1978

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20154

RESEARCH REPORT 7834

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* I wish to thank J. Markusen, S. Liebowitz and A. Ullah for their helpful comments.

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1. Introduction

Empirical applications of production theory have been the subject of many studies in applied economics. With the recent developments in the applications of duality and the introduction of new and more flexible functional forms, empirical production studies have become more sophisticated, using newly developed econometric techniques and allowing for a more general specification of technological conditions. Most of these applications, however, assume perfectly competitive markets, so that all economic agents are price takers and carry out their optimization subject to given prices.

While the price-taking behavior assumption is a convenient one, it does not always provide a good approximation of the real world. Many markets are characterized by monopolistic, or more generally, oligopolistic behavior, therefore, making the price-taking hypothesis inappropriate. Moreover, in many cases we do not know the degree of competitiveness in certain markets and would, therefore, be interested in estimating it, or testing alternative possible hypotheses about its nature. Maintaining price-taking behavior is, again, inappropriate in such cases.

The identification of market structure and the measurement of the degree of competitiveness are in fact among the most important issues in industrial organization. Industrial organization studies usually use such measures as concentration ratios, barriers to entry and a variety of monopoly power indexes, as means for the identification of market structure. Usually, however, they do not provide direct econometric estimations or statistical tests of alternative hypothesis about market structure.[1]

More recently, several studies appeared which provide a framework for econometric analysis of markets where prices are not parametric. In Appelbaum [1978a], [1978b] and Appelbaum and Kohli [1978] a simple framework is provided for testing monopolistic behavior and measuring the degree of monopoly power. Diewert [1978] discusses some of the approaches applying duality principles that were suggested for the analysis of monopolistic behavior. Empirical studies using other than duality principles are by Iwata [1974] and Gollop and Roberts [1978] who consider oligopolistic firms and carry out tests for several hypotheses about the nature of the conjectured variations.

In this paper we extend the use of econometric production theory techniques to a general class of oligopolistic markets. We first generalize some of the duality results to non-competitive markets, providing a partial characterization of the profit functions. We then consider an oligopolistic market with general conjectural variations and provide a framework which enables us to analyze this market empirically, estimate the conjectural variation and test various hypotheses about non-competitive behavior. Furthermore, we provide a measure of the degree of oligopolistic power of a firm that measures the deviation from purely monopolistic and competitive behavioral modes. Using the firm measure we define a degree of oligopoly index for the whole industry that can be used to test for the underlying structure of the industry. The measure of the degree of oligopolistic power we derive is a generalization of both the classical Lerner measure and the Herfindahl index.

Since in many cases detailed firm data are difficult to obtain, we consider the conditions under which our framework is also applicable on an aggregate (industry), rather than firm level, so that industry price and quantity data are sufficient.

In the empirical part we apply our framework in a study of the U.S. crude petroleum and natural gas industry. There have been recently several studies of energy production models[2] and some of them also consider the crude petroleum and natural gas industry (e.g., Hudson and Jorgenson [1974], Jorgenson et al. [1973]). All of these studies, however, assume perfectly competitive markets. In our empirical application we use the same data as in Hudson and Jorgenson [1974] to study the crude petroleum and natural gas industry and find the industry to be significantly non-competitive, but not purely monopolistic.

In Section 2 we generalize some of the duality results to a monopolistic firm. In Section 3 we develop a framework for the analysis of an oligopolistic industry and in Section 4 we apply this framework to the crude petroleum and natural gas industry.

2. Pure Monopoly

Consider a monopolist whose technology is defined by the production function F, where $y_0 \equiv F(y)$ is output produced by the n dimensional vector of inputs y and F is a continuous from above, nondecreasing and quasiconcave function. Furthermore, let y_0 be an intermediate good, so that it is an input demanded by "other" producers[3] each of whose production function is defined by G where $x_0 \equiv G(y_0,x)$ is the output produced and x is an m dimensional vector of inputs (in addition to y_0) used by an "other" producer. If the firm production function G is subject to constant returns to scale (in addition to being quasiconcave and nondecreasing) and all "other" producers face the same prices and behave competitively, then G can also be interpreted as the industry production function for the "other" producers so that x_0 can be interpreted to be industry output, x as a vector of "other" industry inputs, and y_0 as "other" industry demand for the monopolist's output. Let the prices of y_0,y be p_0,p and the prices of x_0,x be w_0,w, respectively.[4]

Assuming that firms in the "other" industry competitively maximize profits, we define the "other" industry's profit function as[5]

$$2.1. \quad H(w_0,w,p_0) \equiv \max_{y_0,x} [w_0\, G(y_0,x) - p_0 y_0 - w' x]$$

where w' is the transposed row vector of w. If H is once differentiable with respect to the prices (w_0,w,p_0) we can obtain the "other" industry's demand and supply functions by applying Hotelling's Lemma[6]

$$2.2. \quad x_0 = \partial H(w_0,w,p_0)/\partial w_0$$

$$x = - \nabla_w H(w_0,w,p_0)$$

$$2.3. \quad y_0 = - \partial H(w_0,w,p_0)/\partial p_0 \equiv J(w_0,w,p_0)$$

where $\nabla_w H$ is the column vector of partial derivatives of H with respect to w.

Using the "other" industry's demand function we can write the monopolist's profit maximization problem as

$$2.4. \quad \max_{y_0,p_0,y} [p_0 y_0 - p' y : y_0 = F(y),\ y_0 = J(w_0,w,p_0)] \equiv \pi(p,w_0 w).$$

Breaking the maximization problem into stages we can write it as the following equivalent problem

$$2.5. \quad \max_{y_0,p_0} [p_0 y_0 - C(y_0,p) : y_0 = J(w_0,w,p_0)]$$

where

$C(y_0,p) \equiv \min_y [p' y : F(y) = y_0]$ is the cost function which is dual to F.[7]

If the cost function is differentiable with respect to p, then the monopolist's demand for y is given by Shephard's Lemma[8] as

2.6. $y = \nabla_p C(y_0, p)$.

Assuming that C and J are differentiable with respect to y_0 and p_0 respectively, the optimality condition for y_0 is obtained from 2.5. as

2.7. $p_0 + \delta = \partial C(y_0, p)/\partial y_0$ or

$$p_0 = \partial C(y_0, p)/\partial y_0 - \delta$$

where $p_0 + \delta$ is the marginal revenue of y_0 and can be written as

2.8. $p_0 + \delta = \partial(p_0 y_0)/\partial y_0 = p_0 + y_0(\partial p_0/\partial y_0)$.

The term δ is a non-competitive "markup" term which is derived from the demand function by implicit differentiation

2.9. $\delta(w_0, w, p_0) = J(w_0, w, p_0)/[\partial J(w_0, w, p_0)/\partial p_0]$

$$= [\partial H(w_0, w, p_0)/\partial p_0]/[\partial^2 H(w_0, w, p_0)/\partial p_0^2].$$

The underlying profit function $H(w_0, w, p_0)$, completely characterizes the markup term δ. For example, from the linear homogeneity in prices of H, it follows that δ is linear homogeneous in (w_0, w, p_0).

The profit function defined by 2.4. is more complicated than the usual profit function since it combines the properties of the demand function (i.e., the technology of the other industry) and the properties of the monopolist's technology. It is, however, still possible to determine some of its properties. It can be shown that π is:[9]

(1) linear homogeneous in (w_0, w, p)

(2) non-increasing in p

(3) non-increasing or non-decreasing in w_i depending on whether x_i is a substitute or complement to y_0 respectively

(4) non-increasing in w_0 if y_0 is not an inferior input in the other industry's technology.

(5) $\partial\pi/\partial w_0 = (\partial J/\partial w_0)\delta$

$$\frac{\partial\pi}{\partial w_i} = (\partial J/\partial w_i)\delta$$

$$\frac{\partial\pi}{\partial p_i} = -x_i$$

(6) π is convex in p.

Unlike the usual profit function it is impossible to obtain the curvature properties of π with respect to (w_0, w, p). Clearly, the problem here is that we do not know the curvature properties of J, and of C as a function of y_0. To be able to determine these properties we need information about the third-order derivatives of the "other" industry's profit function H and about the returns to scale properties of the monopolist's technology.

The complete model for these production relationships is given by the set of optimality conditions which consist of the optimality conditions of the non-competitive firm and those of the demanders of y_0. Thus the full model consists of the systems 2.2., 2.3. and 2.6., 2.7.

The optimality conditions of the non-competitive firm imply a decision rule which is, clearly, different than that of a competitive firm. In fact, the decision rule of a competitive firm is simply obtained by setting $\delta = 0$ in the optimality conditions above. The two different decision rules which follow from the different market structures will, of course, yield different market solutions to the above problems. Thus, by estimating the two models and testing which solution is better supported by the data, it is possible to identify the decision rule that is being followed and hence identify the underlying market structure.

3. Oligopolistic Markets

So far it was assumed that the non-competitive firm behaves as a pure monopolist, in other words, it fully takes into account the behavior of the other side of the market ("other" industry). On one hand we, therefore, have the competitive case ($\delta = 0$), where the demand function of the "other" industry is not incorporated into the decision problem and on the other hand we have the pure monopoly case where this function is fully taken into account and incorporated into the decision rule. These two cases, it might be argued, are quite extreme and therefore, maintaining either one a priori is too restrictive. We should, therefore, look at an intermediate case, where we neither have a pure monopolist, nor a pure competitor. Such a case may arise in all sorts of oligopoly situations, or any case where there exist perceived demand curves, which are different than the actual market curves (e.g., in monopolistic competition models).

We now consider such a general intermediate case and then give a more specific example.

Let α be a vector of parameters, parameterizing the other industry's profit function which is written as $H(w_0,w,p_0;\ \alpha)$. The actual demand curve is then given by $y_0 = J(w_0,w,p_0;\ \alpha)$ and the corresponding markup term is

3.1. $$\delta = [\partial J(w_0,w,p_0;\ \alpha)/\partial p_0]/\partial^2 J(w_0,w,p_0;\ \alpha)/\partial^2 p_0]$$

$$= \delta(w_0,w,p_0;\ \alpha).$$

In the intermediate case when the firm is neither a pure monopolist, nor a perfect competitor, its perceived demand curve is different than the actual one. It is, therefore, given by say, $y_0 = J(w_0,w,p_0;\ \beta)$ where β is a vector of parameters characterizing the particular type of intermediate case. For example, it can characterize a specific conjectural variation.

From the perceived demand curve we get the markup term as $\hat{\delta} = \hat{\delta}(w_0, w, p_0; \beta)$ which is different than the markup in 3.1. in the sense that it is characterized by different parameters.

The non-competitive firm's optimality conditions are now the same as 2.6., 2.7., except that δ is replaced with $\hat{\delta}$.

The two special cases of pure monopoly and perfect competition can be obtained by restrictions on $\hat{\delta}$. If $\hat{\delta} = 0$, we have the perfectly competitive case. If $\hat{\delta} = \delta$ we have the pure monopoly case. To test for competition we, therefore, test whether $\beta \in A$ where $A \equiv \{\beta : \hat{\delta}(\beta) = 0\}$ and to test for pure monopoly we test whether $\beta \in B$ where $B \equiv \{\beta : \hat{\delta}(\beta) = \delta(\alpha)\}$.

The relationship between α and β, or δ and $\hat{\delta}$, depends on the specific assumptions we make about the nature of the non-competitive behavior. An example of such a relationship is the case where $\hat{\delta}$ is proportional to δ i.e., $\hat{\delta} = \theta\ \delta(w_0, w, p_0; \alpha)$.

Let us explicitly consider an oligopoly model that yields a perceived markup term which is proportional to the actual one.

Assume the non-competitive industry producing y_0 is an oligopolistic industry and consists of s firms whose cost functions (defined above) are given by $C^j = C^j(y_0^j, p)$ $j=1\ldots s$, where y_0^j is the output of the j^{th} firm. Assuming all firms face the same input prices the profit maximization problem of the j^{th} firm is given by

3.2. $\max[p_0 y_0^j - C^j(y_0^j, p) : y_0 = J(w_0, w, p_0)]$

where $y_0 = \sum_{j=1}^{s} y_0^j$ is the industry supply. The optimality conditions corresponding to this profit maximization problem are given by

3.3. $y^j = \nabla_p C^j(y_0^j, p)$

3.4. $p_0 + \theta^j \delta = \partial C^j(y_0^j, p)/\partial y_0^j$

where y^j is the j^{th} firm's input demand vector and θ^j is a term characterizing the conjectural variation and is defined by

3.5. $\theta^j = \dfrac{\partial y_0}{\partial y_0^j} \dfrac{y_0^j}{y_0}$

in other words, it is the conjectural elasticity of total industry output with respect to the output of the j^{th} firm. The optimality condition in 3.4. simply says that the firm equates its marginal cost with its perceived marginal revenue. The conjectural (or perceived) elasticity θ^j involves both the firm's output share and its conjectural variation. We do not restrict the conjectural variation to any specific type, so that it can correspond to a general behavioral mode. In the special case of Cournot behavior, $\partial y_0/\partial y_0^j = 1$ and θ^j is simply the output share of the j^{th} firm.

We see, therefore, that a general oligopoly model does in fact yield a proportional relationship between $\hat{\delta}$ and δ. Furthermore, under perfect competition $\theta^j = 0$ and under pure monopoly $\theta^j = 1$ $(y_0 = y_0^j)$, thus providing us with a basis for testing these hypotheses.

Given 3.4. we can generalize the classical Lerner measure of the degree of monopoly power. We define the degree of non-competitive power of the j^{th} firm as

3.6. $\alpha_j = [p_o - \dfrac{\partial C^j(y_o^j, p)}{\partial y_o^j}]/p_o = - \dfrac{\theta^j \delta}{p_o} = \theta^j \epsilon$

where ϵ is the inverse market demand elasticity.

This measure takes two things into account; the inverse demand elasticity, which is the classical Lerner measure, and the conjectural elasticity. It is clear, therefore, that unless $\theta^j = 1$, i.e., we have a pure monopolist, the Lerner measure is not appropriate. Note also that the non-negativity of marginal costs implies that $\alpha^j \leq 1$ and the fact that $\delta < 0$ and $p_o - \partial C^j/\partial p_o \geq 0$ implies that $0 \leq \alpha^j$. In other words, the degree of oligopoly power is between zero and one.

Given 3.6. we define the degree of oligopoly, or of non-competitiveness, of the industry as

$$3.7. \quad L = \sum_j \frac{(p_o - MC^j)}{p_o} S_j = \sum_j \alpha_j S_j = \sum_j \theta^j S_j \epsilon$$

where $S_j = y_o^j/y_o$ and MC^j is the marginal cost of the j^{th} firm.[10] This industry measure is a weighted average of the firm measures. It is the ratio of the sum of non-competitive rents in the industry and total industry revenues.

By substituting the definition of θ^j as in 3.5., we can rewrite 3.7. as

$$3.8. \quad L = \sum_j \frac{\partial y_o}{\partial y_o^j} S_j^2 \epsilon$$

The measure of oligopoly power is therefore a weighted sum of the squared shares of the firms in the industry multiplied by the Lerner index. The weights are given by the conjectural variations, $\partial y_o/\partial y_o^j$. The Herfindahl index which takes the sum of the squared shares, is therefore a special case of 3.8. and will be valid if $\partial y_o/\partial y_o^j = 1$ all j, i.e., if all firms behave as Cournot oligopolists. If all conjectural variations are the same but not necessarily equal to one, say $\partial y_o/\partial y_o^j = \gamma$ all j, then $L = \gamma \epsilon \sum_j S_j^2$, i.e., it is proportional to the Herfindahl index.

The measure given by 3.7. is, therefore, a generalization of both the Lerner and Herfindahl indexes.

Given input and output time series for the different firms in the industry, we can estimate the full model which is given by the system 2.2., 2.3., 3.3. and 3.4. The conjectural elasticities which are in general not constant can be taken as some function of the exogenous variables and estimated within the full model. Given the estimated model we can calculate the generalized measure of non-competitiveness and carry out various tests about the market structure.

Given the necessary data this should not be difficult to do. In practice, however, it is not easy to obtain the required cross-section, time-series data. As a possible alternative we may want to look at the problem on an aggregate level. To do this we have to assume that an aggregate cost function exists and treat the optimality conditions 3.3. and 3.4. on an aggregate level.

As is usually the case with aggregate models, certain aggregation conditions have to be satisfied for the aggregation to be consistent. Similarly here, we have to make a certain assumption that enables us to consider the optimality conditions given by 3.3. and 3.4. on an aggregate industry level.

Consider 3.3. first. The aggregate demand function for the i^{th} input can be obtained as

$$3.9. \quad y_i = \sum_j y_i^j = \sum_j \partial C^j(y_0^j, p)/\partial p_i \qquad i=1\ldots n.$$

Let us assume that the cost functions of the firms in the oligopolistic industry satisfy

$$3.10, \quad C^j(y_0^j, p) = y_0^j\, C(p) + G^j(p) \qquad j=1\ldots s.$$

In other words, the firms have linear and parallel expansion paths, so that marginal costs are constant and equal across firms.[11] Given this assumption the aggregate input demand functions are given by

3.11 $y = y_0 \nabla_p C(p) + \sum_j G^j(p)$

and are expressed in terms of aggregate industry variables only.

It should be noted that the assumption given by 3.10. is a very common one and is usually implicit in aggregate production or consumption studies. The cost functions defined by 3.10. are of the so-called Gorman polar form type,[12] allowing the different firms to have different cost curves but the curves are all linear and parallel.[13]

Given assumption 3.10. it is clear that if we assume $\theta^j = \theta$ all j then 3.4. becomes $p_0 + \theta\ \delta = C(p)$ which is a condition on an aggregate level. Such an assumption is, however, not very appealing, since it restricts the firms' behavioral modes to be similar in some sense.

As it turns out, such an assumption is not necessary, since it is satisfied as a consequence of the existence of an equilibrium. From 3.4.. it is clear that if marginal costs are the same for all firms, then, in equilibrium, the conjectural elasticities must be the same as well. In other words, since all firms equate their marginal cost with their perceived marginal revenues and since marginal costs are the same, then also perceived marginal revenues must be the same.

We conclude, therefore, that as long as an equilibrium exists,[14] it must be the case that in equilibrium $\theta^j = \theta$ for all j=1...s. θ is therefore the equilibrium value of the conjectural elasticities and it will, in general, be a function of all the exogenous variables. This then enables us to write the aggregate optimality condition as

3.12. $p_0 + \theta\ \delta = C(p)$.

It should be clear that all that 3.12. says is that <u>in equilibrium</u>

perceived marginal revenues in the industry are equal to industry marginal costs and are, therefore, the same for all firms. It does not say that the perceived marginal revenue <u>curves</u> themselves are necessarily the same for all firms. These curves will, in general, be different for the different firms. Their intersection with the marginal cost curve is, however, always at the same level of perceived marginal revenue. Therefore, if an equilibrium exists, it must involve equal perceived marginal revenues and thus equal conjectural elasticities.

As an example, consider the special case of Cournot behavior. Under this behavioral assumption the θ^j's are nothing but the output shares, so that if all firms are Cournot oligopolists, the equilibrium will involve equal market shares for all firms.

The industry equilibrium condition given by 3.12. is, of course, different from that in a purely monopolistic, or perfectly competitive industry. Moreover, in a competitive industry we get $\theta = 0$ and in a monopolistic industry we get $\theta = 1$. Thus, by estimating the different models and testing which one is better supported by the data, it is possible to identify the underlying market structure. Furthermore, we can use the estimated models to measure the degree of non-competitiveness of the industry defined by 3.7. Given that $MC^j = MC$ all j we get that $\theta^j = \theta$ all j and therefore, $L = \theta\epsilon$.

Again it can be easily verified that the degree of non-competitiveness satisfies[15]

3.13. $0 \leq L \leq 1$

Furthermore, if we have a perfectly competitive industry L reaches its lower bound and if the industry is purely monopolistic L becomes equal to $-\delta/p_0 = \epsilon$ (the inverse demand elasticity). Therefore, both θ and L provide information on the deviation from perfectly competitive and monopolistic behavioral modes.

For empirical implementation, we only need aggregate industry data, which of course are much easier to obtain than disaggregated firm data. Given the industry data we have to choose specific functional forms for the underlying functions. These functional forms are then used to obtain the complete system of optimality conditions for both sides of the market given by equations 2.2., 2.3., 3.11. and 3.12.

In general θ will not be a constant but a function of various relevant variables. Its equilibrium level, as can be seen from 3.12., will depend on the exogenous variables. Thus we could, for example, approximate θ at the equilibrium points by a linear function of the exogenous variables and estimate it within our model.

When choosing a functional form for the profit function of the other industry, we have to consider two objectives. On the one hand, we want this functional form to be flexible and provide a second order approximation to an arbitrary profit function. On the other hand, we would like it to yield a simple expression for δ. Unfortunately simple δ terms can only be obtained from very restrictive forms. The functional form we choose is the Generalized Leontief, first introduced by Diewert [1971].

4. Empirical Application

Having outlined the theoretical framework, we now apply it to a study of the U.S. crude petroleum and natural gas industry. The data are given in Hudson and Jorgenson [1974] and Jorgenson et al. [1973], where input output series are provided for different sectors of the U.S. economy for the years 1947-1971. The crude petroleum industry's output is, with negligible exceptions (see Minerals Yearbook), used by the petroleum refining industry as an input in the production process. The natural gas industry is, in our model, the natural gas producing industry and does not include gas distribution. In other words, we distinguish between the gas production industry, which is an unregulated extractive industry whose product is often jointly produced with oil and the gas distributing industry which is usually a regulated industry. In our model, therefore, the products and services of the natural gas industry terminate at the point of delivery to the pipeline. The natural gas industry's output is then purchased by the gas utilities industry, which uses it as an input in its production (distribution) process.

In our data sources, the crude petroleum and natural gas industries are aggregated into one industry. Since we were not able to disaggregate and look at the two industries separately, we follow Hudson and Jorgenson [1974] and Jorgenson et al. [1973] in maintaining this aggregation.

We assume that the crude petroleum and natural gas industry uses three competitively priced, aggregate inputs; capital y_K, labour y_L and energy y_E[16] (whose prices are p_K, p_L, p_E) to produce a non-competitively priced output y_0 (crude petroleum and natural gas) whose price is p_0. The crude petroleum and natural gas is an intermediate good used by "another" industry (petroleum refining and gas utility) in conjunction with capital x_K, labour x_L and energy x_E (other than y_0),[17] whose prices are w_K, w_L and w_E, to produce an aggregate output x_0 (refined petroleum and gas for distribution) whose price is w_0. Note that the crude petroleum and natural gas industry generally uses different types of labour, capital and energy inputs, which is why input prices are not the same in the two industries. The price and quantity series for the non-competitive industry are from Hudson and Jorgenson [1974], Jorgenson *et al*. [1973].[18] The price and quantity series for the "other" industry are constructed by Divisia indices of the data for the demanders of x_0.[19]

We carry out the empirical application using the "other" industry's cost function rather than its profit function. In other words, we assume cost minimization only rather than competitive profit maximization. Within this framework we do not have to consider the "other" industry's output-price determination explicitly, which in view of the nature of the "other" industry (petroleum refining and gas utilities) is quite appealing. Furthermore, it reduces the number of parameters by 5.

Since the cost function can be considered as a special case of the profit function (output being fixed), we can derive similar conditions to 2.2., 2.3. above using the cost function.

We write the "other" industry's unit cost function (assuming constant returns to scale) as

$$4.1. \quad H \equiv \sum_i \sum_j a_{ij}(w_i w_j)^{1/2} + 2 \sum_i a_i (w_i p_0)^{1/2} + a p_0 \qquad i,j = K,L,E$$

where $a_{ij} = a_{ji}$ and the crude petroleum and natural gas industry's cost function as

$$4.2. \quad C = \sum_i \sum_j b_{ij}(p_i p_j)^{1/2} y_0 + \sum_i b_i \, p_i \qquad i,j=K,L,E$$

where $b_{ij} = b_{ji}$. (and $\sum_i b_i \, p_i = \sum_j G^j(p)$) .

From 3.1. we get the markup term as

4.3. $\delta = -2p_0[(ap_0^{1/2}/\Sigma\ a_i\ w_i^{1/2}) + 1] = -\ 2p_0y_0/(y_o-a)$

The equilibrium conjectural elasticity is taken to be a function of all exogenous variables, i.e., $\theta = \theta(w,p,x_o)$. This allows for θ to vary over time, reflecting changes in the economic environment. Thus, as the set of exogenous variables changes over time so will θ. Instead of using all the 7 exogenous variables to explain variations in θ, we could look at some of the principal components of the vectors of exogenous variables. We choose the first three principal components, which together explain 94% of the variation of the exogenous variables.[20,21] As a first approximation we take θ as a linear function of these three principal components.

The full model is therefore given by

4.4.
$$x_L/x_0 = a_{LL} + a_{KL}(w_K/w_L)^{1/2} + a_{LE}(w_E/w_L)^{1/2} + a_L(p_0/w_L)^{1/2}$$
$$x_K/x_0 = a_{KK} + a_{KL}(w_L/w_K)^{1/2} + a_{KE}(w_E/w_K)^{1/2} + a_K(p_0/w_K)^{1/2}$$
$$x_E/x_0 = a_{EE} + a_{KE}(w_K/w_E)^{1/2} + a_{LE}(w_L/w_E)^{1/2} + a_E(p_0/w_E)^{1/2}$$
$$y_0/x_0 = a + a_K(w_K/p_0)^{1/2} + a_L(w_L/p_0)^{1/2} + a_E(w_E/p_0)^{1/2}$$

$$y_K/y_0 = b_{KK} + b_{KL}(p_L/p_K)^{1/2} + b_{KE}(p_E/p_K)^{1/2} + b_K/y_0$$
$$y_L/y_0 = b_{LL} + b_{KL}(p_K/p_L)^{1/2} + b_{LE}(p_E/p_L)^{1/2} + b_L/y_0$$
$$y_E/y_0 = b_{EE} + b_{KE}(p_K/p_E)^{1/2} + b_{LE}(p_L/p_E)^{1/2} + b_E/y_0$$
$$p_0 = b_{KK}p_K + b_{LL}p_L + b_{EE}p_E + 2b_{KL}(p_Kp_L)^{1/2} + 2b_{KE}(p_Kp_E)^{1/2} + 2b_{LE}(p_Ep_L)^{1/2}$$
$$+ 2\theta p_0y_0/(y_0-a).$$

where $\theta = T_0 + T_1V_1 + T_2V_2 + T_3V_3$ and V_1, V_2, V_3 are the first three principal components of the vectors of exogenous variables.

For empirical implementation the two models have to be imbedded within a stochastic framework. To do this, we assume that equations 4.3. and 4.4. are stochastic due to errors in optimization. We define the additive disturbance term in the i^{th} equation at time t as $e_i(t)$, $t=1...T$. We also define the column vector of disturbances at time t as e_t. We assume that the vector of disturbances is joint normally distributed with mean vector zero and non-singular covariance matrix Ω

4.5. $$E[e^j(s)\, e'^j(t)] = \begin{cases} \Omega & t=s \\ 0 & t\neq s \end{cases} .$$

Since we have a simultaneous system in which both the supply and demand equations appear, it is necessary to use a simultaneous estimation technique that will take account of this simultaneity. To do this we use the full information maximum likelihood method, treating y_o, p_o, x_K, x_L, x_E, y_K, y_E, and y_L as endogenous variables and all the others as exogenous. It can be easily verified that the order conditions for identification are satisfied. The rank conditions are, however, difficult to check since we cannot get an explicit solution for the system.

There are 23 free parameters to be estimated.[22] The maximum likelihood estimates and standard errors are given in Table 1. Given the parameter estimates we calculate the conjectural elasticity and the degree of oligopoly index and report the figures in Table 2.

To identify the underlying market structure we first test the null hypothesis that θ is globally zero, i.e., that $T_o = T_1 = T_2 = T_3 = 0$, against the alternative that not all are equal to zero. The x^2 statistic is 29.408 so that the null hypothesis is rejected ($x^2_{(4).01} = 13.3$), implying that θ is not globally zero, i.e., the market is not globally perfectly competitive. Since θ is not a constant but a function of the exogenous variables and given the signs of the estimated parameters (T_o, T_1, T_2, T_3) it is clear that the rejection of the above null hypothesis does not necessarily imply the rejection of $\theta = 0$. The restrictions $T_o = T_1 = T_2 = T_3 = 0$ are sufficient but not necessary for θ to be zero. Therefore, to test whether θ itself is equal to zero we calculate the estimated θ and its standard error both evaluated at the sample mean and test for its significance locally. We find that $\hat{\bar{\theta}} = .070538$ with a standard deviation of .0107. The conjectural elasticity is therefore significantly positive, implying that the market structure is significantly different than a perfectly competitive one.

We next test the null hypothesis that θ is globally equal to one. This involves the test for the null hypothesis that $T_o = 1$, $T_1 = T_2 = T_3 = 0$, against the alternative that the parameters are unrestricted. The x^2 static is 140.758, so that the null hypothesis is badly rejected, implying that θ is not globally equal to one, i.e., the industry is not globally purely monopolistic. Again, these restrictions are sufficient but not necessary for θ to equal one, so that we carry out a local test at the sample mean. Given that at the sample mean $\hat{\bar{\theta}} = .070538$ with standard deviation of .0107, it is clear that the conjectural elasticity is significantly different than one. We conclude therefore that the market structure is significantly different than a pure monopolistic one. Furthermore, given the estimated conjectural elasticities (shown in Table 2) it is clear that the actual market structure is closer to a perfectly competitive than to a pure monopolistic one. This is also reflected in the x^2 statistics of the global tests (which reflect the maximum of the likelihood functions) and in the fact that the local rejection of $\theta = 1$ is much more decisive than the local rejection of $\theta = 0$.

Table 1

Parameter Estimates
(Standard Errors in Parentheses)

a_{KK}	-.04896 (.0173)	T_3		.00951 (.0019)
a_{KL}	.33607 (.0151)	a	.943 (.017)	-.00923 (.0019)
a_{KE}	.01150 (.0032)	b_{KK}	.650 (.296)	.19277 (.0213)
a_K	.01224 (.0017)	b_{KL}	.001 (.109)	.06657 (.0144)
a_{LL}	.17760 (.0194)	b_{KE}	1.695 (.282)	.0844 (.0163)
a_{LE}	.06271 (.0015)	b_{LL}	-.275 (.075)	-.03072 (.0235)
a_L	.01811 (.0016)	b_{LE}	1.156 (.131)	.08773 (.0233)
a_{EE}	-.03054 (.0031)	b_{EE}	-2.00 (.336)	.10705 (.0330)
a_E	-.00501 (.0016)			
T_0	.07053 (.0107)	b_K	.84147 (.1078)	
T_1	.01607 (.0024)	b_L	.79068 (.1627)	
T_2	-.01477 (.0017)	b_E	-1.07229 (.1027)	

Table 2

Degree of Non-Competitiveness Measures (L) and Conjectural Elasticities 1947 - 1971.

θ	L
.155995	.0781083
.0701915	.0351408
.127994	.0640837
.0968773	.0484990
.0830557	.0415738
.116904	.0585148
.103094	.0516151
.103080	.0515935
.0727307	.0364005
.0657321	.0328969
.127912	.0640141
.161235	.0806927
.156572	.0783567
.145098	.0726131
.142639	.0713821
.133492	.0668024
.142369	.0712428
.152714	.0764186
.137312	.0687099
.159786	.0799524
.179596	.0898620
.207803	.103973
.218506	.109326
.239778	.119967
.223324	.111734

Thus we conclude that the crude petroleum and natural gas industry is neither perfectly competitive nor purely monopolistic; it is, however, much closer to a competitive than to a monopolistic industry. The degree to which the industry is non-competitive is given by the degree of oligopoly power measures $\hat{L}$ in Table 2. These measures are fairly low but significantly different than zero. At the sample mean $\bar{\hat{L}} = .1402$ with a standard deviation of .0201, i.e., it is significantly positive.

Finally, the estimates of both θ and L indicate that the market structure has become somewhat more non-competitive over the sample years. This is particularly true since the mid 60's.

5. Conclusion

We have provided a framework within which a non-competitive firm or industry can be empirically studied and different hypotheses on pricing behavior can be tested. We also provide a measure of oligopolistic power of an industry that can be used to identify the underlying market structure of an industry.

An application to the U.S. crude petroleum and natural gas industry 1947-1971, shows that the industry is characterized by significant oligopolistic behavior.

Footnotes

[1]See for example Bain [1965], Scherer [1970], Shepherd [1970], Cowling and Waterson [1976], Hause [1977].

[2]See for example Berndt and Wood [1974], Fuss [1977], Griffin [1977].

[3]Alternatively we could assume that y_0 is a consumer good and the demand function can be derived by Roy's identity from the indirect utility function.

[4]The prices in p may or may not be the same as in w.

[5]For a discussion of profit functions see Diewert [1973], [1974] and Lau [1974], [1975].

[6]See Hotelling [1932], Diewert [1974], Lau [1974], [1975].

[7]See Diewert [1971] for its regularity properties.

[8]See Shephard [1953] [1970], Diewert [1971].

[9](1) The linear homogeneity follows from the linear homogeneity of C in p and the zero homogeneity of J in (w_0,w,p_0) (which in turn follows from the linear homogeneity of H).

(2) since C is non-decreasing in p.

(3) follows from (5).

(4) follows from (5).

(5) These results follow directly from the envelop theorem or Hotelling's Lemma.

(6) follows from the concavity of C in p.

[10]A similar measure is suggested in Cowling and Waterson [1976] where the conjectural variations are assumed to be constant.

[11]This is the usual condition necessary for the aggregation over firms (or consumers). See Gorman [1953], Blackorby, Primont and Russel [1978].

[12]See references in 11.

[13]This also is implicitly the maintained hypothesis in the studies by Berndt and Wood [1975], Hudson and Jorgenson [1974] and Jorgenson et al. [1973].

[14]As is well known an equilibrium may not exist or may be unstable. In such cases, there is not much scope for empirical investigations.

[15]This corresponds to the usual result in the case of a pure monopolist that in his relevant range of operation the (negative) inverse demand elasticity is between zero and one.

[16]The energy input is an aggregate of inputs like electricity, coal, gasoline etc., but not crude petroleum or natural gas.

[17]See footnote 16.

[18]For details of the data construction see Faucett [1973].

[19]See Jorgenson et al. [1973].

[20]For a discussion of the use of principal component techniques see Malinvaud [1970], pp. 717-18.

[21]The inclusion of the fourth principal component (explaining 97%) was insignificant in its effect on the parameter estimates and the maximum of the likelihood function.

[22]We, therefore, have 177 degrees of freedom.

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