Mothballing in a Duopoly: Evidence from a (Shale) Oil Market

Nicola Comincioli[a], Verena Hagspiel[b], Peter M. Kort[c,d], Francesco Menoncin[a], Sergio Vergalli[a]

[a]*Department of Economics and Management, University of Brescia, Brescia, Italy*
[b]*Department of Industrial Economics and Technology Management, Norwegian University of Science and Technology, 7491 Trondheim, Norway*
[c]*Department of Econometrics and Operations Research & CentER, Tilburg University, LE 5000 Tilburg, The Netherlands*
[d]*Department of Economics, University of Antwerp, 2000 Antwerp, Belgium*

Abstract

The combination of horizontal drilling and hydraulic fracturing to produce oil and natural gas has grown dramatically over the last few years taking the market by surprise with the name of "Shale Revolution". The first effects of shale revolution have been an increase of oil and gas supply, especially for the US and a drop in crude oil prices in 2014-2016. One of the remaining open question is why OPEC did not react reducing production to maintain high prices. In the literature the answer falls into three main categories: (1) OPEC tried to defend its market share by flooding the market in an attempt to drive out shale producers; (2) the shale oil revolution changed the market weights leaving the only choice to accept low prices; (3) OPEC was uncertain about the potential of shale oil and needed to test its resilience under low prices. In order to better study and understand the market strategies, we propose a real options model where a leader and a follower producer play a continuous output game. We solve the theoretical model and perform an empirical estimation to analyze the strategy of OPEC versus shale oil producers.

The global oil market is experiencing many changes especially due to new technologies used to extract crude oil and natural gas. The combination of horizontal drilling and hydraulic fracturing to produce oil and natural gas was developed in the 1970s (Mănescu and Nuňo (2015)) but has grown dramatically over the last few years taking the market by surprise with the name of "Shale Revolution"[1]. In 2013 the Unites States production is estimated to have produced 3.5 mb/d of shale oil which is three times higher than the amount it produced in 2010 (Energy Information Administration-EIA, 2014). The level of US crude oil production reached almost that of Saudi Arabia and Russia in 2015 (Bataa and Park (2017)). By 2020, US shale oil is estimated to reach 4.8 mb/d, representing about a third of total US supply (Mănescu and Nuňo (2015)). Therefore, the first effect of shale revolution has been (and probably will be) an increase of oil and gas supply, especially for the US. The second (indirect) effect is on the 2014-2016 drop in crude oil prices[2]. Indeed, as pointed out

[1]Formally, shale oil refers to a subset of unconventional oil (know as "tight oil") in which conventional oil (light oil with low sulphur content) is trapped in very low-permeability tight formations (known as shales) which makes extraction difficult. However, as stressed by Mănescu and Nuňo (2015) "the convention in the press is to use the terms *shale oil* and *tight oil* interchangeably when referring to oil extracted from all low-permeability formations (i.e. not only oil from shale formations)". Therefore, we follow this convention throughout the paper and refer to the entire tight oil category as "shale oil'".

[2]The Western Texas Intermediate (WTI) crude oil price reached U.S.$26.21 per barrel in February 2016, which is a record low since July 2002, while the U.S. real import price fell more than 73% June 2014–February 2016, making it the most rapid decline within this time frame since 1973.

by Ansari (2017), "although results have given evidence for a variety of drivers, including demand and geopolitical circumstances, the shale oil revolution is widely considered to be the main driver of price developments". This has also been a profound implication for global strategic competition in the oil market. Let us remind that the fluctuations of international crude oil prices could have huge impacts (Chen et. al, 2016) on the economic output (Wei et al., 2008; Wang and Zhang, 2014), inflation and unemployment (Uri (1996); Du et al., 2010), stock market (Cong et al. (2008)) and fundamental industries (Jiao et al., 2012). Therefore, it is very important to study price fluctuation and the commodities market strategies also for policy makers. Given the increase of US oil supply and therewith, increasing competition in the oil market, the expected reaction of OPEC was a reduction of supply to maintain price and profit shares. Surprisingly, OPEC maintained stable production.

Therefore, many analysts predicted that a new normal era for the global oil market had begun, and that the oil price would remain somewhere between U.S.$35 and U.S.$50 per barrel in the future (see Hartmann and Sam (2016) and Barnato (2016) 'Oil's new normal may be lower than you think,' CNBC May 31, 2016.)

One of the remaining open question is why OPEC did not react reducing production to maintain high prices. There is no consensus regarding the reason behind OPEC's initial decision. Researchers' results in these regards fall into three main categories: (1) OPEC tried to defend its market share by flooding the market in an attempt to drive out shale producers (Behar and Ritz (2017); Brown and Huntington, 2017; Coy, 2015; Gause, 2015; Mănescu and Nuño, 2015); (2) the shale oil revolution nullified OPEC's market power (shale oil has taken OPEC's role as the swing producer), leaving its members no choice but to accept low prices (Baffes et al., 2015; Baumeister and Kilian, 2016; Dale, 2016; Kaletsky, 2015; The Economist, 2015); and (3) OPEC was uncertain about the potential of shale oil and needed to test its resilience under low prices (Fattouh et al., 2016; Huppmann and Livingston, 2015).

The first category is in line with a standard market entry game: in a dynamic environment, if a new player wants to enter in the market, it may be rational for the incumbent firm to enforce a downward-pressure on prices in order to drive out the contestant, despite short-run losses for the incumbent. In this line, Behar and Ritz (2017) show that increasing the conventional oil supply is the dominant strategy when shale costs are high. The algebraic analysis of their approach reveals discontinuous best responses. This could mean that a switch to the flooding strategy occurs when parameter thresholds are crossed, which is why market prices may jump as a response to even small parameter shocks. Nevertheless, for the incumbent's threat to work, it requires (i) effectiveness, (ii) credibility, and (iii) temporal sustainability.

The second category claims that these conditions could not hold and that OPEC had to accept the presence and dominance of US shale oil. The quick expansion of shale resulted in a change of the weights in the market: the quick responsiveness of shale oil creates competition in which shale oil can substitute conventional OPEC oil. The effect is that the only remaining choice for OPEC is to follow the rules of competition. Baffes et al. (2015) note that OPEC's decision to freeze output, "implies that OPEC will no longer act as the swing oil producer [and that] ... marginal cost of unconventional oil producers may play this role."

Lastly, a possible third explanation is that OPEC was driven by uncertainty and a desire for industry consolidation. Indeed, a pragmatic OPEC most likely attempted to gain crucial information regarding shale's performance in lower price ranges (Huppmann and Livingston; 2015). In a more formal way, Fattouh et al. (2016), by using a parametrised static game under uncertainty show that, without sufficient knowledge about US shale elasticity, it is rational for Saudi Arabia not to cut output. Hence, there is a strong incentive for Saudi Arabia to learn which game it is playing.

Also recently the relationship among shale revolution, oil prices and strategies in the energy markets has been an interesting topic[3] that has pushed research and discussion. In order to understand the strategic behaviour of conventional and unconventional oil producers in a context of uncertainty better, we develop a real option framework between leader and a follower producer.

We consider two firms, representing OPEC and a representative shale-oil producer. Firm 1 (OPEC in the example) is the market leader and the more efficient producer. Upon investing paying a sunk cost I_1, Firm 1 is flexible in the sense that it is able to produce any production amount $q_1(t)$ it wants. Firm 1's production costs are zero.

Firm 2 is less efficient (Shale-oil producer in the example). Whenever it is in the production stage, it incurs a positive cost C. To be able to produce, Firm 2 must invest I_2. Firm 2 is a dedicated (non-flexible) producer in the sense that it either can produce a fixed $\bar{q}_2$ or zero. The firm is able to mothball. When it is in a mothballing state it does not produce and has to pay maintenance costs equal to $M < C$. To go from the production to the mothballing stage, Firm 2 incurs a sunk cost E_M. To restart production, i.e. going from the mothballing to the production stage, requires spending a sunk cost being equal to R.

We assume that the inverse demand function is given by

$$p = X(\alpha - \eta Q),$$

with

$$dX = \mu X dt + \sigma X dz,$$

Here dz is the increment of a Wiener process. Furthermore, Q is the total market output, i.e. either

$$Q = 0,$$

if none of the firms are active producer, or

$$Q = q_1(t),$$

if only Firm 1 produces actively, or

$$Q = q_1(t) + \bar{q}_2,$$

if both firms produce actively.

We assume that the two firms are playing a Stackelberg production game with Firm 1 as the Stackelberg leader, starting at the moment that the follower enters the market. We motivate this by the fact that OPEC was playing its strategy against shale producers that are already in the market. Therefore, in setting the output, Firm 1, as the Stackelberg leader, announces its output first. Then Firm 2 reacts. It either chooses to be active. i.e. $q_2 = \bar{q}_2$, or q_1 is so large, and thus price p is so low, that Firm 2 refrains from production so that $q_2 = 0$ (this is what happened in Vienna on November 30).

Figure 1 illustrates the investment and output game. In this work we first focus on the production output game, deriving the optimal strategy of the leader using the fact that it is

[3] In the Economist Espresso from November 30, 2017, we read about an OPEC meeting in Vienna. Among others, it states that "soaring prices would further stimulate American shale production". In the Economist Espresso from December 1, 2017, it is stated that "OPEC agreed to extend its oil-production cut of 1.8m barrels per day by nine months, to the end of 2018. The cartel is walking a fine line in trying to draw down global surpluses and nudge prices up without sparking new production by nimble American shale producers".

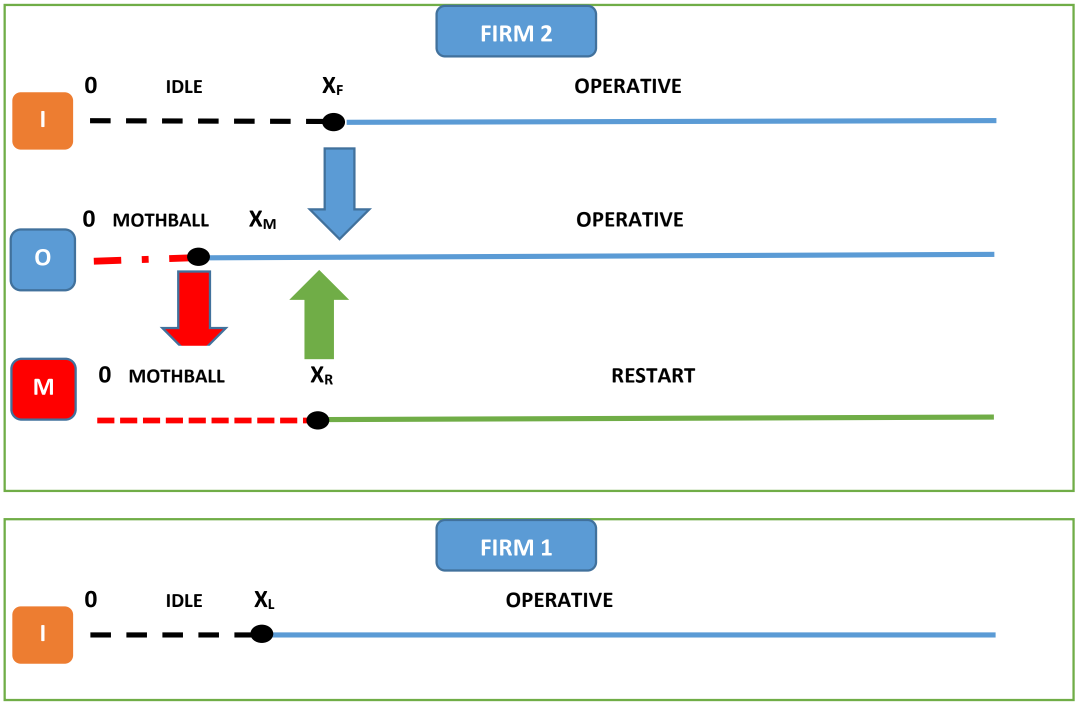

Figure 1: Illustration decision problem of both firms.

able to produce flexible as opposed to the leader. Given the solution of the theoretical model we then estimate the model parameters empirically.

The theoretical model described is based on a peculiar demand function for oil, according to which prices are linear in quantities but parameters describing this relation are shocked by an unobserved GBM, whose behavior depends on a specific set of parameters. Since the interaction of the market leader and follower is modeled in a framework in which the oil price plays a central role, we first need to estimate the whole set of four parameters (slope and intercept of the linear inverse demand function and drift and diffusion parameters of the GBM) describing price behavior in order to obtain an empirical validation of the model. In a second step we use these estimates to compute the triggers at which a change-in-state occurs (from the operation to the mothballing state and vice versa). Finally, we validate the model with observed market data.

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