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THE ESTIMATION OF THE DEGREE OF OLIGOPOLY POWER

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This paper extends the use of econometric production theory techniques to a general class of oligopolistic markets. We provide a framework which enables us to 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 and a degree of oligopoly index for the whole industry that can be used to test for the underlying structure of the industry.

As an example we provide an application to the U.S. rubber, textile, electrical machinery and tobacco industries and find the first two to be characterized by competitive behavior and the last two by oligopolistic behavior.

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

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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 (1978, 1979) and Appelbaum and Kohli (1979) 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. Other empirical studies 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 oligopolistic behavior.

In this paper we extend the use of econometric production theory techniques to a general class of oligopolistic markets. We consider a fairly general oligopolistic market and provide a framework which enables us to analyze this market empirically 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.

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 provide an example of the application of our framework. We use our approach to estimate the degree of competitiveness in four U.S. (1947–1971) manufacturing industries. The industries chosen are: textile, rubber, electrical machinery and tobacco. On the basis of previous studies,[2] our prior notion is that the first two are competitive whereas the last two are non-competitive. Our empirical application does in fact confirm these prior notions. We find that the rubber and textile industries are insignificantly non-competitive, whereas the electrical machinery and tobacco industries are significantly oligopolistic.

2. Theoretical framework

Consider a non-competitive industry in which s firms produce a

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

[2]See references in footnote 1 and Palmer (1973).

homogeneous output y using n inputs, $x=(x_1,\ldots,x_n)$. Let the cost function of the jth firm be given by $C^j=C^j(y^j,w)$ where y^j is the output of the jth firm and w is the price vector of the inputs.

Let the market demand curve facing the industry be given by

$$y=J(p,z), \tag{1}$$

where p is the price of y, z is a vector of exogenous variables, e.g., prices or quantities of other inputs and outputs used by the demanders of y and $\partial J/\partial p<0$.

Assuming all firms in the non-competitive industry face the same input prices, their input demand functions can be derived from their cost functions by applying Shephard's Lemma,[3]

$$x^j=\partial C^j(y^j,w)/\partial w, \qquad j=1,\ldots,s, \tag{2}$$

where x^j is the jth firm's input demand vector and $\partial C^j/\partial w$ is the column vector of partial derivatives of C^j with respect to w.

Furthermore, the jth firm's profit maximization problem is given by

$$\max[py^i-C^j(y^j,w): y=J(p,z)], \tag{3}$$

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

$$p(1-\theta^j\varepsilon)=\partial C^j(y^j,w)/\partial y_j, \tag{4}$$

where θ^j, defined by

$$\theta^j=(\partial y/\partial y^j)(y^j/y), \tag{5}$$

is the conjectural elasticity of total industry output with respect to the output of the jth firm, and ε is the inverse market demand elasticity, defined by

$$\varepsilon=-(\partial p/\partial y)(p/y). \tag{6}$$

The optimality condition in (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

[3]See Shephard (1970), Diewert (1971).

Cournot behavior, $\partial y/\partial y^j=1$ and θ^j is simply the output share of the jth firm. Furthermore, under perfect competition $\theta^j=0$ and under pure monopoly $\theta^j=1$ $(y=y^j)$, thus providing us with a basis for testing these hypotheses and more important, providing us with two benchmarks which can be used to identify the actual underlying market structure.

Given (4) we define the degree of oligopoly power of the jth firm as[4]

$$\alpha_j=[p-\partial C^j(y^j,w)/\partial y^j]/p=\theta^j\varepsilon. \tag{7}$$

Thus, the measure of oligopoly power is composed of two parts: the inverse demand elasticity and the conjectural elasticity. It is clear, therefore, that unless $\theta^j=1$, i.e., we have a pure monopolist, the inverse demand elasticity above is not appropriate. Note also that the non-negativity of marginal costs implies that $\alpha^j\leqq 1$ and the fact that $\varepsilon>0$ and $p-\partial C^j/\partial y\geqq 0$ implies that $0\leqq\alpha^j$. In other words, the degree of oligopoly power is between zero and one.

Given (7) we define the degree of oligopoly power of the industry as

$$L=\sum[(p-MC^j)/p]S_j=\sum_j\alpha_j S_j=\sum_j\theta^j S_j\varepsilon, \tag{8}$$

where $S_j=y^j/y$ and MC^j is the marginal cost of the jth firm.[5] 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 (5), we can rewrite (8) as

$$L=\sum_j\frac{\partial y}{\partial y^j}S_j^2\,\varepsilon. \tag{9}$$

The measure of oligopoly power is therefore a weighted sum of the squared shares of the firms in the industry multiplied by the inverse demand elasticity. The weights are given by the conjectural variations, $\partial y/\partial y^j$. The Herfindahl index which takes the sum of the squared shares, is therefore a special case of (9). If all conjectural variations are the same, say $\partial y/\partial y^j=\gamma$ for all j, then $L=\gamma\varepsilon\sum_j S_j^2$, i.e., it is proportional to the Herfindahl index and in the special case where $\varepsilon(\partial y/\partial y^j)=1$, it is equal to it.

The measure given by $\sum\theta^j S^j\varepsilon$ is, therefore, a generalization of the *composition* of the Lerner index.

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 (1), (2), (4).

[4] α_i is, of course, the classical Lerner (1934) measure of monopoly power.

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

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 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 (2) and (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 (2) and (4) on an aggregate industry level.

Consider (2) first. The aggregate demand function for the ith input can be obtained as

$$x_i = \sum_j x_i^j = \sum_j \partial C^j(y^j, w)/\partial w_i, \qquad i = 1, \ldots, n. \tag{10}$$

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

$$C^j(y^j, w) = y^j\, C(w) + G^j(w), \qquad j = 1, \ldots, s. \tag{11}$$

In other words, the firms have linear and parallel expansion paths, so that marginal costs are constant and equal across firms.[6] Given this assumption the aggregate input demand functions are given by

$$x = y\,[\partial C(w)/\partial w] + \sum_j \partial G^j(w)/\partial w, \tag{12}$$

and are expressed in terms of aggregate industry variables only.

It should be noted that the assumption given by (11), is a very common one and is usually implicit in aggregate production or consumption studies. The cost functions defined by (11) are of the so-called Gorman polar form type,[7] allowing the different firms to have different cost curves but the curves are all linear and parallel.[8]

Given assumption (11) it is clear that if we assume $\theta^j = \theta$ for all j, then (4)

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

[7]See references in footnote 6.

[8]This also is implicitly the maintained hypothesis in most empirical studies in production theory. See Berndt and Wood (1975), Hudson and Jorgenson (1974) and Jorgenson et al. (1973).

becomes $p(1-\theta\,\varepsilon)=C(w)$ 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 (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,[9] it must be the case that in equilibrium $\theta^j=\theta$ for all $j=1,\dots,s$. θ is therefore the *equilibrium value* of the conjectural elasticities and it will, in general, be a functions of all the exogenous variables. This then enables us to write the aggregate optimality condition as

$$p(1-\theta\,\varepsilon)=C(w). \tag{13}$$

It should be clear that all that (13) says is that *in equilibrium*, 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 *curves* 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 (13) 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 the estimation of the model which will yield an estimated value for θ, will indicate the deviation of the underlying market structure from the two benchmarks of perfect competition and pure monopoly ($\theta=0$ and $\theta=1$ respectively), identifying the market structure. The measure of oligopoly power defined by (8) can then be obtained as $L=\theta\,\varepsilon$.

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

It can be easily verified that this measure should satisfy $0 \leqq L \leqq 1$.[10] Furthermore, it is important to notice that if the industry is perfectly competitive L reaches its lower bound, $L=0$. However, if the industry is purely monopolistic L will be equal to the inverse demand elasticity, $L=\varepsilon$. Thus, both θ and L provide information, on the degree of competitiveness in the industry. In other words, they both provide information on the deviation from the perfectly competitive and purely monopolistic cases.

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 used to obtain the complete system of optimality conditions, given by eqs. (1), (12) and (13) which can then be estimated.

In general θ will not be a constant but a function of various relevant variables. Its equilibrium level, as can be seen from (13), 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.

3. Econometric application

Having outlined the theoretical framework we now provide an example of its use and apply it to four U.S. manufacturing industries. The industries chosen are (1) rubber, (2) textile, (3) electrical machinery and (4) tobacco which correspond to the manufacturing industry classification of the *Survey of Current Business*. According to previous studies[11] and prior notions, the textile and rubber industries are believed to be competitive. The other two are believed to be non-competitive.

We assume that there are three competitively priced inputs in each of the industries considered, labour x_L, capital x_K, and intermediate inputs x_M, whose prices are w_L, w_K and w_M respectively. The price and quantity series are obtained from various issues of the *Survey of Current Business*.

We specify the demand function facing the industries as a Cobb–Douglas function

$$\ln y = a - \eta \ln (p/S) + \rho \ln (q/S), \tag{14}$$

where S is the implicit GNP price deflator and q is GNP in current dollars. The demand elasticity is therefore constant and given by $\eta = 1/\varepsilon$.

[10] 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.

[11] See footnote 2.

We also assume that the industry cost function is given by a generalized Leontief cost function (of the Gorman polar form)

$$c=\sum_i\sum_j b_{ij}(w_i w_j)^{\frac{1}{2}}\, y+\sum_i b_i w_i, \qquad i,j=K,L,M, \tag{15}$$

where

$$b_{ij}=b_{ji} \quad \text{and} \quad \sum b_i w_i=\sum_j G^j(w).$$

The equilibrium conjectural elasticity is taken to be a function of the exogenous variables: $\theta=\theta(w)$. This allows for θ to vary over time, reflecting changes in the economic environment.

The full model for each of the industries considered is, therefore, given by

$$\begin{aligned}
x_K/y&=b_{KK}+b_{KL}(w_L/w_K)^{\frac{1}{2}}+b_{KM}(w_M/w_K)^{\frac{1}{2}}+b_K/y,\\
x_L/y&=b_{LL}+b_{KL}(w_K/w_L)^{\frac{1}{2}}+b_{LM}(w_M/w_L)^{\frac{1}{2}}+b_L/y,\\
x_M/y&=b_{MM}+b_{KM}(w_K/w_M)^{\frac{1}{2}}+b_{LM}(w_L/w_M)^{\frac{1}{2}}+b_M/y,\\
\ln y&=a+\eta\ln(p/S)+\rho\ln(q/S),\\
p&=[b_{KK}w_K+b_{LL}w_L+b_{MM}w_M+2b_{KL}(w_K w_L)^{\frac{1}{2}}\\
&\quad+2b_{KM}(w_K w_M)^{\frac{1}{2}}+2b_{LM}(w_L w_M)^{\frac{1}{2}}]/[1-\theta/\eta],
\end{aligned} \tag{16}$$

where θ is approximated linearly as

$$\theta=A_0+A_K w_K+A_L w_L+A_M w_M.$$

For empirical implementation the model has to be imbedded within a stochastic framework. To do this, we assume that eq. (16) are stochastic due to errors in optimization. We define the additive disturbance term in the ith equation at time t as $e_i(t)$, $t=1,\dots,T$. 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,

$$\begin{aligned}
E[e^j(s)\,e'^j(t)]&=\Omega \quad \text{if} \quad t=s,\\
&=0 \quad \text{if} \quad t\neq s.
\end{aligned} \tag{17}$$

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, p, x_K, x_L, and x_M as endogenous variables and all the others as exogenous.

In all four cases (industries) there are 16 free parameters to be estimated.[12] Given the maximum likelihood estimates we calculate the conjectural elasticities and degree of oligopoly power measures for the four industries and report the figures in tables 1 and 2.

Table 1

Estimated conjectural elasticities (θ), 1947–71.

Year	Rubber	Textile	Electrical machinery	Tobacco
1947	0.00946520	0.0433975	0.316363	0.410502
1948	0.00951863	0.0423163	0.304498	0.410101
1949	0.00943526	0.0440973	0.292672	0.408816
1950	0.00965933	0.0410223	0.272180	0.408331
1951	0.0100278	0.0380707	0.267334	0.407141
1952	0.0100346	0.402576	0.261697	0.406483
1953	0.0100906	0.0404246	0.265230	0.403365
1954	0.0995763	0.0428213	0.251667	0.405771
1955	0.0102751	0.0405951	0.250314	0.405682
1956	0.0103537	0.0404579	0.241951	0.405218
1957	0.0104045	0.0410680	0.230562	0.404342
1958	0.0103723	0.0420758	0.217210	0.403430
1959	0.0106750	0.0394806	0.198954	0.402222
1960	0.0107127	0.0397067	0.201956	0.400641
1961	0.0106811	0.0399262	0.195739	0.400186
1962	0.0109451	0.0379540	0.188658	0.399388
1963	0.0110375	0.0372998	0.184968	0.399040
1964	0.0112339	0.0352629	0.166044	0.398352
1965	0.0115014	0.0331210	0.151500	0.398494
1966	0.0118677	0.0306277	0.131497	0.398008
1967	0.0119973	0.0306791	0.124162	0.397184
1968	0.0124960	0.0269013	0.110225	0.396257
1969	0.0128993	0.0249370	0.11001	0.394963
1970	0.0128640	0.0250812	0.10772	0.391243
1971	0.0132242	0.0236459	0.09441	0.390263

To identify the underlying market structure we should test whether $\bar{\theta}$ is zero or not. A sufficient condition for θ to be zero is $A_0 = A_L = A_M = A_K = 0$. Therefore, we first test for this condition against the alternative that not all the A's are zero. The χ^2 statistics which are given in table 3 indicate that the null hypothesis is rejected for all four industries. Since θ is not a constant[13]

[12]There are therefore 109 degrees of freedom.

[13]We tested for the hypothesis that θ is globally constant and rejected the hypothesis (at 0.01 significance level) in all but the tobacco industry. These conclusions are also, casually confirmed, in table 1.

Table 2

Estimated degrees of oligopoly power and demand elasticities, 1947–71.

Year	Rubber	Textile	Electrical machinery	Tobacco
1947	0.0440287	0.0790901	0.311207	0.664777
1948	0.0442773	0.0771196	0.299534	0.664128
1949	0.0438895	0.0803656	0.287901	0.662046
1950	0.0449317	0.0747614	0.267743	0.661261
1951	0.0466456	0.0693822	0.262977	0.659335
1952	0.0466775	0.0733677	0.257431	0.658268
1953	0.0469380	0.0736722	0.260907	0.656782
1954	0.0463193	0.0780400	0.247564	0.657116
1955	0.0477960	0.0739828	0.246260	0.656972
1956	0.0481615	0.0737327	0.238007	0.656220
1957	0.0483978	0.0748446	0.226804	0.654801
1958	0.0482484	0.0766813	0.213669	0.653324
1959	0.0496561	0.0719518	0.195711	0.651368
1960	0.0498314	0.0723637	0.198664	0.648808
1961	0.0496847	0.0727638	0.192549	0.648072
1962	0.0509128	0.0691695	0.185582	0.646779
1963	0.0513424	0.0679773	0.181953	0.646215
1964	0.0522562	0.0642651	0.163337	0.645101
1965	0.0535004	0.0603617	0.149030	0.645331
1966	0.0552045	0.0558177	0.129353	0.644545
1967	0.0558070	0.0559113	0.122138	0.643209
1968	0.0581268	0.0490265	0.108428	0.641709
1969	0.0600027	0.0454466	0.108224	0.639613
1970	0.0598389	0.0457094	0.105971	0.633589
1971	0.0615143	0.0430936	0.009287	0.632002
Demand elasticity[a]	0.2159	0.5487	1.0165	0.6175
	(2.195)	(3.005)	(2.647)	(3.053)

[a]Standard errors in parentheses.

but a function of the exogenous variables the rejection of the above null hypothesis does not necessarily imply the rejection of $\theta=0$. The restrictions $A_0=A_L=A_M=A_K=0$ 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 values and their standard errors all evaluated at the sample means and test for their significance locally. The t values which are given in table 3 indicate that the conjectural elasticity is insignificant in the rubber and textile industries, but significant in the other two industries. Thus, we conclude that the degree of non-competitiveness is insignificant in the rubber and textile industries, but significant in the electrical machinery and tobacco industries.

Although it is clear that the industries are not purely monopolistic (they have more than one firm), we calculate one-sided confidence intervals in table

Table 3

Restrictions	χ^2 statistics ($\chi^2_{(4)0.01} = 13.3$) Rubber	Textile	Electrical machinery	Tobacco
$A_0 = A_L = A_M = A_K$	16.455	29.001	49.773	98.074
Estimates at sample mean[a]				
$\hat{\theta}$	0.0186	0.03684	0.2001	0.4019
	(1.065)	(0.739)	(3.678)	(3.052)
$\hat{L}$	0.0559	0.0671	0.1960	0.6508
	(1.417)	(2.457)	(6.998)	(10.949)
99% (one-sided) confidence interval for $\hat{\theta}$	$\hat{\theta} < 0.0590$	$\hat{\theta} < 0.1527$	$\hat{\theta} < 0.3266$	$\hat{\theta} < 0.7080$

[a] t values in parentheses.

3, which indicate that in fact in all cases the industries are significantly different from purely monopolistic industries.

Finally, let us examine the estimated measures of the degree of oligoploy power, given in table 2. Table 2 also gives the demand elasticities and their standard errors. As we have shown above these measures are given by $L = \theta/\eta$, thus they are directly related to θ and inversely related to the elasticity of the market demand curve. In view of this, it is clear that different demand conditions will lead to different oligopoly power measures, even if the degree of competition remains unchanged. For example, a low demand elasticity will tend to yield a high L and vice versa. Information on L is, therefore, not sufficient in order to determine the degree of competition, unless we also know the demand elasticity (which enables us then to calculate θ). Thus if we want to use L to measure the degree of competition we have to know η and to remember that with pure monopoly $L = 1/\eta$, i.e., it is the deviation from $1/\eta$ that is important. On the other hand, if we are interested in the degree of oligopoly power itself, which combines the degree of competition and demand conditions and provides an index of total non-competitive rents, L itself provides the necessary information.

An examination of table 2 shoes that the rubber and textile industries have the lowest oligopoly power measures. Note, however, that while these estimates are fairly low, they are much higher than the estimates of θ, which is due to the low demand elasticities.

The oligopoly power measures for the electrical machinery industry are higher than in the first two, but due to the fact that the demand elasticity is near unity, these estimates are close to the estimates of θ in this industry.

Finally, the oligopoly power measures in the tobacco industry are the highest reflecting a high degree of non-competitiveness (high θ) and a low demand elasticity.

4. 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.

As an example, we provide an application to the U.S. rubber, textile, electrical machinery and tobacco industries and find the first two to be characterized by competitive behavior, where the last two characterized by significant oligopolistic behavior.

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