the sensitivities of OPEC behaviour with respect to (1) US shale production and (2) global demand conditions—corresponding to parts (i) and (ii) of Proposition 3.

**Example 1.** Let  $\alpha = 250$ ,  $\beta = 1$ ,  $C_i = 0$ ,  $C_j = 50$  and  $\lambda = 1$ ; all players except  $i, j$  are inactive,  $K_\ell \equiv 0$ . A1 and A2 boil down to  $K_j < 150$  and  $K_i \geq 200$ . OPEC's profits under accommodation  $\Pi_i^* = (125 - \frac{1}{2}K_j)^2$  using (3) while  $\Pi_i^{**} = S_i^{**}P^{**} = 200 \times 50 = 10,000$  under the squeeze using (5). As claimed by Proposition 2,  $\Pi_i^{**} \geq \Pi_i^* \Leftrightarrow K_j \geq \bar{K}_j = 50$ . Imagine that US shale's  $K_j$  gradually grows from zero: OPEC produces  $S_i^* = (125 - \frac{1}{2}K_j)$  under accommodation, offsetting  $K_j$  at a rate of 50%. At  $\bar{K}_j$  the regime then switches to squeeze and OPEC's production jumps to  $S_i^{**} = 200$  by Proposition 3(i), for which it has spare capacity by A2. (The price falls smoothly from  $P^*(0) = 125$  to  $P^*(\bar{K}_j) = 100$ , and then crashes to  $P^{**} = 50$ .) Figure 1 illustrates how OPEC profits are lower when US shale capacity is higher; it also reveals how OPEC profits are higher under the squeeze than they would have been had it continued to accommodate. Figure 2 shows how, as a result, OPEC supply rises once US shale capacity becomes sufficiently large.

INSERT FIGURES 1 & 2 AROUND HERE

**Example 2.** Let  $\beta = 1$ ,  $C_i = 0$ ,  $C_j = 50$ ,  $\lambda = 1$ ,  $K_\ell \equiv 0$  but now let  $K_j = 50$ . A1 is  $\alpha > 150$  (global demand is always high enough for US shale to be viable) while A2 becomes  $K_i \geq (\alpha - 50)$ . OPEC's profits under accommodation  $\Pi_i^* = \frac{1}{4}(\alpha - 50)^2$  using (3) and  $\Pi_i^{**} = (\alpha - 50) \times 50$  under the squeeze using (5). Direct comparison shows that  $\Pi_i^{**} \geq \Pi_i^* \Leftrightarrow \alpha \leq 250 \equiv \underline{\alpha}$ . Imagine that global demand gradually declines, beginning from, say,  $\alpha = 350$  (requiring  $K_i \geq 300$  for A2). OPEC produces  $S_i^* = \frac{1}{2}(\alpha - 50) \leq 150$  under accommodation, offsetting declining  $\alpha$  at a rate of 50%. Once demand has weakened to  $\underline{\alpha}$ , there is a regime switch, at which point OPEC's production jumps from  $S_i^*(\underline{\alpha}) = 100$  to  $S_i^{**}(\underline{\alpha}) = 200$  using (4). Production then declines towards

$S_i^{**} = 100$  as  $\alpha \rightarrow 150$ . (The price  $P^*(\alpha)$  falls smoothly from  $P^*(350) = 150$  to  $P^*(\underline{\alpha}) = 100$ , crashing to  $P^{**} = 50$  with the regime switch.) Figure 3 illustrates how OPEC profits are “more sensitive” to demand under accommodation—which is more profitable for “high” demand, while the squeeze is preferred for “low” demand. Again, profits are lower under the squeeze—but they would have been even lower had OPEC accommodated US shale in a low-demand market. Figure 4 illustrates how OPEC production can optimally rise in response to weaker demand.

INSERT FIGURES 3 & 4 AROUND HERE

## 4 Qualitative empirical discussion

This section begins with a discussion of how oil market developments in the run up to late 2014 would have driven a regime switch in light of our comparative-statics results from Proposition 1. We then give an account of OPEC’s decision in its November 2014 meeting to adopt a “market-share strategy” and its actions since. Finally, we explain the subsequent responses of other oil-market players.

### 4.1 Drivers of regime switch

This part describes the four developments from Proposition 1 that favoured OPEC’s decision to squeeze US shale, namely: (i) weakening demand; strengthening supply from (ii) US shale and (iii) non-OPEC non-shale sources, as well as (iv) coordination difficulties among OPEC members. One factor acting against these is (v) falling US shale oil costs. Finally, although it is not a direct driver of the regime choice, we discuss OPEC capacity as it is indirectly relevant via A2.

**Weakening global demand (lower than expected  $\alpha$ ).** Having grown weakly in recent years, demand growth slowed further from 1.2 million barrels per day (mbd) in 2013 to only 0.9 mbd in 2014, a growth rate of less than 1 percent (Figures 5 and 6). As a result, Q3 2014 actual demand levels were 0.5 mbd lower than forecast in the International Energy Agency’s (IEA) June Monthly Oil Market Report (MOMR) and Q4 demand levels were almost 0.4 mbd lower than forecast in the September report. In other words,  $\alpha$  was lower than anticipated. According to Proposition 1, weakening demand makes a decision to squeeze more likely.

Demand for oil is structurally restrained by disappointing economic growth after the Global Financial Crisis. Global GDP grew on average by  $3\frac{1}{3}$  percent in 2013-4, which is slower than in previous years and left GDP levels below forecasts (IMF, 2012; 2014). In addition, the composition of GDP is shifting to less energy-intensive sectors. Further constraints to oil demand include efficiency improvements, fuel switching to natural gas and biofuels, and environmental restrictions (IEA, 2014; Verleger, 2016).

INSERT FIGURES 5 & 6 AROUND HERE

**Higher US shale output (higher  $K_j$ ).** Reversing a decline since the early 1980s, US crude oil output rose from about 5 mbd in 2008 to  $6\frac{1}{2}$  mbd in 2012. Accelerating output reached about  $8\frac{1}{2}$  mbd in 2014 and an estimated  $9\frac{1}{2}$  mbd in 2015 (Energy Information Administration, 2013, 2016a). (Using the slightly broader definition of oil reported by the IEA (2016a), US output reached an estimated 13 mbd in 2015.) The increase is attributable to growth in oil extracted from unconventional sources. Production of light tight oil (LTO), which is one measure of shale production, almost doubled from  $2\frac{1}{4}$  mbd in 2012 to  $4\frac{1}{4}$  mbd in 2014.<sup>17</sup> Over the two years, this was the primary source of incremental global supply and almost matched growth in global demand.

Realized values repeatedly exceeded forecasts by agencies, indicating a surprise element. For example, US output in 2014 was  $\frac{3}{4}$  mbd higher than anticipated by the Energy Information Administration (EIA) early in its January 2013 Short-term Energy Outlook, and output for the third quarter of 2014 alone exceeded IEA forecasts for that quarter made in June 2014 by the same amount. Moreover, forecasts for future output also rose due to base effects and revised expectations about the pace of technical progress. For example, EIA estimates for 2019 LTO output were revised upwards by about  $\frac{3}{4}$  mbd between the 2014 and 2015 editions of their Annual Energy Outlook (2014, 2015A) despite a decline in prices that had already begun. In terms of our framework, actual and anticipated US shale production volumes were becoming too large for OPEC to accommodate.

**Higher non-OPEC non-shale output (higher  $K_\ell$ ).** After accounting for the rise in US shale, non-OPEC output from other sources also rose. The contribution to global supply growth was small in 2013, but output rose by 1.4 mbd in 2014. Much of the increase came from Brazil and Canada. Russia's oil output was until recently higher than for the United States, holding steady at 10.9 mbd in 2014. There was also a surprise element; output for Q4 of 2014 was some 0.3 mbd higher than anticipated by the IEA in September of that year. The rise in non-OPEC output made a decision by OPEC to squeeze US shale more likely.

**OPEC coordination difficulties (lower  $\lambda$ ).** Increased coordination difficulties would make OPEC producers less likely to cooperate to accommodate non-OPEC producers in the face of weakening demand. Although OPEC is literally the textbook model of cartels, there is an extensive literature debating this. OPEC has at times been characterized as being closer to a fringe of non-cooperative (OPEC and non-OPEC) producers that is led by Saudi Arabia (Huppmann and Holz, 2012; Huppmann, 2013; Nakov and Nuno, 2013) or a small subset of OPEC members (Bremond, Hache and Mignon, 2012). Smith (2005) argues that OPEC members are more cooperative as a cartel which is possibly led by a core group. Almoguera et al. (2011) conclude OPEC behaves more like (uncooperative) Cournot competitors with a non-OPEC fringe.<sup>18</sup>

<sup>17</sup> Alternative measures yield similar results. Production in the Eagle Ford and Bakken formations alone doubled to about  $2\frac{1}{2}$  mbd, while proxies reported by the World Bank (Baffes et al, 2015) indicate a doubling from 2 mbd to 4 mbd. US oil extracted by fracking rose by a similar magnitude to account for about half of US crude production in 2014, while conventional output declined slightly (EIA, 2016b).

<sup>18</sup> Others have discussed the dominant role of Saudi Arabia as a swing producer that has targeted a specific price that balances the trade-off between short-term government funding needs and discouraging long-term incentives

Structural factors that could contribute to this lack of coordination include differences in characteristics across members—with those in worse fiscal situations feeling less able to cut output and those with more reserves having a longer-term perspective; the absence of internal compensation or an effective enforcement mechanism; and monitoring costs. Iraq’s formal exemption from the quota following its history of sanctions and OPEC’s relatively low global market share by historical standards may have acted to reduce scope for coordination (Fattouh and Mahadeva, 2013; Huppmann and Holz, 2015).

Huppmann and Holz (2012) find that OPEC’s degree of market power declined significantly in the aftermath of the 2008 financial crisis, which in our context corresponds to a drop in  $\lambda$ . The media has recently reported widening rifts among members, including increasingly unproductive OPEC meetings. Long accustomed to arriving early at OPEC’s two meetings per year to build consensus among members, Saudi Arabia’s oil minister reportedly arrived at the last minute to the mid-2014 event, stayed only for a few hours, and suggested a reduction in meeting frequency to just once a year as he believed there was little point in talking.<sup>19</sup>

**Lower marginal costs for US shale (lower  $C_j$ ).** Cost estimates for US shale vary considerably due to uncertainties as well as inconsistencies in cost definition (Kleinberg, Paltsev, Ebinger, Hobbs, and Boersma, 2016).<sup>20</sup> Some proprietary estimates include only the costs of finding and extracting the oil, while others add overheads, transportation, or a hurdle rate for the cost of capital. Wellhead breakeven prices averaged \$75 in 2014 with a range of \$56 to \$85 reflecting variation across US shale plays (Rystad Energy, 2016). This commonly cited proxy does not cover all costs and may not be the most comprehensive. For the same year, Kleinberg et al. (2016) distinguish between full cycle costs, the most comprehensive and closest to "long-run" costs, of \$60-\$90; half-cycle costs, which include capital expenditure (including on new wells) needed to sustain production in a field, of \$50-\$70; and lifting costs, broadly equivalent to pure variable or operating costs, of below \$15. These are in reality average rather than marginal costs (although our model assumes equivalence).

It has been widely reported that these costs have been falling. For example, Rystad Energy (2016) show a decline of \$30 between 2013 and 2015. Drivers include technology improvements such as shorter well completion times;<sup>21</sup> superior seismic data thanks to software, sensors and lasers; the use of sand, better liquids, or even microbes for fracking; refracking of wells; and stripping idle rigs for parts (*The Economist*, 2015; Brousseau, 2016). These improvements would have acted to discourage or postpone OPEC’s decision to try to curtail shale production.

**Higher OPEC spare capacity (higher  $K_i$ ).** The “call on OPEC crude” is the difference

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to substitute away from oil before reserves are exhausted (Behar and Pant, 2015; Cairns and Calfucura, 2012). In a 1998 interview, Mr Al-Naimi stated that Saudi Arabia had formally abandoned the role of swing producer in the 1980s (Westelius, 2013).

<sup>19</sup>Reported by *The Wall Street Journal*, 5 October 2014 “OPEC Members’ Discord Adds to Slide in Oil Prices”.

<sup>20</sup>Ebinger (2014) notes “While various pundits have opined on this question, the truth of the matter is that no analyst really knows the full range of production costs across the unconventional crude oil production continuum since this information is highly proprietary.”

<sup>21</sup>For example, the time between permit applications and production declined by about 10 percent between the start of 2012 and 2014 (Currie, 2016).

between global oil demand and non-OPEC supply (and OPEC NGLs).<sup>22</sup> In 2014, the call declined by 1.8 mbd to less than 30 mbd, leaving it 1 mbd short of crude output. The implied  $5\frac{1}{2}$  mbd of spare crude capacity compares with only about 3 mbd in 2011. Over the same period, OPEC'S NGL capacity increased by  $\frac{1}{2}$  mbd.

In 2011, Libya's conflict saw its oil output collapse by 1 mbd. Production was restored in 2012, but renewed political and security disruptions once again cut output in 2013-14. Saudi Arabia increased output to offset Libya's disruptions, while other countries including the UAE and Kuwait also decided to raise output. When Libya's output began to recover, there was no corresponding net decrease by other members. In fact, Saudi Arabia and other countries increased output further in 2012 and sustained high oil output in subsequent years.<sup>23</sup>

Trends in Iran and Iraq broadly offset one another between 2011 and 2014. Iraq continued to increase its capacity in 2014, which surprised many given Islamic State's territory gains in that country. Although Iran's technical capacity may have remained intact, the US oil embargo imposed binding constraints on Iran's ability to sell oil. However, the interim deal signed with the P5+1 in August 2013 helped Iran's output stabilize in 2014.<sup>24</sup>

## 4.2 OPEC's actions and market responses

As the oil price decline continued in the second half of 2014, many OPEC members repeatedly signaled a regime switch, indicating they opposed cutting output and intended to defend market share. Saudi officials indicated their belief that shale producers' costs are high (approaching \$100), that Saudi costs are less than \$10, and that market equilibrium should be restored by reductions in supply from high cost producers (Middle East Economic Survey, 2014).<sup>25</sup>

Nonetheless, the OPEC meeting in November 2014 surprised many by the seemingly collective decision not to reduce its quota to match the demand for its crude, or at least to reduce actual output to meet the quota. In our framework, this is consistent with the formal announcement by OPEC to squeeze US shale production rather than accommodate it. In its December 2015 meeting, OPEC reiterated its commitment to market-share. However, in November 2016, OPEC agreed to a production cut, but the reductions are modest and, at the time of writing, it is not clear that the targets will be met for a sustained period.

Data have been consistent with a market share strategy. The call on OPEC remained below 30 mbd in 2015, yet OPEC production increased by  $1\frac{1}{4}$  mbd. 2016 data indicate a rise of another 1 mbd as Saudi Arabia and other important players produce near record highs. This implies a rise in OPEC's market share to 40.5 percent. Upward revisions of future capacity growth acted to re-enforce the decision to squeeze (IEA, 2016b). Much of the capacity growth

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<sup>22</sup> As mentioned earlier, NGLs are not part of OPEC's quota of 30 mbd.

<sup>23</sup> Further discussion is available in Behar and Pant (2015).

<sup>24</sup> Libya and Iran were not the only countries to experience supply disruptions. Verleger (2016) notes that unanticipated global supply outages rose from 1 mbd to 3 mbd after 2011.

<sup>25</sup> "Saudi Arabia ... enjoys very low production costs. And we are more efficient than other producers. It is an advantage we will use, as any producer would..." - Saudi Arabia Oil Minister, Mr Al-Naimi (2015: [www.saudiembassy.net/announcement/announcement03041501.aspx](http://www.saudiembassy.net/announcement/announcement03041501.aspx)).

is accounted for by traditional political rivals<sup>26</sup> and by additional members,<sup>27</sup> so discord among OPEC has intensified and arguably acted to make a coordinated cut less feasible. The excess supply pressures that had built up in 2014 did not unwind in 2015, leaving oil cheaper at the end of 2015 than at the start and averaging \$50 for the year. Although excess supply started to decrease in 2016, oil prices are set to average less than \$45 (IMF, 2016).

In response, US shale supply started scaling back. Late-2016 production was  $\frac{3}{4}$  mbd (16 percent) below the peaks attained in early 2015 (EIA, 2016c) and 1 mbd lower than the 2016 forecast published the previous year (EIA, 2015b).<sup>28</sup> This is consistent with the squeeze, but US output has been more resilient than many market participants expected. Between 2014 and 2016, wellhead breakeven costs have fallen by almost half to about \$40 (Rystad Energy, 2016) owing to further efficiency gains and by concentrating on the best oil wells (*The Economist*, 2016). Producers have used oil price hedges and financing innovations to avert or postpone bankruptcy (Verleger, 2016). Non-OPEC non-shale multinationals have responded to the weaker oil price by laying off workers, cutting investment, and in some cases postponing or canceling some exploration projects (*The Economist*, 2016). As a result, non-OPEC capacity forecasts for the next 5 years have been reduced (IEA, 2015; IEA, 2016b). In terms of actual production, 2016 estimates indicate a modest decline of  $\frac{1}{2}$  mbd ( $1\frac{1}{2}$  percent) relative to 2015 (IEA, 2016a).<sup>29</sup>

Lower prices contributed to a demand acceleration of  $1\frac{1}{2}$  mbd in 2015 (IEA, 2016a). However, this rise is small considering the oil price decline, suggesting renewed weakness that has acted to re-enforce the market share strategy. 2015 GDP growth of  $3\frac{1}{4}$  percent was below forecasts and lower than every year since 2009 (IMF, 2016). Oil demand growth is expected to slow again to  $1\frac{1}{4}$  mbd in 2016 (IEA, 2016a).

## 5 Quantitative empirical calibration

This section matches the events described above to the model by combining observed data and empirically supported parameter values. We start with two snapshots from before the oil price crash (in 2012 and 2014) that confirm that the model predicts the high oil prices and relatively restrained OPEC production consistent with an accommodate equilibrium. We proceed to a set of six illustrative counterfactual scenarios that demonstrate a squeeze. They show in a

<sup>26</sup>Confidence in Iraq’s ability to continue capacity growth was restored and could coincide with growth from Iran following the final nuclear deal signed in July 2015.

<sup>27</sup>Indonesia and Gabon rejoined OPEC in December 2015 and July 2016, respectively, making an additional 1 mbd of capacity available for an OPEC squeeze. Following reports of suspension at the November 2016 OPEC meeting, Indonesia’s status is uncertain. To facilitate comparison in the figures and charts presented in this section, Indonesia and Gabon are excluded from OPEC in all years. In the calibrations to be presented in the next section, they are only part of OPEC in the predicted data for future years.

<sup>28</sup>There is econometric evidence that US shale oil is more price-responsive than conventional oil (Bjornland et al, 2016).

<sup>29</sup>The distinction between output reductions for shale and capacity/investment reductions for non-shale resources can be explained by differences in product lifecycles. Shorter production cycles mean that full-cycle or long-run costs are relevant over a shorter objective time frame for shale than for conventional sources. US shale’s costs are the world’s highest only over a shorter time frame. Conventional oil extraction entails large upfront sunk costs but low subsequent marginal variable costs. As a result, it would take extremely low prices to induce rapid exit from “high long-run cost” conventional resources such as the Canadian oil sands.

stylized way how market developments or a revised calculation by OPEC could induce a change of strategy. Finally, we have two instances where we apply the model to future data to show it generates a squeeze equilibrium, which in turn predicts higher OPEC supply and low prices in line with forecasts.

## 5.1 Calibration approach and data

This subsection describes how values are sourced or calculated; see also Appendix B for a listing of our data sources. Actual oil prices and forecasts (based on futures markets) are the nominal Average Petroleum Spot Price (APSP) taken from the IMF’s World Economic Outlook (WEO) database, specifically those used for the October 2016 World Economic Outlook .

On the demand side, actual historical or future forecast demand quantities in millions of barrels per day (mbd) are sourced from various issues of the MOMR and IEA (2016b). A key parameter is  $\beta$ , which is chosen so as to ensure demand elasticities that are consistent with estimates in the literature. Setting  $\beta = 8$  implies an elasticity of demand of almost  $-0.15$  when oil prices are \$100 and around  $-0.07$  when oil prices are \$50. This range falls comfortably within the confines of empirical work.<sup>30</sup> Unless otherwise indicated, we solve for the shift parameter  $\alpha$  using actual demand, actual prices, and  $\beta$  (recall that our demand curve is  $D(P) = (\alpha - P)/\beta$ ).

Actual historical global supply and inventory changes, which account for discrepancies with respect to global demand, are also sourced from MOMR issues, as are OPEC and non-OPEC supply. However, to distinguish US shale production from more conventional US output, we refer to the Energy Information Administration (EIA, 2015a; EIA, 2016c).<sup>31</sup> For non-OPEC supply, capacity is assumed to equal actual output. For OPEC, sustainable capacity estimates are taken from the IEA (2013, 2015, 2016b). As mentioned earlier, non-OPEC statistics do not distinguish between crude and NGLs, but OPEC statistics do. We add NGLs to OPEC crude output/capacity, resulting in volumes that are higher than more widely reported crude-only volumes. For supply forecasts, non-OPEC capacity/output is derived from IEA (2016b) and shale capacity is taken from EIA (2015a). The IEA does not produce OPEC supply forecasts but OPEC capacity is taken from IEA (2016b).

We set marginal costs for US shale using Kleinberg et al. (2016) and Rystad Energy (2016); for OPEC, we use Middle East Economic Survey (2014). OPEC’s pricing power  $\lambda$  is solved for the value that makes calculated prices and quantities consistent with the data and other parameters as per equation (2) which determines OPEC’s supply behaviour.

## 5.2 Accommodate examples

We present results for the second quarter of 2014 because it preceded the decline in oil prices as well as 2012 for robustness (Table 1). Our main finding is that it was then still optimal for

<sup>30</sup>Surveys by Atkins and Jayazeri (2004) and Smith (2009) indicate a range of 0 to  $-0.11$ . Hamilton (2009) finds elasticities that are very close to zero, but some more recent studies have found higher demand responses. Kilian and Murphy (2014) have a preferred estimate of  $-0.27$ , which is similar to the median among a time-varying range of elasticities in Baumeister and Peersman (2013), who themselves find elasticities have declined over time.

<sup>31</sup>Specifically, we use their data for tight oil in the lower 48 US states. Similar levels or growth rates are attained using proxies based on individual states or for the main shale oil fields (Baffes et al, 2015).



OPEC to follow an accommodate strategy.

In both years, oil prices ( $P$ ) were close to \$105. Actual demand ( $D$ ) was 90.7 mbd in 2012 and 92 mbd in 2014. Setting  $\beta = 8$  implies a price elasticity of demand of about  $-0.15$  in both years. Then  $P$ ,  $D$ , and  $\beta$  can be substituted into the demand function to solve for  $\alpha$  for each year. Global supply exceeded demand by 0.2 mbd in 2012 and by 3.4 mbd in the second quarter of 2014, implying large inventory builds. As discussed earlier, shale capacity ( $K_j$ ) was  $2\frac{1}{4}$  mbd in 2012 and  $4\frac{1}{4}$  mbd in 2014, while OPEC capacity ( $K_i$ ) remained constant and other non-OPEC capacity ( $K_\ell$ ) rose.

Short-run marginal costs are set at  $C_i = \$10$  for OPEC in both years. Given the shorter production cycles of shale, we seek to capture its “full-cycle” costs. Kleinberg et al. (2016) elect to provide a range rather than a specific aggregate value; in light of this, we choose for 2014 a number towards the top of the range,  $C_j = \$85$ , to proxy marginal cost. We set US shale costs in 2012 at  $C_j = \$90$  to permit modest efficiency gains prior to 2014. We calculate that  $\lambda \approx \frac{1}{3}$  for both 2012 and 2014. This is broadly consistent with the OPEC literature discussed earlier, including numerical model simulations and econometric estimates (Huppmann and Holz, 2012; Almuquera et al., 2011), which imply  $\lambda < \frac{1}{2}$ .

**Table 1: Accommodate examples**

<b>Scenario</b>		<b>1A</b>	<b>1B</b>
Period		2012	2014Q2
$P$	Price (\$/barrel)	105	106
$D$	Demand (mbd)	90.7	92.0
$\beta$	Demand slope	8	8
	Demand elasticity	-.14	-.14
$\alpha$	Demand intercept	831	843
$\alpha/\beta$	Demand parameter	103.8	105.3
$S$	Global supply (actual)	90.9	95.4
$S_i$	OPEC supply (actual)	37.6	36.4
$S_i^*$	OPEC supply (accommodate)	37.4	33.1
$S_i^{**}$	OPEC supply (squeeze)	41.2	39.7
$K_i$	OPEC capacity (mbd)	41.3	41.4
$K_j + K_\ell$	Non-OPEC supply (mbd)	53.3	59.0
$K_j$	US shale capacity (mbd)	2.0	4.0
$K_\ell$	ROW capacity (mbd)	51.3	55.0
$K_i + K_\ell$	Non-shale capacity (mbd)	92.7	96.3
$C_i$	OPEC marginal cost	10	10
$C_j$	US shale marginal cost	90	85
$\lambda$	OPEC pricing power	.32	.36
$\bar{K}_j$	US shale: critical size (mbd)	3.8	5.5

The fitted data confirm that our model assumptions A1 and A2 hold in both scenarios 1A and 1B. Consistent with A1, US shale oil is viable given that price exceeds its cost. A2 also holds in both 2012 and 2014, which means that OPEC had sufficient spare capacity to carry out the squeeze strategy.

The data are consistent with an accommodate equilibrium as per Proposition 2, so OPEC optimally chose not to pursue the squeeze. In particular, the parameters and data imply  $\bar{K}_j = 3.8$  in 2012 while  $\bar{K}_j = 5.5$  in 2014, which is above actual shale capacities of  $K_j = 2$  and  $K_j = 4$  in the respective years. Note however that the gap was already shrinking, so that 2014 was closer to a regime switch than 2012. The calculated quantity supplied by OPEC under such an equilibrium (denoted in Table 1 by  $S_i^*$  as per (2)) matches the actual data (shown as  $S$  in the table after accounting for unplanned inventory accumulation), while supply under a squeeze equilibrium (denoted by  $S_i^{**}$  as per (4)) would have been much higher.

### 5.3 Illustrative squeeze scenarios

Taking 2014 as a starting point, this subsection presents six constructed scenarios where a squeeze is triggered (Table 2). The first five separately show how higher US shale capacity, lower OPEC pricing power, lower demand, higher non-US non-OPEC capacity, or higher US shale costs can individually trigger the switch.<sup>32</sup> The sixth and final illustrative scenario combines multiple drivers to generate a squeeze.

Although stylized, these scenarios show our key point that the regime switch may have been optimal for OPEC from an *ex ante* viewpoint, given the information they may have incorporated in deciding how to react to the initial price decline in the 2<sup>nd</sup> half of 2014.

We in scenario 2A illustrate a case in which all demand and cost parameters (as well as  $\lambda$ ) are held constant at 2014 levels but set  $K_j = 5.5$ . Although illustrative, we choose this value because shale output was forecast to reach 5.5 mbd in 2018-2024 (EIA, 2015a).<sup>33</sup> These forecasts entail capacity above the values of  $\bar{K}_j$  calculated in the previous two scenarios and by construction trigger a switch to a squeeze equilibrium with shale output of zero and OPEC supply of 39.7 mbd ( $S_i^{**}$  from (4)) such that price is lower ( $P^{**} = C_j = 85$ ) and global demand is higher. The OPEC supply and global demand numbers imply an OPEC market share of 42 percent under the squeeze, which is almost a quarter more than the 34 percent implied by the counterfactual accommodate equilibrium. The model assumptions A1 and A2 hold: shale output would have been positive under the counterfactual of an accommodation strategy, and OPEC indeed has the capacity required for a squeeze. So US shale growth of  $\Delta K_j \approx (5.5 - 4.0) = 1.5$  mbd was just enough to trigger a switch.

Another important development discussed in Section 4 is a decline in  $\lambda$  representing OPEC's lower ability to push up prices. In scenario 2B, we also hold all 2014 parameters constant, including  $K_j = 4$ , but now use Proposition 2 to solve for the critical value of  $\lambda$  such that

<sup>32</sup>Changes in OPEC capacity are only indirectly important for ensuring A1 and A2 hold.

<sup>33</sup>The rise in (forecast) shale oil capacity was part of a sequence of positive surprises and lagged upward revisions to forecasts by the EIA. It can also be seen as OPEC having some lag in incorporating these revisions in its internal calculation of the tradeoffs.

$K_j = \bar{K}_j(\lambda)$ . With this value for  $\lambda$ , US shale capacity of  $K_j = 4$  makes OPEC exactly indifferent between the two strategies. The solved value of  $\lambda = 0.32$  is only slightly lower than in scenario 1B (for which  $\lambda = 0.36$ ); this implies that a small reduction in  $\lambda$  is already enough to trigger the decision to squeeze.

**Table 2: Calibrated squeeze counterfactuals**

Scenario		2A	2B	2C	2D	2E	2F
	Trigger	High $K_j$	Low $\lambda$	Low $\alpha$	High $K_\ell$	High $C_j$	Multiple*
$P$	Price (\$/barrel)	85	85	85	85	92	55
$D$	Demand (mbd)	94.7	94.7	91.3	94.7	93.8	94.4
$\beta$	Demand slope	8	8	8	8	8	8
	Demand elasticity	-11	-11	-12	-11	-12	-07
$\alpha$	Demand intercept	843	843	816	843	843	810
$\alpha/\beta$	Demand parameter	105.3	105.3	101.9	105.3	105.3	101.3
$S_i^*$	OPEC supply (accommodate)	32.0	34.2	30.6	30.6	33.1	32.8
$S_i^{**}$	OPEC supply (squeeze)	39.7	39.7	36.4	36.4	38.9	39.4
$K_i$	OPEC capacity (mbd)	41.4	41.4	41.4	41.4	41.4	41.4
$K_j+K_\ell$	Non-OPEC supply (mbd)	60.5	59.0	59.0	62.4	59.0	60.5
$K_j$	US shale capacity (mbd)	5.5	4.0	4.0	4.0	4.0	5.5
$K_\ell$	ROW capacity (mbd)	55.0	55.0	55.0	58.4	55.0	55.0
$K_i+K_\ell$	Non-shale capacity (mbd)	96.3	96.3	96.3	99.7	96.3	96.3
$C_i$	OPEC marginal cost	10	10	10	10	10	10
$C_j$	US shale marginal cost	85	85	85	85	92	55
$\lambda$	OPEC pricing power	.36	.32	.36	.36	.36	.21
$\bar{K}_j$	US shale: critical size	5.5	4.0	4.0	4.0	4.0	5.5

\* Setting  $C_j$  lower and  $K_\ell$  higher; allowing  $\lambda$  and  $\alpha$  to shift endogenously.

Our next two scenarios explore sensitivities to global demand and non-OPEC production. Scenario 2C investigates how weaker global demand can also trigger a squeeze. We again hold all the 2014 parameters constant, including  $K_j = 4$ , but solve for the value of the demand intercept  $\alpha$  such that  $\bar{K}_j(\alpha) = 4$ . The results show that a demand decline of about 3 percent is enough to induce a regime change (the change in mbd is  $\Delta(\alpha/\beta) = (101.9 - 105.3) \approx -3.4$ ).<sup>34</sup> Scenario 2D shows that a rise of  $\Delta K_\ell \approx 3.4$  mbd in non-OPEC non-shale capacity to 58.4 mbd would also have triggered the decision to squeeze.

To understand these sensitivities, note that a demand decline, as measured by fall in  $\alpha/\beta$  (mbd), has exactly the same impact on OPEC's profits as an equally-sized rise in non-OPEC non-shale capacity  $K_\ell$  (that is,  $-\Delta(\alpha/\beta) = \Delta K_\ell \approx 3.4$  mbd in 2C and 2D, respectively). This can be confirmed by inspecting the profit expressions from (3) and (5), or equivalently the expression for  $\bar{K}_j$  from Proposition 2 (in all of which  $-\alpha/\beta$  and  $K_\ell$  enter symmetrically). The

<sup>34</sup>Note that  $\alpha/\beta$  measures the maximum possible demand for crude oil, since  $D(P) = (\alpha - P)/\beta$ .

reason is that both have the same effect of shifting downward the residual demand curve faced by OPEC.

The calibration to 2014 values also shows that rise in non-OPEC non-shale capacity needed to trigger a switch ( $\Delta K_\ell \approx 3.4$  mbd in 2D) is more than twice as large as the required rise in US shale capacity ( $\Delta K_j \approx 1.5$  mbd in 2A). Put differently, a given rise in US shale capacity is more conducive to a regime switch (to squeeze) than an identical rise in other non-OPEC capacity. The reason is that the latter also depresses the price under the squeeze while higher US shale capacity does not (since it, by construction, then ceases to produce).<sup>35</sup>

Scenario 2E investigates the role of US shale costs. In particular, it considers how much US costs  $C_j$  would need to rise in order to induce a squeeze, that is,  $\bar{K}_j(C_j) = 4$ , again holding all other 2014 parameters constant. This shows that a moderate \$7-rise in US costs from \$85 to \$92 would already have been enough to induce OPEC to switch to a squeeze. Compared to scenarios 2A and 2B, this leads to a higher price and lower demand. In reality, as discussed in Section 4.1, US shale costs have been declining, and thus acted *against* a squeeze. For example, extending scenario 2A ( $K_j = 5.5$ ) with a moderate decline in US costs from \$85 to \$78 would lead to  $\bar{K}_j = 7.0$ , which implies that accommodation remains optimal (preserving the “gap” of  $[\bar{K}_j - K_j] = 1.5$  in scenario 1B). One interpretation is that US cost reductions—either actual changes due to efficiency gains or new information prompting a downward revision in their perceived levels—can easily undermine the case for a squeeze.

The illustrative scenarios so far imply prices well above those observed in late 2014 and early 2015. Our scenario 2F generates a lower oil price by allowing multiple parameters to shift in a manner that is qualitatively in line with Section 4. Consistent with declining US shale costs in Rystad Energy (2016), we illustratively set  $C_j = 55 = P^{**}$ . Given this lower price, setting demand to that observed for 2015 (IEA, 2016a) implies a sizeable decline in the solved value of  $\alpha$  relative to 2014, representing a weakening in global demand. Thus, although lower US costs discourage the squeeze, the negative demand shift encourages it, illustrating how demand and supply are interlinked. Letting US shale capacity  $K_j = 5.5$ , we again use Proposition 2 to find the value of  $\lambda$  for which  $K_j = \bar{K}_j(\lambda)$  such that the solved value can be interpreted as the maximum value of  $\lambda$  that triggers the squeeze. OPEC supply  $S_i^{**} = 39.4$  mbd under the squeeze by (4), which is much closer to actual supply (38 mbd) than calculated supply under accommodate ( $S_i^*$ ).

In summary, scenario 2F generates a squeeze equilibrium with a more realistic oil price through higher US shale capacity, lower OPEC pricing power, weaker demand, and falling US production costs. OPEC’s market share is 42 percent of demand compared to 35 percent under the accommodate counterfactual. A1 continues to hold, which implies that shale would have been viable (aided by lower costs but harmed by *inter alia* weaker demand) had it been accommodated. A2 also still holds. In terms of our qualitative discussion from Section 4, this shows that the various factors favoring a squeeze can quantitatively outweigh lower US shale costs.

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<sup>35</sup>To confirm this formally, it is easy to check in the proof of Proposition 1:  $\frac{\partial}{\partial K_\ell}(\Delta \Pi_i) > \frac{\partial}{\partial K_j}(\Delta \Pi_i) > 0$ .

## 5.4 Future squeeze equilibria

This subsection recalibrates the model using forecasts of oil markets in 2020. The two squeeze equilibria imply that the market-share strategy can be rationalized economically as a “less-bad” future option for OPEC; they also yield more plausible forecasts for OPEC output than in an accommodate equilibrium.

In equilibrium 3A, the 2020 oil price of \$56 is used to pin down marginal cost for US shale oil. The demand parameter  $\alpha$  is solved as before, now using third-party forecasts of  $P$  and  $D$ , while  $\beta$  is unchanged. As per Proposition 2,  $K_j = 5.6$  based on EIA (2015a) and so  $K_j = \bar{K}_j(\lambda)$  when  $\lambda = 0.20$ . Hence, OPEC supply is  $S_i^{**} = 41.6$  mbd as per (4). Under a counterfactual accommodate equilibrium as per (2), OPEC supply ( $S_i^*$ ) would be almost 7 mbd lower. Furthermore (this is not shown in Table 3), shale output would equal capacity, OPEC’s market share would be 35 percent, and the price would be \$73.

**Table 3: Illustrative future squeeze equilibria**

<b>Scenario</b>		<b>3A</b>	<b>3B</b>
	Extent of squeeze	All shale	Some shale
$P$	Price (\$/barrel)	56	56
$D$	Demand (mbd)	100.5	100.5
$\beta$	Demand slope	8	8
	Demand elasticity	-.07	-.07
$\alpha$	Demand intercept	860	860
$\alpha/\beta$	Demand parameter	107.5	107.5
$S$	Global supply (actual)	100.5	100.5
$S_i^*$	OPEC supply (accommodate)	34.9	38.3
$S_i^{**}$	OPEC supply (squeeze)	41.6	38.8
$K_i$	OPEC capacity (mbd)	43.7	43.7
$K_j+K_\ell$	Non-OPEC supply (mbd)	58.9	61.7
$K_j$	US shale capacity (mbd)	5.6	2.8
$K_\ell$	ROW capacity (mbd)	58.9	58.9
$K_i+K_\ell$	Non-shale capacity (mbd)	102.6	102.6
$C_i$	OPEC marginal cost	10	10
$C_j$	US shale marginal cost	56	56
$\lambda$	OPEC pricing power	.20	.16
$\bar{K}_j$	US shale: critical size	5.6	2.8

A less stylized equilibrium includes non-zero US shale output in a way that reduces OPEC supply while leaving global supply, prices, and demand unaltered. Equilibrium 3B relaxes the assumption that US shale is a homogenous group. Reflecting that the level (and change) of costs varies considerably across shale plays (Rystad Energy, 2016), it instead lets a futures price of \$56 only squeeze out those with higher costs. (In terms of the model setup,  $j$  becomes the subset of

US shale plays with costs above \$56.) Setting  $K_j = 2.8$  to represent the more expensive half of US shale, and following the same procedure as in equilibrium 3A, a squeeze equilibrium would result in OPEC producing 38.8 mbd and lower-cost US shale producing 2.8 mbd. We find that  $K_j = \bar{K}_j(\lambda) = 2.8$  when  $\lambda = 0.16$ . Intuitively, for it to be worth squeezing out only half of US shale, accommodation must be even less attractive. An interesting implication of this low value of  $\lambda$  is that the counterfactual price under accommodate is only \$4 higher than the squeeze price. In this sense, US shale becomes the *de facto* “price-setter” in this future scenario *regardless* of which equilibrium is played.

## 6 Conclusions

The debate about OPEC’s November 2014 switch to a “market-share” strategy has drawn considerable attention. Many oil-market analysts view the decision as a battle of “OPEC vs shale” aimed at squeezing higher-cost US players out of the market. We have contributed to this debate with an equilibrium model that helps understand how fundamental market developments can rationalize such a regime switch by OPEC as a profit-maximizing strategy. This can explain why OPEC supply may optimally rise in response to high-cost supply growth (such as US shale) or weaker global demand—and induce an oil price collapse.

Our calibration of the model shows it was better for OPEC to accommodate expanding US shale production up to 2014 despite having the spare capacity to squeeze them out of the market. Stylized comparative statics show how changes to OPEC’s information set at the time could prompt the late-2014 switch to a market-share strategy. Calibration to forecasts of future market data shows how evolving developments can sustain a regime switch to a squeeze. Through the lens of the model, the market-share strategy can be the better of the two options—given US shale capacity, OPEC coordination prospects, weak global oil demand, and other market factors.

It remains to be seen whether the initial logic of the squeeze will play out and vindicate the strategy in the coming years. As of late 2016, the squeeze appears to have been less successful than OPEC might have calculated: the decline in US shale output has so far been fairly modest, and the squeeze has perhaps been more costly than anticipated given the continued depression of oil prices (IEA, 2016b). One potential reason is that US shale costs have fallen more than might have been anticipated; relatedly, the subtleties underlying the calculation of breakeven prices may have initially been misunderstood by some market participants (Kleinberg et al., 2016).

In terms of our framework, further new information on these factors could prompt another OPEC regime switch back to accommodate. OPEC’s November 2016 meeting may be a signal of such a reversion—though it is too early to tell how substantial this will end up being. It is also possible that the attempted squeeze and the re-entry of Iran have made coordinated accommodation so problematic that OPEC reluctantly yet rationally persists with the squeeze.

OPEC’s market-share strategy and low oil prices may have squeezed high-cost producers beyond US shale. Many conventional producers have sustained production but reduced investment

in *future* capacity, which suggests they will also be squeezed over a longer time horizon (IEA, 2016b; Toews and Naumov, 2016). Furthermore, the adoption of fracking in other countries—which could have been profitable in a high-price environment—may have been deterred. This paper has not pretended to forecast the future of the oil industry but rather to provide a coherent economic framework to think about the key drivers of regime switches, including the one that took place at the end of 2014.

Finally, our approach can be applied to other energy sectors. For example, natural gas is also characterized by significant supply-side concentration. In the EU, Gazprom plays a dominant role in that it accounts for around 30% of gas imports. It competes against domestic supplies in some EU countries, other pipeline exporters, and liquefied natural gas (LNG)—which likely all have higher costs. Recent gas-policy discussions suggest that the demand slowdown and likely future competition from US shale gas arriving in Europe as LNG mean that Gazprom should begin a “price war” to regain market share and squeeze higher-cost LNG players (and possibly coal production) out of the European market (Henderson 2016). This regime choice has some close parallels with the oil-market setting, and our model could similarly be used to quantify the conditions under which a market-share strategy becomes optimal for Gazprom.

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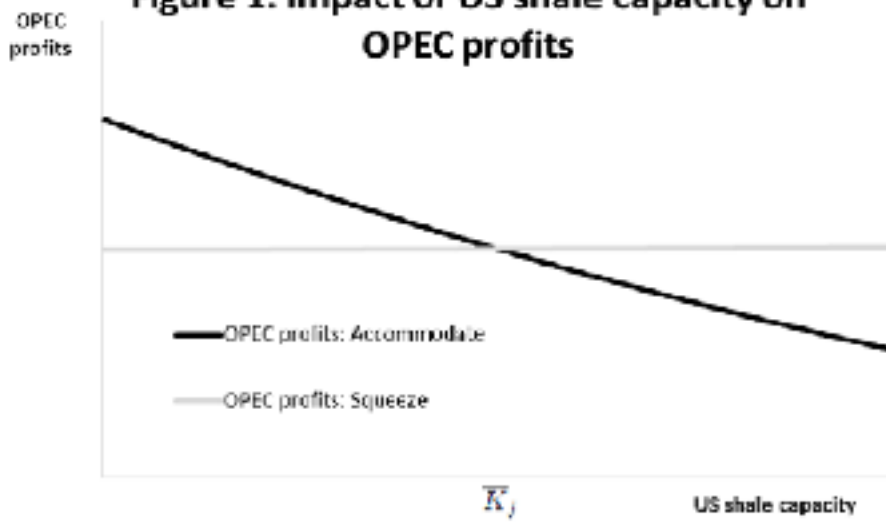


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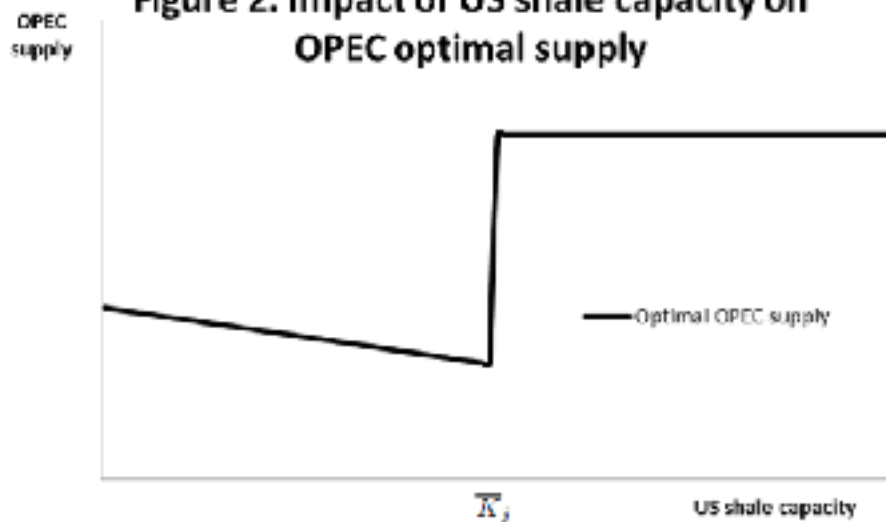
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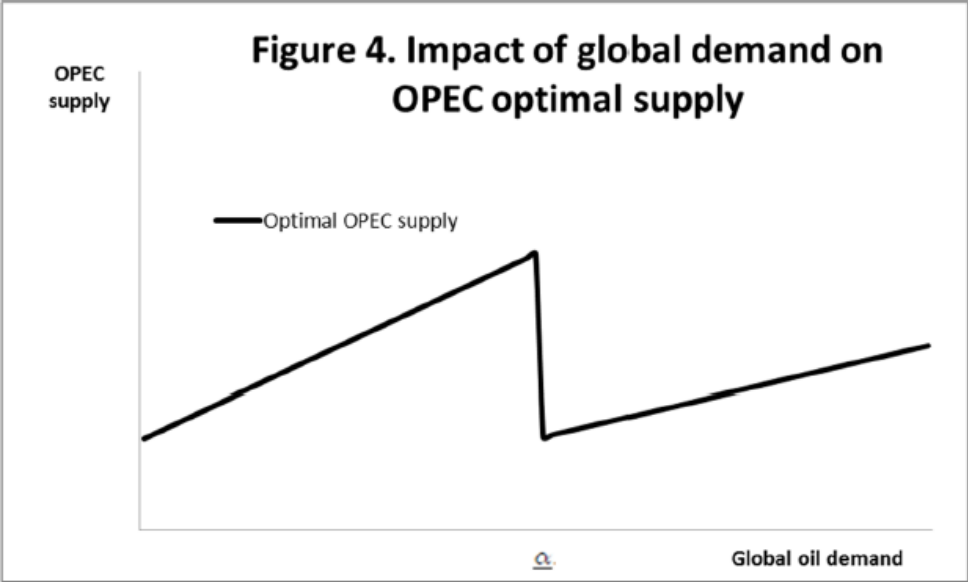
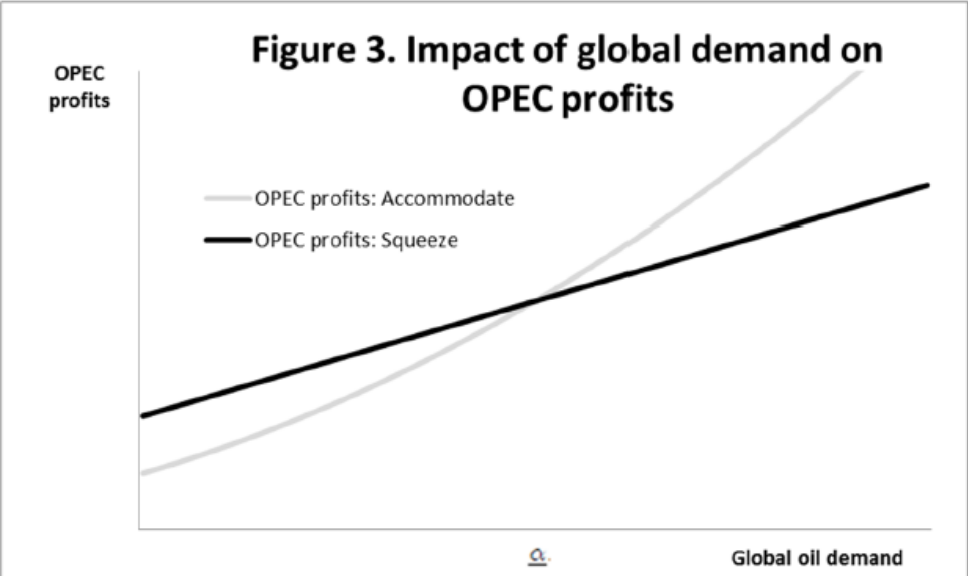
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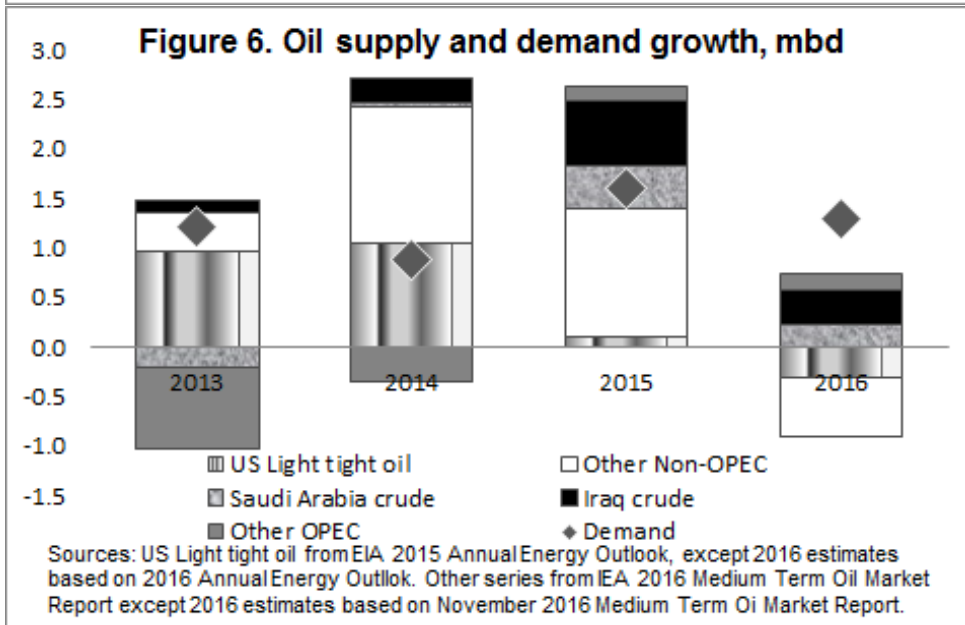
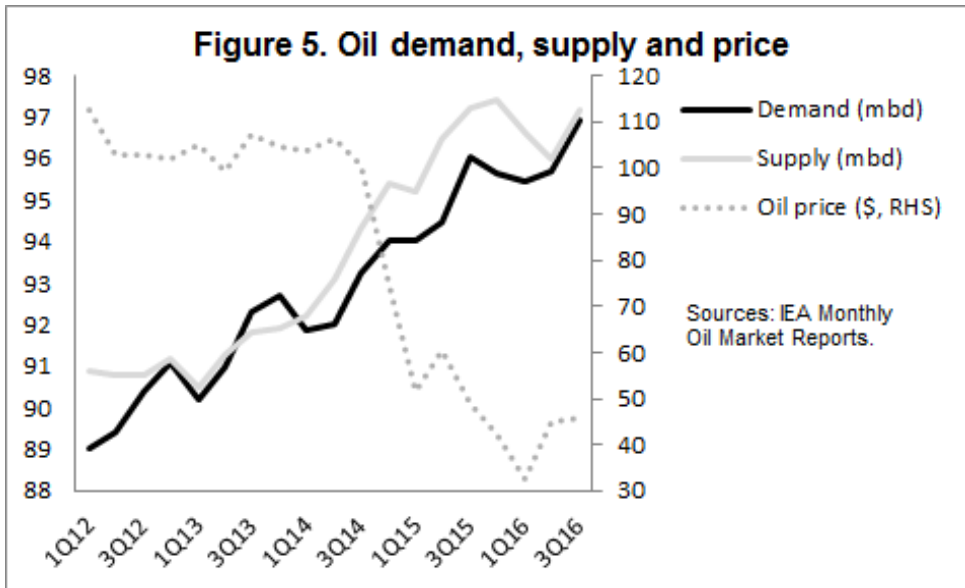
**Figure 1. Impact of US shale capacity on OPEC profits**



**Figure 2. Impact of US shale capacity on OPEC optimal supply**







## Appendix A: Proofs

**Proof of Proposition 1.** Using (3) and (5), the profit difference  $\Delta\Pi_i \equiv (\Pi_i^{**} - \Pi_i^*)$  equals:

$$\Delta\Pi_i = \frac{1}{\beta} \left[ [(\alpha - C_j) - \beta K_\ell] (C_j - C_i) - \lambda \left( \frac{(\alpha - C_i) - \beta(K_j + K_\ell)}{(1 + \lambda)} \right)^2 \right]. \quad (6)$$

For the comparative statics of (i) to (v), in turn, differentiation shows that

$$\frac{\partial}{\partial K_j}(\Delta\Pi_i) = \frac{2\lambda}{(1 + \lambda)^2} [(\alpha - C_i) - \beta(K_j + K_\ell)] > 0$$

is implied by A1, and

$$\frac{\partial}{\partial \lambda}(\Delta\Pi_i) = -\frac{1}{\beta} \left[ \frac{(1 - \lambda)}{(1 + \lambda)^3} [(\alpha - C_i) - \beta(K_j + K_\ell)]^2 \right] < 0$$

holds whenever  $\lambda < 1$ , and

$$\frac{\partial}{\partial \alpha}(\Delta\Pi_i) = \frac{1}{\beta} \left[ (C_j - C_i) - \frac{2\lambda}{(1 + \lambda)^2} [(\alpha - C_i) - \beta(K_j + K_\ell)] \right] < 0$$

also holds since  $(C_j - C_i) < \frac{\lambda}{(1 + \lambda)} [(\alpha - C_i) - \beta(K_j + K_\ell)]$  is A1 and  $\frac{2\lambda}{(1 + \lambda)^2} \geq \frac{\lambda}{(1 + \lambda)}$  since  $\lambda \in (0, 1]$ , and

$$\frac{\partial}{\partial C_j}(\Delta\Pi_i) = \frac{1}{\beta} [(\alpha - C_j) - \beta K_\ell - (C_j - C_i)] > 0$$

holds by A1, and finally

$$\frac{\partial}{\partial K_\ell}(\Delta\Pi_i) = -(C_j - C_i) + \frac{2\lambda}{(1 + \lambda)^2} [(\alpha - C_i) - \beta(K_j + K_\ell)] > 0$$

also holds as a consequence of A1, thus proving parts (i)–(v).

**Proof of Proposition 2.** This expression for the difference in profits from (6) can easily be rearranged to obtain the condition that  $\Delta\Pi_i(\alpha, \beta, \lambda, C_i, C_j, K_j, K_\ell) > 0 \Leftrightarrow K_j > \bar{K}_j$ , where  $\bar{K}_j$  is defined in the proposition. Plugging the critical value  $\bar{K}_j$  into (1) yields:

$$\begin{aligned} P^*(\bar{K}_j) &= \frac{C_i + \lambda[\alpha - (\alpha - C_i) + (1 + \lambda)\sqrt{(1/\lambda)[(\alpha - C_j) - \beta K_\ell](C_j - C_i)}]}{(1 + \lambda)} \\ &= C_i + \sqrt{(1/\lambda)[(\alpha - C_j) - \beta K_\ell](C_j - C_i)}, \end{aligned}$$

as claimed. It remains to check that the condition for the regime switch is itself compatible with A1. To do so, rewrite A1 as

$$K_j < \left[ \frac{1}{\beta} \left( (\alpha - C_i) - \frac{(1 + \lambda)}{\lambda} (C_j - C_i) \right) - K_\ell \right] \equiv \hat{K}_j,$$

so we require that  $\bar{K}_j < \hat{K}_j$ , which holds if and only if:

$$\begin{aligned} (\alpha - C_i) - (1 + \lambda)\sqrt{(1/\lambda)[(\alpha - C_j) - \beta K_\ell](C_j - C_i)} &< (\alpha - C_i) - [(1 + \lambda)/\lambda](C_j - C_i) \iff \\ (1/\lambda)(C_j - C_i) &< \sqrt{(1/\lambda)[(\alpha - C_j) - \beta K_\ell](C_j - C_i)} \iff \\ (C_j - C_i) &< \lambda[(\alpha - C_j) - \beta K_\ell]. \end{aligned}$$

The last expression holds by A1, thus completing the proof.

**Proof of Proposition 3.** For part (i), since the price is lower under the squeeze,  $P^{**} < P^*$  by Proposition 2, market demand must be higher,  $D(P^{**}) > D(P^*)$ . As non-OPEC ex-US players production  $K_\ell$  is unchanged, OPEC's production must also be higher,  $S_i^{**} \equiv \{D(P^{**}) - K_\ell\} > \{D(P^*) - K_j - K_\ell\} \equiv S_i^*$ . For part (ii), using the previous expressions for  $i$ 's demand from (1) for  $\alpha'$  and (2) for  $\alpha''$  shows that  $S_i^{**}(\alpha'') > S_i^*(\alpha')$  is equivalent to:

$$\begin{aligned} \frac{(\alpha'' - C_j) - K_\ell}{\beta} &> \frac{[\alpha' - \beta(K_j + K_\ell) - C_i]}{(1 + \lambda)\beta} \iff \\ \lambda[\alpha'' - C_j - \beta K_\ell] + \beta K_j &> (\alpha' - \alpha'') + (C_j - C_i) \iff \\ \{\lambda[(\alpha'' - C_j) - \beta(K_j + K_\ell)] - (C_j - C_i)\} + \beta(1 + \lambda)K_j &> (\alpha' - \alpha'') \equiv \Delta\alpha \end{aligned}$$

as claimed, and recalling that  $\{\lambda[(\alpha'' - C_j) - \beta(K_j + K_\ell)] - (C_j - C_i)\} > 0$  is A1.

## Appendix B: Data sources

*Oil prices (historical and assumed) P:* IMF World Economic Outlook database (October 2016).

*Demand volumes (historical and forecast):* International Energy Agency Medium Term Oil Market Report (2015, 2016) and Monthly Oil Market Report (numerous issues).

*Demand parameters:*  $\beta = 8$ , in line with existing empirical work;  $\alpha$  solved using  $P$ ,  $D$ , and  $\beta$ .

*Global supply volumes; inventory changes (realized):* International Energy Agency Medium Term Oil Market Report (2015, 2016) and Monthly Oil Market Report (numerous issues).

*OPEC supply volumes (historical):* International Energy Agency Medium Term Oil Market Report (2015, 2016) and Monthly Oil Market Report (numerous issues).

*OPEC supply volumes (forecast):* Solved endogenously.

*OPEC capacity (historical and forecast):* International Energy Agency Medium Term Oil Market Report (2015, 2016).

*US shale capacity/supply (realized and forecast):* Energy Information Administration (2015).

*Non-OPEC capacity/supply (realized and forecast):* International Energy Agency Medium Term Oil Market Report (2015, 2016) and Monthly Oil Market Report (numerous issues).

*US shale marginal cost:* Selected by authors based on Kleinberg et al. (2016) and Rystad Energy (2016) or equal to oil price forecasts (future squeeze equilibria).

*OPEC marginal cost:* Middle East Economic Survey (2014)

*OPEC pricing power:* Solved endogenously.