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OPEC VS US SHALE OIL: ANALYZING THE SHIFT TO A MARKET-SHARE STRATEGY?

Alberto Behar Robert A. Ritz

31 March 2016

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

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Abstract

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1 Introduction

In 2014, global oil supply overtook demand and the oil price started to decline. In its November 2014 meeting, OPEC[1] decided not to reduce supply and prices fell further. Many oil-market analysts interpreted this as the formal decision to squeeze higher-cost US shale oil production back out of the market. It also stood in contrast with OPEC's coordinated cut during the Global Financial Crisis and Saudi Arabia's role as a "swing producer", which seeks to accommodate changes in demand or production by other players. A former adviser to Saudi Arabia's Oil Minister Ali al-Naimi summarized: "His biggest move was the latest one of defending Saudi market share, and abandoning the OPEC swing role".[2]

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".[3]

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.[4] 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 the high-cost non-OPEC producers to remain profitable. The second strategy, referred to as "squeeze", is to drive up production—and hence drive down price—and thereby induce high-cost producers, specifically US shale oil, to exit the market. We show that either of these two strategies can be *optimal* for OPEC depending on market fundamentals on demand and supply.

Our theory shows that the market-share strategy becomes relatively more attractive for OPEC under these conditions: (i) slower global oil demand; (ii) greater US shale oil production; (iii) reduced cohesiveness within OPEC; and (iv) higher output in other non-

[1] As at the end of 2015, the members of The Organization of the Petroleum Exporting Countries (OPEC) are (in order of crude oil capacity for 2015): Saudi Arabia, Iraq, Iran, United Arab Emirates, Kuwait, Venezuela, Nigeria, Angola, Algeria, Indonesia, Qatar, Ecuador, and Libya, although Libya's capacity is at present highly constrained by its security situation. This amounts to cumulative production capacity of $35\frac{1}{2}$ mbd. Actual crude ($31\frac{1}{2}$ mbd) and NGL ($6\frac{1}{2}$ mbd) output exceeded 40% of global demand in 2015.

[2] Quoted in *Wall Street Journal* (4 June 2015) "Saudi Arabia's Celebrity Oil Minister Ali al-Naimi Prepares for Potential OPEC Swan Song".

[3] Ise (1926) quoted in Yergin (2008).

[4] 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.

OPEC countries. We show that a *regime switch* from accommodate to squeeze becomes optimal when US shale oil grows beyond a specific point. The model can rationalize OPEC's decision to raise output in the face of weaker demand, and explain a large drop in the oil price. We provide formal results and economic intuition in the main text.

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[5] 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 having sufficient spare capacity for a squeeze. Second, to illustrate selected comparative statics, we show how some parameter changes can prompt a rational decision by OPEC to squeeze US shale oil 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 fall 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 the 2014 switch in OPEC's strategy and the subsequent oil price crash. However, we do not wish to claim that it is the most likely of a range of possible economic or political motivators.[6]

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.[7] 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 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.

The market-share strategy is premised on OPEC having "low" costs and US shale having "high" costs.[8] US shale almost surely has higher costs than OPEC, yet are the

[5] 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.

[6] As argued by Fattouh, Poudine and Sen (2015) for Saudi Arabia, many OPEC countries remain highly undiversified and hence highly reliant on oil for meeting domestic spending pressures, making revenue the prime consideration.

[7] 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.

[8] "[The policy to defend market share] is also a defense of high efficiency producing countries, not only of market share. We want to tell the world that high efficiency producing countries are the ones that deserve

world's highest only over a given 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 exit from "high long-run cost" conventional resources such as the Canadian oil sands.[9] The US shale life-cycle is much shorter, which makes the US supply response to prices quicker and the main focus of oil-market analysts. Our static model's marginal costs include upfront expenses for US shale but exclude initial investments for other producers. In our empirical work, we consider a wide range of cost parameters for US shale in light of the considerable variation in cost estimates. A number of conventional producers have sustained current production but reduced investment in future capacity, which suggests they will also be squeezed over a longer time horizon (IEA, 2016; Toews and Naumov, 2016).

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 (2015) 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.[10]

There are a number of analyses of the oil price crash; for discussions of its causes and implications see, for example, Arezki and Blanchard (2014), Hussain et al. (2015), Baumeister and Killian (2015), Hamilton (2015), and Mohaddes and Raissi (2016). Many suggest that supply-side factors have been more important in explaining the oil price crash than demand factors.[11] Smith (2009) demonstrates how the combination of low demand and supply elasticities in the oil market can account for historical levels of oil price volatility—without any role for any volatility-enhancing financial speculation. Our results show how an oil price decline induced by weaker demand or an exogenous rise in supply can be magnified because it induces a regime switch in OPEC behaviour and an endogenous increase in supply. In a similar vein, Verleger (2016) emphasizes how market structure plays a vital role in understanding oil price movements.

There remains considerable debate on the extent to which OPEC members cooperate (Smith, 2005; Bremond, Hache, and Mignon, 2012; Nakov and Nuno, 2013; Huppmann, 2013). Almoguera, Douglas and Herrera (2011) suggest that OPEC's behaviour is a mix

market share. That is the operative principle in all capitalist countries." Minister Al-Naimi, Middle East Economic Survey Interview, 21 December 2014.

[9] 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.

[10] They also note that OPEC allowing for more price volatility introduces uncertainty for prospective entrants and can discourage entry as a result.

[11] Although the relative importance of each factor is difficult to pin down, OPEC's renouncement of price support and rapid expansion of oil supply from unconventional sources appear to have played a crucial role since mid-2014. Empirical estimates also indicate that supply (more than demand) factors have accounted for the lion's share of the plunge in oil prices (Baffes et al, 2015; Beidas-Strom and Osorio-Buitron, 2015).

of near-collusive episodes and subsequent non-cooperative breakdowns. Huppmann and Holz (2012) find that OPEC's degree of market power has declined in recent years, and Fattouh and Mahadeva (2013) attribute fluctuations in this power to market conditions.

The approach we take is flexible in that we calibrate OPEC's degree of market power to fit the data across each of our scenarios. In this way, we obtain a set of parameters which describe the level of competition in the market and are broadly in line with those from the prior 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 squeeze strategy pursued by OPEC against US shale oil in our model is a form of "limit pricing"; see Tirole (1988, Chapter 9) for an overview of the industrial-organization theory literature.[12] In related work, Andrade de Sá and Daubanes (2014) 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 tax.

Plan for the paper. Section 2 sets up our model of the oil market, and analyses the equilibrium outcomes under "accommodate" and "squeeze". 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 from the model are consistent with market experience. Section 5 presents our quantitative calibration of the model to oil market data over a range of scenarios. Section 6 concludes.

2 A simple equilibrium model of the oil market

2.1 Setup of the model

We assume that 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

[12] Classic limit-pricing theory relies on the incumbent player raising price again following the exit of the weaker entrant. Under perfect information, this leads to a credibility problem: the 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). By contrast, we show that OPEC's profits under the squeeze strategy can be *permanently* higher than under accommodate—despite a (much) lower oil price and without requiring a subsequent "harvesting" period with again-higher prices.

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. 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 *vice versa*).

OPEC has market power and can choose between two strategies:

1. "Accommodate": Maximizing its profits taking as given that US shale oil produces up to its capacity level K_j;

2. "Squeeze": Lowering the market price to C_j, thus squeezing US shale oil 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 introduce 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 λ represent weaker pricing power.[13] As will become clear, our theory does not hinge on the precise value of λ, 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:

A1. $(C_j - C_i) < \lambda[(\alpha - C_j) - \beta(K_j + K_\ell)]$
A2. $(\alpha - C_j) \leq \beta(K_i + K_\ell)$

The first assumption ensures that US shale oil (player j) 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 λ cannot be too small. The second assumption ensures that OPEC has sufficient capacity to be able to carry out the "squeeze" strategy. Note that A1 and A2 together imply $(C_j - C_i) < \lambda\left[(\alpha - C_j) - \beta(K_j + K_\ell)\right] \leq \lambda\beta(K_i - K_j)$, so that OPEC has significantly higher production capacity than US shale, specifically $K_i > K_j + (C_j - C_i)/\lambda\beta$, with $C_j > C_i$. We verify that these parameter assumptions are satisfied in the empirical calibration of the model.

[13] 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.

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. OPEC faces residual demand $\{D(P) - K_j - K_\ell\}$ and thus chooses price to:

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

As noted above, the parameter $\lambda \in (0, 1]$ captures how effective OPEC is at raising price. We thus write the first-order condition as $0 = \{\lambda[(\alpha - P) - \beta(K_j + K_\ell)] - (P - C_i)\}$. The parameter λ 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

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

This price declines with lower values of λ, and falls towards i's marginal cost C_i as $\lambda \to 0$.[14] However, our assumption A1 is equivalent to λ 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:

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

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 λ falls, that is, as OPEC becomes less effective as raising 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 $\lambda \to 0$, it almost fully accommodates changes in non-OPEC production.

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

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

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.

[14] It is easy to check that the second-order condition is satisfied for any $\lambda > 0$.

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_ℓ (given their individual costs 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

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

By A2, there is 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:

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

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

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 US shale.

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 becomes 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 US shale oil K_j is larger;
(ii) the internal cohesiveness of OPEC λ is lower;
(iii) the global demand for crude oil α is lower;
(iv) the marginal cost of US shale oil C_j is higher;
(v) the production capacity of other non-OPEC players K_ℓ is larger.

The comparative statics from Proposition 1 are intuitive. First, larger US shale oil production 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. The difference is 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 lower demand relatively favours the squeeze strategy.[15]

Fourth, higher costs of US shale oil have no impact on the accommodate equilibrium from OPEC's viewpoint: since US shale remains viable by A1, and produces up to capacity, higher costs simply mean less profits for US shale oil 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 US shale oil is sufficiently large,*

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

and otherwise accommodates if $K_j \leq \overline{K}_j$. At this "regime switch", the oil price falls discontinuously from $P^*(\overline{K}_j) = C_i + \sqrt{(1/\lambda)\left[(\alpha - C_j) - \beta K_\ell\right](C_j - C_i)}$ 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 $K_j > \overline{K}_j$. Under this condition, the subsequent gain in market share outweighs the fall in price.

[15] 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 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.

Proposition 2 thus delivers a critical value $\overline{K}_j$ for US shale oil production capacity 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.

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

Proposition 3 *(i) Suppose that an increase in US shale capacity, from $K_j' \leq \overline{K}_j$ to $K_j' > \overline{K}_j$, 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 α' to α'', induces to a regime switch from accommodate to squeeze, that is, $K_j \leq \overline{K}_j(\alpha')$ but $K_j > \overline{K}_j(\alpha'')$. This leads to an increase in OPEC's production, $S_i^{**} > S_i^*$, as long as the demand decline $\Delta\alpha \equiv (\alpha' - \alpha'') < [\{\lambda[(\alpha'' - C_j) - \beta(K_j + K_\ell)] - (C_j - C_i)\} + \beta(1+\lambda)K_j]$ is not too large.

Proposition 3 is of interest because it shows how OPEC's *optimal* supply responses can take an unexpected form. Standard intuition from economic theory, as well as the usual logic around the behaviour of a "swing producer", suggest that higher rival output and lower demand should prompt a "soft" response in 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 the optimal response to lower demand can be to produce *more*.

Numerical example. A simple numerical example illustrates the workings of the model. Let the demand conditions $\alpha = 250$, $\beta = 1$ and on the supply side let $C_i = 0$, $C_j = 50$ as well as $\lambda = 1$ and suppose that all players except i,j are inactive, i.e., $K_\ell \equiv 0$. Our parameter conditions A1 and A2 then boil down to $K_i \geq 200$ and $K_j < 150$. Using Proposition 2, it is easy to check that the critical $\overline{K}_j = 50$ and the corresponding price $P^*(\overline{K}_j) = 100$. Imagine now that player j's K_j gradually grows from zero; the price gradually falls from $P^*(0) = 125$ to $P^*(\overline{K}_j) = 100$ using (1), at which point there is a regime switch and the price crashes to $P^{**} = 50$ as i squeezes j back out of the market. In terms of supply, "OPEC" initially produces $S_i^* = (125 - \frac{1}{2}K_j) \leq 125$ under accommodation, and hence offsets growing K_j at a rate of 50%. Upon reaching $\overline{K}_j$, the squeeze requires "OPEC's" production to jump to $S_i^{**} = 200$, by Proposition 3(i), for which spare capacity is available as per A1. To check that "OPEC" indeed makes higher profits, observe that profits under accommodation $\Pi_i^* = (125 - \frac{1}{2}K_j)^2 \leq 15{,}625$ using (3) while under the squeeze $\Pi_i^{**} = S_i^{**}P^{**} = 200 \times 50 = 10{,}000$ using (5). It is easy to see that $\Pi_i^{**} \geq \Pi_i^*$ whenever $K_j \geq \overline{K}_j = 50$, as claimed.

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 then. Finally, we explain the subsequent responses of other oil-market players to this regime switch.

4.1 Drivers of regime switch

This section describes the five developments that favoured OPEC's decision to squeeze US shale (Figure 2), namely (i) weakening demand; strengthening supply from (ii) US shale, (iii) non-OPEC non-shale sources, and (iv) OPEC, as well as coordination difficulties among OPEC members. An additional factor, which acted against these, is the falling costs in US shale oil production.

1. Weakening global demand (lower α). 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 1 and 2). The slowdown was largely unanticipated. In particular, 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. According to Proposition 1, such weakening demand makes switch to a decision to squeeze more likely.

Demand for oil is structurally restrained by relatively 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 less than had been forecast (IMF, 2012; 2014). In addition, the composition of GDP growth is switching 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).

2. Higher US shale output (higher K_j). Reversing a long period 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 $9\frac{1}{4}$ mbd in 2015 (Energy Information Administration, 2013, 2015). (Using the slightly broader definition of oil reported by the IEA, US output reached an estimated 12.8 mbd in 2015.) Almost all of 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.[16] Over the two years, this was the

[16] Alternative proxies yield similar results. Production in the Eagle Ford and Bakken formations alone doubled to about $2\frac{1}{2}$ mbd, while alternative proxies reported by the World Bank (Baffes et al, 2015) indicate a doubling from 2 mbd to 4 mbd.

primary source of incremental global supply and itself would have been almost enough to match growth in global demand (Figure 2).

These 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, 2015) 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.

3. Higher non-OPEC non-shale output (higher K_ℓ). 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 (Figure 2). Although sources of growth were fairly broad-based, much of the increase came from the Americas, including 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 some surprise element to the non-OPEC non-shale rise; output for Q4 of 2014 was some 0.3 mbd higher than anticipated by the IEA in September of that year. On the net, the rise in non-OPEC output made a decision by OPEC to squeeze US shale more likely.

4. Higher OPEC spare capacity (higher K_i). The term "call on OPEC crude" is the difference between global oil demand and non-OPEC supply (and OPEC NGLs).[17] In 2014, the call declined by 1.8 mbd to 30 mbd, leaving it 1 mbd short of crude output implying $5\frac{1}{2}$ mbd of spare crude capacity. In comparison, spare capacity was only about 3 mbd in 2011. Over the same period, OPEC'S NGL capacity increased by $\frac{1}{2}$ mbd.[18]

In 2011, Libya's conflict saw its oil output collapse by two thirds (1 mbd). Libya's production was restored in 2012, but renewed political and security disruptions once again cut output by two thirds 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.

Trends in Iran and Iraq broadly offset one another between 2011 and 2014. Iraq continued to increase its capacity, with 2014 being no exception, to the surprise of many given that 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

[17] As mentioned earlier, NGLs are not part of OPEC's quota of 30 mbd.
[18] Further discussion is available in Behar and Pant (2015).

sell oil. However, the interim deal signed with the so-called p5+1 in August 2013 helped Iran's output stabilize in 2014.[19]

5. OPEC coordination difficulties (lower λ). 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 its behavior. OPEC behavior 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 the evidence is that OPEC members are more cooperative as a cartel that is possibly led by a core group of producers. Almoguera et al. (2011) conclude OPEC behaves more like (uncooperative) Cournot competitors with a non-OPEC fringe.[20]

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 λ. 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.[21]

6. 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.[22] Arezki and Blanchard (2014), citing Rystad Energy, indicate an average breakeven for North American shale of \$62, but have a range of ±\$20 to reflect variation across different US shale plays.

[19] Libya and Iran were not the only countries to experience supply disruptions. Verleger (2016) that unanticipated global supply outages rose from 1 mbd to 3mbd after 2011.

[20] Others have emphasized 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 to substitute away from oil before reserves are exhausted (Behar and Pant, 2015; Cairns and Calfucura, 2012).

[21] Reported by *The Wall Street Journal*, 6 October 2014 "Rifts in Oil Cartel Set Off Price War".

[22] 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."

They interpret this as the price at which it becomes profitable to extract. Ebinger (2014) indicates a similar range but also distinguishes between costs that include drilling and wells that have already been completed. Consistent with this, Citi estimates that half-cycle costs (around $40) could be half as low as full cycle costs.[23]. 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. Sigonney (2015) presents long term marginal costs including a 10 percent profit hurdle rate ranging from $40 to $100 as at 2014.

However, it has been widely reported that these costs have been falling, which further complicates comparability across references. Rostand (2015) calculates that breakevens, which including finding, development and extraction but exclude overheads, transport, or the weighted average cost of capital, have declined from $93 in 2009 to $58 in 2013. The main drivers include technology improvements such as shorter well completion times;[24] 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.

4.2 OPEC's actions

As the oil price decline continued in the second half of 2014, many OPEC members – principally Saudi Arabia and its neighbors – repeatedly signaled a regime switch, indicating they opposed cutting output and intended to defend market share (Middle East Economic Survey, 2014). Saudi officials have indicated their belief that shale producers' costs are high (approaching $100) and Saudi Arabia's costs are less than $10, that spare capacity is high, and that oil prices would not fall far for long (Middle East Economic Survey, 2014). Moreover, they have said market equilibrium should be restored by reductions in supply from high cost producers.[25]

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 would be consistent with the formal announcement by OPEC to squeeze US shale production rather than accommodate it.

In 2015, the call on OPEC remained at 30 mbd, yet OPEC production increased by 1.2 mbd, consistent with pursuit of market share. The biggest contributors were Saudi Arabia (0.4) mbd and Iraq (0.7) mbd, while no other major OPEC members scaled back output (Figure 2). OPEC capacity increased by $\frac{1}{4}$ mbd. However, prospects of future capacity growth were revised up in 2015, acting to re-enforce the decision to squeeze.

[23] Reported by *FTAlphaville* 8 October 2014 "It's a super market price war! (in oil)".

[24] For example, the time between permit applications and production declined by about 10 percent between the start of 2012 and 2014 (Currie, 2016).

[25] "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's Oil Minister, Mr Al-Naimi (2015: www.saudiembassy.net/announcement/announcement03041501.aspx).

In particular, confidence in Iraq's ability to continue capacity growth was restored and, unlike before, this growth would potentially coincide with growth from Iran. In particular, the final nuclear deal signed in July 2015 and subsequent actions taken by Iran brought with it the prospect of rising Iranian capacity in 2016 and beyond including initial supply from floating storage, in 2016 and beyond. Finally, Indonesia rejoined OPEC in late 2015, making more capacity available for a coordinated OPEC squeeze.[26] Consequently, despite some scaling back of investments in response to lower oil prices, the IEA (2015, 2016) increased its estimates of OPEC capacity in 2016 by $\frac{3}{4}$ mbd to 42.6 mbd between the 2015 and 2016 editions of its Medium Term Oil Market Report.

Because of an increase in the number of OPEC members and because much of the capacity growth is accounted for by traditional political rivals, discord among OPEC intensified and arguably acted to make a coordinated cut less feasible.

4.3 Market responses

The November 2014 OPEC decision accelerated the oil price decline to about $50 in the first quarter of 2015. A subsequent recovery during 2015 proved short-lived, as the excess supply pressures that had built up in 2014 did not unwind. As a result, oil was cheaper at the end of 2015 than at the start, and averaged $50 for the year as a whole. Since that decision, other structural factors have continued to favor pursing market share. In particular, US and other non-OPEC capacity has continued rising, and global demand has continued to disappoint. Importantly, OPEC output responded in a way consistent with the squeeze: it decided to increase output and not decrease it.

US shale supply started showing signs of scaling back. Following the decline in oil prices, debate shifted to the speed of the US shale supply response. As of early 2015, the response of shale was hard to determine; some commentators emphasized slowing growth in output as weakness while others pointed to ongoing rises in levels as strength. There is empirical evidence that lower oil prices lead to reduced drilling for new wells (Toews and Naumov, 2016). Rig counts initially gave mixed signals but ended the year some 62 percent lower than at the end of 2014 and at their lowest level since 1999 (Williams, 2016). Yet rig counts can be an imperfect leading indicator of output or output growth. The number of existing wells being fracked, arguably a better predictor, was still rising (*The Economist*, 2016a).

Those expecting resilient production to continue refer to efficiency gains from learning-by-doing and cost cutting. Rystad Energy Data cited in (*The Economist*, 2016b) for selected US shale plays suggests breakeven oil prices declined by about 40 percent between 2013 and 2015,[27] and recent corporate filings report cost savings of 25-30 percent per well

[26] Indonesia's crude output amounts to about 0.7 mbd. To facilitate comparison in the figures and charts presented in this section, Indonesia is classified as being part of OPEC in all years. In the calibrations to be preseted in the next section, Indonesia is only part of OPEC in the predicted data for future years (subsection 5.4).

[27] The breakevens refer to rig and drilling costs reaching $50, which likely exclude transportation as well

(IEA, 2016). Others cite oil-price hedging by producers and their ability to secure ongoing financing to sustain operations in hope of a price recovery as merely temporary factors that were delaying the inevitable.[28]

Nonetheless, in the latter parts of 2015, there were indications that US LTO levels had peaked in the middle of that year as well as clearer signs of declining output levels reported in the September 2015 edition of the OMR. This is consistent with US shale production starting to be squeezed. 2016 LTO output was revised down to about 4 mbd (EIA, 2015b). At face value, output in 2016 would be substantially lower than its peak and than in 2014. An alternative measure of the squeeze is a comparison between the latest available projections and earlier ones before low oil prices had been factored into projections. 2016 shale output was forecast to be about 5 mbd in early 2015, some 1 mbd higher than the latest available forecasts.

Non-OPEC non-shale capacity investment was cut drastically. Multinationals like BP, Chevron, ExxonMobil, Shell and Total have responded to the weaker oil price by laying off workers, cutting investment, and in some cases postponing and canceling some of their exploration projects (*The Economist*, 2016a). A widely-cited estimate by Wood MacKenzie is that close to $400 billion worth of large upstream oil & gas projects have been put on hold (as of January 2016). Non-OPEC non-shale supply is also expected to be negatively affected by decreases in Russia due to the recent tightening of sanctions on that country as well as the lower oil price outlook (IEA, 2015).

However, 2015 saw net growth of an estimated 1.2 mbd. Shell's Chief Financial Officer has reportedly stated that, having already incurred investment costs, the incentive is to produce "as flat out as you can" (*The Economist*, 2016a) and that true marginal variable costs are much lower after factoring in mothballing expenses. Russia's production increased marginally in 2015, but the sources of growth were again Canadian sands and Brazilian waters. These are both high cost oil sources and by many measures higher than for US shale. However, the price responses are much slower than is the case for US shale as the projects entail high upfront capital costs, which have already been incurred, and long project lifecycles. In other words, the coming months are the long run for many shale plays and only the short run for other oil resources.[29]

Demand growth rose as result of the lower oil price. Lower prices contributed to demand acceleration of 1.6 mbd in 2015 (IEA, 2016). However, this rise is relatively small considering the oil price decline, suggesting renewed weakness that has acted to re-enforce the market share strategy. 2015 GDP growth expectations were revised down

as capital and other "fixed" costs. For wells that have already been completed *The Economist* (2016a) reports a decline in cash costs to below $20.

[28] Verleger (2016) argues that financial market innovation has allowed allow disruptive smaller producers to withstand low prices.

[29] Non-OPEC capacity forecasts for the next 5 years have been reduced between IEA (2015) and IEA (2016), reflecting some scaling back of investment as well as the exclusion of Indonesia after it rejoined OPEC.

to $3\frac{1}{4}$ percent, which is lower than every year since 2009. In particular, growth in relatively energy-hungry Emerging Market and Developing Economies including China likely declined for the fifth consecutive year from in 2015 (Oct 2015 WEO). Moreover, demand growth is expected to slow again to 1.2 mbd in 2016 (IEA, 2016) and structural pressures on demand could also intensify after the December 2015 Paris Climate Change conference.

5 Quantitative empirical calibration

This section matches the events described above to the model through a combination of observed data and empirically supported parameter values. We start with two snapshots (in 2012 and 2014) reflecting the period before the oil price crash, confirming that the model predicts the high oil prices and relatively restrained OPEC production consistent with an "accommodate"equilibrium. We proceed to a set of three illustrative scenarios in which to demonstrate a squeeze. They show in a 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 predicted data for the future 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

Actual prices and forecasts (based on futures) are the Average Petroleum Spot Price (APSP) taken from the IMF's World Economic Outlook database, specifically those used for the January 2016 World Economic Outlook Update.

On the demand side of the model, actual historical or future forecast demand quantities in millions of barrels per day (mbd) are sourced from various issues of the MOMR and IEA (2016). A key parameter is β, which is chosen so as to ensure demand elasticities that are consistent with estimates in the literature for a relevant range of observed prices and quantities. Setting $\beta = 8$ implies an elasticity of demand of almost -0.15 when oil prices are near \$100 and around -0.07 when oil prices are at \$50. This range falls comfortably within the confines of empirical work.[30] We solve for the demand shift parameter (α) using actual demand, actual prices, and β (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, 2015).[31] For non-

[30] 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, and Mohaddes and Pesaran (2015) offer -0.21. Both of these are similar to the median among a time-varying range of elasticities in Baumeister and Peersman (2013), who themselves find elasticities have declined over time.

[31] 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 supply, capacity is assumed to be equal to actual supply. For OPEC, sustainable capacity estimates are taken from the IEA (2013,2015,2016). 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 (2016) and shale capacity is taken from EIA (2015). The IEA does not produce OPEC supply forecasts but OPEC capacity is taken from IEA (2016).

We set marginal cost for US shale based on the references in section 4.1 as well as presentations of proprietary information. Although the model is not explicitly dynamic, we include "full-cycle" marginal costs because, as discussed earlier, the full cycle is measured in months for shale and not years. In contrast, the long-run is much longer for conventional producers including OPEC, which makes the short-run marginal costs more appropriate. Numerical values will be indicated in the subsections that follow.

Our parameter for OPEC's pricing power λ 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, which included the peak in oil prices, and an earlier year, 2012, for robustness; these are represented as examples 1A and 1B in Table 1. Our main finding is that it was then still optimal for 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 β can be substituted into the demand function to solve for α 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 mbd in 2012 and 4 mbd in 2014, while OPEC capacity (K_i) remained constant other non-OPEC capacity (K_ℓ) rose.

Marginal costs are set at $C_i = \$10$ for OPEC in both years and and $C_j = \$90$ in 2012 and $C_j = \$85$ for US shale in 2012 and 2014, respectively. As discussed in subsections 4.1 and 5.1, this variable is difficult to pin down, but we choose values towards the top of the range to represent full cycle costs and allow for a modest cost reduction between 2012 and 2014. We calculate that $\lambda \approx \frac{1}{3}$ for both 2012 and Q2 2014. This is broadly consistent with the OPEC literature discussed earlier, including numerical model simulations and econometric estimates (Huppmann and Holz, 2012; Almoguera et al., 2011) which implies that $\lambda < \frac{1}{2}$.

The fitted data confirm that our theory 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.

We find that 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 $\overline{K}_j = 3.8$ in 2012 while $\overline{K}_j = 5.5$ 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 is already shrinking, so that 2014 is 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 in Table 1 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 three constructed scenarios where a squeeze is triggered and US shale output is zero. The first two separately show how higher US shale capacity and lower OPEC coordination individually trigger the switch. The third illustrative scenario combines the first two of these with lower marginal costs for US shale and lower global demand, thus capturing four of the five drivers discussed above, to generate a squeeze.[32]

Although stylized, these scenarios show our key point that the regime switch was 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 2nd half of 2014.

We in scenario 2A illustrate a case in which all demand and cost parameters (as well as λ) are held constant at 2014 levels but allow $K_j = 5.5$. Although illustrative, we chose this value because shale output was forecast to reach 5.5 mbd in 2018-2024 (EIA, 2015).[33] These forecasts would already imply a capacity in excess of the values of $\overline{K}_j$ calculated in the previous two scenarios. This, by construction, triggers a switch to a squeeze equilibrium with shale output of zero and OPEC supply of 39.7 mbd (S_i^{**} from equation 4) such that price is lower ($P^{**} = C_j = 85$) and global demand is higher. The model assumptions A1 and A2 again hold: shale output would have been positive under the counterfactual of an accommodation strategy, and OPEC indeed has the capacity required for a squeeze.

Another important development discussed in Section 4 is a decline in λ, representing OPEC's lower ability to push up prices. In scenario 2B, we again hold all the 2014 parameters constant, including $K_j = 4$, but now use Proposition 2 to solve for the critical value of λ such that $K_j = \overline{K}_j(\lambda)$. With this value for λ, 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 that in scenario 1B (for which $\lambda = 0.36$); this implies that a

[32] Changes in OPEC capacity are only indirectly important for ensuring A1 and A2 hold.

[33] The rise in (forecast) shale oil capacity can be seen as the latest in a sequence of persistent positive surprises and 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.

small reduction in λ is already enough to trigger the decision to squeeze.

The illustrative scenarios so far imply prices well above those observed in late 2014 and early 2015. Our scenario 2C generates a lower price by allowing multiple parameters to shift in a manner that is qualitatively consistent with Section 4. As discussed earlier, a number of commentators have pointed to the declining marginal costs of US shale, especially since oil prices began to fall, so we set $C_j = 55 = P^{**}$.[34] Given this lower price, setting demand to that observed for 2015 implies a sizeable decline in the solved value of α (relative to 2014), which implies a weakening in global demand. Thus, although lower US costs discourage the squeeze, the negative demand shift encourages it. Letting US shale capacity $K_j = 5.5$, we again use Proposition 2 to find the value of λ for which $K_j = \overline{K}_j(\lambda)$ such that the solved value can be interpreted as the maximum value of λ 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 the accommodate equilibrium (S_i^{*}).

In summary, scenario (2C) generates a squeeze equilibrium with a more realistic oil price through higher US shale capacity, lower OPEC pricing power, weaker demand, and falling production costs. 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 (which point to accommodation).

5.4 Future squeeze equilibria

This subsection recalibrates the model using forecasts of 2020 oil market data. The first retains the notion of all US shale being squeezed out of the market by then. The second allows for some US shale to remain active. These squeeze equilibria imply that the market-share strategy can be rationalized economically as a "less-bad" option for OPEC in the future, and also yield more plausible forecasts for OPEC output than would be the case in an accommodate equilibrium.

In equilibrium 3A, the oil price for 2020 of \$58 is used to pin down marginal cost for US shale oil of $C_j = \$58$. By assumption, β is unchanged. The demand shift parameter (α) is solved as before, except this time using third-party forecasts of P and D as described in subsection 5.1 rather than historical values, and increases by a plausibly moderate amount between 2014 and 2020. As per Proposition 2, $K_j = 5.6$ based on EIA (2015) and so $K_j = \overline{K}_j(\lambda)$ when $\lambda = 0.21$. Equivalently, $\lambda \leq 0.21$ is sufficient for a squeeze.

Hence, as per (4), OPEC supply is $S_i^{**} = 41.6$ mbd. Under a counterfactual accommodate equilibrium as per (2), OPEC supply (S_i^{*}) would be about 7 mbd lower, shale output would equal capacity, and price would be \$75 (this is not shown in Table 1). It can be confirmed that A1 holds, which means that US shale would viably be able to pro-

[34] This value is only illustrative and was chosen to bring price close to the average observed in 2015. Nonetheless, it is close to the mid-point of more recent cost estimates and would also imply a decline broadly in line with some claimed cost reductions since the start of the squeeze.

duce at capacity in 2020 were it not for OPEC's decision to squeeze them out. A2 holds, which means that OPEC capacity will by then have grown sufficiently to expand output by enough to execute the squeeze.

A less stylized 2020 equilibrium includes non-zero US shale output in a way that reduces OPEC supply while leaving global supply, prices, and demand unaltered. In particular, equilibrium 3B relaxes the assumption that US shale is a homogenous group and instead allows for varying costs such that the futures price of $58 would only squeeze out those with higher costs. In terms of the model setup, this is equivalent to n being the subset of US shale capacity consisting of those shale plays with costs above $58.

In particular, setting $K_j = 3$ and following the same procedure as in equilibrium 3A,[35] a squeeze equilibrium would result in OPEC producing 38.6 mbd and US shale producing 2.6 mbd instead of its capacity of 5.6 mbd. We find that $K_j = \overline{K}_j(\lambda) = 3$ when $\lambda = 0.17$. Intuitively, for it to be worth squeezing out about half of US shale oil, the accommodate equilibrium would have to be even less attractive. Other things equal, this would be plausible given deteriorating prospects for OPEC coordination.

An interesting implication of this low value of λ is that the counterfactual price under the accommodate equilibrium is now only $5 higher than the squeeze price. In this sense, US shale oil effectively becomes the price-setter in this future scenario *regardless* of which equilibrium is played.

6 Conclusions

The debate on the rationale for and the repercussions of OPEC's November 2014 switch to a "market-share" strategy has drawn considerable attention in energy markets. Many oil-market analysts—and OPEC itself—viewed 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 OPEC's regime switch as a profit-maximizing strategy. Such a shift can explain why OPEC supply can optimally rise in response to US shale growth 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 plausible updates to OPEC's information set prompted a switch to a market-share strategy in late 2014. 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

[35] This choice of $K_j = 3$ is in line with proprietary estimates of values by shale oil field and with the median and range published by Arezki and Blanchard (2014).

the OPEC strategy in the coming years. As of early 2016, the squeeze appears to have been less successful than OPEC might have calculated: a substantial decline in US shale output does not (yet) appear imminent, and the squeeze has perhaps provided more costly than anticipated given the continued decline in oil prices (IEA, 2016). One potential reason is that the costs of US shale have fallen more strongly than might have been anticipated. In terms of our framework, this could prompt a further OPEC regime switch back to accommodate. 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. This paper has not pretended to forecast the future of the industry but rather to provide a coherent economic framework to think about the key drivers of such regime switches, including the one that took place at the end of 2014.

Finally, while we have focused on the oil market, we note that our approach can also be applied to understand competition in other energy-intensive sectors. For example, natural gas is also characterized by significant supply-side concentration. In the EU, Gazprom plays a dominant role in the sense 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 production 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.

References

[1] Almoguera, Pedro A. Christopher C. Douglas, and Ana Maria Herrera (2011). “Testing for the cartel in OPEC: Non-cooperative collusion or just non-cooperative?” *Oxford Review of Economic Policy*, 27(1):144–168

[2] Andrade de Sa, Saraly and Julien Daubanes (2014). “Limit Pricing and the (In)Effectiveness of a the Carbon Tax.” Working Paper at ETH Zurich, November 2014.

[3] Arezki, Rabah and Olivier Blanchard (2014), “Seven Questions About The Recent Oil Price Slump.” *iMFdirect blog.* Posted 22 December 2014.

[4] Atkins, Frank and Tayyebi Jazayeri (2004), “A Literature Review of Demand Studies in World Oil Markets”. *University of Calgary Department of Economics Discussion Paper*, 2004-07.

[5] Baffes, John, M. Ayhan Kose, Franziska Ohnsorge, and Marc Stocker. "The Great Plunge in Oil Prices: Causes, Consequences, and Policy Responses." *Development Economics Group Research Note, PRN/15/01.* World Bank.

[6] Baumeister, Christiane and Lutz Kilian (2015). "Understanding the Decline in the Price of Oil Since June 2014". *CEPR Discussion Paper*, 10404

[7] Baumeister, Christiane and Gert Peersman (2013). "The Role of Time-varying Price Elasticities in Accounting for Volatility Changes in the Crude Oil Market". *Journal of Applied Econometrics*, 28:1087-1109

[8] Behar, Alberto and Malika Pant (2015). "Outlook for the Global Oil Market and Implications for Saudi Arabia," In Ahmed Al-Darwish, Naif Alghaith, Alberto Behar, Tim Callen, Pragyan Deb, Amgad Hegazy, Padamja Khandelwal, Malika Pant, and Haonan Qu, *Saudi Arabia: Tackling Emerging Economic Challenges to Sustain Growth.* International Monetary Fund Middle East and Central Asia Department. Washington, DC.

[9] Beidas-Strom, Samya and Carolina Osorio-Buitron (2015). "The Oil Price Collapse: Demand or Supply?". *Uneven Growth: Short- and Long-Term Factors, World Economic Outlook, April 2015.* International Monetary Fund. Washington, DC.

[10] Bremond, Vincent, Emmanuel Hache and Valerie Mignon (2012). "Does OPEC still exist as a cartel? An empirical investigation". *Energy Economics*, 34:125-131.

[11] Brusseau, Alain (2016). *Oil Market Developments.* Mimeograph. International Monetary Fund. 3 February

[12] Cairns, Robert and Enrique Calfucura (2012). "OPEC: Market failure or power failure?". *Energy Policy*, 50 : 570-580.

[13] Ebinger, Charles (2014), "World Oil Demand: And Then There Was None". *Brookings PlanetPolicy.* Posted 17 October 2014.

[14] Energy Information Administration (2014). *Annual Energy Outlook 2014.* Washington, DC.

[15] Energy Information Administration (2015). *Annual Energy Outlook 2015.* Washington, DC.

[16] Energy Information Administration (2015b). *Short-term Energy Outlook, September 2015.* Washington, DC.

[17] Fattouh, Bassam and Lavan Mahadeva (2013). "OPEC: What Difference Has It Made?". *Annual Review of Resource Economics*, 5:427-443

[18] Fattouh, Bassam, Rahmatallah Poudineh and Anupama Sen (2015). "The Dynamics of the Revenue Maximization - Market Share Trade-off: Saudi Arabia's Oil Policy in the 2014-2015 Price Fall". *Oxford Institute for Energy Studies Working Paper*, WPM 61.

[19] Hamilton, James D. (2009). "Understanding crude oil prices." *The Energy Journal*, 30(2): 179–206

[20] Hamilton, James D. (2015). "Demand factors in the collapse of oil prices." *Econbrowser blog*, posted 11 January 2015.

[21] Henderson, James (2016). Gazprom – Is 2016 the Year for a Change of Pricing Strategy in Europe? Working Paper at Oxford Institute for Energy Studies, January 2016.

[22] Huppmann, Daniel (2013). Endogenous Shifts in OPEC Market Power: A Stackelberg Oligopoly with Fringe. Working Paper at DIW Berlin, July 2013.

[23] Huppmann, Daniel and Franziska Holz (2012). Crude oil market power: A shift in recent years? *The Energy Journal*, 33(4):1–2

[24] Huppmann, Daniel and Franziska Holz (2015). What about the OPEC Cartel? *DIW Roundup: Politik im Fokus*, 58.

[25] Hussain, Aasim, Rabah Arezki, Peter Breuer, Vikram Hassar, Thomas Helbling, Paulo Medas, Martin Sommer, and an IMF Staff Team (2015). "Global Implications of Lower Oil Prices". *International Monetary Fund Staff Discussion Note*, SDN/15/15.

[26] International Energy Agency (2013). *Medium-term Oil Market Report, 2013.* Paris.

[27] International Energy Agency (2014). *Medium-term Oil Market Report, 2014*. Paris.

[28] International Energy Agency (2015). *Medium-term Oil Market Report, 2015.* Paris.

[29] International Energy Agency (2016). *Medium-term Oil Market Report, 2016.* Paris.

[30] International Monetary Fund (2012). *Coping with High Debt and Sluggish Growth, World Economic Outlook, October 2012*. Washington, DC

[31] International Monetary Fund (2014). *Legacies, Clouds, Uncertainties, World Economic Outlook, October 2014*. Washington, DC

[32] Killian, Lutz and Daniel Murphy (2014). "The Role of Inventories and Speculative Trading in the Global Market for Crude Oil". *Journal of Applied Econometrics*, 29:454-478.

[33] Middle East Economic Survey (2014). *Saudi Sees $90/B Crude As Price Floor.* 3 October 2014.

[34] Mabro, Robert (1998). “The Oil Price Crisis of 1998”. *Oxford Institute for Energy Studies*, SP 10.

[35] Mohaddes, Kamiar and M. Hashem Pesaran (2015). Country-Specific Oil Supply Shocks and the Global Economy: A Counterfactual Analysis. *Cambridge EPRG Working Paper*, 1512.

[36] Mohaddes, Kamiar and Mehdi Raissi (2016). The U.S. Oil Supply Revolution and the Global Economy. *Cambridge EPRG Working Paper*, 1604.

[37] Nakov, Anton and Galo Nuno (2013). Saudi Arabia and the Oil Market. *Economic Journal* 123, 1333-1362.

[38] Rostand, Antoine (2015). *What Future Evolution for US Light Tight Oil?.* Schlumberger Presentation, World Policy Conference, 21 November 2015.

[39] Sigonney, Pierre (2015). *International Oil Companies in the Evolving Energy Landscape.* Total Presentation, World Policy Conference, 21 November 2015.

[40] Smith, James (2005) “Inscrutable OPEC: Behavioral Tests of the Cartel Hypothesis,” *The Energy Journal* 26(1), 51–82.

[41] Smith, James (2009). “World Oil: Market or Mayhem?”. *Journal of Economic Perspectives* (vol. 23, no. 3, 2009).

[42] The Economist (2015). *The oil industry: After OPEC.* 16 May 2015.

[43] The Economist (2016a). *Oil Conundrum.* 23 January 2016.

[44] The Economist (2016b). *DUC and cover.* 12 March 2016.

[45] Tirole, Jean (1988). *The Theory of Industrial Organization.* MIT Press.

[46] Toews, Gerhard and Alexander Naumov (2016). The Relationship Between Oil Price and Costs in the Oil Industry. *The Energy Journal* 36, 237–254.

[47] Verleger, Philip K. Jr. (2016). Structure Matters: Oil Markets Enter the Adelman Era. *The Energy Journal* 36, 129–157.

[48] Williams, James (2016). *North America Rotary Rig Counts.* WTRG Economics. 5 January 2016.

[49] Yergin, Daniel (2008). *The Prize: The Epic Quest for Oil, Money & Power.* Free Press. New York.

Appendix A: Proofs

Proof of Proposition 1. Using (3) and (5), the difference in OPEC profits $\Delta\Pi_i \equiv (\Pi_i^{**} - \Pi_i^{*})$ between the two strategies equals

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

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

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

is implied by A1, and

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

holds whenever $\lambda < 1$, and

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

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

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

holds by A1, and finally

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

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

$$\Delta\Pi_i(\alpha, \beta, \lambda, C_i, C_j, K_j, K_\ell) > 0 \iff K_j > \overline{K}_j \quad ,$$

where $\overline{K}_j$ is defined in the proposition. Plugging the critical value $\overline{K}_j$ into (1) yields:

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

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

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

so we require that $\overline{K}_j < \widehat{K}_j$. Performing the calculations shows that:

$$\begin{aligned} \overline{K}_j &< \widehat{K}_j \iff \\ (\alpha - C_i) - (1+\lambda)\sqrt{\frac{1}{\lambda}\left[(\alpha - C_j) - \beta K_\ell\right](C_j - C_i)} &< (\alpha - C_i) - \frac{(1+\lambda)}{\lambda}(C_j - C_i) \iff \\ \frac{1}{\lambda}(C_j - C_i) &< \sqrt{\frac{1}{\lambda}\left[(\alpha - C_j) - \beta K_\ell\right](C_j - C_i)} \iff \\ (C_j - C_i) &< \lambda\left[(\alpha - C_j) - \beta K_\ell\right] \end{aligned}$$

where 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 strategy, $P^{**} < P^*$ by Proposition 2, market demand is higher, $D(P^{**}) > D(P^*)$ because demand is downward-sloping. Since production from non-OPEC ex-US players K_ℓ is unchanged, it follows that OPEC's production must also be higher, that is, $S_i^{**} \equiv \{D(P^{**}) - K_\ell\} > \{D(P^*) - K_j - K_\ell\} \equiv S_i^*$.
For part (ii), using the previous expressions for i's demand from (1) for α' and (2) for α'' shows that $S_i^{**}(\alpha'') > S_i^*(\alpha')$ is equivalent to:

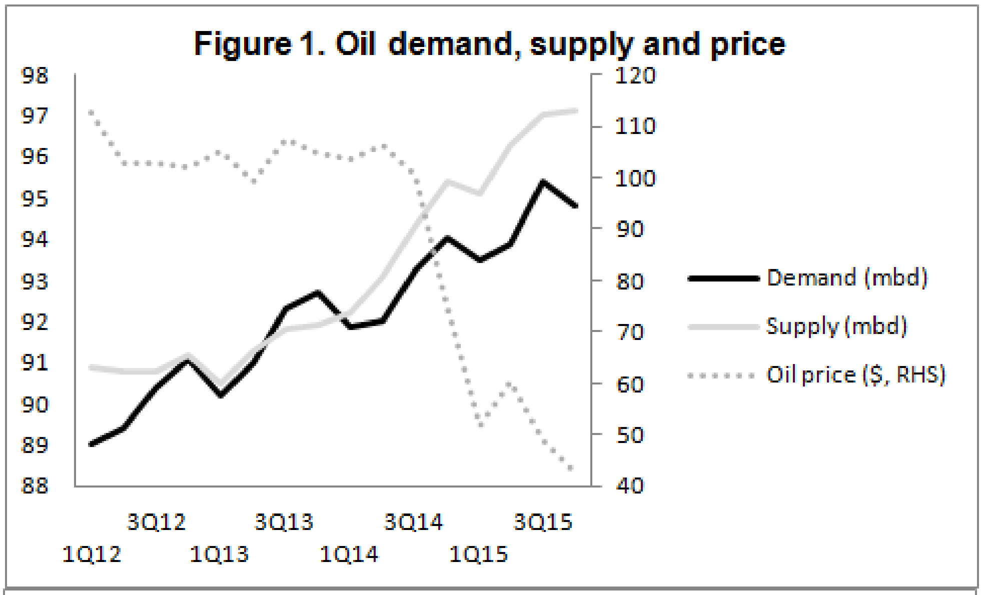
$$\begin{aligned} \frac{(\alpha'' - C_j)}{\beta} - K_\ell &> \frac{[\alpha' - \beta(K_j + K_\ell) - C_i]}{(1+\lambda)\beta} \iff \\ \lambda[\alpha'' - C_j - \beta K_\ell] + \beta K_j &> (\alpha' - \alpha'') + (C_j - C_i) \iff \\ \left\{\lambda[(\alpha'' - C_j) - \beta(K_j + K_\ell)] - (C_j - C_i)\right\}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

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): IMF World Economic Outlook database (January 2016 World Economic Outlook Update vintage)
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; α solved for using P, D, and β
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 non-shale 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: In line with industry reports; equal to oil price forecasts (squeeze).
OPEC marginal cost: As per industry reports.
OPEC coordination power: determined endogenously.



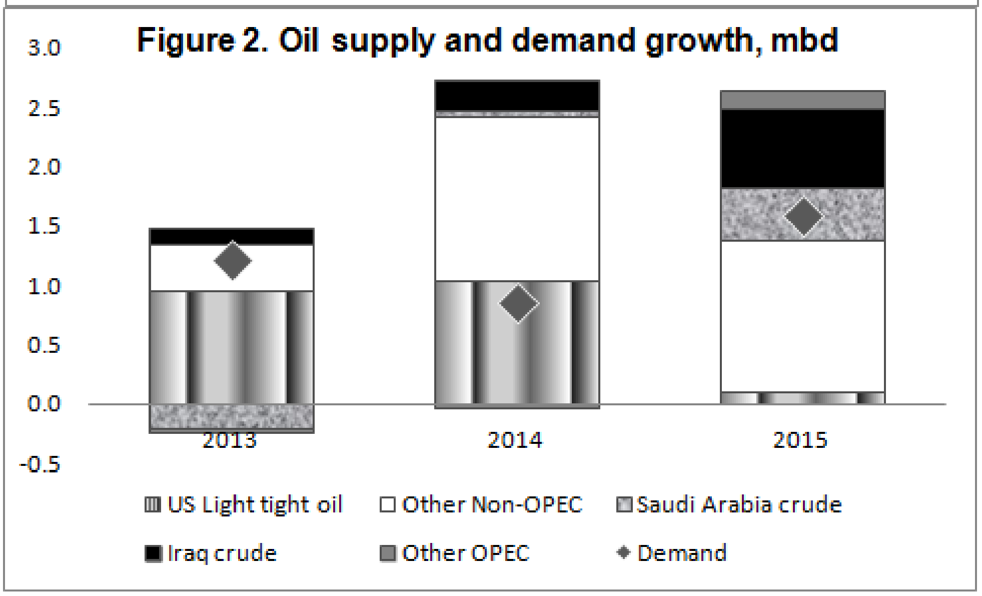


Table 1: Calibrating the model

	Scenario:	Accommodate examples		Squeeze scenarios (using 2014Q2)			Squeeze equilibria	
		1A	1B	2A	2B	2C	3A	3B
		2012	2014Q2	High K_j	Low λ	Multiple*	2020	2020
							All shale	Some shale
P	Price ($/barrel)	105	106	85	85	55	58	58
D	Demand (mbd)	90.7	92.0	94.7	94.7	94.4	100.5	100.5
β	Inverse demand slope parameter	8.0	8.0	8	8	8	8.0	8.0
$P(D\beta)^{-1}$	Demand elasticity	-0.14	-0.14	-0.11	-0.11	-0.07	-0.07	-0.07
α	Demand shift parameter (mbd)	831	843	843	843	810	862	862
$\alpha(\beta)^{-1}$	Demand shift parameter (mbd)	104	105	105	105	101	108	108
S	Global supply actual	90.9	95.4				100.5	100.5
S_i	Leader supply actual	37.6	36.4					
S_i^*	Leader supply (accommodate)	37.4	33.1	32.0	34.2	32.8	34.8	38.0
S_i^{**}	Leader supply (squeeze)	41.2	39.7	39.7	39.7	39.4	41.6	38.6
K_i	Leader capacity	41.3	41.4	41.4	41.4	41.4	43.5	43.5
K_j+K_l	Follower supply (mbd)	53.3	59.0	60.5	59.0	60.5	58.9	61.9
K_j	Shale capacity (mbd)	2.0	4.0	5.5	4.00	5.5	5.6	3.0
K_l	ROW capacity (mbd)	51.3	55.0	54.96	54.96	54.96	58.9	58.9
K_i+K_l	Non-shale capacity (mbd)	92.7	96.3	96.35	96.35	96.35	102.4	102.4
C_i	Marginal cost (OPEC)	10	10	10	10	10	10	10
C_j	Marginal cost (non-OPEC)	90	85	85	85	55	58	58
λ	OPEC co-ordination power	0.32	0.36	0.36	0.32	0.21	0.21	0.17
Conditions checks								
A1		holds	holds	holds	holds	holds	holds	holds
left		80	75	75	75	45	48	48
right		100	104	100	91	56	69	53
A2		holds	holds	holds	holds	holds	holds	holds
left		741	758	758	758	755	804	804
right		741	771	771	771	771	819	819
Regime conditions								
Proposition 2		Accomm.	Accomm.	Squeeze	Squeeze	Squeeze	Squeeze	Squeeze
$K_j - \overline{K}$		-1.8	-1.5	0.0	0.0	0.0	0.0	0.0
$\overline{K}$		3.8	5.5	5.5	4.0	5.5	5.6	3.0

* Setting C_j lower and K_j higher; allowing λ and α to shift lower endogenously.