Destabilizing Commodity Market Speculation

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Abstract:

We show that under quantity 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 facility can have a destabilizing effect on commodity prices. The speculator can profit by lowering the price of when buying and raising the price when selling commodity contracts, thereby increasing the commodity price volatility. There is no information asymmetry or private information in our model. Also, we do not consider any explicit coordination among these strategic sellers and/or the speculator. While possible, our results also suggest that destabilizing speculation may be difficult to sustain.

Keywords: Commodity Market, Commodity Trading, Commodity Price Manipulation, Commodity Price Volatility, Cournot Competition, Speculation, Speculator, Strategic Seller.

JEL Classification Code: G32, G34, G38, K20

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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 in 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 $108.62 in October 2013. 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."

Speculation in commodity future markets is not a new emergence. It has been there since the turn of 19th century to enable commodity traders – particularly small producers to protect themselves against excessive short-term price volatility.[3] That is, hedging by traditional or commercial speculation in the futures markets protects buyers against sudden price increases, and sellers against sudden price drops. For commodity buyers and sellers, speculation has been a form of indirect price insurance.

One key distinction between recent commodity price spikes and previous price increases is the role played by *speculators*. 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 since 2004 regime switches in oil price has been much more frequent, along with prominence of "speculative investments" in the data. Chevallier (2011) investigates the presence of outliers in the volatility of carbon prices and finds evidence in support of instability in the volatility of carbon prices. Mason and Rowley (2012) document that between 1999 and 2004, the biggest difference between

[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]Read, for example, Cowing (1965) for a excellent discussion on the history of commodity speculation,1890-1936.

the high and low price per barrel in any given year was about \$16; whereas, from 2005 onwards this difference has been increasing. This difference was about \$53 in 2005 and in the year 2008 it was close to \$150 per barrel.[4] In contrast, Irwin and Sanders (2012) take the position that the large swings in oil 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/forward prices of commodity when all market participants have *rational expectations*. We consider a model economy with a single commodity, 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.[5] In such an economy, we show that the speculator with access to physical storage facility can lower the market price when he buys to build inventories and raise the price when he sells to reduce inventories, thereby causing large fluctuations in commodity prices.[6]

The common view is that speculators who act competitively, provide liquidity in the market and thereby, dampens price fluctuations. Typically, these speculators buy when prices are low – thereby increasing the price. Similarly, these speculators sell when prices are high – thereby causing the price to come down. In contrast, we show that when there is only one large speculator, the speculator buys at the same time causes the price to drop and subsequently, the speculator sells and causes the price to rise. Thus, our speculator instead of stabilizing prices cause the commodity price to be more volatile.

Flow of information among various agents plays an important role in our model. Since the strategic sellers take the demand curve as given when determining their profit maximizing supply, each strategic seller needs to know the exact market demand function

[4]See Domanski and Heath (2007), Sornette et al. (2008) and Tang and Xiong (2010) for more discussions on oil price movements and volatility. Further, Sockin and Xiong (2013) show that speculator-driven run-ups in commodity futures prices may not dampen real demand because of an information feedback effect.

[5]See Hart and Kreps (1986) and Jagannathan et al. (1990) examples of destabilizing speculation in the presence of private information. Also, Schwartz (2012) shows that the revelation of speculators' positions is informative to other investors implying that such position may contain private information.

[6]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.

when the speculator is active in the commodity market. Similarly, these strategic sellers must be fully aware that only reason our speculator wants to buy the commodity in period 1, because s/he wants to sell his acquired inventory in period 2 – that is, act as an additional competitor in period 2. Also, the strategic sellers must believe that the commitments made through the speculator's demand/supply schedule will be fulfilled – that is, there is zero possibility of default. In that case, we show that the speculator using his carefully crafted "buy order schedule" can make each strategic seller to increase his/her own supply resulting in a lower equilibrium market clearing price in period 1. From the perspective one strategic seller, the additional supply to the market when all of his/her rivals choose not to increase their own supply, must offsets the loss from selling at a lower price to the nonstrategic buyers. Subsequently, the speculator uses carefully crafted "sell order schedule" to induce each strategic seller to reduce their own supply in period 2, and thereby, allow the speculator to liquidate his/her inventory at a higher price. Hence, the speculator through his trades causes the commodity price to be much more volatility. We show that such a behavior is rational and sustainable in equilibrium.

Given that we have assumed absence of any uncertainty in our environment and further assume that interest rates are zero, there will be no trading in the spot market, and spot and forward prices will be the same. Thus, our speculator will only operate in the commodity forward market.

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. For example, in a seminal work Muth (1961) argues the case for rational expectation with an example which deals with the economic effects of inventory storage and speculation. Similarly, Newbery (1984) was the first to explore the implications of market power for the choice of storage rule and the degree of price stabilization. He finds that with production uncertainty and linear demand, strategic large suppliers choose more stable prices and price stability increases with these suppliers' market share. Thille (2003) developed a dynamic game that models the effects of forward trading and storage in an imperfectly competitive market. Contrary to our finding it finds that the pro-competitive effects of forward trading are weakened by the addition of storage. Chatterjea and Jarrow (1998) show that price manipulation can occur in the Treasury auction market if "when-issued" market dealers are able to use their information about the net order flow in market order to corner the auction and squeeze the shorts. Similarly, Cooper and Donaldson (1998) paper discuss commodity price manipulation through the use of similar corner-and-squeeze strategy. Attari et al. (2006) show how pump-and-dump strategies can be

used to take prices away from their fundamental value.[7]

High cost of storage will erode profits and deter destabilizing speculation. On the other hand, costless storage may encourage "too many" speculators in period 1 and thus, market clearing price may even rise in period 1. Thus, our model may not be applicable to markets where storage is near costless, viz., gold and financial products. 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, 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 increases.

The remainder of this article is organized as follows: In Section 2 we derive a simple 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. We conclude in Section 4.

2 A Numerical Example

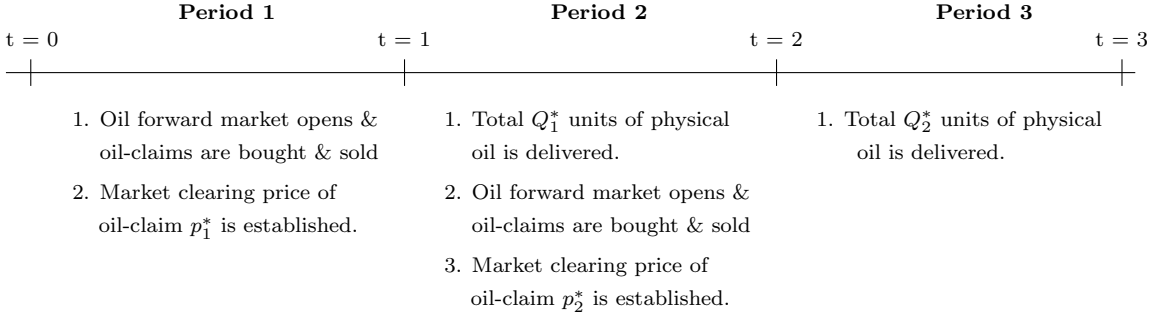
We consider a four date/three-period forward market for a "difficult-to-store" commodity – say, crude oil. For convenience we use dollar as numeraire. We assume that there is no uncertainty in our framework; that is, demand and supply of oil is perfectly predictable. More importantly, we assume a perfect contracting environment – an environment where there is no possibility of natural and/or strategic default at the time of delivery. And in addition given our assumption that the risk-free rate of interest is zero (no time value of money), it follows that there is no difference between a unit of forward contract – a contract that delivers one unit of physical oil in the next period and the spot purchase of oil in the next period.

We will use the term "oil-claim" to describe a unit of forward contract that entitles its holder to claim a unit of physical oil in the next period at the current market-clearing price. For example, a buyer of a unit oil-claim in period 1 gets delivery of a unit of physical oil in period 2 at the market clearing price established in period 1.[8] Since most

[7]Recently, Kyle and Viswanathan (2008) argue that a trading strategy is an illegal price manipulation if it simultaneously undermines both pricing accuracy and market liquidity. This paper helps to redefine an important policy question: what qualifies as "illegal price manipulation" and what can be construed as just "routine rational exploitation" of market power or private information?

[8]Whereas a buyer of a unit of oil-claim in period 2 gets delivery of a unit of physical oil in period 3 at the market clearing prices established in period 2.

of the real actions – buying and selling of oil-claims occur only in period 1 and period 2, we will ignore period 3 for most part of our analysis. We denote equilibrium market clearing price and market clearing quantity of oil-claim by p_1^* and Q_1^* in period 1 and by p_2^* and Q_2^* in period 2.[9] Temporal evolution of events in our numerical example is depicted in the figure below.



We assume three types of market participants: Firstly, there are large number of small consumers/retailers – we call them "nonstrategic" traders – who take market price of a unit of oil-claim in each period, p_t as given and place their individual orders to buy oil in small quantities that will be delivered in the next period. Secondly, there are two identical strategic sellers (or quantity duopolist), who supply oil-claims to meet consumers'/retailers' excess-demand for oil-claim and in the process maximize their own firm value. We call these two strategic sellers: seller a and seller b. Both these sellers maintain their position of dominance by behaving duopolistically and influence market clearing price by adjusting their own supply of oil-claim.[10] Lastly, there is one large speculator, who buys oil-claim from the strategic sellers in period 1 with the sole objective of selling oil-claim in the same local market in period 2. We assume that the speculator's buy-sell objective is common knowledge.

First we consider the case without the speculator – we call this the "benchmark" case. In our benchmark case the two periods are exactly identical; hence, we do not temporally distinguish between strategies adopted and quantities offered by each strategic seller and the resulting market clearing price. Next, we allow our speculator to enter the local oil market. Given that the strategies adopted by the speculator in period 2 is quite different compared to his/her strategies in period 1 – we start temporally distinguishing between the strategies adopted and quantities offered by each strategic seller and the resulting

[9]We will not differentiate between quantity demanded and quantity supplied unless it is absolutely essential to do so. Hence, Q_1^* and Q_2^* sometimes will proxy for aggregate supply and sometimes for aggregate demand. This will help us to reduce significantly number of notations.

[10]We show in Section 3 that our results hold if we assume m identical strategic sellers instead of two.

market price.

Absence of demand/supply uncertainties, asymmetric information – any kind of friction and our assumption that these strategic sellers are exactly identical makes the problem at hand a simple duopoly problem. Hence, we solve the oil market equilibrium following Gibbons (1992).

We assume that each strategic seller maximizes aggregate profit or value of their respective firms, V, subject to their choice variable – the number of units of oil-claim to be supplied in each period. Thus, we can write the objective function of strategic seller a as follows:

$$V_a = \max_{q_{a_1}} \pi_{a_1}(q_{a_1}, \bar{q}_{b_1}) + \max_{q_{a_2}} \pi_{a_2}(q_{a_2}, \bar{q}_{b_2}), \tag{1}$$

where $\pi_{a_1}(\cdot)$ and $\pi_{a_2}(\cdot)$ are the profits, q_{a_1} and q_{a_2} are the number of units of oil-claim offered by strategic seller a, and $\bar{q}_{b_1}$ and $\bar{q}_{b_2}$ are strategic seller a's assumption about strategic seller b's supply of the same in period 1 and period 2 respectively. Hence, value of strategic seller a's firm is just the aggregate equilibrium profit earned in two periods. Specifically,

$$V_a^* = \sum_{t=1}^{2} \pi_{a_t}^*(q_{a_t}^*, q_{b_t}^*), \tag{2}$$

where $q_{a_t}^*$ is the equilibrium units of oil-claim offered and $\pi_{a_t}^*$ is the equilibrium profit earned by strategic seller a in each period. Similarly, we can derive value function for strategic seller b.

In absence of the speculator, we assume that the consumers/retailers have the following linear demand function for oil-claim:

$$Q_t = 100 - p_t, \qquad t = 1, 2, \tag{3}$$

where Q_t is the total number of units of oil-claim demanded by these price-taking consumers/retailers and p_t is the price per unit of oil-claim. Thus, the equilibrium market clearing price of oil-claim in each period t is determined by the following demand and supply conditions:

$$Q_t^* = 100 - p_t^*, \tag{4}$$

and

$$Q_t^* = q_{a_t}^*(p_t^*, q_{b_t}^*) + q_{b_t}^*(p_t^*, q_{a_t}^*), \qquad t = 1, 2, \tag{5}$$

where $q_{a_t}^*$ and $q_{b_t}^*$ are the number of units of oil-claim offered by each strategic seller in each period t in response to the market clearing price p_t^* and his/her competitor's supply, $q_{a_t}^*/q_{b_t}^*$. Equations (4) and (5) together constitutes an equilibrium in the local

oil market, because none of the two strategic sellers has any incentive to change his/her supply of oil-claim so long as his/her competitor does not change his/her supply – i.e., no incentive to deviate unilaterally.

2.1 Benchmark Case

If we further assume that each strategic seller acquires/produces oil at a fixed cost of \$10 per unit in each period, then each strategic seller maximizes the following profit function in each period (ignoring the time subscript):

$$\pi_a = \max_{q_a} \quad q_a \times (100 - q_a - \bar{q}_b) - 10\, q_a, \tag{6}$$

$$\pi_b = \max_{q_b} \quad q_b \times (100 - \bar{q}_a - q_b) - 10\, q_b. \tag{7}$$

respectively. Next, we derive strategic seller a's reaction function by equating seller a's marginal revenue with his/her marginal cost:

$$q^{'}_{a_1} = \frac{90 - q_{b_1}}{2}. \tag{8}$$

Similarly, we derive strategic seller b's reaction function:

$$q^{'}_{b_1} = \frac{90 - q_{a_1}}{2}. \tag{9}$$

Since we restrict our attention to symmetric equilibrium, we solve Equations (8) and (9) only after imposing an additional condition that q_a^* has to be equal to q_b^* in equilibrium. This gives the following solution: $q_a^* = q_b^* = 30$ units of oil-claim supplied in each period and the equilibrium market clearing price of $p^* = \$40$. Thus, each strategic seller earns, $\pi_a^* = \pi_b^* = (40 - 10) \times 30 = \$900$ as economic profit and value of each of their firms is given by:

$$V_a^* = \pi_{a_1} + \pi_{a_2} = V_b^* = \pi_{b_1} + \pi_{b_2} = \$900 + \$900 = \$1800. \tag{10}$$

In this simple two-period model without any kind of market/information friction – like demand/supply uncertainty and/or asymmetric information – it is not at all surprising that there does not exist any *oil price volatility*. Each strategic seller supplies 30 units of oil-claim in each period taking the aggregate supply equal to 60 units in each period and hence, setting a market clearing price of \$40 per unit and in the process earning \$900 as economic profit.[11]

[11]Physical oil is delivered after one period – together these two strategic seller delivers 60 units of physical oil to the holders of these oil-claims in period 2, and another 60 units of physical oil to the

Next, we consider the case where the speculator enters the oil market. In particular, we analyze the impact of speculator's entry on the market equilibrium. Once again we highlight the following information about the speculator's strategies: Our speculator enters the oil market and buys oil-claim in period 1; s/he buys oil-claim with the sole objective of selling these oil-claim in period 2 and speculator's buy-sell objective is common knowledge. Under these conditions we show that even though the speculator buys oil-claim in period 1 s/he is able to bring *down* the market clearing price of oil-claim. In period 2, on the other hand, even though the speculator liquidates his/her acquired inventory of oil claim, we show that s/he manages to *raise* the market clearing price of oil significantly.

We understand that there exists considerable interdependence between the strategies adopted by two strategic sellers and the speculator in period 1 and strategies adopted by them in period 2. But we will solve period 1 and period 2 sequentially and then analyze the interdependence of these two periods at the very end.

2.2 Strategic Sellers' & Speculator's Strategies in Period 1

The market demand function for oil-claim – without the speculator's order – remains unchanged. Our speculator enters the oil market in period 1 and places the following order schedule: s/he wants to long 6 units of oil-claim only if the market clearing price of a unit of oil-claim, p_1 is less than or equal to \$37. Otherwise, s/he does not want to take any position in oil-claim. Specifically, the speculator places the following buy order in the market in period 1:

$$Q_{s_1} = \begin{cases} 0 & p_1^* \geqslant 37 \\ [0,6] & p_1^* = 37 \\ 6 & p_1^* \leqslant 37 \end{cases} \tag{11}$$

where p_1^* is the equilibrium market clearing price of a unit of oil-claim in period 1. Speculator's demand is an additional source of demand for the strategic sellers; thus, in presence of speculator, kinked inverse demand function for oil-claim in period 1 is as follows:

$$p_1 = \begin{cases} 100 - q_{a_1} - q_{b_1} & \text{if } Q_1^* \leqslant 63 \\ 37 & \text{if } 63 \leqslant Q_1^* \leqslant 69 \\ 106 - q_{a_1} - q_{b_1} & \text{if } Q_1^* \geqslant 69 \end{cases} \tag{12}$$

holders of these oil-claims in period 3.

where $Q_1^* = q_{a_1}^* + q_{b_1}^*$ is the aggregate demand/supply of oil-claim in period 1. In period 1 there are two sources of demand for oil-claim: Q_{n_1} units from nonstrategic consumers/retailers and Q_{s_1} units from the speculator. Thus, we can express aggregate demand, $Q_{n_1} + Q_{s_1}$ equals aggregate supply $q_{a_1} + q_{b_1}$ and we represent the equalized value by Q_1^*. We depict this inverse kinked demand function in figure 1 below.

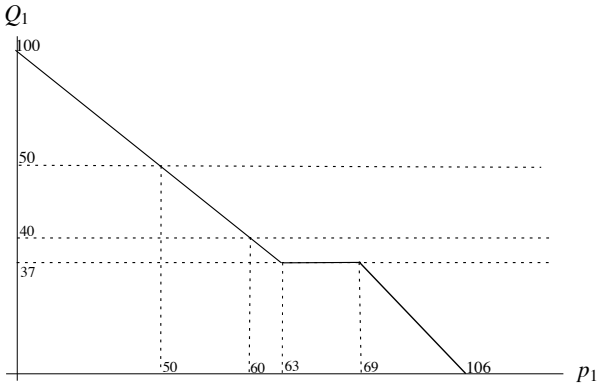


Figure 1: In this figure we depict the kinked inverse oil demand function for oil in period 1. At thirty-seven dollars price per unit of oil-claim aggregate demand for oil-claim is a range, [63, 69] rather than an unique number. The total demand for oil-claim can be divided into two sources: 63 units of oil-claim are demanded by the consumers/retailers and $[0, 6]$ unit(s) of oil-claim demanded by the speculator.

Since each strategic seller acquires/produces oil at a fixed cost of 10 dollars per unit, strategic seller a maximizes the following profit:

$$\pi_{a_1}(q_{a_1}, \bar{q}_{b_1}) = \begin{cases} q_{a_1} \times (100 - q_{a_1} - \bar{q}_{b_1} - 10) & \text{if } q_{a_1} + \bar{q}_{b_1} \leqslant 63 \\ q_{a_1} \times (37 - 10) & \text{if } 63 \leqslant q_{a_1} + \bar{q}_{b_1} \leqslant 69 \\ q_{a_1} \times (106 - q_{a_1} - \bar{q}_{b_1} - 10) & \text{if } q_{a_1} + \bar{q}_{b_1} \geqslant 69 \end{cases} \tag{13}$$

where $p_1 = 100 + Q_{s_1} - Q_1 = 100 + Q_{s_1} - Q_{n_1} - Q_{s_1} = 100 - Q_{n_1}$. Similarly, we can write the profit function of strategic seller b as follows:

$$\pi_{b_1}(\bar{q}_{a_1}, q_{b_1}) = \begin{cases} q_{b_1} \times (100 - \bar{q}_{a_1} - q_{b_1} - 10) & \text{if } \bar{q}_{a_1} + q_{b_1} \leqslant 63 \\ q_{b_1} \times (37 - 10) & \text{if } 63 \leqslant \bar{q}_{a_1} + q_{b_1} \leqslant 69 \\ q_{b_1} \times (106 - \bar{q}_{a_1} - q_{b_1} - 10) & \text{if } \bar{q}_{a_1} + q_{b_1} \geqslant 69 \end{cases} \tag{14}$$

To establish the local optimum, given constant marginal costs, strategic seller a solves the equation: $MR_{a_1} = 10$ and strategic seller b solves the equation $MR_{b_1} = 10$. When $MR_{a_1} = MR_{b_1} = 37 > MC = 10$, then it is optimal for strategic seller a and b to offer 69 units of oil-claim to consumers/retailers and speculator together. This results in the

reaction functions $q_{a_1}^{'} = \phi(q_{b_1})$ and $q_{b_1}^{'} = \phi(q_{a_1})$, which we expect to become identical in view of symmetry of the present case. Equating marginal revenues to marginal cost we obtain the following solutions for the strategic seller a's reaction function:

$$q_{a_1}^{'} = \begin{cases} \frac{90-q_{b_1}}{2} & q_{a_1}^* + q_{b_1}^* \leqslant 63, \\ 69 - q_{b_1} & 63 \leqslant q_{a_1}^* + q_{b_1}^* \leqslant 69 \\ \frac{96-q_{b_1}}{2} & q_{a_1}^* + q_{b_1}^* \geqslant 69 \end{cases} \tag{15}$$

Similarly, we derive the following solutions for the strategic seller b's reaction function:

$$q_{b_1}^{'} = \begin{cases} \frac{90-q_{a_1}}{2} & q_{a_1}^* + q_{b_1}^* \leqslant 63, \\ 69 - q_{a_1} & 63 \leqslant q_{a_1}^* + q_{b_1}^* \leqslant 69 \\ \frac{96-q_{a_1}}{2} & q_{a_1}^* + q_{b_1}^* \geqslant 69 \end{cases} \tag{16}$$

2.2.1 Derivation of Oil Forward Market Equilibrium in Period 1

All three reaction functions are potential candidates for the equilibrium outcome. We propose an equilibrium and then prove that it is indeed an oil-forward market equilibrium by ruling out any unilateral deviation by any one of two strategic sellers. First let us consider the following set of reaction functions:

$$q_{a_1}^{'} = \frac{90 - q_{b_1}}{2} \quad \text{and} \quad q_{b_1}^{'} = \frac{90 - q_{a_1}}{2}. \tag{17}$$

Solving these two reaction functions, we obtain the optimal quantity supplied by each strategic seller: $q_{a_1} = q_{b_1} = 30$ units of oil-claim at market clearing price of 40 dollars per unit – same as the benchmark case. Incorporating this market clearing price into speculator's demand function we obtain actual speculator's demand in period 1: $Q_{s_1}(40) = 0$ units of oil-claim. This implies that 40 dollars is indeed a market clearing price and the aggregate supply in period 1: $30 + 30 = Q_1 = Q_{n_1} + Q_{s_1} = 60 + 0 < 63$, which is consistent with the set of reaction functions that we are considering. Hence, this outcome is a potential candidate for the forward market equilibrium.

But is this an equilibrium? To answer this question we have to show that unilateral deviation is unprofitable. It is quite straightforward to show that if one strategic seller, say seller b, chooses to offer 30 units of oil-claim, then it is optimal for strategic seller a to increase his/her supply to $q_{a_1}^d = 39$ units. Thus, strategic seller a's deviation profit, denoted by $\pi_{a_1}^d$, is as follows:

$$\pi_{a_1}^d(q_{a_1}^d, 30) = 39 \times (106 - 39 - 30 - 10) = 39 \times (37 - 10) = \$1,053. \tag{18}$$

This is because $q^d_{a_1} + 30 = 69$ and relevant inverse demand function for oil-claim is $p_1 = 37 = 106 - 39 - 30$. Note that strategic seller a earns 153 dollars more than what s/he would have earned (900 dollars) if s/he sticks to offering 30 units of oil-claim in period 1. What happens to strategic seller b's profit? Actually, it drops and is given by:

$$\pi_{b_1}(39,\, q_{b_1}) = 30 \times (106 - 30 - 39 - 10) = \$810, \tag{19}$$

which is strictly less than 900 dollars. Thus, when the speculator is active in the oil market, $q_{a_1} = q_{b_1} = 30$ cannot be an equilibrium response in period 1. This is because unilateral deviation by any one of the strategic sellers is profitable for him/her.

Next, we look for an equilibrium where each strategic seller chooses the number of units of oil-claim to offer using their second set of reaction functions, depicted by Equations 15 and 16. The number of units of oil-claim offered by each strategic seller must satisfy the aggregate demand condition: $63 \leqslant Q_1 \leqslant 69$. Here both marginal revenue ($37) and marginal cost ($10) are fixed; hence, offering the maximum amount, 69 units of oil-claim is the optimal response. Solving for the symmetric quantities we find that $q_{a_1} = q_{b_1} = 34.5$. Thus, each strategic seller earns

$$\pi_{a_1} = \pi_{b_1} = 34.5 \times (106 - 34.5 - 34.5 - 10) = 34.5 \times (37 - 10) = \$931.50. \tag{20}$$

The offering pair $q_{a_1} = q_{b_1} = 34.5$ indeed constitutes an equilibrium response. The following profit function also corroborates the fact that any unilateral deviation is unprofitable for the deviant strategic seller. Assuming that the strategic seller b offers 34.5 units of oil-claim in period 1, if strategic seller a offers a different number of oil-claim, say $q^d_{a_1}$, then strategic seller a's profit function can be defined as follows:

$$\pi^d_{a_1}(q^d_{a_1},\, 34.5) = \begin{cases} q^d_{a_1} \times (100 - 34.5 - q^d_{a_1} - 10) & q^d_{a_1} \leqslant 28.5 \\ q^d_{a_1} \times (37 - 10) & 28.5 \leqslant q^d_{a_1} \leqslant 34.5 \\ q^d_{a_1} \times (106 - 34.5 - q^d_{a_1} - 10) & q^d_{a_1} \geqslant 34.5 \end{cases} \tag{21}$$

In figure 2, we depict the profits of the deviant strategic seller a for different choices of quantity of oil-claim offered by him/her when strategic seller b sticks to offering 34.5 units.

From figure 2, it is easy to verify that $\pi^d_{a_1} \leqslant \$931.5$ for all $q^d_{a_1}$. Hence, unilateral deviation is not profitable. Each strategic seller offers, $q^*_{a_1} = 34.5$ units of oil-claim resulting in an aggregate supply of 69 units of oil-claim in period 1. Out of these 69 units: 63 units are bought by the consumers/retailers and remaining 6 units are bought by the

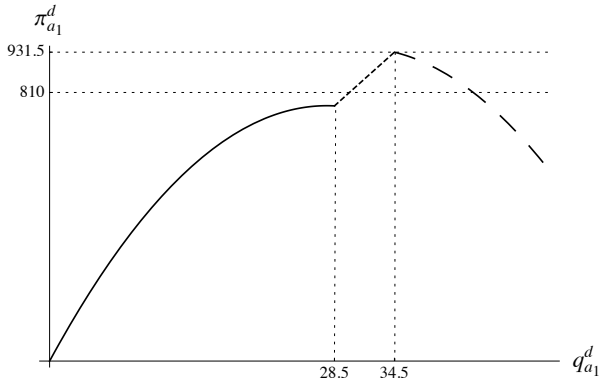


Figure 2: In this figure we depict the profit of the deviant strategic seller a, $\pi^d_{a_1}$. We depict firm's profit as a function of different choices of units of oil-claim offered, $q^d_{a_1}$ by the deviant strategic seller in period 1.

speculator. The equilibrium market clearing price is given by: $p_1^* = 106 - 34.5 - 34.5 = 100 - 31.5 - 31.5 = \$37$ per unit. We show that as the speculator enters the oil forward market in period 1, s/he buys 6 units of oil-claim –i.e., s/he increases oil-demand by 13.0% – and at the same time manages to *drop* the equilibrium market clearing price of oil by 7.5% from \$40 per unit to \$37 per unit.[12]

Next, we derive the oil forward market equilibrium in period 2. Now, there is one new source of supply: the speculator's inventory acquired in period 1. We are going to analyze the implication of speculator's entry on the supply side of the market. We will consider all the possible ways our speculator can liquidate his/her oil inventory.

2.3 Strategic Sellers' & Speculator's Strategies in Period 2

In period 2, the speculator holds 6 units of oil in his/her inventory. Both strategic sellers are fully aware that the speculator considers his/her oil position acquired in period 1 as a "sunk cost," and will liquidate his/her entire inventory of oil-claim in period 2 – i.e, will deliver inventory of physical oil in period 3.

Next we consider different ways that the speculator may liquidate his/her entire inventory of oil-claim in period 2:

- Strategy I_s: The speculator acts as an independent "price-taker" and consequently dumps his/her entire inventory of oil-claim directly into the market at the market clearing price, $\hat{p}_2$ – a price established by independent supply decisions of the two

[12]It is easy to show that if you solve for the symmetric response of both strategic sellers using third set of reaction functions, $\frac{96-q_{k_1}}{2}$, the aggregate oil-claim offered does not satisfy the minimum supply requirement.

strategic sellers in period 2.

- Strategy II_s: Alternatively, all three major players: speculator, strategic seller a and strategic seller b take more prominent leadership role and explicitly specify strategies if p_2^* is greater than or equal to \$50. Similarly, all three major players explicitly specify their strategies if p_2^* is strictly less than \$50.

We will analyze the impact of these two liquidation strategies of the speculator in sections *2.3.1* and *2.3.3* in details.

2.3.1 Price-taking Speculator and the Oil Forward Market in Period 2

In this section, we assume that the speculator follows Strategy I_s. In period 2, our speculator wants to sell. We denote speculator's supply by q_{s_2}.[13] Given the speculator's price-taking strategy, the demand/supply conditions in the market can be depicted as follows:

$$\begin{aligned} q_{a_2} + q_{b_2} + q_{s_2} = q_{a_2} + q_{b_2} + 6 &= 100 - p_2, \\ q_{a_2} + q_{b_2} &= 94 - p_2. \end{aligned} \tag{22}$$

We call this expression depicted in Equation (22), as the net demand function. Given their competitor's response, each strategic seller maximizes profits; hence, each strategic seller's profit function may be written as:

$$\pi_{a_2} = q_{a_2} \times (94 - q_{a_2} - \bar{q}_{b_2}) - 10\, q_{a_2} \tag{23}$$

$$\pi_{b_2} = q_{b_2} \times (94 - \bar{q}_{a_2} - q_{b_2}) - 10\, q_{b_2} \tag{24}$$

Each seller ends up selling, $q_{a_2}^* = q_{b_2}^* = 28$ units of oil-claim in the market, resulting in an aggregate supply of 62 units. Consequently, the market clearing price, p_2^* is \$38 per unit and each strategic seller earns

$$\hat{\pi}_{a_2} = \hat{\pi}_{b_2} = 28 \times (94 - 28 - 28) - 10 \times 28 = (38 - 10) \times 28 = \$784.00 \tag{25}$$

as profits in period 2. Under this scenario, the speculator earns

$$\hat{\pi}_s = (38 - 37 - k_s) \times 6 = 6 - 6\, k_s \tag{26}$$

[13]Note that negative demand is supply; hence, $q_{s_2} = -Q_{s_1}$. Thus, $q_{s_2} = 6$ implies that the speculator wants to sell 6 units of oil-claim in period 2.

dollars as profit, where k_s is the exogenous per-unit-storage costs of our speculator. If k_s is such that $\hat{\pi}_s \geqslant 0$, then this naive price-taking-selling strategy of the speculator is feasible.

2.3.2 Temporal Strategic Interdependence

What is the value of each strategic seller's firm? In period 1 each strategic seller earned \$931.50 as profit, which is \$31.50 more than what they would have earned, had not the speculator enter the oil market in period 1. In period 2 each strategic seller is hammered – each earns only \$784 as profit – good \$116 less than what they would have earned if there was no speculator.

But whether the speculator plays a seller's role or not in period 2 completely depends on these two strategic sellers' behavior in period 1.[14] If neither of these two strategic seller offers to sell these 6 units of oil-claim to the speculator in period 1, then it is not possible for the speculator to dump this acquired inventory in the market in period 2.

Now the question is, which strategy should be adopted by strategic seller a and strategic seller b when the speculator is active in the local oil market as a price-taker in period 2? Should they accommodate his/her buy order into their supply function or ignore it? To find that out, let us formally define "Strategy I" as the strategy to increase their own supply of oil-claim in period 1 and in the process absorb speculator's demand and "Strategy II" as the strategy to maintain supply of oil-claim at level of the benchmark quantity, q^*. We have the following payoffs for seller a and seller b:

(1) If both strategic sellers ignore the speculator's buy order in period 1, i.e., adopt Strategy II, then each of their firm is valued \$1,800 (= \$900 + \$900).

(2) If one of the strategic sellers follows Strategy II, i.e., keep his/her supply at q^* units of oil-claim, then this non-deviant seller's firm is valued \$1,594 (= \$810 + \$784). Whereas, its competitor, the other seller, if s/he follows Strategy I and increase his/her supply to absorb entire speculator's demand, then this deviant seller's firm is valued \$1,837 (= \$1,053 + \$784).

(3) If both strategic sellers a and b follow Strategy I, i.e., both increase their supply, then each of these sellers' firm is valued \$1,715.50 (= \$931.50 + \$784)

For better comparison, we tabulate below, seller a's and seller b's firm values under both strategies:

[14] Remember, we have assumed that the speculator has no access to physical oil other than buying it from the strategic sellers in period 1.

		Strategic Seller b	
		Strategy I	Strategy II
Strategic Seller a	Strategy I	\$1715.50, \$1715.50	\$1837.00, \$1594.00
	Strategy II	\$1594.00, \$1837.00	\$1800.00, \$1800.00

The first number and the second number in each of these four cells of the above table – (I, I), $(\mathrm{I},\ \mathrm{II})$, $(\mathrm{II}, \mathrm{I})$ and $(\mathrm{II}, \mathrm{II})$ – represents strategic seller a's firm value and strategic seller b's firm value respectively.

Looking at the payoff structure it is obvious that for each of these two strategic sellers adopting strategy I is strictly better than adopting strategy II, irrespective of what the other strategic seller adopts. This implies that each strategic seller fully knowing that the speculator is going to hammer their profits in period 2 will equip the speculator in period 1 with the necessary inventory of oil-claim. Equilibrium is characterized by some *oil price volatility* and increased supply of oil in both periods – 69 units in period 1 and 62 units in period 2 and both greater than the benchmark quantity of 60 units. Consumers/retailers are strictly better off and each strategic seller is strictly worse-off. Obviously all these happen only if the speculator is at least weakly better off. Thus, we assume that unit cost of storing oil, $k_s < 1$.

In the next section, we revisit the oil market equilibrium in period 2. We will consider a different role for our speculator and our strategic sellers and show that if our speculator acts as a market-leader and with some help from the strategic sellers, they together can achieve an equilibrium in period 2 characterized by much higher profits for all three of them, low aggregate supply of oil-claim, higher oil prices and significantly high oil price volatility.

2.3.3 Speculator's Leadership and the Oil Forward Market in Period 2

Now let us consider the situation where our speculator takes more prominent role in determining the oil market equilibrium in period 2. His/her supply function is as follows:

$$q_{s_2} = \begin{cases} 5 & \text{if } p_2^* \geqslant 50, \\ 6 & \text{otherwise.} \end{cases} \tag{27}$$

We claim that in period 2, the two strategic sellers specify a supply function such that each strategic seller finds it in their best interest to supply only 22.5 units of oil-claim at a price of \$50 per unit. where p_2^* is the equilibrium market clearing price of oil in

period 2. Similarly, each strategic seller states the following supply function:

$$q_{a_2} = \begin{cases} 22.5 & \text{if } p_2^* \geqslant 50, \\ 24.5 & \text{otherwise,} \end{cases} \tag{28}$$

and

$$q_{b_2} = \begin{cases} 22.5 & \text{if } p_2^* \geqslant 50, \\ 24.5 & \text{otherwise.} \end{cases} \tag{29}$$

Each strategic seller commits to supplying 2 units more in case the rival seller deviates and supplies more than 22.5 units. Since we assume instantaneous production process, there is no real loss as far as the strategic sellers are concerned; but the speculator is willing to waste one unit of physical oil in order to provide incentives for raising the equilibrium market clearing price at or above \$50.

Given $100 - p_2$ is still the demand function for oil-claim in period 2, it means that aggregate supply of oil-claim has to equal 50 units in order to set the equilibrium market clearing price of oil-claim at \$50. Thus, the aggregate equilibrium supply/demand in period 2:

$$Q_2^* = q_{a_2}^* + q_{b_2}^* + q_{s_2}^* = 22.5 + 22.5 + 5 = 50 \text{ units of oil-claim,} \tag{30}$$

where $q_{s_2}^*$ is the speculator supply in period 2 if each strategic seller supplies 22.5 units. Hence, each strategic seller earns

$$\pi_{a_2}^* = \pi_{b_2}^* = 22.5 \times (100 - Q_2^* - 10) = 22.5 \times \$40 = \$900.00, \tag{31}$$

which is same as the profit earned in the benchmark case, but strictly greater than \$784 – a profit earned if the speculator acts as an independent price-taker.

But is this an equilibrium? Holding the strategy of one strategic seller fixed – say, strategic seller b – is it optimal for strategic seller a to supply 22.5 units or is it better for him/her to offer more claims thereby lowering the per-unit profit, but making it up in volume? Now, if strategic seller b commits to the strategy of supplying as depicted in Equation (29), then strategic seller a's profit function is as follows:

$$\pi_{a_2}^d = q_{a_2}^d \times \left(100 - 24.5 - q_{a_2}^d - 6 - 10\right). \tag{32}$$

Note that the speculator supplies 6 units and strategic seller b supplies 24.5 units, if either one of the strategic seller deviates and produce more than 22.5 units. Thus, it is easy to verify that if strategic seller a deviates, it is optimal for him/her to supply 29.75

units of oil-claim in period 2. Thus, the resulting market clearing price, p_2^d is given by:

$$p_2^d = 100 - 24.5 - 29.75 - 6 = 45.5 - 6 = 39.75 < 50, \tag{33}$$

implying that the speculator's and strategic seller b's strategy to increase their respective supply is indeed optimal. Hence, profit of the deviant strategic seller – i.e., strategic seller a is as follows:

$$\pi_{a_2}^d = 29.75 \times (100 - 24.5 - 29.75 - 6 - 10) = 29.75 \times 29.75 = \$885.063. \tag{34}$$

On the other hand, if strategic seller a sticks to the strategy to offer 22.5 units of oil in period 2, then strategic seller a earns $\pi_{a_2}^* = 22.5 \times (\$50 - 10) = \$900.00$ as profit, which is strictly greater than the deviation profit, $\pi_{a_2}^d = \$885.063$. Hence, the strategic seller a is better-off not deviating from offering 22.5 units of oil-claim in period 2. Also, our speculator earns

$$\pi_s^* = 5 \times \$50 - 6 \times \$37 - 6 \times k_s = \$250 - \$212 - 6\,k_s = 38 - 6\,k_s \tag{35}$$

as profits from the whole transaction. If the speculator has nonnegative profit when he acts as a naive price taker, $\hat{\pi}_s \geqslant 0$, then the speculator makes substantial profit, $\pi_s^* > 0$ when s/he with the strategic sellers implements the leadership-based equilibrium. Since strategic sellers a and b are identical in all respects, same chain of argument should hold for strategic seller b if seller b deviates. We can depict payoffs of each of these two strategic sellers a and b in the table below:

		Strategic Seller b	
		Strategy I+	Strategy II+
Strategic Seller a	Strategy I+	\$1831.50, \$1831.50	\$1953.00, \$1690.00
	Strategy II+	\$1690.00, \$1953.00	\$1800.00, \$1800.00

where "strategy I+" is defined as the strategy to increase his/her own supply to absorb speculator's demand in period 1 and follow the speculator-proposed selling strategy in period 2. Similarly, "strategy II+" is the strategy to not to increase his/her own supply in period 1, but follow the speculator-proposed selling strategy in period 2. These payoffs (or firm values) are derived by adding period 1 and 2's profits.

Each strategic seller considers the other's "fixed" strategy of offering only 22.5 units

of oil-claim to the consumers/retailers from their inventory and the speculator supplies 5 units from his/her inventory – making it 27.5 units in total if the tacit contract is honored by both strategic sellers. But the non-deviant strategic seller increases his/her supply of oil-claim to 24.5 units and the speculator increases his/her supply to 6 units – making it 30.5 units in total if the rival strategic seller deviates and offers more than 22.5 units of oil-claim in period 2. The difference in the meaning of "fixed" occurs because in Section *2.3.1* the speculator sells naively to the consumers/retailers whereas in Section *2.3.3*, the speculator sells strategically conditional on a pre-specified supply schedule.

To summarize our findings, in the benchmark case each strategic seller supplies 30 units of oil-claim in each period. Hence, the benchmark market clearing price, $p^* = \$40$ and benchmark aggregate supply, $Q^* = 60$ units of oil-claim in both periods. In the benchmark case there is no oil price volatility. Once the speculator enters, the market clearing price and quantity of oil-claim in period 1 becomes different from the market clearing price and quantity in period 2; e.g., $p_1^* = \$37 < \$40$ and $Q_1^* = 63$ units, whereas $p_2^* = \$50 > \$40$ and $Q_2^* = 50$ units. Hence, oil price is extremely volatile and there is a significant drop in consumers' welfare. Both strategic sellers have lost \$20 each in period 2 – relative to their benchmark profit of \$900, but they gained \$31.50 relative to the benchmark profit in period 1. The speculator gained substantially.

Even though this example captures the essence of our intuition, in Section 3 below we show that these intuitions hold in more general framework. We keep the model environment exactly same as in our numerical example with only one exception: we allow more than two strategic sellers to operate in the local oil market thereby increasing the competitiveness. Our objective is to establish few new key insights: We want to identify the effects of changes in speculator's storage capacity, changes in degree of market competitiveness and their interactions on oil price volatility.

3 Model

We stick to a four-date/three-period model of forward market for oil. We assume that the market clearing price of a unit of oil-claim (or a unit of physical oil that will be delivered one period later) is established by its demand and supply conditions . Like our numerical example, we denote equilibrium market clearing price of a unit of oil-claim in period 1 by p_1^* and in period 2 by p_2^*. Also, we use Q_1^* to denote the aggregate equilibrium quantity demanded/supplied in period 1 and Q_2^* to denote the aggregate equilibrium quantity demanded/supplied in period 2. Finally, we assume that the cost of producing and/or delivering oil is fixed and is equal to c dollars per unit of oil and

the risk-free rate of interest is zero.

3.1 Oil Forward Market

We assume that the oil market is populated by many small consumers, retailers and small/ medium business owners (henceforth, referred as nonstrategic traders). These nonstrategic traders buy and/or sell small quantities of oil-claim at a time, based on their idiosyncratic needs, not explicitly modeled in this paper. These traders also assume that the market price for oil-claim is given. We denote nonstrategic traders' demand for oil-claim by

$$x^d_{n,\,t} = a_d - b_d\, p_t, \tag{36}$$

where $x^d_{n,\,t}$ is the quantity of oil-claim demanded by the nonstrategic traders and p_t is the market clearing price of oil-claim in period t, where $t = 1, 2$. We assume $b_d > 0$ implying that the quantity demanded falls as price rises. The demand function maps US dollars into quantities of potential future delivery of oil, e.g., "thousands of barrels." We assume $x^d_{n,\,1} = x^d_{n,\,2} = x^d_n$, 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-claim) can be expressed as

$$x^s_{n,\,t} = -a_s + b_s\, p_t, \tag{37}$$

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

$$\hat{x}_n(p_t) = x^d_n - x^s_n = a_d - b_d\, p_t - (-a_s + b_s\, p_t) = a_d + a_s - (b_d + b_s)p_t = \hat{a} - \hat{b}\, p_t, \tag{38}$$

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

The market is also populated by a large speculator and m identical 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-claim at a time and in the process they impact the market clearing price of oil. Our strategic sellers are also oil producers, who produce oil at a constant cost of c dollars per unit. We depict nonstrategic traders' oil-demand and oil-supply functions in Figure 2 below. Any market clearing price above p^{max} in any period t, totally eliminates market demand for oil, $\hat{x}_n(p^{max}) = 0$; this happens because some non-strategic traders themselves produce oil and very few non-strategic traders' demand oil at such high prices. Since the cost of producing oil-claim for each strategic seller is fixed, any price below c is not feasible and aggregate oil-claim demand at $p_t = c$ is equal to Q^{max}.

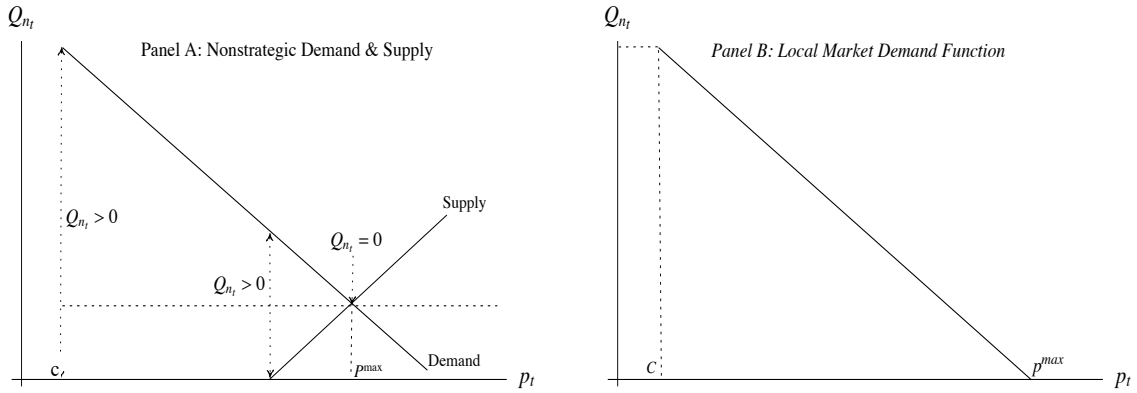


Figure 2: In panel A we depict nonstrategic traders' demand and supply functions for oil-claim. In panel B, we depict the market demand function for oil-claim which is equivalent to the excess demand function of the nonstrategic traders for different per unit price of oil-claim.

3.1.1 Strategic Sellers

We assume that there are m strategic sellers and these strategic sellers engage themselves in oligopolistic competition. Each strategic seller chooses his/her profit maximizing supply, q_i under the assumption that his/her competitors are not going to change their own supply of oil-claim, $\bar{q}_j,\ \forall j \neq i$. Suppose the i^{th} strategic seller, $\forall i = 1, \cdots, m$, decides to supply q_{i_t} units of oil-claim in period t, then the market clearing price of oil-claim satisfies the following condition:

$$\hat{x}_n(p_t) = \hat{a} - \hat{b}\, p_t = q_{1_t} + q_{2_t} + \cdots + q_{m_t} = \sum_{i=1}^{m} q_i = Q_t, \tag{39}$$

where Q_t is the total supply of oil-claim in the market in period t. One can obtain the market clearing price of oil-claim by simply inverting the excess demand function; hence,

$$p_t = \hat{x}_n^{-1}(Q_t) = \frac{\hat{a}}{\hat{b}} - \frac{1}{\hat{b}}(q_{1_t} + q_{2_t} + \cdots + q_{m_t}) = a - b\,Q_t, \tag{40}$$

where $a = \hat{a}/\hat{b}$ and $b = 1/\hat{b}$. The expression depicted in Equation (40) is known as the inverse demand function. If each strategic seller manages to supply q_{i_t} units of oil-claim, then his/her profit function $\pi_{i_t}(\cdot)$ can be expressed as follows:

$$\pi_{i_t}\left(q_{1_t},\, \bar{q}_{2_t},\, \cdots,\, \bar{q}_{m_t}\right) = \left(a - b\left(q_{i_t} + \sum_{i\neq j,\, j=1}^{m-1} \bar{q}_{j_t}\right) - c\right) \times q_{i_t}, \quad \forall i = 1,\, 2, \cdots,\, m. \tag{41}$$

where $\sum_{i\neq j,\, j=1}^{m-1} \bar{q}_{j_t}$ is the quantity supplied by all other strategic sellers except i^{th} strategic seller, and c is the fixed cost of producing oil in each period.

Next, the strategic sellers maximize their aggregate profit or value of their respective firms, V_i by choosing the number of units of oil-claim to supply in each period, q_{i_t}. Again for simplicity, we assume that the risk free rate, r is zero; hence, value maximization simply implies maximizing profits for each period. Thus, we can write the objective function of strategic seller i as follows:

$$V_i = \max_{q_{i_1}} \pi_{i_1}(q_{1_1},\, \bar{q}_{2_1},\, \cdot\cdot,\, \bar{q}_{m_1}) + \max_{q_{i_2}} \pi_{i_2}(q_{1_2},\, \bar{q}_{2_2},\, \cdot\cdot,\, \bar{q}_{m_2} \,|\, p_1^*,\, q_{1_1}^*, \cdot\cdot,\, q_{m_1}^*), \quad i = 1,\, 2,\, \cdot\cdot\, m, \tag{42}$$

where $\pi_{i_1}(\cdot)$ and $\pi_{i_2}(\cdot)$ are the profits of strategic seller i in period 1 and 2, q_{i_1} and q_{i_2} are strategic seller i's supply of oil-claim in period 1 and 2 respectively.

3.1.2 Speculator

Our speculator maximizes his/her profits. His/her profit depends on three things: his/her demand for oil-claim (subject to storage capacity), the equilibrium market clearing price at which s/he buys inventory of oil in period 1 and the equilibrium market clearing price at which s/he liquidates his/her acquired inventory in period 2. Specifically,

$$\pi_s = z_s \times \left(p_2^* - p_1^* - k_s\right), \tag{43}$$

where k_s is the speculator's per unit storage cost. Thus, our speculator profits if and only if $p_2^* > p_1^* + k_s$. Remember, our speculator buys in period 1 and s/he sells in period 2; hence, s/he needs to lower price in the period s/he buys and raise price in period s/he

sells.

3.2 The Benchmark Case: Market Equilibrium without the Speculator

The equilibrium in this market is simply the Nash equilibrium (or fixed point) of this oligopolistic competition.[15] Let us describe the m-tuple $(q_1^*, q_2^*, \cdot\cdot\cdot, q_m^*)$ as the equilibrium supply response of m strategic sellers; then the optimal market clearing price of oil-claim in each period is given by

$$p_t^* = a - b\,Q_t^*, \tag{44}$$

where

$$Q_t^*(p_t^*) = q_{1_t}^*(q_{2_t}^*, \cdot\cdot, q_{m_t}^*, p_t^*) + \cdot\cdot\cdot + q_{m_t}^*(q_{1_t}^*, \cdot\cdot, q_{m-1_t}^*, p_t^*), \quad \forall t, \forall i. \tag{45}$$

The expression $q_{i_t}^*(q_{1_t}^*, \cdot\cdot, q_{i-1_t}^*, q_{i+1_t}^*, \cdot\cdot, q_{m_t}^*, p_t^*)\ \forall i$, is the number of units of oil-claim offered by strategic seller i in period t in response to the market clearing price p_t^* and his/her $m-1$ competitors' offer of oil-claim. Again, this constitutes an oil market equilibrium, because none of the strategic seller has any incentive to change the number of units of oil-claim s/he has offered so long as his/her competitors do not change their offerings – i.e., no incentive to deviate unilaterally. Since both periods are identical we ignore time subscript unless it is absolutely necessary.[16] Thus, the equilibrium market clearing price in the oil-claim market in each period is as follows:

$$p_t^* = a - b\,Q^* = a - b \times (q_1^* + q_2^* + \cdot\cdot\cdot + q_m^*), \qquad t = 1,\, 2. \tag{46}$$

There is one restriction on the market clearing price: The market clearing price in each period, p^* has to be less than p^{max}, the price of oil-claim that makes nonstrategic traders' excess demand equal to zero. From now on we will concentrate on the "symmetric market equilibrium" only. We derive the symmetric oil market equilibrium with the speculator in Section *3.2.1* below.

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

[16] 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, $Q_1^* = Q_2^* = Q^*$ and $p_1^* = p_2^* = p^*$.

3.2.1 Symmetric Market Equilibrium

We add another constraint, $q_1^* = q_2^* = \cdot\cdot = q_m^*$ and use Equation 41 to solve for the symmetric market equilibrium. When all m strategic sellers offer equal number of oil-claim, then it is optimal for each strategic seller to offer

$$q_{i_t}^* = \frac{a-c}{b \times (m+1)}, \qquad \forall i = 1,\, 2,\, \cdot\cdot,\, m, \text{ and } t = 1,\, 2. \tag{47}$$

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

$$Q_t^* = \sum_{i=1}^{m} q_{i_t}^* = \frac{m\,(a-c)}{b \times (m+1)}, \qquad t = 1,\, 2. \tag{48}$$

Thus, the equilibrium market clearing price of oil-claim in each period,

$$p_t^* = a - b\,Q_t^* = \frac{a + m\,c}{(m+1)}, \qquad t = 1,\, 2. \tag{49}$$

Note that price in each period is independent of time; hence, there is no *oil price volatility* in this two-period model. We deliberately ignored any "dynamism" other than the speculator's strategies in our stylized environment, so that we can focus on the effects of speculator's strategies on oil price volatility. Next, we solve each strategic seller's per period profit:

$$\pi_{i_t}^* = (p^* - c) \times q_{i_t}^* = \frac{(a-c)^2}{b \times (m+1)^2}, \quad \forall i = 1,\, 2,\, \cdot\cdot, m \text{ and } t = 1,\, 2. \tag{50}$$

as profits in each period. Each strategic seller's firm value, V_i is as follows:

$$V_i = 2 \times \pi_i^* = \frac{2 \times (a-c)^2}{b \times (m+1)^2}, \quad \forall i = 1,\, 2,\, \cdot\cdot, m. \tag{51}$$

We depict demand and supply functions of oil-claim in a market with nonstrategic traders and m strategic traders in Figure 3.

Like our example, we rename $q_{i_t}^*$ as just q^* and Q_t^* (i.e., we ignore both seller and time subscripts) and call it our benchmark seller quantity and aggregate quantity of oil-claim respectively. Also, we will rename p^* as the benchmark market clearing price and π^* as each strategic seller's benchmark profit. Next, we consider the case where the speculator enters the oil market. We analyze the impact of speculator's entry on the market equilibrium. We show how a speculator, if s/he enters the market in period 1,

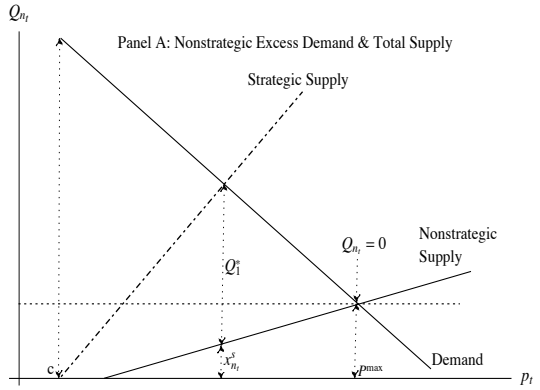


Figure 3: This figure depicts nonstrategic traders' excess demand for oil-claim (Q_{n_1}) and strategic sellers' aggregate supply (Q_1^*) as function of market price in any period t, p_t. The aggregate supply consists of nonstrategic traders supply, $x_{n_1}^s$ and the strategic sellers' optimal supply, Q_1^*.

buys oil-claim in period 1 and at the same time makes the market clearing price of oil drop from p^* to $\bar{p}_1$.

3.3 Strategic Sellers' & Speculator's Strategies in Period 1

We closely follow the setup developed in Section *2.2*. Speculator enters the oil-claim market in period 1. We assume s/he has no access to oil – but has the right to buy and/or sell oil-claim – take delivery of/deliver oil – in the local market in both periods. The speculator possesses a storage facility and we assume that capacity of his/her storage is exogenously fixed. We denote the storage capacity by R_s. Also, we denote speculator's demand function in period 1 by $Q_{s_1}(\cdot)$ and quantity demanded by z_s. We impose a strict condition that z_s has to be less than R_s. In sync with our example, speculator's demand function can be described as follows:

$$Q_{s_1} = \begin{cases} z_s & p_1 \leqslant \bar{p}_1, \\ [z_s,\, 0] & p_1 = \bar{p}_1, \\ 0 & p_1 \geqslant \bar{p}_1. \end{cases} \tag{52}$$

The speculator takes into account the equilibrium market clearing price and market clearing quantity in absence of his own order. Let us assume that the speculator's contingent price, $\bar{p}_1$ is a function of the benchmark price. Specifically, we assume that

$$\bar{p}_1 = p^* - \delta_1, \tag{53}$$

where $\delta_1 \geqslant 0$. Given the following linear demand function, $\frac{a-p_1}{b}$, market clearing price can be less than or equal to $\bar{p}_1$ if and only if the aggregate quantity offered in period 1, say $\bar{Q}_1$ is as follows:

$$\bar{Q}_1 \geq \frac{a-\bar{p}_1}{b} = \frac{a-p^*+\delta_1}{b} = \frac{a-p^*}{b} + \frac{\delta_1}{b} = Q^* + \frac{\delta_1}{b}, \tag{54}$$

where Q^* is the benchmark aggregate quantity. This further implies that each strategic seller needs to offer

$$\bar{q}_{i_1} \geq \frac{\bar{Q}_1}{m} = \frac{Q^*}{m} + \frac{\delta_1}{b\,m} = q^* + \frac{\delta_1}{b\,m}. \tag{55}$$

If $\bar{q}_{i_1} \geqslant q^* + \frac{\delta_1}{b\,m}$, then $Q_{s_1}(\bar{p}_1) = z_s$. Hence, each strategic seller earns

$$\begin{aligned} \bar{\pi}_{i_1} &= (\bar{p}_1 - c) \times \left(\bar{q}_{i_1} + \frac{z_s}{m}\right) = (p^* - \delta_1 - c) \times \left(q^* + \frac{\delta_1}{b\,m} + \frac{z_s}{m}\right) \\ &= \pi^* + (p^* - c)\left(\frac{\delta_1}{b\,m} + \frac{z_s}{m}\right) - \delta_1 \times \left(q^* + \frac{\delta_1}{b\,m} + \frac{z_s}{m}\right), \end{aligned} \tag{56}$$

$\forall i = 1, 2, \cdot\cdot, m$. Hence, each strategic seller's change in profit relative to the benchmark case,

$$\Delta\,\bar{\pi}_{i_1} = (p^* - \delta_1 - c)\left(\frac{\delta_1}{b\,m} + \frac{z_s}{m}\right) - \delta_1 \times q^*. \tag{57}$$

The first term on the right hand side is the additional quantities sold relative to the benchmark quantity q^* at the current market clearing price $\bar{p}_1$ net of costs of production c. The second term is the loss to each strategic seller due to a drop in market clearing price by δ_1 relative to the benchmark case. Our speculator chooses δ_1 and z_s.

From Equation 70 it is easy to verify that $\Delta\,\bar{\pi}_{i_1}$ can be greater than, equal to or less than zero. Assuming that $p^* - \delta_1 > c$ holds, if all strategic sellers choose to supply q^* except the j-th seller, who supplies:

$$\bar{q}^d_{j_1} = q^* + \frac{\delta_1}{b} + z_s, \tag{58}$$

then the j-th seller's change in profit w.r.t the benchmark case can be expressed as follows:

$$\Delta\bar{\pi}^d_{j_1} = (p^* - \delta_1 - c)\left(\frac{\delta_1}{b} + z_s\right) - \delta_1 \times q^*. \tag{59}$$

If $\Delta\bar{\pi}^d_{j_1} > 0$, then the deviant firm earns more profit than that of the benchmark case. Thus, if all other strategic sellers choose to stick to the benchmark level of supply, it is

strictly better for the deviant firm to increase his/her supply to bring the market clearing price down and in the process absorb speculator's demand. Thus, only $\Delta\bar{\pi}^d_{j_1} > 0$ is a sufficient condition for the supply to increase in period 1. Since δ_1 and z_s are speculator's choice variables, we can assume that the speculator chooses these variables in a way to induce each strategic seller to increase his/her own supply and absorb speculator's demand. This gives us our first formal result stated in Proposition 1 below.

Proposition 1. *For all $z_s \leq R_s$, the necessary condition for each strategic seller to increase his/her supply of oil-claim from q^* to $\bar{q}_{i_1}$ in period 1 is as follows:*

$$\delta_1 \leq \bar{\delta}_1 = \frac{1}{2}\left(\sqrt{\frac{b\,z_s\,(4\times(a-c)+b\times(m+1)\,z_s)}{m+1}} - b\,z_s\right).$$

Proof. Follows from Equation 59. □

This result is interesting! Even if all of m strategic sellers earn less than the benchmark profit π^* when they choose to increase their supply of oil claim from q^* to $\bar{q}_1$ at the market clearing price of $\bar{p}_1$ in period 1, they will each find it optimal to do so as long as deviation profits, $\bar{\pi}^d_{j_1}$, is strictly greater than π^*. This is because "increasing own supply" of oil-claim is a dominant strategy for all m strategic sellers irrespective of what their competitors' do. For example, if $m-1$ strategic sellers choose not to increase their supply of oil-claim, then it is good for the j-th strategic seller to increase his/her supply. Similarly, if $m-1$ strategic sellers choose to increase their supply, it is still better for the j-th seller to increase his/her supply.

Given speculator's choice of demand for oil, z_s, in period 1 (possibly dictated by his/her storage capacity), if the speculator's contingent price, $\bar{p}_1 = p^* - \delta_1$ implies a discount that is too large, $\delta_1 > \bar{\delta}_1$, then none of these m strategic sellers will be willing to increase their own supply required to accommodate speculator's demand. Hence, for all $\delta_1 > \bar{\delta}_1$, we will observe quantity choices and price just like the benchmark case.

Next, we look at few important comparative statics of $\bar{\delta}_1$ w.r.t. changes in speculator's demand (z_s), competitiveness of the oil market (m) and size of the oil market (a) and price-sensitivity of oil demand (b). These findings are summarized in Corollary 1 below.

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

i. as the speculator's demand z_s increases in period 1, maximum possible price discount, $\bar{\delta}_1$, that the speculator can extract in period 1, increases;

ii. as the number of strategic sellers, m, operating in the local market, increases, maximum possible price discount, $\bar{\delta}_1$ that the speculator can extract in period 1 relative, decreases;

iii. as the size of the local oil market, a increases, maximum possible price discount, $\bar{\delta}_1$, that the speculator can extract in period 1, increases;

iv. as the price-sensitivity of oil demand, b increases in the local market, maximum possible price discount, $\bar{\delta}_1$, that the speculator can extract in period 1, increases;

Proof. Please see Appendix 1. □

Hence, for all $\delta_1 \leqslant \bar{\delta}_1$ and $z_s < R_s$, the local oil market will be characterized by higher aggregate supply of oil-claim, $\bar{Q}_1$ and lower market clearing price, $\bar{p}_1$. Consumers/retailers are strictly better-off as they get higher supply of oil at a lower price per unit. Our speculator enters the oil market, buys relatively large quantity of oil and at the same time makes the equilibrium market clearing price to drop significantly.

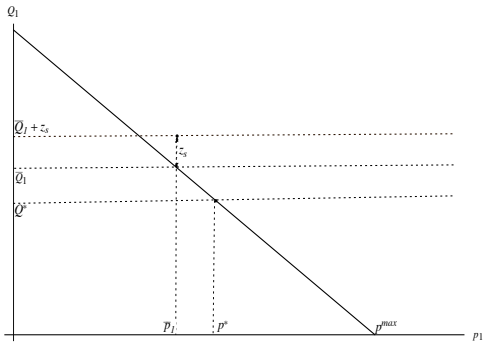


Figure 4: We depict nonstrategic traders' oil-claim demand and the speculator's demand as a function of market clearing price in period 1. If the market clearing price of oil in period 1, $\bar{p}_1 \leqslant p^* - \delta$, then the speculator demands z_s units of oil-claim. If the market clearing price of oil in period 1, $\bar{p}_1 > 0$, then the speculator's demand is zero.

In Section *3.4* we depict various ways our speculator can liquidate his/her inventory of oil that he acquired in period 1. We analyze the impact of speculator's strategies, and the impact of strategic sellers' response to speculator's strategies on market clearing price and market clearing quantity of oil-claim in period 2.

3.4 Speculator and the Oil Market Equilibrium in Period 2

In period 2, the speculator has z_s units of oil in possession. Again, we closely follow the framework established in Section *2.3*. We assume that the oil position acquired by

the speculator in period 1 is a retrospective cost that has already been incurred and cannot be recovered; i.e., the cost 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 cost 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.[17] There are two ways the speculator can liquidate his/her oil inventory:

- *Strategy 1*: The speculator acts as an independent "price-taker" and consequently dumps his/her entire inventory of oil-claim directly into the market at the market clearing price, p_2 – a price established by independent supply decisions of the two strategic sellers in period 2. .
- *Strategy 2*: Alternatively, the speculator assumes a more prominent leadership role; supplies his/her oil inventories to the strategic sellers directly at a certain specified market clearing price, say $\bar{p}_2$, which should be greater than or equal to $p^* + \delta_2$. If market clearing price in period 2 is less than $p^* + \delta_2$, then s/he reverts back to *Strategy 1*.

We assume that the speculator's sales plans are known to other market participants in advance. If the speculator acts as a price-taker, s/he just dumps all his/her inventory at the market clearing price, say $\hat{p}_2$. If s/he acts as a leader, s/he sells entire inventory to the strategic sellers, who together with their own supply sell those additional units at the market clearing price, say $\bar{p}_2$ specified by the speculator.

3.4.1 Market Outcomes when Speculator acts as Price-taker

If the speculator acts a price-taker then the market clearing price is established by the equilibrium quantities supplied by each m strategic seller after acknowledging that the speculator is going to sell an additional z_s units of oil-claim at the market clearing price. All m strategic seller knows that the market supply-demand situation is as follows:

$$\sum_{i=1}^{m} q_{i_2} + z_s = m\, q_2 + z_s = a - p_2. \tag{60}$$

where $q_{i_2} = q_2, \forall i$, is the quantity offered by each strategic seller in this symmetric case. Rearranging, we obtain the market demand function net of speculator's supply as follows:

$$m\, q_2 = (a - z_s) - p_2 = A - p_2. \tag{61}$$

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

After substituting A for a, we find a demand function exactly similar to our benchmark case. Hence, the market outcomes are also similar to the benchmark case and are given by:

$$\hat{q}_{i_2} = \frac{A - c}{(m+1) \times b} = \frac{(a - z_s) - c}{b \times (m+1)}, \tag{62}$$

which set a market clearing price equal to

$$\hat{p}_2 = \frac{A + m\,c}{(m+1)} = \frac{(a - z_s) + m\,c}{(m+1)}, \tag{63}$$

and lead to a profit earned by each strategic seller,

$$\hat{\pi}_{i_2} = \hat{q}_{i_2} \times (\hat{p}_2 - c) = \frac{((a - z_s) - c)^2}{b \times (m+1)^2}. \tag{64}$$

For obvious reasons, it all depends upon what happens to the speculator's profit. Our speculator is going to engage in strategic ferrying of oil from period 1 to period 2 only if s/he earns nonnegative profit. Speculator's profit function can be stated as follows:

$$\pi_s = (\hat{p}_2 - \bar{p}_1 - k_s) \times z_s, \tag{65}$$

where k_s is the per unit storage costs of the speculator.[18] Next, we summarize our results in Proposition 2 below.

Proposition 2. *If the speculator's per unit storage costs, k is strictly less than $\delta_1 - \frac{z_s}{1+m}$, then there exists an equilibrium in the oil market, characterized by higher oil-claim supply, lower profit for each oligopolist and some oil price volatility. Specifically, each oligopolist earns*

$$\frac{(2(a-c) - z_s)z_s}{b \times (1+m)^2}$$

less than the benchmark profit, π^*, in period 2 and the market clearing price of oil-claim in period 1 is different than the market clearing price of oil-claim is period 2:

$$\Delta p = \hat{p}_2 - \bar{p}_1 = \delta_1 - \frac{z_s}{m+1}.$$

Proof. Please see Appendix 1 for the proof. □

Since per unit storage cost, k_s cannot be negative, it follows from Equation (65) that

[18] Remember, our speculator who him/herself gets delivery of physical oil in period 2 and liquidates his/her oil-claim position in period 2 itself, can deliver his/her physical oil only in period 3. Thus, our speculator incurs storage costs between period 2 and period 3.

the market clearing price in period 1, $\bar{p}_1$ is lower than the market clearing price in period 2, $\hat{p}_2$; that is, $\Delta p > 0$.

3.4.2 Market Outcomes when Speculator acts as Leader

$$\bar{p}_2 = p^* + \delta_2, \tag{66}$$

where $\delta_2 \geqslant 0$. We also need $\bar{p}_2 < p^{max}$, a price at which nonstrategic traders' excess demand for oil is zero.

Given our linear demand function, $\frac{a-p_2}{b}$, market clearing price can be less than or equal to $\bar{p}_2$ if and only if the aggregate quantity offered in period 1, say $\bar{Q}_2$ is as follows:

$$\bar{Q}_2 \leq \frac{a-\bar{p}_2}{b} = \frac{a-p^*-\delta_2}{b} = \frac{a-p^*}{b} - \frac{\delta_2}{b} = Q^* - \frac{\delta_2}{b}, \tag{67}$$

which further implies that each strategic seller needs to offer

$$\bar{q}_{i_2} \leq \frac{\bar{Q}_2}{m} = \frac{Q^*}{m} - \frac{\delta_2}{b\,m} = q^* - \frac{\delta_2}{b\,m}. \tag{68}$$

If $\bar{q}_{i_2} = q^* - \frac{\delta_2}{b\,m}$, then $p_2 = \bar{p}_2$ implying that $Q_{s_2}(\bar{p}_2) = -z_s$. Hence, each strategic seller earns

$$\begin{aligned} \bar{\pi}_{i_2} &= (\bar{p}_2 - c) \times \left(\bar{q}_{i_2} - \frac{z_s}{m}\right) = (p^* + \delta_2 - c) \times \left(q^* - \frac{\delta_2}{b\,m} - \frac{z_s}{m}\right) \\ &= \pi^* - (p^* + \delta_2 - c)\left(\frac{\delta_2}{b\,m} + \frac{z_s}{m}\right) + \delta_2 \times q^*, \end{aligned} \tag{69}$$

$\forall i = 1, 2, \cdot\cdot, m$. Hence, each strategic seller's change in profit relative to the benchmark case,

$$\Delta\,\bar{\pi}_{i_2} = -(p^* + \delta_2 - c)\left(\frac{\delta_2}{b\,m} + \frac{z_s}{m}\right) + \delta_2 \times q^*. \tag{70}$$

Next, consider the situation where $(m-1)$ strategic sellers – with the exception of the j^{th} strategic seller – choose to comply with the speculator's coordinated oil-claim supply. Then, total supply of oil-claim from $(m-1)$ strategic sellers is as follows:

$$(m-1) \times q^* - \frac{(m-1) \times \delta_2}{b\,m}. \tag{71}$$

What should the j^{th} strategic seller do? If s/he complies, then s/he earns $\bar{\pi}_{j_2}$ as profit in period 2. On the other hand if s/he deviates and supply more than $\bar{q}_{j_2}$, then s/he knows that the speculator will not sell indirectly through them but will rather dump all

his/her inventory directly in the market. Thus, if the j^{th} strategic seller deviates, then s/he supplies

$$\bar{q}^d_{j_2} = q^* - \frac{z_s}{2} + \frac{(m-1)\times\delta_2}{2\,b\,m}. \tag{72}$$

at the market clearing price

$$p^d = p^* - \frac{bz_s}{2} + \frac{(m-1)\times\delta_2}{2m} \tag{73}$$

Thus, the deviant strategic seller supplies $\frac{(m+1)\delta_2 - b\,m\,z_s}{2\,b\,m}$ units more than the non deviant strategic sellers at a lower price p^d and hence, s/he earns

$$\bar{\pi}^d_{j_2} = \pi^* - (p^* - c)\left(\frac{z_s}{2} - \frac{(m-1)\times\delta_2}{2\,b\,m}\right) - (p^* - c)\left(\frac{bz_s}{2} - \frac{(m-1)\delta_2}{2\,m}\right) + \frac{1}{b}\left(\frac{b\,z_s}{2} - \frac{(m-1)\times\delta_2}{2\,m}\right)^2 \tag{74}$$

Proposition 3. *The deviant strategic seller is better off selling $\bar{q}_{i_2}$ units of oil-claim rather than $q^d_{j_2}$ units of oil-claim in the market in period 2 if*

$$\delta_2 \leq \bar{\delta}_2 = \frac{2\sqrt{b(m-1)m(m+1)^2 z_s\left((a-c)(m+1) - 2\,b\,m\,z_s\right)}}{(m+1)^3} - \frac{b\times(3-m)\times m\,z_s}{(m+1)^2}$$

Proof. Directly follows from equation (74). □

4 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/her 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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