Destabilizing Oil Market Speculation: An Example

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Abstract:

We show that under Cournot competition with only a few strategic sellers and a large number of small price taking consumers/retailers, a speculator with a deep pocket and access to sufficient storage can have a destabilizing effect on oil prices. The speculator can profit by lowering the forward price of oil when buying oil contracts and raising the forward price of oil when selling oil contracts, thereby increasing the oil price volatility. There is no information asymmetry or private information in our model. We only consider noncooperative strategies and noncollusive equilibrium. While possible, our results also suggest that destabilizing speculation may be difficult to sustain.

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1 Introduction

The steep rise and subsequent steep decline in crude oil forward prices since 2004 has been a cause for serious concern to oil importing countries. For example, European Brent crude oil prices increased steadily from about $39.60 per barrel in December 2004 to $70.26 per barrel by April 2006. Thereafter it crashed to $53.68 by January 2007, only to rise sharply to $90.93 by December 2007. The price increased further to $132.72 by July 2008 and then crashed to $39.95 in December 2008. Since then it has risen steadily to $112.86 in September 2012. Whether speculation in oil prices has been the cause of such large fluctuations in oil prices has been a subject of intense debate.[1] For example, according to OPEC Secretary General Abdulla Salem El Badri[2], "speculators are at least partly to blame for high oil prices – not any lack of supply on world markets."

There has been some support in the academic literature for the popular view that high and volatile oil prices are in part due to the activities of speculators. Singleton (2012) argues that "..informational frictions and the associated speculative activity may induce prices to drift away from fundamental values, and may result in booms and busts in prices," and "..the evidence suggests that hedge fund trading in spread positions in forward, impacted the shape of term structure of oil forward prices." Vansteenkiste (2011), after reviewing oil prices between January 1992 and April 2011, concludes that until 2003 the movements in oil prices were more or less in sync with the fundamentals; but from 2004 regime switches in oil price are much more frequent and "speculative investments" are more prominent in the data. Mason and Rowley (2012) documents that between 1999 to 2004, the biggest difference between the high and low price per barrel in any given year was about $16; whereas, from 2005 onwards this difference was about $53 and in the year 2008 it was close to $150 per barrel.[3] In contrast, Irwin and Sanders (2012) take the position that the large swings in oil

[1]The Telegraph on July 15, 2012 reported that " Concerns are growing about the reliability of oil prices, after a report for the G20 found the market is wide open to manipulation or distortion."

[2]CNN Mondy, 7 December 2011

[3]See Sornette et al. (2008) and Tang and Xiong (2011) for more discussions on oil price movements and volatility.

prices are due to changes in supply and demand which are moderated by the activities of speculators.

We examine a related issue: whether speculative activities can have a large impact on spot prices of commodity when all market participants have *rational expectations*. We consider a model economy, with a single commodity that we refer to as "oil" for convenience, a single large speculator and two other groups of market participants: a large number of small price-taking "nonstrategic" buyers; and a few large strategic sellers who are also oil producers. The strategic sellers take the nonstrategic buyers' excess demand for oil in any period as given and choose their own supply to maximize profits. All market participants have the same beliefs.[4] In such an economy, we show that the speculator with access to physical storage facility[5] can lower the market price when buying to build inventories and raise the price when selling to reduce inventories, thereby causing large fluctuations in commodity prices.

Communication among various agents in our model economy plays an important role. Strategic sellers know and take as given the speculator's demand/supply schedule, i.e. they know speculator's intention to buy and/or sell at various prices, and decide on the quantity of oil to supply. Also, the strategic sellers believe that the commitments made through the speculator's demand/supply schedule will be fulfilled without default. In that case, the speculator, through "limit buy orders" can make the strategic sellers increase the supply of oil-claim resulting in a lower market clearing price in period 1. From the perspective of the strategic sellers, the additional sale to the speculator more than offsets the loss from selling at a lower price to the nonstrategic buyers. Subsequently, the speculator uses limit sell order to induce the strategic sellers to reduce their supply in period 2, and liquidates the

[4]See Hart and Kreps (1986) and Jagannathan et al. (1990) examples of destabilizing speculation in the presence of private information.

[5]Meyer (2009) observes that a number of traders store crude oil in sizable quantities in chartered oil tankers. According to Kaminska (2011) "at the end of June 2011, the four major banks owned commodity inventories valued at $8.1 billion – with JP Morgan Chase ($3.5 billion) and Morgan Stanley ($3.3 billion) reporting the largest holdings and Goldman Sachs a much smaller stock ($0.7 billion). This is equivalent to about 120 million barrels of crude..." In contrast, the US commercial crude oil inventory was about 337.2 million barrels in September 2011.

oil inventories at a higher price, increasing price volatility. We show that such a behavior is rational and sustainable in equilibrium.

Although we believe that our specific application of oligopoly theory to analyze destabilizing speculation in the oil market is novel, our work is part of a more general stream of research devoted to analyzing speculative activities leading to price manipulation.[6]

The common view is that speculators who act competitively provide liquidity in the market, thereby damping price fluctuations. In contrast, when there is only one large speculator, the speculative "buy order" causes the price of oil to drop and the speculator's "sell order" causes the price of oil to rise. High cost of storage will erode profits and deter destabilizing speculation. On the other hand, costless storage may encourage entry by a number of speculators to enter the market in period 1. Their demand for oil can lead to an increase in the price of oil in the first period, thereby offsetting the effects due to the activities of the speculator, making large speculative positions not viable. Thus, our model may not be applicable to markets where storage is near costless, viz., gold and financial products. In our model the speculator needs to credibly communicate the demand/supply schedule to all the strategic sellers. We do not consider the role of forward market in our model economy. Whether it will encourage or curtail destabilizing speculation is left to future research.

Since high storage and borrowing costs make speculation costlier, an implication is that destabilizing speculation is more likely when interest rates are low and storage facilities are easily available. To the extent such periods are likely to be associated with low inventories of oil, our model implies a positive correlation between price volatility and inventory levels, but that correlation is likely to be reversed when the share of inventories held by speculative positions increase.

The remainder of this article is organized as follows: In Section 2 we derive a simple

[6]See, for example, Kyle and Viswanathan (2008) for detailed discussion on what qualifies as illegal price manipulation and what can be construed as routine rational exploitation of market power or private information to generate rents for the speculator. Also, see Attari et al. (2006) and Cooper and Donaldson (1998) for a discussions of price manipulation through the use of corner-and-squeeze and pump-and-dump strategies respectively.

numerical example that illustrates key features of our model. In Section 3 we present our model economy and we analyze the oil market equilibrium with only nonstrategic traders and strategic sellers. In Section 4, we allow for a large speculator and we show the existence of limit order based manipulation strategies. We conclude in Section 5.

2 A Numerical Example

First consider a three-period forward market for oil. We assume that there is no supply/demand uncertainty. More importantly, we assume there is no possibility of a default at the time of delivery– i.e., we assume a perfect contracting environment.

In such an environment there is not much difference between forward market for oil and/or a spot market for oil; hence, we will use the term "oil" synonymously with an unit contract that we call "oil-claim" and that delivers an unit of oil next period at the contracted price.[7] There are three types of market participants:

- Consumers/retailers who buy oil in small quantities in each period. These consumers /retailers take the market price of oil as given in any period and place their individual orders.
- Two identical strategic sellers, who supply oil to meet consumers/retailers demand for oil.
- A large speculator, who buys oil in period 1 from the strategic sellers with the sole objective of selling oil in the same market in period 2.

We denote the strategic sellers as strategic seller a and strategic seller b respectively. We further assume that both strategic sellers are identical in all respects and are engaged in

[7]Only difference here is that oil is delivered one period later – period 1 purchases in period 2 and period 2 purchases in period 3. Even though there are some evidence of contemporaneous demand for oil, we assume that the consumers/retailers are also interested in one-period lagged delivery of oil. For example, Mr Rich, who died recently, was best known, at least in business circles, for revolutionizing oil trading in the early 1970s. He is credited with *creating the spot market* which allowed for immediate, one-off purchase of cargoes, rather than the years-long contracts then imposed by oil majors.

the business of selling oil in the market. Both strategic seller a and strategic seller b can maintain their position of dominance by behaving oligopolistically and influence market clearing price of oil by adjusting their own supply of oil-claim. First we consider the case when our speculator is not allowed to participate in the oil market. Absence of demand/supply uncertainties and assumption of only two identical strategic sellers makes the problem a simple duopoly. We solve the oil market equilibrium following Gibbons (1992) in Section *2.1*.

We assume that each strategic seller tries to maximize aggregate profit or value of the strategic seller subject to their choice variable which is quantity of oil sold in each period

$$V_j = \max_{q_{j_1}, q_{j_2}} \left(\pi_{j_1} + \frac{\pi_{j_2}}{1+r} \right), \qquad j = a,\, b, \tag{1}$$

and q_{j_1} and q_{j_2} are strategic seller j's choice of quantity of oil sold in period 1 and period 2 respectively and r is the risk free rate of interest. In the absence of the speculator, the market clearing price of oil-claim in each period is determined by the following demand and supply conditions:

$$q^*_{a_t} + q^*_{b_t} = q^*_t = 100 - p^*_t \qquad \text{for } t = 1, 2, \tag{2}$$

and q^*_t is the aggregate quantity of oil-claim demanded (or supplied) in each period t; $q^*_{a_t}$ and $q^*_{b_t}$ are quantities of oil-claim supplied by each strategic seller in each period t and p^*_t is the equilibrium market clearing price of oil in each period t.

2.1 Market Equilibrium without the Speculator

We assume that the strategic sellers produce oil at a fixed cost of 10 dollars per unit of oil in each period. Thus, strategic sellers maximize the following profit functions in each period:

$$\pi_{a_t} = q_{a_t} \times (100 - q_{a_t} - \bar{q}_{b_t}) - 10\, q_{a_t}, \tag{3}$$

$$\pi_{b_t} = q_{b_t} \times (100 - \bar{q}_{a_t} - q_{b_t}) - 10\, q_{b_t}. \tag{4}$$

where $t = 1, 2$. Thus, each strategic seller supplies $q^*_{a_t} = q^*_{b_t} = 30$ units of oil in each period; the resulting market clearing price, $p^*_t = 40$ dollars in each period; hence, each strategic seller earns, $\pi_{a_t} = \pi_{b_t} = (40-10)\times 30 = 900$ dollars as profits in each period. There is no difference between quantities, prices and profits in period 1 and period 2 – they look identical. Thus, values of strategic seller a and strategic seller b are equal and have the following expression

$$V_a = V_b = 900\left(1 + \frac{1}{1+r}\right). \tag{5}$$

Not surprising there is no oil price volatility in this simple two-period model. Price of oil in each period is equal to 40 dollars and eash strategic seller earns 900 dollars as economic profit in each period. Total of 60 units of oil-claims are sold to the consumers/retailers – 30 units of oil-claims are sold in period 1 and 30 units of oil-claim are sold in period 2. Our sellers deliver 30 units of physical oil to their respected buyers in period 2 and other 30 units of physical oil to the respected buyers in period 3.

Next we allow the speculator to enter the forward market. Then we analyze the impact of our speculator's entry on the forward market equilibrium in period 1 in Section *2.2*. Note that the speculator enters the oil market in period 1 and buys oil-claims with the sole objective of selling the acquired oil in period 2 (or delivering in period 3). Also, it is important to note that both strategic sellers are fully aware (an takes into account) of the speculator's motif to sell the oil acquired in period 1 in the same market in period 2.

2.2 Sellers' Strategies with the Speculator in Period 1

Remember, market demand – without the speculator order – is unchanged. Hence, the inverse demand function, $p_1(q_1) = 100 - q_{a_1} - q_{b_1}$ is still the demand for oil from infinitesimally small oil buyers.

Our speculator enters the oil market in period 1 and place the following order schedule: He wants to take position in 6 units of oil-claim only if the forward price of oil in period

1 is strictly below \$37. For any forward price strictly greater than \$37 , the speculator is not willing to take any position in oil-claims. If forward price is strictly equal to \$37, then the speculator's demand for oil is any number between 0 and 6 units of oil. Specifically, the speculator places the following buy order in the market in period 1:

$$q_{h_1} = \begin{cases} 6 & p_1^*(q_1) \leqslant 37 \\ [0,6] & p_1^*(q_1) = 37 \\ 0 & p_1^*(q_1) \geqslant 37 \end{cases} \tag{6}$$

where $p_1^*(q_1^*) = 100 - q_{a_1}^* - q_{b_1}^*$ is the forward market clearing price of oil-claims in period 1. This is an additional source of oil-claim demand for the strategic sellers; thus, in the presence of the speculator the kinked inverse demand function for oil-claim demand in period 1 is as follows:

$$p_1(q_1) = \begin{cases} 100 - q_{a_1} - q_{b_1} & \text{if } q_1^* < 63 \\ 37 & \text{if } 63 \leqslant q_1^* \leqslant 69 \\ 106 - q_{a_1} - q_{b_1} & \text{if } q_1^* > 69 \end{cases} \tag{7}$$

where q_{a_1} and q_{b_1} are supply of oil-claim by each strategic seller in the presence of the speculator and $q_1 = q_{a_1} + q_{b_1}$ is the aggregate quantity supply of oil-claim in period 1 and q_1^* is the equilibrium aggregate supply of oil-claim in period 1.

To establish the local optimum, given constant marginal costs, strategic seller a solves the equation: $\text{MR}_{a,1} = 10$ and strategic seller b solves the equation $\text{MR}_{b,1} = 10$. When $\text{MR}_{a,1} = \text{MR}_{b,1} = 37 > \text{MC} = 10$, then it is optimal for strategic seller a and b to produce 69 together. This results in the reaction functions $q_{a_1}^{'} = \phi(q_{b_1})$ and $q_{b_1}^{'} = \phi(q_{a_1})$, which we will expect to become identical in view of the symmetry of the present case. Equating (6)

to the marginal costs (=10) gives us two solutions for strategic seller a's reaction function:

$$q_{j_1}^{'} = \begin{cases} \frac{90-q_{k_1}}{2} & q_1^* < 63 \\ 69 - q_{k_1} & 63 \leqslant q_1^* \leqslant 69 \\ \frac{96-q_{k_1}}{2} & q_1^* > 69 \end{cases} \tag{8}$$

where j_1 is the quantity supplied by strategic seller $j = a,\ b$ in period 1 and k_1 is the quantity supplied by strategic seller $k = a,\ b$ where $k \neq j$.

2.2.1 Derivation of Oil Forward Market Equilibrium

Since both strategic sellers are identical to each other (by our assumption), we expect each of them to sell/offer equal quantitates of oil-claims in each period; i.e., we consider equilibrium that are characterized by the following condition: $q_{a_1}^* = q_{b_1}^*$. Similarly, sum of the individual oil-claims sold in each period must as well satisfy the aggregate quantity for which the a reactions functions are defined. For example, if $q_{a_1}^* = q_{b_1}^* = 30$ such that $q_{a_1}^* + q_{b_1}^* = 60 < 63$, then the relevant aggregate demand function that determines the forward market clearing price is $100 - q_{a_1}^* - q_{b_1}^*$ and not the others.

We will propose an equilibrium and then prove that it is indeed an oil-forward market equilibrium by ruling out any unilateral deviation by any one strategic seller. First we will look for an equilibrium where each strategic seller chooses the number of oil-claims to offer using their respective reaction function, i.e., Equation 8 and then we will check whether sum of oil-claims offered by each strategic seller satisfies the appropriate aggregate quantity condition. For example, if we consider the following reaction function:

$$q_{j_1}^{'} = \frac{90 - q_{k_1}}{2}, \tag{9}$$

and solve for the symmetric outcome we obtain the quantities as follows: $q_{a_1}^* = q_{b_1}^* = 30$. Next, we check if the aggregate quantity condition associated with the reaction function

depicted in Equation 9 is satisfied or not. We find that $q^*_{a_1} + q^*_{b_1} = 60 < 63$. Hence, a potential candidate for the forward market equilibrium is as follows:

1. Price of an oil-claim in period 1: $p^*_1 = 40$
2. Each strategic seller offers, $q^*_{j_1} = 30$ units of oil claims in period 1
3. In aggregate both strategic sellers offer, $q^*_1 = 60$ units of oil claims in period 1
4. Each strategic seller offers, $\pi^*_{j_1} = 900$ dollars as profit in period 1.

But is this an oil forward market equilibrium in period 1? To answer this question we have to show that unilateral deviations by any one strategic seller is unprofitable. It is quite straightforward to show that if one strategic seller, say strategic seller b, chooses to offer 30 units of oil-claims in period 1, then it is optimal for strategic seller a to increases its offering, $q^d_{a_1}$ to 39 units of oil-claims in period 1. Thus, strategic seller a's deviation profit, denoted by $\pi^d_{a_1}$ is as follows:

$$\pi^d_{a_1}(q^d_{a_1}, q^*_{b_1}) = 39 \times (106 - 39 - 30 - 10) = 39 \times (37 - 10) = \$1,053. \tag{10}$$

This is because $q^d_{a_1} + q^*_{b_1} = 69$ and relevant demand for oil-claim is $106 - q_{a_1} - q_{b_1}$. Note that strategic seller a earns 153 dollars more than what he earned (900 dollars) in period 1 when there was no speculator. What happens to strategic seller b's profit? Actually, it drop and is given by:

$$\pi_{b_1}(q^d_{a_1}, q^*_{b_1}) = 30 \times (106 - 30 - 39 - 10) = \$810, \tag{11}$$

which is strictly less than 900 dollars (by 90 dollars) earned by seller b in period 1 when there was no speculator. Thus, when the speculator is active in the oil forward market, $q_{a_1} = q_{b_1} = 30$ cannot be an equilibrium in period 1.

Next, we look for an equilibrium where each strategic seller chooses the number of oil-claims to offer using their respective reaction functions, depicted by Equation 8 and the number of oil-claims offered by each strategic seller must satisfy the aggregate quantity condition, in this case $63 \leqslant q^*_1 \leqslant 69$. Solving for the symmetric quantities we find that

$q^*_{a_1} = q^*_{b_1} = 34.5$. Thus, each strategic seller earns

$$\pi^*_{a_1} = \pi^*_{b_1} = 34.5 \times (100 - 34.5 - 34.5 - 10) = \$931.5. \tag{12}$$

Given that strategic seller b sells 34.5, if strategic seller a produces less than 34.5, then strategic seller a's profit function is defined as:

$$\pi^d_{a_1} = \begin{cases} q^d_{a_1}(100 - 34.5 - q^d_{a_1} - 10) & q^d_{a_1} < 28.5 \\ q^d_{a_1} \times (37 - 10) & 28.5 \leqslant q^d_{a_1} \leqslant 34.5 \end{cases} \tag{13}$$

Given that strategic seller b sells 34.5, if strategic seller a produces more than 34.5, then strategic seller a's profit function is defined as:

$$\pi^d_{a_1} = \begin{cases} q^d_{a_1} \times (106 - 34.5 - q^d_{a_1} - 10) & q^d_{a_1} > 34.5 \end{cases} \tag{14}$$

It is easy to verify that $\pi^d_{a_1} \leqslant 931.5$ for all $q^d_{a_1}$. Hence, each strategic seller agreeing to supply $q^*_{a_1} = q^*_{b_1} = 34.5$ unit of oil and the market clearing price, $p^*_1 = \$37$ constitutes an equilibrium in the oil forward market.

Next, we depict the oil forward market equilibrium in period 2. Now, there is one new supply source: the speculator's inventory. Hence, we are going to analyze the implications for the market if the speculator has multiple possibilities in which he/she can liquidate his/her inventory.

2.3 Oil Futures Market Equilibrium with Two Strategic Sellers and the Speculator in Period 2

In period 2, the speculator holds 6 units of oil in his inventory he acquired in period 1. Again, the speculator makes sure that both strategic sellers are aware of his intention to sell this oil in period 2's forward market. We assume that each strategic seller knows:

- The oil position acquired by the speculator in period 1 is a "sunk cost"
- The speculator must liquidate the acquired oil inventory by the end of period 2.

Formally, the speculator places the following limit sell order in period 2: Specifically, the speculator places the following net buy order in the pre-market in period 2:

$$q_{h_2} = \begin{cases} -6 & \text{offer price } \geqslant 50 \\ 0 & \text{otherwise.} \end{cases} \tag{15}$$

Each strategic seller knows that if the speculator's sell order is not executed in the pre-market, then the speculator intends to act as a price-taker and sells all 6 units of oil in the market directly at the market clearing price.

Consequently, if neither of the two strategic sellers do not accommodate the speculator, i.e., absorb his inventory into their own selling plans, then the speculator acts as an independent price-taker and dumps his inventory directly into the market. The demand/supply conditions in the market given the speculator's price taking strategy can be depicted as follows:

$$\begin{aligned} x_{a_2} + x_{b_2} + q_{h_2} = x_{a_2} + x_{b_2} + 6 &= 100 - p_2, \\ x_{a_2} + x_{b_2} &= 94 - p_2. \end{aligned} \tag{16}$$

Each strategic seller maximizes the following profit function:

$$\pi_{a_2} = x_{a_2} \times (94 - x_{a_2} - \bar{x}_{b_2}) - 10\, x_{a_2} \tag{17}$$

$$\pi_{b_2} = x_{b_2} \times (94 - \bar{x}_{a_2} - x_{b_2}) - 10\, x_{b_2} \tag{18}$$

and each ends up selling, $x^*_{a_2} = x^*_{b_2} = 28$ units of oil resulting in aggregate supply of 62 units of oil in the market at the market clearing price, $p^*_2 = 38$ dollars. Each strategic seller earns $\pi^*_{a_2} = \pi^*_{b_2} = (38 - 10) \times 28 = \$784.00$ as profits in period 2. Similarly, the speculator earns

$\pi_h^* = \$(\frac{38}{1+r_h} - 37 - c_h) \times 6$ as profit, where r_h and c_h are borrowing and per unit storage costs of the speculator.

Now let us consider the situation when both strategic sellers allow the speculator as another strategic seller in the market and maximize profit together. Given $100 - p_2$ is still the demand function, it means that each strategic seller has to supply only 25 units of oil in the market. Hence, each strategic seller earns

$$\hat{\pi}_{a_2} = \hat{\pi}_{b_2} = 25 \times (100 - 25 - 25 - 10) = 25 \times 40 = \$1000.00, \tag{19}$$

from market operations. But if the market clearing price is 50 dollars in period 2, each strategic seller buys 3 units of oil from H at a costs of 50 dollars per unit. After incorporating the fact that the domestic supply of oil-claim costs 50 dollars per unit rather than 10 dollars per unit, each strategic seller earns

$$\bar{\pi}_{a_2} = \bar{\pi}_{b_2} = 25 \times (100 - 25 - 25 - 10) = 25 \times 40 - \frac{1}{2} \times 6 \times (50 - 10) = \$880.00. \tag{20}$$

Note that profit of each strategic seller is 880 dollars, which is strictly less than 900 dollars but strictly greater than 784 dollars.

Now, if one strategic seller (say, seller a) commits to supply 25 units of oil in period 2, then using Equation(4) we know that it is better for the second strategic seller to supply 32.5 units. If the second strategic seller deviates and supplies 32.5 units of oil, then the market clearing deviation price of oil in period 2, p_2^d is as follows:

$$p_2^d = 100 - 25 - 32.5 - q_{h_2} = 42.5 - q_{h_2} < 50, \tag{21}$$

because the speculator's supply, $q_{h_2} \geqslant 0$. Hence, the speculator dumps the 6 units of oil directly in the market. Resulting market clearing price of oil in period 2,

$$p_2^d = 100 - 25 - 32.5 - 6 = 36.5, \tag{22}$$

giving a profit of

$$\pi_{b_2}^d = 32.5 \times (100 - 25 - 32.5 - 6 - 10) = 32.5 \times 26.5 = \$861.25 \tag{23}$$

to the deviant or strategic seller b. On the other hand, if seller b sticks to the strategy to sell 25 units of oil in period 2, then strategic seller b earns $\bar{\pi}_{b_2} = \$880.00$ as profits, which is strictly greater than the deviation profit, $\pi_{b_2}^d = \$861.25$. Hence, the second strategic seller is better off not deviating, rather selling 25 units of oil in period 2. Also, H earns $\bar{\pi}_h = \left(\frac{50}{1+r_h} - 37 - c_h\right) \times 6$ as profit. Since sellers a and b are identical, same chain of argument should hold for seller a if seller a deviates.

In the benchmark case (i.e., the no speculator case) each strategic seller supplies, $x_a^* = x_b^* = 30$ units of oil per period to the market. Hence, market clearing price is same in both periods, $p_1^* = p_2^* = 40$ and there is no oil price volatility. Once the speculator enters the market, market clearing price of oil in period 1 is different than market clearing price of oil in period 2. In period 1, market clearing price of oil is $\bar{p}_1 = 37 < 40$ and aggregate supply of oil-claim is 63 units. In period 2, market clearing price of oil is $\bar{p}_2 = 50 > 40$ and aggregate supply of oil-claim is just 50 units. Hence, oil price becomes extremely volatile. Even though this example captures the essence of our intuition, in section 3 below we show that these intuitions can hold in more general framework.

3 The Model Economy

Let us begin by describing a three-date/two-period model for the oil market. We assume that the market clearing price of oil is established by demand and supply conditions. We denote the market clearing price of oil in period 1 by p_1 and in period 2 by p_2. For convenience we will use "dollars" as numeraire.

We assume that the market is open for a short time at the beginning. All agents can put limit orders to buy and/or sell oil and the order book is assumed to be public information.[8] A buy limit order can only be executed at the limit price or lower, and a sell limit order can only be executed at the limit price or higher. A limit order is not guaranteed to execute, because a limit order can only be filled if the market clearing price of oil reaches the limit price. Further, we allow traders to put conditional limit orders – limit orders that become market order if certain conditions are met (or not met).[9] The market clearing price is set, and oil and dollars are exchanged at that price at the end of the period.

We assume that the market is populated by many small consumers and small/medium business owners (henceforth, nonstrategic traders). Each nonstrategic trader buys or sells small quantities of oil at a time, based on their idiosyncratic needs not explicitly modeled in this paper. These traders assume that the market price for oil is given, and they know that they will not be able to influence the market price by their own actions. We denote nonstrategic traders' demand for oil by

$$q^d_{n,\,t} = a_d - b_d\, p_t, \tag{24}$$

where $q^d_{n,\,t}$ is the quantity of oil-claim demanded by the nonstrategic traders in period t, $t = 1, 2$, when the market price of oil is p_t. We assume $b_d > 0$ implying that the quantity demanded falls as price rises. The demand function maps US dollars into quantities of oil,

[8] See, for example, Parlour and Seppi (2008) for more discussion of limit order markets.

[9] While limit orders do not guarantee execution, they help ensure that a trader does not pay more than a pre-determined price for oil. See, Berber and Caglio (2004) for discussion on order submission strategies.

e.g., "thousands of barrels." We assume $q^d_{n,1} = q^d_{n,2} = q^d_n$, because nonstrategic demand remains exactly the same in both periods. Similarly, the supply of oil-claim from these nonstrategic traders (e.g., local production of oil) can be expressed as

$$q^s_{n,t} = -a_s + b_s\, p_t, \tag{25}$$

where $q^s_{n,t}$ is the quantity of oil supplied by the nonstrategic traders in each period when the market price of oil is p_t. Again, we assume that $b_s > 0$ and also, $q^s_{n,1} = q^s_{n,2} = q^s_n$. Thus, like any standard model, nonstrategic traders' demand for oil decreases and supply of oil-claim increases as oil price increases and this is true for both period 1 and period 2. Hence, we are ready to define nonstrategic traders' excess demand for oil as a function of oil price p_t, where $t = 1, 2$. Thus, nonstrategic traders' excess demand for oil in any period, say $\hat{q}_n$, is given by

$$\hat{q}_n(p_t) = q^d_n - q^s_n = a_d - b_d\, p_t - (-a_s + b_s\, p_t) = a_d + a_s - (b_d + b_s)p_t = \hat{a} - \hat{b}\, p_t, \tag{26}$$

where $\hat{a} = a_d + a_s$ and $\hat{b} = b_d + b_s$. Note that technically $\hat{q}_n(p_t) \gtreqless 0$. We assume that under "normal" market conditions $\hat{q}_n(p_t) > 0$, implying that the nonstrategic traders are net buyers of oil; and as p_t increases, nonstrategic traders' excess demand for oil, $\hat{q}_n(p_t)$ declines.

The market is also populated by a large speculator and m strategic sellers. Both the speculator and the m strategic sellers have some market power; that is, they buy and/or sell large quantities of oil at a time and in the process they impact the market clearing price for oil. We assume that all strategic sellers are also oil producers. We will assume that the unit price of producing oil is c dollars. We assume $\hat{q}_n(c) > 0$, implying that at the cost of producing an unit oil, nonstrategic traders are net buyers of oil. We depict nonstrategic traders' oil-claim demand and nonstrategic traders' oil supply functions in Figure 2. Any market price above $\bar{p}$ in any period t totally eliminates market demand for oil as this makes $\hat{q}_n(\bar{p}) = 0$. Similarly, since we assume that the fixed costs of producing oil for the strategic

sellers is c, any price below is not feasible and aggregate oil-claim demand at $p_t = c$ is equal to $\bar{q}$ $(= \bar{q}^d - \underline{q}^s)$.

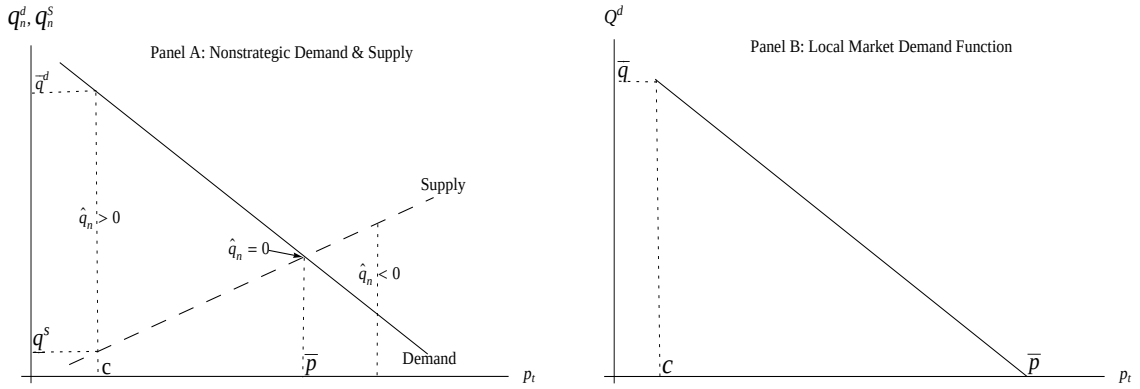


Figure 2: In panel A we depict nonstrategic traders' demand and supply functions for oil. In panel B, we depict the market demand function for oil which is equivalent to the excess demand function of the nonstrategic traders.

3.1 Oil Market Equilibrium without the Speculator

We assume that these m strategic sellers engage themselves in oligopolistic competition. Each strategic seller chooses his/her profit maximizing supply, x_i, that maximizes his/her own profit, under the assumption that all other strategic sellers (his/her competitors) are not going to change their supply, $\bar{x}_j,\ \forall j \neq i$. Suppose the i^{th} strategic seller $\forall i = 1, \cdots, m$, decides to supply x_i units of oil in the market. The market clearing price in any period has to satisfy the following condition:

$$\hat{q}_n(p_t) = \hat{a} - \hat{b}\, p_t = x_1 + x_2 + \cdots + x_m = \sum_{i=1}^{m} x_i = X, \tag{27}$$

where X represents the aggregate supply of oil-claim to the market. We can obtain the market clearing price of oil by simply inverting the excess demand function. Hence,

$$p_t = q_n^{-1}(X) = \frac{\hat{a}}{\hat{b}} - \frac{1}{\hat{b}}(x_1 + x_2 + \cdots + x_m) = a - b\, X, \tag{28}$$

where $a = \hat{a}/\hat{b}$ and $b = 1/\hat{b}$, where the expression depicted in Equation (28) is known as the inverse demand function. Thus, the economic profit earned by each strategic seller, if he/she manages to sell x_i units of oil in the market is given by:

$$\pi_i\left(x_1,\, \bar{x}_2,\, \cdots,\, \bar{x}_m\right) = \left(a - b\left(x_i + \sum_{i \neq j,\, j=1}^{m-1} \bar{x}_j\right) - c\right) \times x_i, \quad \forall i = 1,\, 2, \cdots,\, m. \tag{29}$$

where $\sum_{i \neq j,\, j=1}^{m-1} \bar{x}_j$ is the quantity supplied by all other strategic sellers except i^{th} strategic seller. The equilibrium in this market is simply the Nash equilibrium (or fixed point) of this oligopolistic competition.[10] Let us describe the m-tuple $(x_1^*,\, x_2^*,\, \cdots,\, x_m^*)$ as the equilibrium supply response of m strategic sellers; then the optimal market clearing price of oil in each period is given by

$$p^* = a - b\, X^* = a - b\,(x_1^* + x_2^* + \cdots + x_m^*). \tag{30}$$

There is one restriction on market clearing price: The market clearing price in any period, p^* has to less than $\bar{p}$, the price of oil that makes nonstrategic traders' excess demand equal to zero. If all m strategic sellers are exactly identical, then it is optimal for each strategic seller to supply,

$$x_i^* = \frac{a - c}{b \times (m+1)} \tag{31}$$

units of oil in each period and the resulting aggregate supply of oil-claim in the market in each period is given by

$$X^* = \sum_{i=1}^{m} x_i^* = \frac{m\,(a-c)}{b \times (m+1)}. \tag{32}$$

Thus, the optimal market clearing price of oil in each period,

$$p^* = a - b\, X^* = \frac{a + m\, c}{(m+1)}. \tag{33}$$

[10] See, for example, Gibbons (1992) for detailed derivation and discussion on oligopolistic models.

Note that price in each period is p^*; hence, there is no oil price volatility. This is so because we have ignored any kind of uncertainty, in oil-claim demand and/or oil supply in our stylized environment. Thus, each strategic seller earns

$$\pi_i^* = (p^* - c) \times x_i^* = \frac{(a-c)^2}{b \times (m+1)^2}, \quad \forall i = 1, 2, \cdot\cdot, m. \tag{34}$$

as profits in each period.[11] We depict demand and supply functions of oil in a market with nonstrategic traders and m strategic traders in Figure 3. As we will see in the next section,

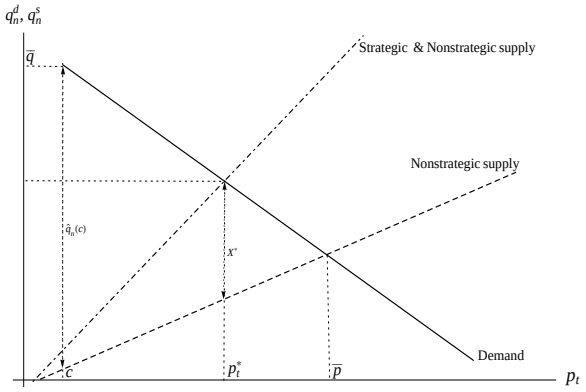


Figure 3: This figure depicts nonstrategic traders' excess demand for oil ($\hat{q}_n$) and strategic sellers' optimal aggregate supply (X) as function of market price in any period t, p_t. The aggregate supply consists of nonstrategic traders supply, $q_n^s(p^*)$ and the strategic sellers' optimal supply, X^*.

how a speculator, if he can enter the market in period 1, uses limit order to buy oil and at the same time make the market clearing price of oil to drop from p^* to $\bar{p}_1 = p^* - \beta$.

4 The Speculator's Demand and Market Equilibrium in Period 1

Next we now consider the effect of a large speculator with deep pockets. We assume that a speculator enters the oil market in period 1. We assume that the speculator has no access to oil producing facility (other than a small inventory like each nonstrategic trader) but has

[11] Notice that we have ignored the times subscript t, because period 1 and period 2 is exactly the same in every respect; thus, the aggregate supply of oil-claim in the market, $X_1^* = X_2^* = X^*$ and $p_1^* = p_2^* = p^*$.

the right to buy and/or sell oil in the market in both periods. Also, we assume that the speculator possesses a storage facility; we denote the speculators' storage capacity by z_s.

We assume that the speculator places limit orders – a demand plan that he let know other market participants well in advance. The speculator's limit order states the quantity of oil the speculator wants to purchase conditional on market clearing price of oil. Obviously, before putting the order the speculator takes into account nonstrategic traders' excess demand function as well as the quantities offered by all m strategic sellers in the market as response to nonstrategic traders excess demand. The speculator also takes into account the optimal market clearing price in the absence of his limit orders. This "limit buy" order of the speculator can be best described as the following function:

$$z_1(p_1) = \begin{cases} +z_1 & \text{if } p_1 \leq \bar{p}_1; \\ +\alpha\, z_1 & \text{if } \bar{p}_1 < p_1 \leq p^*; \\ -\alpha^2\, z_1 & \text{if } p_1 > p^*. \end{cases} \tag{35}$$

where z_1 is a quantity demand of the speculator and $z_1(\cdot)$ is the demand function of the speculator. Quantity of oil that the speculator buys in period 1 cannot be more than his storage capacity. The speculator's demand function, $z_1(\cdot)$ explicitly state how much the speculator will buy (or sell) in period 1 if the oil price happens to be p_1 in period 1. Speculator demand quantities, $\{z_1,\, \alpha\, z_1,\, -\alpha^2\, z_1,\, \cdot\cdot\}$ at different market clearing clearing price cutoffs, $\{\bar{p}_1,\, p^*,\, \cdot\cdot\}$.[12] Let us assume that

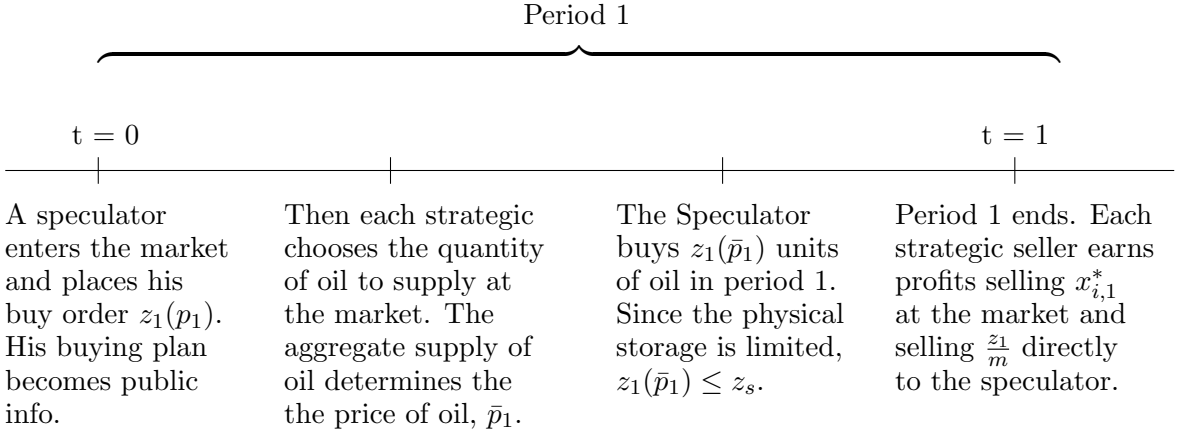
$$\bar{p}_1 = p^* - \beta, \tag{36}$$

where $\beta > 0$; thus, $\bar{p}_1 < p^*$, the market clearing price in the absence of the speculator. Also, we need $\bar{p}_1 > c$, per unit of costs of producing oil. Given the speculator's limit order function as depicted by Equation (35) and *the law of demand*, it follows that the speculator demands less if $p_1 \in (p^* - \beta,\, p^*]$ rather than if $p_1 \in [c,\, p^* - \beta]$. This further implies that

[12]Even though we call the demand function stated in Equation (35) as buy order, $z_1(\cdot)$ can take positive or negative values conditional on different realizations of price. See, for example, Rosu (2009), Easley and O'Hara (1991) and Garman (1976) for detailed discussion on limit order.

$\alpha\, z_1 < z_1$ which means $\alpha < 1$. We assume that the speculator's maximum demand in period 1, z_1, depends on various exogenous factors like physical storage capacity, z_s, available to the speculator, his cost of storage, c_s and possibly his costs of borrowing, r_s. In particular, we assume that $z_1 \leq z_s$, as commodity like oil is very hard to store without proper storage facility.

With the speculator buy order in period 1 in place we proceed to show that the speculator once active in the oil market can manipulate the existing market participants – the m large strategic sellers in a manner as to cause the price of oil to move in his favor. We continue to assume that all m strategic traders only sell (do not buy). Also, they have some market power and they act independently. Each strategic seller takes into account the demand function of the nonstrategic traders, limit order of the speculator, and the amount he believe will be supplied by other strategic sellers to decide the quantity of oil he wants to produce or buy from the speculator. We show that under these conditions, it is possible for our speculator to buy z_1 units of oil in period 1 at a price less than p^*; that is, the speculator extract more supply of oil-claim from the strategic sellers and yet, make the oil price to drop in period 1. The figure below shows the event line in period 1.



4.1 Strategic Sellers' Strategies in Period 1

Let us first look at each strategic seller's profit maximization problem in period 1. There are now two sources of demand: The market demand of oil (or the excess demand from the nonstrategic traders) and the speculator's demand. But the actual quantity demanded by the speculator in period 1 depends on the market clearing price in period 1; hence, there is interdependence. Given the demand function of the speculator each strategic seller's profit function now looks like

$$\pi_{i,1}(x_{1,1}, \cdot\cdot, x_{m,1};\ p_1^*,\ z_1(p_1^*)) = (p_1(x_{1,1}, \cdot\cdot, x_{m,1}) - c) \times x_{i,1} + (p_1^* - c) \times z_1(p_1^*) \tag{37}$$

$\forall i = 1, 2, \cdot\cdot, m$, and where p_1^* is the market clearing price of oil in the market in period 1; and $p_1(\cdot)$ is the inverse demand function. Substituting the linear demand function from Equation (28) we get

$$\pi_{i,1}(x_{1,1}, \cdot\cdot, x_{m,1};\ p_1^*,\ z_1(p_1^*)) = (a - b\,(x_{1,1} + \cdot\cdot + \bar{x}_{m,1}) - c) \times x_{i,1} + p_1^* \times z_1(p_1^*) \tag{38}$$

where $i = 1, 2, \cdot\cdot, m$. Since there is no change in the demand and supply conditions in the oil market, $x_{i,1}^*$ still maximizes each strategic seller's profits from only the market operations. If each strategic seller decides to stick to the profit-maximizing level of supply, then the market clearing price in the market in period 1, $p_1^* = p^*$ and $x_{i,1}^* = x_i^*$. Hence, profit earned by each strategic seller from the market operation (or selling oil in the market),

$$\pi_{i,1}^*(x_{1,1}^*, \cdot\cdot, x_{m,1}^*) = (p^* - c) \times x_i^*, \quad \forall i = 1, 2, \cdot\cdot, m. \tag{39}$$

But using Equation (35), we know that the speculator buys only $\alpha\, z_1$ units of oil if the market clearing price of oil in period 1 is less than or equal to p^*. Hence, total profit of each strategic seller after incorporating the speculator's demand if each of them chooses to sell

the profit maximizing quantity, x_i^* units of oil in the market in period 1 is given by

$$\pi_{i,\,1}(x_{1,1}^*,\,\cdot\cdot,\,x_{m,\,1}^*,\,p^*,\,\alpha,\,z_1) = (p^*-c)\times x_i^* + \frac{1}{m}\times(p^*-c)\times\alpha\,z_1 = (p^*-c)\times\left(x_i^* + \frac{\alpha\,z_1}{m}\right), \quad (40)$$

$\forall i = 1,\,2,\cdot\cdot,\,m$. Next, consider the situation where each strategic seller increase their supply just enough to drop the market clearing price of oil in period 1, p_1^* just equal to $\bar{p}_1$. In order to make the market clearing price drop to $\bar{p}_1$ each strategic seller needs to sell

$$\bar{x}_{i,\,1} = \frac{a-\bar{p}_1}{b\,m} = x_i^* + \frac{\beta}{b\,m}, \quad \forall i = 1,\,2,\cdot\cdot,\,m. \quad (41)$$

Hence, each strategic seller earns

$$\bar{\pi}_{i,\,1}(\bar{x}_{1,1},\,\bar{x}_{2,1},\,\cdot\cdot,\,\bar{x}_{m,\,1}) = (\bar{p}_1-c)\times\bar{x}_{i,\,1} = (p^*-c)\times x_i^* + (p^*-c)\times\frac{\beta}{b\,m} - \beta\times x_i^* - \frac{\beta^2}{b\,m}, \quad (42)$$

$\forall i = 1,\,2,\cdot\cdot,\,m$. Hence, each strategic seller change in profit from market operation,

$$\Delta\pi_{i,\,1} = \bar{\pi}_{i,\,1}(\bar{x}_{1,1},\,\cdot\cdot,\,\bar{x}_{m,\,1}) - \bar{\pi}_{i,\,1}(x_{1,1}^*,\,\cdot\cdot,\,x_{m,\,1}^*) = -\frac{\beta}{b\,m}\left((m-1)\times x_i^* + \beta\right), \quad (43)$$

which is strictly negative. At the same time each strategic seller knows that a lower market clearing price in the market in period 1 implies higher demand of oil from the speculator. Using Equation (35) we know that

$$z_1(\bar{p}_1) = z_1 = \alpha\,z_1 + (1-\alpha)\times z_1 = z_1(p^*) + (1-\alpha)\times z_1, \quad (44)$$

which implies that the increased supply of oil-claim in the market by the strategic sellers causes the speculator's demand for oil to increase by $(1-\alpha)\times z$ units. Hence, there are three effects of increased supply:

1. Increased aggregate supply in the market, $\sum_{i=1}^{m}(\bar{x}_{i,\,1} - x_{i,\,1}^*) = \frac{\beta}{b}$ units of oil;
2. increased sell to the speculator, $z_1\times(1-\alpha)$ units of oil; and

3. lower price of oil, $p^* - \bar{p}_1 = \beta$ dollars per unit.

If the speculator chooses β and α such that each strategic seller's reduced profit from selling to the market is outweighed by their gains from selling a larger quantity of oil to the speculator, then the speculator can buy z_1 units of oil at the same time reduce market clearing price of oil. Change in total profit of each strategic seller,

$$\begin{aligned} \Delta\,\bar{\pi}_{i,\,1} &= \text{change in profits from the market} + \text{additional profits from the speculator} \\ &= -\frac{\beta}{b\,m}\left((m-1)\times x_i^* + \beta\right) + p^* \times z_1 \times (1-\alpha) - \beta \times z_1. \end{aligned} \tag{45}$$

The necessary condition for each strategic seller to increase the supply of oil-claim in the market just enough to drop the market clearing price of oil in period 1 from p^* to $p^* - \beta$ is $\Delta\,\bar{\pi}_{i,\,1} \geqslant 0$.

In order to show that Equation (45) is also the sufficient condition for increased supply of oil-claim in the market in period 1, we need to show that it is optimal for each strategic seller to supply $\bar{x}_{i,\,1}$ units of oil in the market regardless of what its competitors do in period 1. If all $m-1$ strategic sellers sell $\bar{x}_{i,\,1}$ to the retail market, we need to show that it is not optimal for the m^{th} strategic seller to deviate from the strategy to sell $x_{m,\,1} = \bar{x}_{m,\,1}$ units of oil in the market in period 1. The m^{th} strategic seller chooses x_m to maximize

$$\pi_{m,1}\left(\bar{x}_{1,1},\, \cdot\cdot,\, \bar{x}_{m-1,1},\, x_{m,1}\right) = \left(a - b \times \left(\bar{x}_{1,1} + \cdot\cdot + \bar{x}_{m-1,1} + x_{m,\,1}\right) - c\right) \times x_{m,\,1}. \tag{46}$$

If all m strategic sellers are identical and if $m-1$ of these identical strategic sellers each supply $\bar{x}_{i,1}$, $\forall i = 1,\, 2,\, \cdot\cdot,\, m-1$, then m^{th} strategic seller finds it optimal to supply

$$x_{m,1}^d = \bar{x}_{i,1} - \frac{(m+1)\times\beta}{2\,b\,m} = x_i^* - \frac{(m-1)\times\beta}{2\,b\,m}, \tag{47}$$

where $x_{m,1}^d$ denotes the quantity sold by the m^{th} strategic seller as a deviant strategic seller and $\forall j = 1, 2, \cdot\cdot, m-1$. Given $\beta > 0$, it follows that $x_{m,\,1}^d < x_i^*$ and $x_{m,\,1}^d < \bar{x}_{i,\,1}$, $\forall i =$

1, ··, $m-1$. This further implies that if the m^{th} strategic seller chooses to deviate and sell $x^d_{m,1}$ instead of $\bar{x}_{m,1}$, then the market clearing price,

$$p^d_1 = a - b \times \left(\bar{x}_{m,1} - \frac{(m+1) \times \beta}{2\,b\,m} + \bar{x}_{1,1} + \cdots + \bar{x}_{m-1,1} \right) = \bar{p}_1 + \frac{(m+1) \times \beta}{2\,m} > \bar{p}_1, \quad (48)$$

which further implies that the speculator's demand for oil in period 1 drops to $\alpha\, z_1$ from z_1. Thus, the m^{th} strategic seller's total profit,

$$\pi^d_{m,1}(\bar{x}_{1,1},\, \cdot\cdot,\, \bar{x}_{m-1,1},\, x^d_{m,1},\, z_1(p^d_1))$$

$$= \left(\bar{p}_1 + \frac{(m+1) \times \beta}{2\,m} - c \right) \times \left(\bar{x}_{i,1} - \frac{(m+1) \times \beta}{2\,b\,m} + \frac{1}{m} \times \alpha \times z_1 \right). \quad (49)$$

Given $\bar{x}_{i,1} > x^*_i \,\forall i = 1, 2, \cdot\cdot, m-1$ it is easy to show that $\pi^d_{m,1}(\bar{x}_{1,1},\, \cdot\cdot,\, \bar{x}_{m,1},\, x^d_{m,1},\, z_1(p^d_1))$ is strictly less than $\pi_{m,1}(x^*_{1,1},\, \cdot\cdot,\, x^*_{m,1},\, z_1(p^*))$. Hence, Equation (45) is also the sufficient condition for increased supply and consequently, lower market clearing price of oil in period 1. The Equation (45) depends on the incentive of each strategic seller to capture $1/m$ of the additional speculator's demand, $(1-\alpha) \times z_1$. Hence, we derive condition on the minimum value of the speculator's maximum demand that will induce increased supply of oil-claim in the retail market and consequently, lower the market clearing price of oil. This result is formally stated in Proposition 1 below.

Proposition 1. *If the speculator's storage capacity for oil, $z_s \geqslant \underline{z}_{s,1}$ where*

$$\underline{z}_{s,1} = \frac{\beta \times (m-1) \times (a-c) + \beta^2 \times (m+1)}{b \times (1-\alpha)(a-c) - \beta\, b \times (m+1)},$$

then only it is optimal for each strategic seller to increase his/her own supply of oil-claim in the retail market, regardless of what the other $(m-1)$ competitors do, such that the market clearing price of oil in period 1 drops to $\bar{p}_1 = p^* - \beta$ from p^*.

Proof. Follows directly from Equation (45). □

Intuition of the proposition is quite straightforward: Each strategic seller is better off supplying $\bar{x}$ rather than x^* at the market in period 1, regardless of what his/her competitors do, if and only if additional speculator's demand induced by lower market price of oil, $^1/_m \times (1-\alpha) \times z_1$, is large enough to outweigh each strategic seller's loss incurred due to increased supply at the market. Each strategic seller's loss from market operation depends on the size of β whereas the size of the speculator's incentive depends on α and z_1, which in turn depends on the storage capacity owned by the speculator, z_s. If the capacity of the speculator's storage facility, z_s is relatively small, the speculator may fail to induce the strategic sellers to increase market supply and consequently, drop the market clearing price from p^* to $p^* - \beta$ in period 1. These insights are formally stated in Corollary 1 below.

Corollary 1. *For any given set of initial values of the model parameters,*

i. as α increases so does the speculator's inventory size, $\underline{z}_s$, required to induce higher oil supply in the retail market in period 1;

ii. as the size of the price discount in period 1, β increases so does the speculator's inventory size, $\underline{z}_s$, required to induce higher oil supply in the retail market in period 1; and

iii. as the number of strategic sellers operating in the market, m increases so does the speculator's inventory size, $\underline{z}_s$, required to induce higher oil supply in the retail market in period 1.

Proof. Please see Appendix 1. □

Note that in our setup we assume that the speculator's demand does not directly affect the market equilibrium; this is so because the speculator uses limit order conditional on equilibrium market clearing price to fulfill his oil buying in period 1. Although, indirectly the speculator is able to impact the market outcome significantly; that is, the speculator able to buy oil and at the same time lower the market clearing price of oil in the market in period 1. We depict the market demand function for oil in the market and the speculator's

limit order function for oil in Figure 4 below. In Section *4.2* the speculator uses limit orders to liquidate his inventory of oil that he acquired in period 1 and at the same time raise the market clearing price of oil in the market in period 2 from p^* to $\bar{p}_2 = p^* + \delta$.

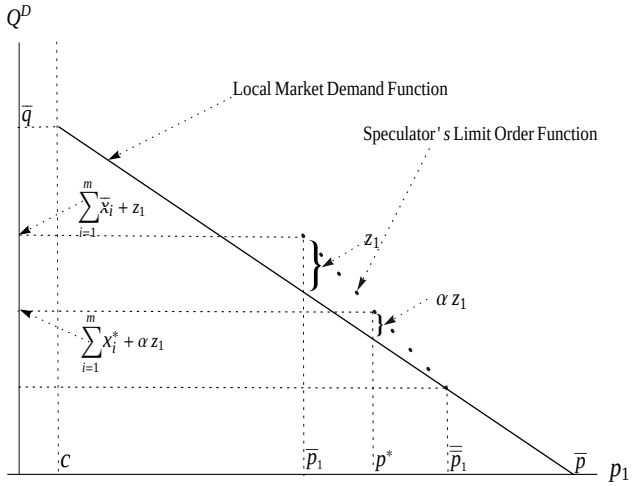


Figure 4: We depict nonstrategic traders' oil-claim demand and the speculator's order as a function of market clearing price in period 1. If the market clearing price of oil in period 1, $\bar{p}_1 \leqslant p^* - \beta$, then the speculator demands z_1 units of oil. If the market clearing price of oil in period 1, $p^* - \beta < \bar{p}_1 \leqslant p^*$, then the speculator demands only $\alpha\, z_1$ units of oil.

4.2 The Speculator and the Oil Market Equilibrium in Period 2

In period 2, the speculator has z_1 units of oil in possession. We assume that the oil position acquired by the speculator in period 1 is a retrospective costs that have already been incurred and cannot be recovered; i.e., the costs of purchasing the oil inventory in period 1 is a "sunk cost" as far as the speculator is concerned. Each strategic seller knows that such sunk costs will not affect the speculator's selling decision in period 2 and hence, the speculator will for sure liquidate the acquired oil inventory in period 2.[13] There are two ways the speculator can liquidate his oil inventory:

- *Strategy 1*: Place limit orders to sell the inventory at pre-specified market clearing price, say $\bar{p}_2$.

[13]For more details on sunk costs and credible threats see Rasmusen (2005) book on game theory.

- *Strategy 2*: If the limit order is not executed, liquidate the entire unsold inventory as the $(m+1)^{\text{th}}$ strategic seller.

Formally, the speculator places the following limit sell order at the beginning of period 2:

$$z_2(p_2) = \begin{cases} +z_1 & \text{if } p_2 \geq \bar{p}_2; \\ 0 & \text{otherwise.} \end{cases} \tag{50}$$

We assume that the speculator places his limit sell order – a sell plan that he let know other market participants in advance. Speculator's limit sell order states his intended quantity supply of oil-claim to the strategic sellers at different market clearing prices of oil. Let us assume that the price cutoff set by the speculator in period 2

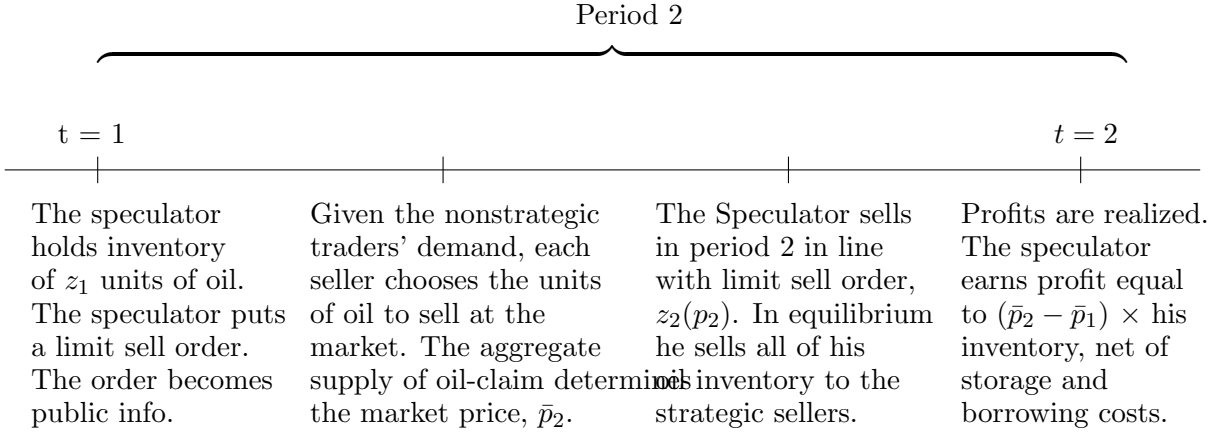
$$\bar{p}_2 = p^* + \delta, \tag{51}$$

where $\delta > 0$. Thus, $\bar{p}_2 > p^*$, the market clearing price in the absence of the speculator. We also need $\bar{p}_2 < \bar{p}$, price at which nonstrategic traders excess demand for oil is zero.

Next we proceed to show that the speculator once active in the oil market in period 2 can manipulate the existing market participants – the m large strategic sellers in a manner as to cause the oil price to move in favor of the speculator. Specifically, we show that faced with the speculator's limit sell strategy depicted in Equation (50), the m strategic sellers will get to an equilibrium such that the market clearing price of oil rises to $\bar{p}_2$ and the speculator is able to sell his z_2 units of oil at a price higher than the price he paid in period 1, $\bar{p}_1$. The figure below shows the event line of period 2.

4.3 Strategic Sellers' Strategies in Period 2

If the speculator's limit order is not executed, then the speculator sells the oil in the market using a market order – an order to sell at the market clearing price. Consequently, the



demand/supply conditions in the market are modified as follows:

$$x_1 + x_2 + \cdots + x_m + z_2 = a - b\,p_2. \tag{52}$$

Thus, the economic profit earned by each strategic seller, if he/she manages to sell x_i units of oil in the market is given by:

$$\pi_i\,(x_1,\, x_2,\, \cdots,\, x_m) = \left(a - b\left(x_i + \sum_{i \neq j,\, j=1}^{m-1} x_j + z_2\right) - c\right) \times x_i, \quad \forall i = 1,\, 2, \cdots,\, m. \tag{53}$$

Again, the equilibrium in this market is simply the Nash equilibrium (or fixed point) of this oligopolistic competition. Let us describe the m-tuple $(\hat{x}_1,\, \hat{x}_2,\, \cdots,\, \hat{x}_m)$ as the equilibrium supply response of m strategic sellers; then the optimal market clearing price of oil in each period is given by

$$\hat{p}_2 = a - b\,\hat{X} = a - b\,(\hat{x}_1 + \hat{x}_2 + \cdots + \hat{x}_m + z_2). \tag{54}$$

If all m strategic sellers are exactly identical and engage in oligopolistic quantity competition, then each strategic seller chooses to supply,

$$\hat{x}_{i,2} = \frac{a - c}{b \times (m+1)} - \frac{z_2}{b \times (m+1)} = x_i^* - \frac{z_2}{b \times (m+1)} \tag{55}$$

units of oil in each period and the resulting aggregate supply of oil-claim in the market in period 2 is given by

$$\hat{X} = \frac{m\,(a-c)}{b \times (m+1)} + \frac{z_2}{b \times (m+1)} = X^* + \frac{z_2}{b \times (m+1)}. \tag{56}$$

Thus, the optimal market clearing price of oil in period 2,

$$\hat{p}_2 = a - b\,\hat{X} = a - b\,X^* - b \times \frac{z_1}{b \times (m+1)} = p^* - \frac{z_2}{m+1}. \tag{57}$$

Each strategic seller earns

$$\hat{\pi}_{i,2}(\hat{x}_{1,2},\, \cdot\cdot,\, \hat{x}_{m,2},\, z_1) = (\hat{p}_2 - c) \times \hat{x}_{i,2} = \pi^*_{i,2} - \frac{z_1\,(2(a-c) - z_1)}{(m+1)^2} \tag{58}$$

as profits in period 2.

Next, consider the situation where each strategic seller decrease their supply just enough to raise the market clearing price of oil to $\bar{p}_2$ in period 2. In order to make the market clearing price increase to $\bar{p}_2$ each strategic seller needs to sell

$$\bar{x}_{i,2} = \frac{a - \bar{p}_2}{b\,m} = x^*_{i,2} - \frac{\delta}{b\,m}, \quad \forall i = 1,\, 2, \cdot\cdot,\, m. \tag{59}$$

If each strategic seller supplies $\bar{x}_{i,2}$ in period 2, then each earn

$$\begin{aligned} \bar{\pi}_{i,2}(\bar{x}_{1,2},\, \cdot\cdot,\, \bar{x}_{m,2},\, z_1,\, \delta) &= (\bar{x}_{i,2} - \frac{z_1}{m}) \times (\bar{p}_2 - c) = (x^*_{i,2} - \frac{\delta}{b\,m} - \frac{1}{m} z_1) \times (p^* + \delta - c) \\ &= \pi^*_{i,2} + \delta\, x^*_{i,2} - (p^* + \delta - c) \left(\frac{\delta}{b\,m} + \frac{z_1}{m} \right). \end{aligned} \tag{60}$$

$\forall i = 1,\, 2,\, \cdot\cdot,\, m$. Necessary condition for each strategic seller to supply $\bar{x}_{i,2}$ units of oil in the market in period 2 is that each strategic seller's profit from supplying $\bar{x}_{i,2}$ units of oil in the market in period 2, $\pi^*_{i,2}(\bar{x}_{1,2},\, \cdot\cdot,\, \bar{x}_{m,2},\, z_1,\, \delta)$ is greater than the profit each strategic seller earns if the speculator liquidate his inventory as the $(m+1)^{\text{th}}$ strategic seller, $\pi_{i,2}(\hat{x}_{1,2},\, \cdot\cdot,\, \hat{x}_{m,2},\, z_1)$.

Proposition 2 below formally states the required condition.

Proposition 2. *Each strategic seller is better off selling $\bar{x}_{i,2}$ units of oil rather than $\hat{x}_{i,2}$ units of oil in the market in period 2 if $\delta < \bar{\delta}$, where*

$$\bar{\delta} = \frac{(m^2-1) \times \frac{a-c}{m+1} - m\, z_1}{m+1} = (m-1) \times x_i^* - \frac{m}{m+1} \times z_1$$

Proof. Directly follows from equation (60). □

The intuition is quite straight forward: If $\delta > \bar{\delta}$, then each strategic seller has to reduce their own sell significantly in order to accommodate the speculator's supply. Even though the strategic seller gets high per unit price of oil, too high a δ may cause the unfavorable quantity effect dominate the favorable price effect. Hence, knowing this the speculator will choose a $\delta \leq \bar{\delta}$ such that each strategic seller finds it optimal to sell $\bar{x}_{i,2}$ units of oil rather than $\hat{x}_{i,2}$ units of oil in the market in period 2. The value of $\bar{\delta}$ depends on the number of strategic sellers, the size of the speculator's inventory acquired in period 1. These insights are formally stated in Corollary 2 below.

Corollary 2. *For any given set of initial values of the model parameters,*

i. as the size of the speculator's oil inventory acquired in period 1, z_1 increases, the maximum price, $\bar{p}_2$ at which the speculator can liquidate his inventory in the oil market in period 2 decreases;

ii. as the number of strategic sellers operating in the market, m, increases, so does the maximum price, $\bar{p}_2$, at which the speculator can liquidate his inventory in the oil market in period 2 increases.

Proof. Please see Appendix 1. □

Now let us consider the situation where all m strategic sellers are identical. Also, suppose all except one strategic sellers each decided to sell $\bar{x}_{i,2}$ units of oil each in period 2. Then

using Equation (29) we know that it is better for the m^{th} strategic seller to supply

$$x^d_{m,2} = \bar{x}_{i,2} + \frac{\delta \times (m+1)}{2\,b\,m} > \bar{x}_{i,2}. \tag{61}$$

$\forall i = 1, 2, \cdot\cdot, m-1$. This further implies that if the m^{th} strategic seller chooses to deviate and sell $x^d_{m,2}$ instead of $\bar{x}_{m,2}$, then the market clearing price,

$$p^d_2 = a - b \times \left(\bar{x}_{m,\,2} + \frac{\delta \times (m+1)}{2\,b\,m} + \bar{x}_{1,2} + \cdot\cdot + \bar{x}_{m-1,\,2} \right) = \bar{p}_2 - \frac{\delta \times (m+1)}{2\,m} < \bar{p}_2, \tag{62}$$

which further implies that the speculator's limit order to sell is not executed and thus, the speculator dumps his unsold inventory, z_1 units of oil in the market. Thus, the market clearing price of oil in period 2 if the m^{th} strategic seller deviate from selling $\bar{x}_{i,1}$ units of oil and rather sells $x^d_{m,1}$ units,

$$p^d_2 = \bar{p}_2 - z_1 - \frac{\delta \times (m+1)}{2\,m} = p^* - z_1 - \frac{\delta \times (m-1)}{2\,m} < \bar{p}_2 \tag{63}$$

giving a profit of

$$\pi^d_{m,2}(\bar{x}_{1,2},\, \cdot\cdot,\, \bar{x}_{m-1,2},\, z_1) = (p^d_2 - c) \times x^d_{m,2}$$

$$= \left(\bar{p}_2 - z_1 - \frac{\delta \times (m+1)}{2\,m} - c \right) \times \left(\bar{x}_{i,2} + \frac{\delta \times (m+1)}{2\,b\,m} \right)$$

to the deviant or the m^{th} strategic seller. Hence, the m^{th} strategic seller is better off not deviating and sticking to the strategy to supply $\bar{x}_{i,2}$ units of oil in the market in period 2 if and only if

$$\bar{\pi}_{m,2}(\bar{x}_{1,2},\, \cdot\cdot,\, \bar{x}_{m,2},\, z_1,\, \delta) > \pi^d_{m,2}(\bar{x}_{1,2},\, \cdot\cdot,\, \bar{x}_{m-1,2},\, z_1) \tag{64}$$

Since both the strategic sellers are identical, same chain of argument should hold for the first strategic seller if he decides to deviate; i.e., Equation (64) should hold $\forall i = 1, 2, \cdot\cdot, m$.

Proposition 3 formalizes this intuition.

Proposition 3. *If the speculator's storage capacity for oil,* $z_s \geqslant \underline{z}_{s,2}$ *where*

$$\underline{z}_{s,2} = \frac{\gamma^2(m+1)^3}{2\,b\,m \times (2\,(m-1) \times (a-c) + \gamma \times (m-3) \times (m+1))},$$

then only it is optimal for each strategic seller to decrease his/her own supply of oil-claim in the retail market, regardless of what his/her $(m-1)$ *competitors do, such that the market clearing price of oil in period 2 rises to* $p^* + \delta$ *from* p^*.

Proof. Directly follows from equation (64) after substituting the expression for the profits. □

Thus, we show that a speculator who has access to physical storage capacity, $z_s \geq \max[\underline{z}_{s,1}, \underline{z}_{s,2}]$, can buy z_1 units of oil in period 1 at a price of $p^* - \beta$ per unit. Then, the speculator can sell z_1 units in period 2 at a price of $p^* + \delta$ per unit. Thus, we claim that the speculator manufactures "oil price volatilities," and profit from it at the expense of many small/medium consumers and business owners.

5 Conclusion

We constructed a model economy in which a large reputable speculator with access to sizable investible funds can influence the behavior of all other rational market participants in such a way that the speculator can actually lower the price when buying the commodity in period 1 and raise the market clearing price when selling the commodity in period 2, thereby causing larger price swings. The speculator achieves this by credibly communicating his demand and supply schedules at various prices to the strategic sellers who supply the commodity. The large speculator behaves like a Stackelberg leader and that drives the strategic sellers to behave in a way that allows the speculator to engage in destabilizing but profitable speculation. While possible, our results also suggest that destabilizing speculation may

be difficult to sustain, since implementation of these strategies require a level of market credibility and more importantly easy access to large investible funds that may be difficult to obtain.

Further, each strategic seller takes the speculator's order book and the supply of other producers as given and decide how much oil to supply in the spot market. Given that some of the producers are very large, they could use credible limit orders to stabilize prices, making large destabilizing speculative positions difficult to maintain.

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