Are There Barriers To Entry in Offshore Production of Oil and Gas?

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Abstract

Two issues are addressed in this paper. First, I present what I believe to be a flaw in the persistence in profits hypothesis. In response, I suggest a possible modification to account for markets in which rents are present. Second, I present my preliminary findings in my attempt to determine whether offshore barriers to entry are present in US crude oil and natural gas production. I review my early stage results at estimating a translog cost function for US crude oil and natural gas producing firms.

1 Introduction

Recent profit margins of publicly traded energy companies have brought public criticism and suspicion of unfair pricing practices. Opposing this view, Taylor and Van Doren (2006) state, “No evidence exists of collusion or price fixing among investor-owned oil companies or gasoline retailers in domestic markets.” Indeed, it appears that publicly traded oil firms have little ability to alter the world price of crude oil. Only 25% of the world’s petroleum reserves are accessible to these companies the remaining 75% are controlled by state owned oil companies\(^1\) and OPEC nations. With limited access to the remaining scarce resources, publicly traded energy companies have little incentive to restrict supply.

One reason it may appear that oil firms earn large profit and hence have market power is that they earn rent on an exhaustible resource. Carlton and Perloff (1999) define rent as “a payment to the owner of an input beyond the minimum necessary to cause it to be used.” Firms may earn rent for a couple of reasons. In the case of crude oil and natural gas

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\(^1\)Examples of state owned oil companies are Gazprom and Pemex.
extraction, the amount of rent that a firm receives varies substantially depending on unique geological features and its own technical efficiency.

Alternatively, a firm may earn profit or excess rents when barriers to entry exist. When considering offshore crude oil and natural gas production there may be barriers to entry in the form of financial constraints; however, barriers to entry are not a sufficient condition for anti-competitive behavior to exist. After all there is more than one firm producing off the shores of the United States. In addition, there exists extensive research suggesting that offshore auctions are competitive although these studies have focused on the bidding process and typically only consider years prior to 1970.

Another type of barrier to entry that may exist are the leases themselves. Contracts are imperfect and therefore unable to extract all rent. The typical lease contract involves an upfront fixed payment, a percentage of future revenue earned from the extraction of the resource and a rental charge until production has been initiated. The rental portion of the contract is not pertinent to the remainder of our discussion and therefore shall be ignored. The royalty earned on a lease contract should vary with the amount known about the proposed resource site. However the royalties charged in offshore lease auctions are fairly standard with little variation. It is the upfront payment that determines the winner of the lease. Given the duration in which leases may last and the uniqueness of costs due to the differences in geological formations, the rents earned from these leases may be sustainable for long periods of time.

Using the same unit root testing methodologies as subsection 3.3 below, I find that the timeseries properties of the real price of oil exhibit unit root behavior. This fact precludes the possibility of a contract being able to fairly capture all rent whether positive or negative. It is therefore likely that any contract will leave some rent unclaimed or alternatively garner excess rent (i.e. the winner’s curse).

The United States is different than most nations in that surface property rights translate into subsurface mineral rights. Most nations consider resource rights to be solely held by the national government. If the allocation of production rights to national resources is
inefficient and creates barriers to entry then these inefficiencies generate barriers to entry. If these barriers do exist it would imply a direct rent transfer in either direction as a result of unexpected changes in the price of the resource.

Although the title suggests that I am only conducting an empirical test, this paper also aspires to correct what I see as a flaw in an existing hypothesis. The persistence in profits (PIP) hypothesis examines the timeseries behavior of profits in order to make an inference about market structure. The testing procedure evaluates timeseries of profits as a measure to determine if either an individual firm or an industry enjoys market power. I adapt the PIP measure of market performance because I believe that given certain attributes of the oil industry the original PIP measure will lead to false conclusions. Furthermore, it is worthwhile to point out that persistence in profit implies barriers to entry, not market power.

In the second segment of this paper I estimate a cost function to obtain estimates of my sample of firms’ marginal costs. In this study I examine the profits of public energy companies while narrowing the scope to exploration, development and production of crude oil and natural gas. It is this segment of production that most critics are concerned with when considering the profitability of large integrated energy firms. I limit the scope of the study by only examining US offshore exploration and production which have a fair amount of readily available lease data. I also include non-integrated exploration and production firms as well. To obtain these estimates I use a translog cost function on US offshore oil and gas production firms.

In section 2 I discuss the overall structure of the oil and natural gas markets. Section 3 is broken up into three subsections. In subsection 3.1 I review the PIP empirical testing procedure. In subsection 3.2 I discuss the potential error when implementing it in regards to exhaustible resource markets. In subsection 3.3 I discuss my proposed empirical method for adapting the PIP hypothesis. In section 4 I discuss my preliminary results from estimated translog cost function. In section 5 I discuss the sources of the two different sets of data I used in the studies. In the last section I offer a summary of the overall essays and plans for completion.
2 Market Structure

The commingling of ideas in this paper necessitates that I discuss three different markets: the world crude oil market, the US offshore crude oil market, and the US offshore natural gas market. Despite being different markets, the underlying theme remains the same. A competitive market should drive both profit and rent for the marginal publicly traded energy firm to zero in the long run.

The world oil market is best described by the dominant firm model with OPEC representing the dominant firm and the remainder of the world representing the fringe. While I believe this assumption reflects the reality of the situation, it is not a necessary assumption for my argument. The publicly traded energy companies represent a portion of the fringe. Although the fringe represents the remainder of the world, for my purposes, everything in the fringe except the publicly traded energy companies is irrelevant; therefore, within my diagrams the fringe represents publicly traded energy companies in either the world market or the US offshore market. Because oil is a fungible commodity the market structure does not change if we narrow our focus to the US offshore oil production segment. In either case, it is assumed the fringe does not possess enough production potential to eliminate any pricing power OPEC may possess.

An illustration of the oil market can be seen in Figure B which depicts the dominant firm having market power. The dominant firm sets the price such that marginal revenue equals marginal cost thereby setting the world price. The fringe, depicted in Figure A, produces where marginal cost equals the world price.

A competitive market should drive profit and rent to zero for the marginal firm. That is to say, if the market is competitive no firm should earn profit in long run. However, in a market where firms have different average costs not only because of technology differences but also because of the long term nature of leasing, only the least efficient firms should earn zero rent in the long run. It is important to note the difference between rents earned by firms and profit. Rents are earned through expertise which is represented by the upward sloping
supply curve. Technical know how allowed these firms to appropriate the most cost effective resources and leasing has allowed them to maintain earning rent. Therefore, if we want to determine whether there are barriers to entry within a market where rent is prevalent it is the marginal firm that we want to examine.

The outer continental shelf (OCS) production market is an interesting market. If barriers to entry exist there is no implication of market power in the oil market since the supply of any one company that participates in OCS production is not enough to affect the world price of oil. This would presumably force firms to produce at marginal cost. This may not be the case for natural gas production. Natural gas markets have been found to be segmented. That is to say, there is not one world natural gas market and therefore OCS production would be a significant amount of US natural gas consumption. The natural gas market would be more accurately described by a competitive market with an upward sloping long-run supply curve.

3 Persistence in Profit hypothesis

3.1 Overview of the PIP hypothesis

Typically two unit root tests are run by the researcher when trying to determine if market power exists. In the first test a corporation’s profits are compared to the average of the remaining industry participants. The typical measure for profit used in testing procedures for the PIP hypothesis\(^2\) is profit plus interest payments divided by total assets where profits are measured by net income. A measure of deviation from the industry average profit is then constructed

\[ \rho_{i,t} \equiv \pi_{i,t} - \bar{\pi}_{I,t}, \]

where \(\pi_{i,t}\) is defined to be firm i’s profit and \(\bar{\pi}_{I,t}\) is defined to be industry I’s average profit.

The analysis is typically undertaken by using a form of the Dickey Fuller Unit Root test. Variations of the testing procedure include using Augmented Dickey Fuller tests and/or panel

\(^2\)The following is taken from Geroski (1990).
unit root tests. The following is a basic Dickey Fuller test for a unit root

\[ \Delta \rho_{i,t} = \Theta_0 + \gamma_1 \rho_{i,t-1} + \xi_t, \]  

(2)

where \( \Theta_0 \) is a constant (termed a drift) and \( \xi_t \) is an i.i.d. white noise process. \( \gamma_1 \) is the coefficient of interest in this regression. It can be interpreted as the speed at which the individual firm’s profit level returns to the average profit level for the industry. The duration of time in which a firm earns abnormal profits determines whether it is considered to have market power. Abnormal profits are defined as extended deviations in the profit level of a single firm from the remaining firms’ average profit level.

The second test used in the testing of the PIP hypothesis is to determine whether the industry as a whole possesses some abnormal profit level. Here the deviation in industry profit level from the average of all other industries in the sample is measured in a similar fashion as the first test. This second test requires a measure of profit for all industries. \( \bar{\pi}_{A,t} \) represents the average return for all industries located in the region in which the study takes place. The structure of the empirical test is identical with the corresponding variables as seen in the following two equations:

\[ \rho_{I,t} \equiv \bar{\pi}_{I,t} - \bar{\pi}_{A,t}, \]  

(3)

\[ \Delta \rho_{I,t} = \Theta_0 + \gamma_1 \rho_{I,t-1} + \xi_t. \]  

(4)

A specific example can be seen in the panel data experiment of Bentzen, Madsen, Smith, and Dilling-Hansen (2005). Bentzen et al. (2005) test for a unit root in measured Danish rates of return for individual firms as well as industries. Their sample consists of 1,310 Danish firms under the criterion of full data availability for the years 1990-2001. Bentzen et al. find mixed results in their study. Data on individual firms generally lead to rejection of unit root behavior of profits. Industry data alternatively leads to mixed results of unit root behavior. The authors suggest that the inability to reject a unit root is suggestive of market power.
This sentiment is generally echoed throughout the publications expounding upon the PIP hypothesis.

3.2 Criticism

Although my focus is on nonrenewable resource markets, I believe my criticism applies to the PIP hypothesis whenever the industry exhibits an upward sloping supply curve. Reserve pools of different quality provide the difference in average costs, as well as possible differences in technological sophistication, but barriers to entry provide the means to sustain them. In this case the above testing strategy proves insufficient since it is unable to differentiate between economic rent and economic profit. To expand on this point I discuss all the possible cases that can be encountered.

The first case to consider occurs when profits of the individual firm exhibit a unit root and those of the industry as a whole do as well. If these two unit roots are cointegrated then the timeseries of $\rho_t$ will be stationary and any permanent difference between the two series will not be measured by $\gamma_1$. This is due to the difference between the individual firm and the average of the industry being taken as the steady state relationship when estimating $\gamma_1$; $\gamma_1$ will capture the rate of return from a temporary shock to the steady state relationship between the firm and the average. Both permanent economic profit and economic rent will be excluded from the estimated coefficient, $\gamma_1$. The second case occurs when both timeseries are unit roots but not cointegrated. In this case, the difference between the two series will also be a unit root and will never revert to any stationary mean. Therefore, $\gamma_1$ will not reflect any permanent difference between the two series. The third case occurs when the industry mean is a unit root. Here the difference will again be a unit root and as in case two will never revert to a stationary mean. The fourth case occurs when the individual firm timeseries is stationary and the industry timeseries is a unit root. Again, this would be similar to cases two and three. The last case to consider occurs when both the individual firm and the industry average are stationary. This is the case that is assumed by the PIP hypothesis. These same cases also apply to the broader industry testing procedure.
All but the last case outlined above can describe a market for an exhaustible resource. When considering markets with exhaustible resources the testing procedure is unable to differentiate between economic rent and economic profit. In fact, in the earlier writings on the PIP hypothesis this point was recognized.

Absolute cost disadvantages refer, at base, to some factor of production that is denied the potential entrant who, but for this omitted factor, would be as efficient as established firms. Of all the possible causes of absolute cost advantages so defined, the first which comes to mind is preferred access to natural resources. Geroski, Gilbert, and Jacquemin (1990)

Therefore, in an industry with increasing long-run marginal costs, firms earn economic rents and these rents must be accounted for when attempting to estimate long-run profit. Regardless of whether barriers to entry exist or not, unit root tests will indicate that firms are earning permanent profits. Identifying which portion of producer surplus is attributable to profit from the portion due to economic rent will be impossible with PIP testing methodology.

3.3 Testing

I test the timeseries behavior of a sample of eight energy firms profits for unit root behavior.4 I conduct the tests on the sample as both a group and individually; in both cases I normalize by GDP to control for the business cycle. I find that the timeseries behavior of the group of eight firms as a whole exhibits unit root behavior. When I test the firms individually some of the timeseries exhibit unit roots but others do not. The results of these tests can be found in Table 1 through 4.

These findings would cause the PIP test to fail to reject the null of a unit root and as such imply that barriers to entry exist. Given the unique attributes of the oil industry, it seems likely the current PIP measure of market performance will lead to false conclusions about

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3 The eight firms are British Petroleum, Conocophillips, Chevron, Hess, Occidental, Royal Dutch, Sunoco, and Exxon-Mobil.

4 The specifics of these tests are included in the appendix.
persistence in profit. I plan to adapt this empirical testing methodology as currently it does not take into account that average costs can vary in a competitive industry for prolonged periods of time. Although these differences (rents) will eventually dissipate, it is unlikely that that they will in the span of time necessary to make inference. These rents must be taken into account when determining if barriers to entry exist within an industry or market.

I now turn to the question of whether the technique can be adjusted to account for rent. In the appendix I provide a simple model that illustrates how barriers to entry lead to a unit root in profits. This suggests a method for controlling for rent, which is to find the least efficient firm in the industry. In a competitive industry with an upward sloping supply curve that firm will not earn rent. Next, conduct a unit root test only on the least efficient firm controlling for the business cycle by normalizing profits on GDP instead of the average of all the firms within the industry. This method should provide a correct test for barriers to entry.

4 Translog Cost Function

As an additional method to isolate profits, I estimate a translog cost function for offshore oil and gas production. In this estimation, total costs are a function of both crude oil and natural gas production, as well as the input prices of exploratory (minus geological and geophysical) and developmental effort, geological and geophysical effort, and the resource to be extracted. Analyzing this segment of production will provide additional information surrounding the presence of barriers to entry by isolating the upstream profitability of large integrated energy firms and nonintegrated firms as well. This study will use a different data set than my previous one as I have chosen to only study offshore oil production in the United States. I use data on prices as well as shares of these inputs, the total quantity of output and total cost to the firm to estimate this cost function. The data I have obtained is not set up such that I can estimate a standard cost function. This form of cost function is not unprecedented; Sardosky (1991) uses a similar form to estimate the scarcity of oil in Alberta.
I estimate the following multiple output translog cost function

$$\ln C(v, w, t) = \alpha_0 + \sum_{i=1}^{2} \alpha_i \ln v_i + \alpha_4 t + \sum_{j=1}^{3} \beta_j \ln w_j + \frac{1}{2} \sum_{i=1}^{2} \alpha_{ii} (\ln v_i)^2 + \frac{1}{2} \sum_{j=1}^{3} \sum_{j' = 1}^{3} \beta_{jj'} (\ln w_j)(\ln w_{j'}) + \frac{1}{2} \sum_{j=1}^{3} \gamma_{ij} (\ln v)(\ln w_j) + \alpha_4 t^2 + \sum_{j}^{3} \beta_{ij} (\ln w_j)t,$$

where $v$ represents the outputs natural gas and crude oil and $w$ represents the input prices. I also include a trend to control for technical change. The two outputs are millions of cubic feet of natural gas and millions of barrels of oil. I convert natural gas to barrels of oil equivalent to ensure common units.

I define the price of exploratory (minus geological and geophysical) and developmental effort by the ratio of total expenditures on developmental effort and exploratory effort minus geological and geophysical effort per total amount of developmental feet drilled and exploratory feet drilled to the contemporaneous increase in barrels of oil equivalent reserves. I define the price of geological and geophysical effort by ratio of total expenditures on geological and geophysical effort to contemporaneous net increase acreage of land. I am assuming the more land a firm possesses the more effort it requires to explore. I initially attempted to use distance to shore as the price of geological and geophysical effort but this data was obtained from another source and did not match up well. Finally, I define the price of land as the sum of the following two ratios. Total expenditures on acquisitions of leases to the contemporaneous increase in the number barrels of oil equivalent in reserves. The second term is the total expenditures on royalties and taxes per barrels of oil equivalent contemporaneously produced. All nominal values are converted into real terms using the producer price index.

I include a time trend, its square and interaction terms with prices. I include dummy variables to achieve the fixed effects estimator. I do not include coefficients for the dummy variables in any of my results for reasons of confidentiality. I have not included separate interaction terms for each output and the input prices. Including interaction terms for both oil and gas with input prices appears theoretically incorrect to me. Firms do not differentiate
between oil and gas production when considering input prices, at least not in the exploration phase. It may be a consideration once the content of the well is known but only drilling is used in this phase of production. Instead I have included their sum interacted with the input prices. I impose all the typical restrictions

\[
\sum_{j=1}^{3} \alpha_j = 1 \\
\sum_{j=1}^{3} \beta_{1j} = 0 \\
\sum_{j=1}^{3} \beta_{2j} = 0 \\
\sum_{j=1}^{3} \beta_{3j} = 0,
\]

which result in the necessary linear homogeneity condition in prices as well as \( \beta_{jk} = \beta_{kj} \) for \( j \neq k \). The associated share equations for the cost function are

\[
S_j = \alpha_j + \sum_{j'} \alpha_{jj'} w_{jj'} + \alpha_j t \quad \text{for} \ j = 1, 2, 3.
\]

The shares are simply the ratio of their expenditures to total cost. I estimate this system of equations (dropping the share equation for geological and geophysical effort) using the general method moments estimator with continuously updated weight matrix and the Newey-West robust variance matrix. I include two sets of lags within the Newey-West robust variance matrix. Using a likelihood ratio test against the alternative of one additional lag being included I am able to reject the null with a p-value of 0.409.

In this stage of my research it seems a bit premature to infer too much detail from the initial results. However, the trend, with the exception of its interaction with exploratory and developmental effort, does not seem relevant. This would suggest that technology has been countered by exhaustibility. These results can be seen in Table 5. Both output of oil and gas appear as statistically insignificant in Table 5. Given the relative importance of discovering oil versus natural gas and the lack of statistical significance in Table 5 it would be worthwhile combining the two output variables into one. The fitted share equation are all positive for all periods. However the own price elasticities for two of the inputs are positive.
5 DATA

In my first empirical exercise, I obtained data from the Center for Research in Security Prices (CRSP) database at the University of Chicago.\textsuperscript{5} I have chosen net income excluding extraordinary items as a measure for real profits. I have excluded extraordinary items since they appear to be outliers within the sample. It appears that these items are infrequent and the magnitudes are only of a size of influence when large exogenous events occur (e.g. the first Gulf War, the 1986 price crash, etc). The inclusion of extraordinary items would only increase the volatility of the timeseries and therefore the probability of failing to reject a unit root. I collect GDP data from the FRED II database at the Federal Reserve Bank of St. Louis (http://research.stlouisfed.org/fred2/). The sample is quarterly and spans from 1974:1 to 2005:4. Of course, we only observe accounting profits, not economic profits, but Mueller (1990) cites Edwards, Kay, and Mayer (1987), Lindberg and Ross (1981) as evidence of accounting profits as a sufficient measure of economic profits.

The data I use to estimate the cost function is collected by the Energy Information Administration (the statistical arm of the Department of Energy). This confidential data set is a panel containing 47 US based energy firms and spans from 1978 to 2006. It also includes three foreign owned subsidiaries: BP America, Shell Oil, and Total Holdings USA. Because I am only concerning myself with offshore production, 16 of the 50 firms must be eliminated.

6 Conclusion

I have shown that an existing empirical testing methodology will give false conclusions in certain situations and found a potential improvement. I have started to conduct an independent experiment which should allow me to determine if barriers to entry exist in US offshore oil and gas production. In order to the complete these studies, a closer analysis of the data for the translog cost function will be conducted. In addition, I may need to address the

\textsuperscript{5}CRSP was accessed at the University of Pennsylvania’s WRDS website (http://wrds.wharton.upenn.edu/).
potential problem of using contemporaneous values in input prices. Once completed, this project should lend credibility to my criticism and stated alternative method regarding persistence in profits. Overall any discovery of barriers to entry will have potentially important policy implications for the existing government policy for allocating resource rights.

A Model

The idea that barriers to entry lead to a unit root in profits, and that stationarity in profit imply competition, can be illustrated with the following model. Letting demand be represented by the following equation

\[ y^d_t = -a_1 p_t + x_{d,t} \quad a_1 > 0, \]  

where \( y_t \) is the amount of oil demanded at time \( t \), \( p_t \) is the price of oil, and \( x_{d,t} \) is a demand shock. \( x_{d,t} \) is assumed to be a permanent demand shock which can be described by a unit root process, \( x_{d,t} = x_{d,t-1} + \epsilon_t \), where \( \epsilon_t \) is assumed to be an i.i.d. white noise process. Let the supply of crude oil be represented by,

\[ y^s_t = b_1 p_t + b_2 n_t + x_{s,t} \quad b_1, b_2 > 0, \]

where \( x_{s,t} \) represents a supply shock and \( n_t \) represents the number of firms in the market at time \( t \). Like the demand shock in equation (8), \( x_{s,t} \) is assumed to be a permanent demand shock which can be described by a unit root process. Finally, the dynamics of the model are represented in the following state equation

\[ \Delta n_t = \nu [p_t - z_t] \quad \nu, z_t > 0, \]

where \( z_t \) represents the marginal cost at time \( t \) of the \( n^{th} \) firm. Assuming that the industry is competitive, firm \( n \) has an \( N^{th} \) share of the market. \( \Delta n_t \) represents the change in \( n \) between periods \( t \) and \( t - 1 \). Equation (10) represents the dynamic behavior of firm entry into the market. When price exceeds the average cost of the marginal firm, firms will have
an incentive to enter the market. Because I treat \( n_t \) as exogenous at any point in time, this system is block recursive, so the equilibrium price and level of output can be solved independently of the dynamic behavior of firms.

\[
y_t = \left( \frac{b_1}{a_1 + b_1} \right) x_{d,t} + \left( \frac{a_1}{a_1 + b_1} \right) x_{s,t} + \left( \frac{a_1 b_2}{a_1 + b_1} \right) n_t = \alpha_1 x_{d,t} + \alpha_2 x_{s,t} + \alpha_3 n_t \quad (11)
\]

\[
p_t = \left( \frac{1}{a_1 + b_1} \right) x_{d,t} - \left( \frac{1}{a_1 + b_1} \right) x_{s,t} - \left( \frac{b_2}{a_1 + b_1} \right) n_t = \beta_1 x_{d,t} + \beta_2 x_{s,t} + \beta_3 n_t \quad (12)
\]

Steady-state in this model occurs when there is no entry or exit, where I have assumed supply constraints. The long-run competitive steady-state equilibrium solution is then described by the following,

\[
\Delta n_t = 0 \quad \Rightarrow \quad p_t = z_t. \quad (13)
\]

That is, a shock may cause short-run profit losses or opportunities but in the long-run no economic profit will exist.

Substituting equation (12) into equation (10) gives a first order difference equation in \( n_t \), where \( n_t \) is a function of model’s exogenous variables:

\[
n_t = \frac{1}{1 - \gamma_3} \sum_{i=0}^{k} (1 - \gamma_3)^{-i} (\gamma_1 x_{d,t-i} + \gamma_2 x_{s,t-i}), \quad (14)
\]

where \( \gamma_3 \equiv \nu \left( \beta_3 + \frac{b_2}{b_1 N} - \frac{\alpha}{b_1 N} \right) \), \( \gamma_1 \equiv \nu \left( \beta_1 + \frac{\alpha}{b_1 N} \right) \),

and \( \gamma_2 \equiv \nu \left( \beta_2 + \frac{1}{b_1 N} - \frac{\alpha}{b_1 N} \right) \). \( p_t \) and \( y_t \) can now be solved entirely in terms of exogenous variables: \( x_{d,t} \), \( x_{s,t} \), and \( n_t \). Inserting \( n_t \) into equations (11) and (12), \( p_t \) and \( y_t \) are now functions of supply and demand shocks only.

An illustration of the model’s behavior can be seen by assuming either a permanent shock to supply or demand occurs. Profit is an I(2) variable which simply means that it contains two unit roots.\(^6\) I first examine how profits will react when there is entry. Taking advantage

\(^6\)I show that profit is an I(2) series in appendix A.1. I also solve for the long-run behavior of \( n_t \) and \( y_t \) when I allow for entry.
of the cointegration relationship, I substitute \( \frac{1}{\mu} (n_t - n_{t-1}) \) for \( p_t - z_t \) in profit and taking the limit of the partial with respect to both supply and demand as \( k \) goes to infinity gives,

\[
\lim_{k \to \infty} \frac{\partial \pi_{t+k}}{\partial x_s} = \lim_{k \to \infty} \left[ \frac{\partial (n_{t+k} - n_{t+k-1})}{\partial x_s} y_t + (n_{t+k} - n_{t+k-1}) \frac{\partial y_{t+k}}{\partial x_s} \right] = 0 + 0 = 0, \tag{15}
\]

\[
\lim_{k \to \infty} \frac{\partial \pi_{t+k}}{\partial x_d} = \lim_{k \to \infty} \left[ \frac{\partial (n_{t+k} - n_{t+k-1})}{\partial x_d} y_t + (n_{t+k} - n_{t+k-1}) \frac{\partial y_{t+k}}{\partial x_d} \right] = 0 + 0 = 0. \tag{16}
\]

Barriers to entry produce the following relationships with a decrease in supply or demand

\[
\frac{\partial \pi_{t+k}}{\partial x_{s,t}} = \left( \beta_2 - \frac{1}{b_1 N} (\alpha_2 - 1) \right) \alpha_1 + \left( \beta_1 - \frac{1}{b_1 N} \alpha_1 \right) \alpha_2 x_{d,t} + 2 \left( \beta_2 - \frac{1}{b_1 N} (\alpha_2 - 1) \right) \alpha_2 x_{s,t}, \tag{17}
\]

\[
\frac{\partial \pi_{t+k}}{\partial x_{d,t}} = 2 \left( \beta_1 - \frac{1}{b_1 N} \alpha_1 \right) \alpha_1 x_{d,t} + \left( \beta_2 - \frac{1}{b_1 N} (\alpha_2 - 1) \right) \alpha_1 + \left( \beta_1 - \frac{1}{b_1 N} \alpha_1 \right) \alpha_2 x_{s,t}. \tag{18}
\]

The first term in both equations represents the own effect while the second term is the cross effect. When supply or demand increases we see the following relationships

\[
\frac{\partial \pi_{t+k}}{\partial x_{s,t}} = (\beta_2 - 1) \bar{y}, \tag{19}
\]

\[
\frac{\partial \pi_{t+k}}{\partial x_{d,t}} = \beta_1 \bar{y}, \tag{20}
\]

where \( \bar{y} \) is a supply constraint. The change in profits is a unit root in one case and stationary in the other.

**B Unit Root Tests**

The determination of the existence of a unit root in the data can be a difficult task. Tests that I have undertaken and plan to undertake include: Elliot et. al. (1996) and Ng and Perron’s (2001) unit root tests, Perron’s (1997) test for an endogenous break in the timeseries,
and Hansen and Caner’s (2001) asymmetric unit root test. Unlike the persistence in profits hypothesis, I do not normalize returns/profits. The empiricist conducting a test of the persistence in profit hypothesis normalizes the sample by subtracting off the mean return/profit of the industry. Because the competitive return is a stationary variable its variance will be finite; therefore, there is no need for normalization as subtracting a finite variance from an infinite variance (the result of a unit root) will result in an infinite variance.

I employ the Elliot et al. (1996) DFGLS test for a unit root, which is similar to the augmented Dickey-Fuller t-test. The specifics of these tests can be found in the appendix to this chapter.

Because a break or shift in trend can be misinterpreted as a unit root, I implement Perron’s (1997) unit root test to investigate this possibility. Perron’s unit root test allows for an endogenous change in the slope or level of the series.

Finally, I test to determine if the unit root is asymmetric in nature; that is, changes in one direction are permanent but in the other direction a change dampens over time and regresses back to its pre-change state. I implement the Caner and Hansen (2001) test for an asymmetric unit root. Of course, an asymmetric unit root still constitutes a unit root despite being stationary in one particular direction.

The authors suggest that their test improves the power of the unit root test over the standard Dickey-Fuller test, when there is an unknown deterministic mean or trend present. Elliot et al. avoid having to estimate the deterministic trend nuisance parameters by using a set of test procedures that are invariant to them. The authors suggest regressing $y_\alpha$ on $Z_\alpha$ where $y_\alpha \equiv (y_1, y_2 - \bar{\alpha}y_1, \ldots, y_t - \bar{\alpha}y_{t-1})$ and $Z_\alpha \equiv (z_1, z_2 - \bar{\alpha}z_1, \ldots, z_t - \bar{\alpha}z_{t-1})$. $z_t$ is defined as the vector $[1, t]'$ and $\bar{\alpha} \equiv 1 + \bar{c}/T$.

$$\bar{c} = \begin{cases} -7 & \text{if drift} \\ -13.5 & \text{if linear trend} \end{cases}$$ (21)

The regression coefficient can be used to construct a new detrended series that does not contain a deterministic component; it is now possible to proceed with the normal Dickey-Fuller procedure. If $\tilde{\xi}$ is our estimated coefficient from the regression of $y_\alpha$ on $Z_\alpha$, we can
construct a new series by the following calculation: \( \tilde{y}_t \equiv y_t - \tilde{\xi}^t z_t \). Differencing this series and performing the following regression

\[
\Delta \tilde{y}_t = \eta_0 \tilde{y}_{t-1} + \eta_1 \Delta \tilde{y}_{t-1} + \ldots + \eta_p \Delta \tilde{y}_{t-p} + \epsilon.
\]

(22)

The new null hypothesis tests if \( \eta_0 = 0 \).

Extending this analysis, Ng and Perron (2001) construct four additional statistics using the detrended data generated above.

\[
MZ_{\alpha} = \left( \frac{T^{-1} \tilde{y}_T^2 - f_0}{2k} \right),
\]

(23)

\[
MSB = \left( \frac{k}{f_0} \right)^{1/2},
\]

(24)

\[
MZ_t = MZ_{\alpha} \times MSB,
\]

(25)

and

\[
MPT = \begin{cases} 
(\bar{c}^2 k - \bar{c} T^{-1} \tilde{y}_T^2) / f_0, & \text{if } x_t = \{1\}, \\
(\bar{c}^2 k + (1 - \bar{c}) T^{-1} \tilde{y}_T^2) / f_0, & \text{if } x_t = \{1, t\}.
\end{cases}
\]

(26)

\( f_0 \) is the zero frequency estimate of the residual spectral density and \( k = \sum_{t=1}^{T-1} (\tilde{y}_t / T)^2 \).

The authors suggest these additional four statistics constitute a battery of tests with good power. These tests generally out perform other unit root tests in the published literature and in particular when facing an autoregressive parameter is close to unity which causes many tests, including the augmented Dickey-Fuller test, to have low power.
Figures: A and B
### Table 1: Summary Statistics

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean</th>
<th>Variance</th>
<th>Skew</th>
<th>Kurtosis</th>
<th>Jarque-Bera</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>-2.928055</td>
<td>0.350871</td>
<td>-0.043701</td>
<td>-0.132376</td>
<td>0.133151</td>
</tr>
<tr>
<td>AHC</td>
<td>-0.752271</td>
<td>0.340290</td>
<td>0.280531</td>
<td>-0.943252</td>
<td>6.424076</td>
</tr>
<tr>
<td>BP</td>
<td>-0.846859</td>
<td>0.347373</td>
<td>0.464318</td>
<td>0.464318</td>
<td>9.312869</td>
</tr>
<tr>
<td>COP</td>
<td>-0.747793</td>
<td>0.340557</td>
<td>0.348149</td>
<td>-0.981064</td>
<td>7.719036</td>
</tr>
<tr>
<td>CVX</td>
<td>-0.909727</td>
<td>0.365269</td>
<td>0.458980</td>
<td>-0.936953</td>
<td>9.176163</td>
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<tr>
<td>OXY</td>
<td>-0.921085</td>
<td>0.800123</td>
<td>-4.983253</td>
<td>43.920161</td>
<td>10817.662628</td>
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<tr>
<td>RD</td>
<td>-0.708363</td>
<td>0.387160</td>
<td>0.188899</td>
<td>-1.082594</td>
<td>6.957172</td>
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<tr>
<td>SUN</td>
<td>-0.899867</td>
<td>0.387332</td>
<td>0.426401</td>
<td>-1.047031</td>
<td>9.725566</td>
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<td>XOM</td>
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<td>0.567473</td>
<td>-0.751934</td>
<td>9.885375</td>
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</tbody>
</table>

### Table 2: Unit Root Tests

<table>
<thead>
<tr>
<th>Group</th>
<th>$\eta_\mu$</th>
<th>$\eta_T$</th>
<th>$MZ_\alpha$</th>
<th>$MZ_T$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>2.618</td>
<td>0.390</td>
<td>-5.71878e-04</td>
<td>0.23404</td>
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<tr>
<td>AHC</td>
<td>2.211</td>
<td>0.389</td>
<td>-5.11330e-06</td>
<td>0.16937</td>
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<tr>
<td>BP</td>
<td>3.187</td>
<td>0.756</td>
<td>-5.06599e-08</td>
<td>0.03507</td>
</tr>
<tr>
<td>COP</td>
<td>2.597</td>
<td>0.516</td>
<td>-1.67116e-07</td>
<td>0.03578</td>
</tr>
<tr>
<td>CVX</td>
<td>3.192</td>
<td>0.700</td>
<td>-3.75868e-08</td>
<td>0.02109</td>
</tr>
<tr>
<td>OXY</td>
<td>2.834</td>
<td>0.285</td>
<td>-2.13766e-07</td>
<td>0.02379</td>
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<tr>
<td>RD</td>
<td>NA</td>
<td>NA</td>
<td>-6.32460e-08</td>
<td>0.03525</td>
</tr>
<tr>
<td>SUN</td>
<td>3.226</td>
<td>0.787</td>
<td>-6.21388e-06</td>
<td>0.14879</td>
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<tr>
<td>XOM</td>
<td>2.120</td>
<td>0.471</td>
<td>-2.43370e-06</td>
<td>0.08689</td>
</tr>
<tr>
<td>5%</td>
<td>0.463</td>
<td>0.146</td>
<td>-17.3</td>
<td>-2.91</td>
</tr>
</tbody>
</table>
Table 3: Elliot, Rothenberg and Stock Tests

<table>
<thead>
<tr>
<th></th>
<th>$DFGLS_{\tau}$</th>
<th>$DFGLS_{\mu}$</th>
<th>$P_{\tau}$</th>
<th>$P_{\mu}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>group</td>
<td>-0.463</td>
<td>-1.837</td>
<td>27.421</td>
<td>15.985</td>
</tr>
<tr>
<td>AHC</td>
<td>-0.042</td>
<td>-1.771</td>
<td>126.282</td>
<td>27.699</td>
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<tr>
<td>BP</td>
<td>-1.333</td>
<td>-2.070</td>
<td>7.890</td>
<td>8.301</td>
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<tr>
<td>COP</td>
<td>-1.622</td>
<td>-1.895</td>
<td>5.769</td>
<td>9.321</td>
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<tr>
<td>CVX</td>
<td>-2.679</td>
<td>-3.844</td>
<td>1.897</td>
<td>1.850</td>
</tr>
<tr>
<td>OXY</td>
<td>-3.563</td>
<td>-4.017</td>
<td>1.208</td>
<td>1.940</td>
</tr>
<tr>
<td>RD</td>
<td>-1.319</td>
<td>-2.373</td>
<td>7.946</td>
<td>6.683</td>
</tr>
<tr>
<td>SUN</td>
<td>0.068</td>
<td>-2.723</td>
<td>72.580</td>
<td>37.803</td>
</tr>
<tr>
<td>XOM</td>
<td>-0.285</td>
<td>-1.988</td>
<td>24.674</td>
<td>11.613</td>
</tr>
<tr>
<td>5%</td>
<td>-1.95</td>
<td>-2.73</td>
<td>3.26</td>
<td>4.65</td>
</tr>
</tbody>
</table>

Table 4: Perron’s test for a structural break

<table>
<thead>
<tr>
<th></th>
<th>IO1</th>
<th>IO2</th>
<th>AO</th>
</tr>
</thead>
<tbody>
<tr>
<td>group</td>
<td>-2.07362</td>
<td>-3.28959</td>
<td>-2.93493</td>
</tr>
<tr>
<td>AHC</td>
<td>-4.34025</td>
<td>-3.70644</td>
<td>-2.36649</td>
</tr>
<tr>
<td>BP</td>
<td>-3.25456</td>
<td>-4.25913</td>
<td>-3.12975</td>
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<tr>
<td>COP</td>
<td>-3.57655</td>
<td>-4.38134</td>
<td>-3.46739</td>
</tr>
<tr>
<td>CVX</td>
<td>-2.73466</td>
<td>-2.39701</td>
<td>-2.87330</td>
</tr>
<tr>
<td>OXY</td>
<td>-10.85040</td>
<td>-95.76854</td>
<td>-11.77414</td>
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<tr>
<td>SUN</td>
<td>-2.37939</td>
<td>-2.93493</td>
<td>-3.29011</td>
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<tr>
<td>XOM</td>
<td>-3.78310</td>
<td>-4.66214</td>
<td>-3.63629</td>
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<td>5%</td>
<td>-4.80</td>
<td>-5.08</td>
<td>-4.65</td>
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</tbody>
</table>
Table 5: GMM-Continuously Updated Weight Matrix

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimated Coefficient</th>
<th>standard error</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_{oil}$</td>
<td>0.037</td>
<td>0.196</td>
<td>0.852</td>
</tr>
<tr>
<td>$\alpha_{gas}$</td>
<td>0.349</td>
<td>0.273</td>
<td>0.201</td>
</tr>
<tr>
<td>$\beta_R$</td>
<td>0.697</td>
<td>0.185</td>
<td>0.000</td>
</tr>
<tr>
<td>$\beta_{E&amp;P}$</td>
<td>0.324</td>
<td>0.136</td>
<td>0.017</td>
</tr>
<tr>
<td>$\alpha_t$</td>
<td>-0.045</td>
<td>0.061</td>
<td>0.466</td>
</tr>
<tr>
<td>$\alpha_{oil,oil}$</td>
<td>0.084</td>
<td>0.061</td>
<td>0.171</td>
</tr>
<tr>
<td>$\alpha_{gas,gas}$</td>
<td>0.017</td>
<td>0.037</td>
<td>0.648</td>
</tr>
<tr>
<td>$\beta_{R,R}$</td>
<td>0.310</td>
<td>0.044</td>
<td>0.000</td>
</tr>
<tr>
<td>$\beta_{R,E&amp;P}$</td>
<td>-0.140</td>
<td>0.036</td>
<td>0.000</td>
</tr>
<tr>
<td>$\beta_{E&amp;P,E&amp;P}$</td>
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<td>0.044</td>
<td>0.000</td>
</tr>
<tr>
<td>$\gamma_{Y,R}$</td>
<td>-0.095</td>
<td>0.033</td>
<td>0.004</td>
</tr>
<tr>
<td>$\gamma_{Y,E&amp;P}$</td>
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<td>0.0291</td>
<td>0.001</td>
</tr>
<tr>
<td>$\alpha_{t,t}$</td>
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<td>0.002</td>
<td>0.608</td>
</tr>
<tr>
<td>$\beta_{R,t}$</td>
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<td>0.000</td>
<td>0.206</td>
</tr>
<tr>
<td>$\beta_{E&amp;P,t}$</td>
<td>-0.002</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

References


