

# HOW SHALE FRACTURED THE OPEC OLIGOPOLY: A GAME THEORY ANALYSIS OF THE OIL MARKET IN 2015

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*Richard Roberts deftly applies the principles of game theory to the oil market's shift from a cartel-driven to a supply and demand based equilibrium. In his model, the dominant Organization of the Petroleum Exporting Countries play against US Shale Producers, who wish to enter the market. In a complex crisis, his clear treatment of the strategic game draws conclusions which can help to explain the dramatic fall in prices.*

## **Introduction**

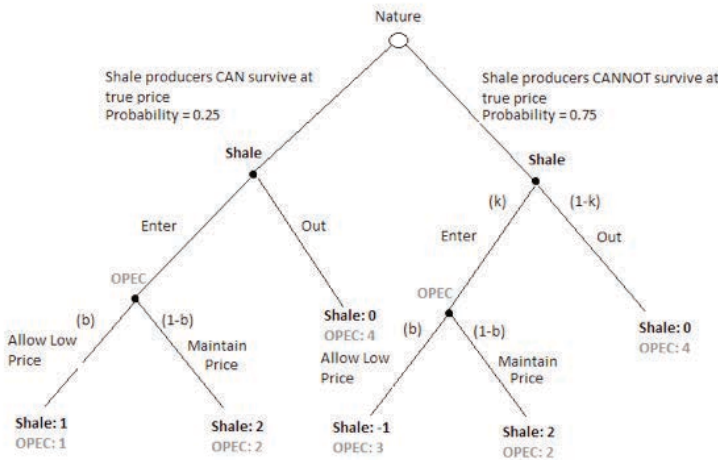
The Organisation of the Petroleum Exporting Countries (OPEC) is an oft-cited example of an oligopoly in introductory economic textbooks. Its ability to essentially dictate the global price of oil in recent decades rather than allowing market forces to determine a true equilibrium price has secured steady and regular returns to member countries. Rather than striving to compete through efficiency and lower prices that would benefit consumers, a number of oil producing economies have instead united to impose price rigidity on the market. Moreover, the significant barriers to entry associated with the incredibly high capital costs of entering the industry, combined with the threat of predatory pricing and the insatiable global demand for oil, has allowed these nations to maintain their dominance despite such uncompetitive behaviour. However, this long standing market dynamic has begun to change. The economic slowdown in China has precipitated a faltering in global demand and this combined with the influx of US shale producers has undermined the supremacy of OPEC.

In June 2014, the price of Brent Crude oil was close to \$100 per barrel. It has now dipped below \$40, representing a nadir in a seven year period since the global economic crisis. This dramatic rout of oil prices is strongly linked to the rise of fracking technology and the resulting global supply glut that has forced OPEC to reconsider its pricing strategy. 'Fracking' refers to hydraulic fracturing, a process whereby a mixture of water, sand and chemicals is blasted into underground shale rocks with the intention of releasing

reserved fossil fuels. Improvements in this technology, combined with the use of horizontal drilling techniques, allowed oil to be extracted from shale rock at commercially viable costs leading to a boom in the U.S. oil industry. This shale revolution has seen U.S. production swell from 5.4 million barrels per day in 2009 to 9.4 million in 2015 (Crooks, 2015) leading to a significant increase in the global supply of oil and presenting OPEC with a decision to make regarding its policy of price rigidity.

In the face of mounting pressure from this surge in oil production and wavering global demand, OPEC met in November 2014 to decide on the best course of action. In a seminal moment in the history of the oil industry, the members of OPEC, led by their de facto leader Saudi Arabia, took the decision not to reduce their official production level and effectively allow market forces to determine the price of oil for the first time since the 1970s, fearing that any contraction in volume would be quickly filled by marginal barrels from the shale producers (Crooks, 2015). The decision to essentially ignore production ceilings was officially corroborated in December 2015 but had for all intents and purposes been the case since that pivotal meeting in November 2014 (Shenk, 2015). This resolution from OPEC implied a seismic shift in their strategy away from dictating prices and towards protecting market share from the usurping forces of non-OPEC producers. The following game theory model outlines the decisions faced by OPEC and by the US shale producers during this period.

### Model



## Outline

The model, above, represents an extensive form game with incomplete information. It illustrates the scenario outlined in the introduction section whereby a dominant organization, OPEC, is confronted by the possibility of the entry of a new player in the industry. This game diverges from similar challenger/incumbent situations by way of the presence of incomplete information. The incumbent, OPEC, is not privy to the cost structure of the new entrant and is unsure of whether or not they could survive at the low price which would arise were they to cease their price rigidity strategy. OPEC is, however, aware of the probability that such an entrant to the market can survive at the lower oil price. OPEC must make a decision to either maintain the false price as they have done previously but lose market share and thus profits to the entrant or, alternatively, forgo this traditional tactic and trust that the Shale Producers will be driven out by an oil price below their average cost.

The type space for the Shale Producers consists of two types; one in which the Shale Producers can survive at the true market price of oil and one in which they cannot survive. Type 1 has probability 0.25 and Type 2 has probability 0.75. To model this random variable, Nature is introduced to the game as a third player and moves first to determine which type the Shale Producers will take on. After Nature moves, only the Shale Producer is aware of its type i.e. OPEC remains oblivious and must rely on the probability distribution to guide its strategy.

## Assumptions

There are a number of governing assumptions associated with this game. Firstly, it is assumed in this model that OPEC are totally ignorant of the cost curve faced by the Shale Producers and that they have no means of estimating same. Rather, they must choose their strategy on the basis of probability. In reality, OPEC could well have a reasonable approximation of the marginal and average costs of producing shale oil based on their own data and also from freely available financial statements of publicly listed firms. If this is the case, OPEC could use this information to guide their decision on whether or not to allow prices to fall.

Secondly, this model assumes that there are just two players in the market-OPEC and Shale Producers. This is a simplification of the real world oil industry where, although OPEC is responsible for upwards of 40 per cent of global oil supply, there are a number of other players such as Russia, China and Brazil who can also influence market prices. This assumption is not overly-constraining as the price-setting power of the OPEC cartel is well-recognized and recognised as a genuine feature of the oil market.

The values in the above model were ascribed to the pay-offs for the following reasons:

1. If the Shale Producers choose 'Out' at the first decision node, regardless of type, they receive no benefit whilst OPEC continue to enjoy their oligopolistic position (0,4).
  
2. In the event that the Shale Producers can survive at the lower price, they choose to enter the market and OPEC allows the price to fall, both they and OPEC receive a payoff (1,1) that is lower than if the price remains high (2,2).
  
3. Similarly, if it is the case that Shale Producers cannot survive at the lower price, they still enter the market and OPEC doesn't allow the price to fall both players receive the same payoff (2,2). However, if OPEC does allow prices to fall it enjoys a larger benefit whilst the Shale Producer receives a negative payoff as it makes a loss and must exit the market (-1,3).

Thus, it is apparent that from OPEC's perspective, the most advantageous outcome is if the Shale Producer does not enter, however, if it does, it is worthwhile to allow prices to fall if the Shale Producer is unable to survive at the low price. 'k' is the probability with which the Shale Producers choose to enter the market when they are unable to survive at the lower price. 'b' represents the probability that OPEC allows a lower price to arise at either node.

## Equilibria

As this is a Bayesian game, there is just one Perfect Bayesian Equilibrium (PBE). In fact, if the players are constrained to using pure strategies, there is no PBE at all. However, an equilibrium is reached if players are permitted to mix strategies. If the Shale Producers are of the type whereby they can survive at the lower oil price, they will always enter the market, however, if they know they are unable to survive they will be less likely to enter the market. So as not to betray their type to OPEC, Shale Producers who cannot survive adopt a randomised approach to entering the market or staying out. As such, the strategies for each player are as follows;

### 1. Shale Producers' strategy:

- If able to survive at the lower oil price, then always enter the market.
- If unable to survive at the lower price, then enter the market with probability k.

**2. OPEC's strategy:**

-Choose to allow the lower oil price with probability  $b$ .

**3. OPEC have the following beliefs:**

-If Shale Producers enter the market, they are able to survive with probability  $(11+3k)$ .

-If Shale Producers choose to remain outside of the market, then they are able to survive at the low oil price with probability  $0$ .

The equilibrium prediction is that the Shale Producers will enter with certainty if they are able to survive at the low price, and if they are unable to survive there is still roughly a 33 per cent chance of them doing so based on their mixed strategy. OPEC believe there is a 50 per cent chance that the Shale Producers are able to survive at the lower oil price given that they have entered the market ( $0.50=0.25/(0.25+0.33*0.75)$ ) and in response there is a 66.67 per cent chance that OPEC will facilitate the lower oil price. The solution to the game is derived in full in the Appendix below.

## Analysis

The primary prediction from this model is that when faced with the prospect of a new entrant who may or may not be able to survive at lower oil prices, OPEC will choose to randomise between maintaining oil prices and allowing prices to fall by increasing supply. This equilibrium is useful in understanding the oil crisis of today as it goes some way to explaining how prices have fallen so dramatically. With the rise of Shale Producers, OPEC, in this instance, opted to pursue a policy of increased production in the hope that the lower price would drive out Shale Producers who generally operate on a higher cost function than OPEC. However, Shale Producers have surprised both OPEC and industry analysts by their resilience to this predatory strategy. Through a combination of hedged contracts, continued improvements in technology, and 'high grading' projects, Shale Producers have proved to be able to survive at the lower oil price i.e. they can be conceived of as being Type 1 in the model above and the game has reached the leftmost outcome where both players receive a pay-off of 1. Thus, the model describes how the real world situation of low prices and surviving shale producers has been reached through the Perfect Bayesian Equilibrium.

An important implication from this game is that it is absolutely critical for entrants to the oil industry to be thoroughly clandestine in relation to their cost functions. By maintaining this secrecy, shale producers leave OPEC with incomplete information which forces them to adopt a strategy that can, in some instances, lead to higher payoffs to the entrant than if perfect information existed. As mentioned previously, this assumpt-

ion of incomplete information may not be entirely representative of the real world but, as with most assumptions, this does not undermine the lessons and implications the model provides.

Of course, the assumptions associated with this model are not completely realistic. There are more than two players in the oil industry and thus decisions taken by OPEC in response to new entrants cannot be made in isolation. In reality, maintaining high oil prices is more complex than is portrayed here. Indeed, the current situation global oil producers now find themselves in (as a result of outcome of the game described above) has been likened to a classical Prisoner's Dilemma (Aumann, 1959). Each player in the game is confronted with the choice between agreeing to reduce their production in order to benefit producers as a whole or to selfishly increase their own production thereby boosting revenues hit by low margins. Indeed, Saudi Arabia said at the most recent OPEC meeting that OPEC would need cooperation from countries outside the group, such as Russia, to support prices without 'others stepping in and taking volumes' (Raval, 2015). It is apparent that the industry is now marooned in a Prisoner's Dilemma as seen in Figure 1, below, at the Nash Equilibrium (Don't Cooperate, Don't Cooperate).

		Country B	
		Cooperate on Supply	Don't Cooperate on Supply
Country A	Cooperate on Supply	(10, 10)	(5, 15)
	Don't Cooperate on Supply	(15, 5)	(7, 7)

*Figure 1: Prisoner's Dilemma Faced by Oil Producers Today*

To move away from the inefficiencies of this Nash Equilibrium, the players in the game must view the oil industry as a repeated, infinite game in which players evaluate discounted payoffs over time. In this context, it may be possible to generate a degree of cooperation within the industry by means of a 'Grim-Trigger' strategy (Harrington, 2015) in which any deviation is punished severely. This is similar to the approach adopted by OPEC before the rise of other oil producers. Now it is faced with the challenge of incorporating these producers into a cooperative agreement or face the prospect of lower prices and profits for the foreseeable future.

## **Conclusion**

In conclusion, principles of game theory have been applied to a real-world situation to shed light on how the current oil crisis has taken shape, and to provide a greater understanding of how the dynamics of the market are shifting from being cartel-driven to a traditional supply and demand based equilibrium. An extensive form game of incomplete information with sequential moves has been successfully modelled and solved to this end.

## References

- Aumann, R. 1959. Acceptable Points in General Cooperative N-Person Games. In: R. Luce and A. Tucker (ed.) Contributions to the Theory of Games IV, Annals of Mathematics Study 40, 1st ed. Princeton, NJ: Princeton University Press.
- Crooks, E. 2015. Oil markets Slide Out of Control. The Financial Times. [on-line], <http://www.ft.com/intl/cms/s/0/83885558-71a2-11e5-9b9e-690fd4e72044.html#axzz3qKbtm6eG> [Accessed: 8 December 2015].
- Crooks, E. 2015. The US Shale Revolution. The Financial Times. [on-line], <http://www.ft.com/intl/cms/s/2/2ded7416-e930-11e4-a71a-00144feab7de.html#slide0> [Accessed: 8 December 2015].
- Harrington, J. 2015. Games, Strategies and Decision Making. New York: Worth.
- Raval, A. 2015. OPEC Discord Fuels Further Oil Price Drop. The Financial Times. [on-line], <http://www.ft.com/intl/cms/s/0/1f84e444-9ceb-11e5-8ce1-f6219b685d74.html#axzz3tey7HSBL> [Accessed: 14 December 2015].
- Shenk, M. 2015. Oil Tumbles to Six-Year Low as OPEC Abandons Production Target. Bloomberg. [on-line], <http://www.bloomberg.com/news/articles/2015-12-06/oil-extends-losses-below-40-as-opec-abandons-production-target> [Accessed: 8 December 2015].



## Appendix

k: the probability that the Shale Producer enters the market given that it cannot survive at the lower oil price.

b: the probability that OPEC allows the lower market price.

Let p denote OPEC's belief that they are at the decision node on the left hand side of the model i.e. that the Shale Producers can survive given that they have entered the market.

$$E U_0(\text{Allow Low Price}) = p(1) + (1-p)(3) = 3 - 2p$$

$$E U_0(\text{Maintain Price}) = p(2) + (1-p)(2) = 2$$

OPEC will prefer to Allow Low Price if:

$$3 - 2p > 2$$

$$1 > 2p$$

$$p < \frac{1}{2}$$

If  $p < \frac{1}{2}$  : OPEC will Allow Low Price

If  $p > \frac{1}{2}$  : OPEC will Maintain Price

If  $p = \frac{1}{2}$  : OPEC is indifferent between playing Allow Low Price and playing Maintain Price

$$p = \text{Prob (Enter)}$$

$$= \text{Prob (Can Survive)} * \text{Prob (Can Survive)} + \text{Prob (Can Survive)} * \text{Prob (Can Survive)} + \text{Prob (Cannot Survive)} * \text{Prob (Cannot Survive)}$$

$$= 1 * (0.25) + 1 * (0.25) + k * (0.75)$$

$$= 1 + 3k$$

**Case 1: For what values of  $k$  will  $p < \frac{1}{2}$  ?**

$$\begin{aligned}
 p &= 1/(1+3k) \\
 1/(1+3k) &= \frac{1}{2} \\
 1 &< 3k \\
 k &> 1/3
 \end{aligned}$$

$$\text{Case 1: } k > 1/3 \Rightarrow p < \frac{1}{2}$$

Since  $p < \frac{1}{2}$ , OPEC will always play Allow the Low Price.

If OPEC will always Allow the Low Price in this case, then the Shale Producers should stay out of the market.

$$\therefore k = 0$$

However, this statement conflicts with the opening statement of Case 1 ( $k$  was said to be to greater than  $1/3$ ) and hence this cannot be deemed an equilibrium.

**Case 2:**

$$k < 1/3 \Rightarrow p > \frac{1}{2}$$

Since  $p > \frac{1}{2}$ , OPEC will always play Maintain Price.

If OPEC will always play Maintain Price in this case, then the Shale Producers should always enter.

$$\therefore k = 1$$

Again, this statement is in conflict with the opening statement of Case 2 ( $k$  was said to be to less than  $1/3$ ) and hence cannot be deemed an equilibrium.

**Case 3:**

$$K = 1/3 \Rightarrow p = \frac{1}{2}$$

Since  $p = \frac{1}{2}$ , OPEC are now indifferent between playing Allow Low Price and Maintain Price.

If  $k = \frac{1}{3}$ , the Shale Producers that cannot survive at the low price is mixing between Enter and Stay Out of the market.

For these Shale Producers to be willing to mix between these strategies, they must be indifferent between them i.e. given OPEC's strategy, the expected payoff from both actions must be equal. This can only be the case if OPEC are also mixing,

$$E U_{\text{Shale}}(b) = -1 \cdot (b) + (2 - 2b)$$

$$= 2 - 3b$$

$$E U_{\text{Shale}}(b) = 0$$

$$0 = 2 - 3b$$

$$3b = 2$$

$$b = \frac{2}{3}$$

OPEC is willing to play Allow Low Price with probability  $\frac{2}{3}$  because they are indifferent between Allow Low Price and Maintain Price at this probability distribution.