Investment and Coordination in Oligopolistic Industries

Richard J. Gilbert, Marvin Lieberman

The RAND Journal of Economics, Volume 18, Issue 1 (Spring, 1987), 17-33.

Stable URL:
http://links.jstor.org/sici?sici=0741-6261%28198721%2918%3A1%3C17%3AIACIOI%3E2.0.CO%3B2-2

Rand Journal of Economics
Vol. 18, No. 1, Spring 1987

Investment and coordination in oligopolistic industries

Richard J. Gilbert*

and

Marvin Lieberman**

We examine investment by firms in 24 chemical product industries to determine whether firms invest preemptively to achieve persistent increases in market share or whether there is evidence of behavior to maintain market share. The data indicate that investment reduces the probability that rival firms will expand capacity, but the effect is temporary. Large firms tend to maintain market share, while smaller firms tend to invest simultaneously with rivals. The role of preemptive investment is limited to that of permitting a firm to invest with a lower probability of redundant investment by rivals. Preemption does not allow a persistent increase in market share, but instead acts as a means by which firms may coordinate capacity investment to help avoid episodes of industry overcapacity.

1. Introduction

■ Competition with irreversible investment poses a problem of coordination, as errors in expectations about rivals' actions can lead to redundant capacity.[1] Dynamic models of oligopoly identify strategies by which firms that recognize their interdependence can coordinate their actions. This article examines investment behavior in 24 chemical product industries and compares the behavior with the predictions of some common models of oligopoly.

The first model is Cournot-Nash in capital investment. This model, described in Gilbert and Harris (1984), determines equilibria in investment plans when firms can commit to a time path of new investment. The equilibria have the property that firms take turns making new investments, and redundant investment is avoided. With identical firms there is an investment round-robin: no firm builds plant $(K + 1)$ until all other firms have built plant K.

The Cournot-Nash model has the characteristic that, in equilibrium, firms maintain approximately constant market shares. But the model is restrictive in its assumptions about

* University of California, Berkeley.

** Stanford University.

The authors are grateful to Drew Fudenberg, Al Klevorick, Paul Ruud, and Robert Wilson for helpful discussions. Choon-Geol Moon provided excellent research assistance.

[1] Richardson (1960) articulates the problems that investment coordination with sunk costs poses for efficient production in competitive as well as oligopolistic industries.

investment behavior. A weaker hypothesis is that firms succeed in coordinating their investment behavior by relying on some mechanism that provides for approximately stationary market shares. Examples of models in which firms maintain market shares include Osborne (1976) and Spence (1978a, 1978b). Dynamic models in which constant market shares are sustained as an equilibrium consequence of threat strategies are described by Friedman (1978) and in a stochastic context by Brock and Scheinkman (1985) and Green and Porter (1984), who build on work by Stigler (1964). Stationary market shares also emerge from the "kinked-demand" model (proposed by Sweezy (1939) and recast in game-theoretic form by Anderson (1984)), when firms have approximately similar technologies and demand.[2]

Another means by which firms may regulate investment is preemption. Preemption can be identified with strategic investment to exploit a first-mover advantage or with a race to appropriate a profitable investment opportunity. Examples of the former include the entry-deterring investment in Dixit (1980) and the growth-deterring investment in Spence (1979) and Fudenberg and Tirole (1983). In either case successful preemption acts to deter or to delay investment by rival firms, and in so doing successful preemption mitigates redundant (although not necessarily excess) capacity.

This article develops a logit model of industry capacity investment to test these various hypotheses of firm investment activity. The probability that a firm expands capacity at each moment of time is taken to be a linear function of observable characteristics of the firm and the industry in which it operates. The hypotheses of maintaining market share and of preemption are formulated as restrictions of the general model to those explanatory variables that are expected to influence investment under the maintained hypothesis.

The results show that firm investment behavior is sensitive to industry capacity utilization and that new plant investment can be successful in deterring expansions by rival firms. The data also show a tendency for firms with large market shares to invest in a way that tends to maintain their market shares. But the hypothesis that firms follow a strict rule of maintaining market share is rejected in favor of a more general model that allows for preemptive investment. Not surprisingly, the Cournot-Nash model of industry investment, which is a restricted version of the model of maintaining market share, is also rejected.

The hypothesis that firms can preempt rival investment independently of the history of market shares also can be rejected in favor of the more general model in which firms adjust to counteract changes in their market shares. The empirical results support the conclusion that preemptive investment can be effective; however, its role is limited to influencing the sequencing of investment and does not extend to persistent deterrence of rival investment. This sequencing role of preemptive investment is important in attaining efficiency when new plant investment exhibits economies of scale, because the probability of redundant investment with corresponding excess capacity is reduced.

The data also reveal an asymmetry in the response of firms to rival investment. The larger firms in an industry tend to invest in opposition to their rivals, while smaller firms tend to follow the investment activity of others. This behavior of "jumping on the bandwagon" by smaller firms can be an equilibrium outcome. Investment activity is a signal about rival firms' expectations of market trends. Equilibria exist where smaller firms may be able to profit from the information that is provided by the investment activity of larger firms, and larger firms may not be able profitably to follow the investments of smaller firms.

The next section describes the data sample and the variables used in the model of industry investment. Section 3 describes the anticipated results under the maintained hy-

[2] Constant market shares would not be expected if firms are price-takers because the lumpiness of capacity additions results in different marginal costs among firms with otherwise similar technologies. Lumpiness also may upset a kinked-demand equilibrium.

potheses of Cournot-Nash investment, maintaining market share, and preemption. Section 4 discusses the results of the model estimations, and the last section offers concluding remarks.

2. Data sample and explanatory variables

■ The data sample covers the 24 chemical products listed in Table 1. There are approximately 20 years of coverage for each product. All are homogeneous, undifferentiated chemicals or related products with well-defined production capacities. Output was often consumed captively in firms' downstream operations, but for all products at least 25% of industry output was sold through arms-length channels. All products in the sample demonstrated positive net output growth from the earliest year of coverage through at least 1975. Thus, the sample represents products with growing demand, although in a few cases output declined after 1975.

The products in the sample are also characterized by intermediate levels of seller concentration. The sample, which was selected from a larger data set, includes products for which the number of producers was three or greater, but less than 20. We performed this screening to limit the sample to industries with oligopoly market structures and to reduce the computational burden.[3]

TABLE 1 **Products Included in Data Sample**

Product Name	Coverage Period	Number of Firms: Minimum	Number of Firms: Maximum	Number of Observations	Number of Expansions
Acrylic Fibers	1953–1982	3	6	146	36
Acrylonitrile	1959–1982	4	6	114	32
Aluminum	1956–1982	4	13	159	30
Aniline	1961–1982	4	6	64	10
Bisphenol A	1959–1982	3	5	89	17
Caprolactam	1962–1982	3	4	34	10
Ethylene Glycol	1960–1982	9	14	161	24
Formaldehyde	1962–1982	14	18	278	59
Isopropyl Alcohol	1964–1982	3	4	60	12
Maleic Anhydride	1959–1982	3	8	102	12
Methanol	1957–1982	8	12	234	33
Pentaerythritol	1952–1982	4	7	123	12
Phenol	1959–1982	8	12	221	39
Phthalic Anhydride	1955–1982	8	12	223	43
Polyethylene-LD	1958–1982	8	15	204	56
Polyethylene-HD	1958–1982	6	14	219	76
Sodium Chlorate	1957–1982	3	10	126	19
Sodium Hydrosulfite	1964–1982	3	6	41	10
Sorbitol	1965–1982	3	5	46	7
Styrene	1958–1982	8	13	169	32
Titanium Dioxide	1964–1982	5	6	99	25
1,1,1-Trichloroethane	1966–1982	3	4	40	6
Vinyl Acetate	1960–1982	5	7	116	28
Vinyl Chloride	1962–1982	9	13	170	26
Total				3,238	654

[3] The data sample also excludes chemicals with production processes involving significant joint products and chemicals for which production capacity can be switched easily from one product to another in response to shifts in market demand. A detailed description of the larger data set from which the sample was selected is available from the authors upon request.

□ **Computation of variables.** The basic data consist of production capacities for each product by firm and year and total industry output for each product by year.[4] We denote these data as follows:

$K_{i,j,t}$ = total capacity of firm i to produce product j on January 1 of year t;
$Q_{j,t}$ = total industry output of product j during year t.

The capacity data represent capacity "stocks" observed on January 1 of each year, while the output data represent "flows" over the course of each year. Both capacity and output are measured in physical units (e.g., pounds or gallons). We analyzed the data at the firm level; there is one observation per firm for each product and year in which the firm was a producer. The sample includes a total of 3,238 observations on 75 firms.

□ **Dependent variable.** We estimated investment behavior by using a logit model of the probability that a firm expands capacity. We set the binary dependent variable equal to 1 for all observations where firm i increased its net production capacity for product j by more than 5% during the observation year:[5]

$$y_{i,j,t} = \begin{cases} 1 & \text{if} \quad \dfrac{K_{i,j,t+1} - K_{i,j,t}}{K_{i,j,t}} > .05; \\ 0 & \text{otherwise.} \end{cases} \tag{1}$$

We chose a dichotomous measure for investment because with economies of scale in new capacity, the ratio in (1) takes on extremely large values for small, growing firms. Defining investment as a dichotomous variable avoids this capacity-scaling problem.[6]

In the chemical industry firms can expand capacity in three ways: by constructing a new "greenfield" plant, by adding additional processing units at an existing plant site, or by expanding existing processing units incrementally, for example, by eliminating bottlenecks in the process flow. Incremental expansions often stem from learning-based improvements achieved at negligible investment cost. Our choice of a 5% threshold on expansion size, although arbitrary, is designed to screen out incremental expansions of this sort.[7]

An expansion is identified with the calendar year in which a capacity addition was completed. Typically, installing a new plant may take up to two years, while expanding an existing plant usually can be done more quickly. Completed expansions thus reflect the influence of firm and industry conditions prevailing one to two years before the observed expansion date.

Some of the independent variables used in this study are based on first-differences over the two-year plant gestation period. As a result, for any given firm, observations begin at least two years after the firm entered the industry. This excludes the initial capacity investment by new entrants, and hence the dependent variable registers expansions by incumbent firms only.[8]

---

[4] The capacity data are from annual issues of the *Directory of Chemical Producers,* published by SRI International. The output data are from U.S. International Trade Commission and Census Bureau publications. Additional data on firm size and financial liquidity are from COMPUSTAT.

[5] The 5% threshold is arbitrary, but virtually identical results were obtained with different threshold values.

[6] Experimentation using a Tobit model with the ratio in (1) as the dependent variable produced results qualitatively very similar to those reported in Table 2 in Section 4.

[7] Of the total number of expansions in the sample, 13% fall below the 5% threshold. The logit results are almost identical if the threshold is set at other small values.

[8] The behavior of incumbent firms in response to entry is examined in Lieberman (1986, 1987, forthcoming).

□ **Independent variables.** We next describe the independent variables.

Capacity utilization. $CU_{j,t}$ represents the average rate of capacity utilization over the prior two-year period:

$$CU_{j,t} = \frac{Q_{j,t-1}}{\sum_i (K_{i,j,t} + K_{i,j,t-1})} + \frac{Q_{j,t-2}}{\sum_i (K_{i,j,t-1} + K_{i,j,t-2})}. \qquad (2)$$

Output growth rate. We define the historical growth rate of output for product j over the prior four-year period as

$$GROW_{j,t} = \left(\frac{Q_{j,t}}{Q_{j,t-4}}\right)^{1/4} - 1. \qquad (3)$$

Firm's capacity share. Firm i's share of total industry capacity to produce j at the start of year t is

$$SHARE_{i,j,t} = \frac{K_{i,j,t}}{\sum_i K_{i,j,t}}. \qquad (4)$$

Change in capacity share. The change in capacity share of firm i from the start of year $(t - 2)$ to the start of observation year t is

$$DELSHR_{i,j,t} = SHARE_{i,j,t}/SHARE_{i,j,t-2}. \qquad (5)$$

We selected a two-year period over which to measure the change in capacity shares because it corresponds to the lag associated with the construction of new plants. A similar construction lead-time was observed by Mayer (1960).

"Bandwagon" effect. We next introduce a variable that records rival capacity expansion. Define the "bandwagon" variable as

$$BAND_{i,j,t} = \frac{\sum_{m \neq i} (K_{m,j,t+1} - K_{m,j,t})}{\sum_{m \neq i} K_{m,j,t}}. \qquad (6)$$

The variable *BAND* is the percentage by which all producers other than firm i collectively increased their capacity during the observation year. The *BAND* variable is inversely related to the change in firm i's capacity share during the observation year that results from the actions of competing firms. It differs from the *DELSHR* variable because *DELSHR* refers to changes in capacity share that result from own as well as rival investment and is measured over the preceding two years. The correlation between *BAND* and *DELSHR* is very small ($R = .03$).[9]

A positive logit coefficient for *BAND* implies that the firm's expansions tended to be correlated with expansions of other firms, after we controlled for the influence of historical growth and capacity utilization. To the extent that each firm is knowledgeable of the investment plans of its rivals, a positive *BAND* coefficient suggests that firms have a tendency to invest simultaneously instead of staggering their investments over time: they tend to "hop on the bandwagon."

Public announcements of investment plans are one source of information about rival firms' investment intentions. The trade literature contains frequent announcements of planned investments. To assess the reliability of these announcements, we analyzed capacity expansion announcements in the trade literature from the start of sample coverage through 1973 for four products in the sample (maleic anhydride, methanol, pentarythritol, and vinyl

---

[9] *BAND* is also only weakly correlated with lagged values of *DELSHR*.

acetate). A total of 92 expansions were announced. Three-fourths of these were carried through to completion. Of the 69 completions, 11 were delayed by more than one year beyond the completion date originally announced, and 12 involved significantly less capacity than what had originally been announced. This pattern was similar across all four products. These observations from the trade literature suggest that capacity expansion announcements can be taken seriously, and that firms are likely to be informed about the current investment decisions of their competitors.

Interaction terms. The major asymmetry across firms producing each product relates to their market shares. To detect possible differences in expansion behavior that vary systematically with market share, we compute multiplicative interaction terms between the capacity share of each firm (*SHARE*) and the level of each of the independent variables (excluding *SHARE* itself).

3. Expected results under the maintained hypotheses

■ We now describe the results we expect under each of our three hypotheses.

□ **Cournot-Nash and round-robin investment hypothesis.** The Cournot-Nash model with identical firms predicts an investment round-robin, with no firm building its $(K + 1)$st plant until every other firm has at least K plants.

The assumptions that firms take rival expansion plans as given and are identical with regard to technology and product characteristics are very restrictive, and it would not be surprising if the "round-robin" investment behavior predicted by the Cournot-Nash model were rarely observed in our sample. Nonetheless, this hypothesis of firm investment can be tested empirically.

Although the round-robin theory assumes that firms are symmetric, we may generalize this to allow for different capacity increments by different firms. Also, firms that are clearly members of a competitive fringe may be excluded from the round-robin. With these modifications, consider an industry with I competitors. Let d_{it} be an indicator variable that takes on a value of 1 if firm i invests at date t, $-1/(I - 1)$ if a rival firm invests at t, and zero otherwise. Define the variable

$$D_{it} = \sum_{\tau=0}^{t} d_{i\tau}, \tag{7}$$

and let the start date ($\tau = 0$) correspond to a point in time at which all firms have made equal numbers of investments (with possibly unequal market shares). If firms invest in a round-robin pattern, then D_{it} will be bounded above by $+1$ and below by -1. (If firms have unequal numbers of investments at the start date, but follow a round-robin, the bounds on D_{it} will differ. But the difference between the upper and lower bounds of D_{it} still will be at most two.)

An examination of the frequency distribution of D_{it} thus allows us to assess quantitatively the presence of an investment round-robin. Any observations of D_{it} separated by more than two units cannot belong to a proper investment round-robin. Of course, even if firms coordinate an investment round-robin, mistakes in actions or observations may occur. We can incorporate this by allowing a confidence level for the fraction of observations of D_{it} that must lie outside a bound of two before the round-robin investment hypothesis can be rejected.

□ **Maintaining-market-share hypothesis.** In Osborne's (1976) and Spence's (1978a, 1978b) static equilibrium models of maintaining market share, firms invest lock-step so that there is no variation in market shares. In a more realistic competitive environment, market shares will fluctuate with random changes in factors that determine demand and supply, even if firms are investing with the objective of maintaining their market shares. Firms following a strategy of maintaining market share could be expected to invest if (and only if) they detect reductions in their market shares that they consider substantial relative to historical random variations. This is consistent with Porter's (1983) interpretation of the oligopoly game in Green and Porter (1984) when market share rather than price is the basis for monitoring oligopoly behavior. It is also consistent with Brock and Scheinkman (1985). Although these models provide for episodes of price wars, the symmetry of firm behavior implies that market shares will remain relatively stable whether firms are in the cooperative or aggressive phases of their equilibrium strategies.

The models in Green and Porter (1984) and Brock and Scheinkman (1985) presume a stationary environment with perfectly divisible production. For the industries in the data sample, market and technological circumstances were subject to rapid change, and new investment exhibited economies of scale. These factors complicate the attainment of equilibrium strategies that support cooperative behavior. Furthermore, indivisibilities in new plant investment make detection of cheating more difficult, because market shares must fluctuate over time. Nonetheless, strategies of the type described in the literature on repeated games are not irrelevant to these industries, and we proceed under the hypothesis that an investment-coordinating strategy involving the maintenance of market share has been attained.

In a maintaining-market-share equilibrium the average rate of investment for each firm over time should be proportional to the product of the growth rate and the market share. Capacity utilization rates *per se* should have no effect on firm investment behavior. Firms should respond negatively to *DELSHR*, the measure of the change in capacity share. They should respond positively to *BAND*. If rival firms announce capacity expansion programs corresponding to a high value for $BAND_{i,j,t}$, firm i must respond with a capacity expansion of its own to maintain its share of industry capacity.

□ **Preemption hypothesis.** Preemption acts to deter or to delay investment by rival firms. Successful preemptive investment should allow an increase in market share that lasts for some time and should not stimulate investment activity by competing firms. In contrast to the behavior pattern in the model where firms maintain market share, a reduction in a firm's market share should not be an inducement to invest when firms engage in effective preemption strategies. The preemption model does not impose a necessary pattern on firms' market shares. Hence, the *DELSHR* variable (and its interaction with *SHARE*) should not have any explanatory value in the preemption model.

We can use industry capacity utilization data to test whether a preemption strategy will work. When a firm invests, total capacity increases, and if there is no change in price, capacity utilization declines. Hence, if industry capacity utilization has any effect on investment, it must be positive if preemption can be effective. Otherwise, investment would only serve to stimulate investment by other firms. Thus, a positive correlation between capacity utilization and the probability of investment is a necessary condition for effective preemption.

Similarly, if all firms other than firm i announce a capacity expansion, the information should cause firm i to consider a delay in its own decisions to expand capacity. This implies that the *BAND* variable should be negatively correlated with investment, although the correlation could be reversed if firms invest simultaneously for reasons that are not captured by other explanatory variables (for example, a process innovation could lower costs and trigger new investment by all firms in the industry).

These relationships between the probability of investment and changes in capacity share and industry capacity utilization should hold whether firms engage in growth-deterring investment as in Spence (1979), Fudenberg and Tirole (1983), or Dixit (1980) or whether they engage in a sequence of investments as in Gilbert and Harris (1984). In both situations the preempting firm fills an investment niche, and its capacity serves to deter investment by rival firms. In the sequencing model of Gilbert and Harris (1984) the deterrence is only temporary. Nonetheless, if such a strategy can be successful for even a short period of time, rival firms should not be prompted to expand in response to the decrease in their market shares and in capacity utilization caused by the preempting firm's capital investment.

4. Results and discussion

■ The major results are summarized in Table 2. The dependent variable is binary; it is equal to one for firm i if the firm expanded by more than 5% in year t and zero otherwise. The first column lists the independent variables and their values at the sample mean. The next column reports parameter estimates and t-statistics for a linear logit model that includes all of the independent variables but omits interaction terms. The next column reports the parameter estimates and t-statistics for the full model and includes interactions with the *SHARE* variable to account for possible interactive effects of market share.[10] The final two

TABLE 2 Logit Analysis of Expansion Probability†
(Y_{it} = 1 if firm i expanded by more than 5% in year t)

Independent Variable (Mean Value)	Model (1)	Model (2)	Maintaining Market Share (3)	Preemption (4)
constant	−.74**	−.58**	−.23**	−.73**
(1.00)	(−11.5)	(−5.8)	(−10.3)	(−12.2)
SHARE	.23**	−.66	—	—
(.137)	(3.8)	(−1.2)		
CU	.58**	.23*	—	.52**
(.818)	(8.2)	(2.1)		(7.2)
CU × SHARE	—	2.38**	—	.38**
(.111)		(3.9)		(4.3)
GROW	.28**	.21	—	.27*
(.088)	(3.7)	(1.8)		(2.5)
GROW × SHARE	—	.76	.72*	.10
(.012)		(1.7)	(2.4)	(.3)
DELSHR	−.02	.09**	−.03	—
(1.020)	(−1.1)	(2.8)	(−1.5)	
DELSHR × SHARE	—	−1.03**	.08	—
(.144)		(−4.0)	(1.2)	
BAND	.10*	.28**	.37**	.24**
(.067)	(2.1)	(3.4)	(5.0)	(3.0)
BAND × SHARE	—	−1.02**	−.72*	−.78*
(.011)		(−2.6)	(−2.2)	(−2.3)
Log Likelihood	−1,565.4	−1,546.0	−1,604.5	−1,561.6
No. of Obs.	3,238	3,238	3,238	3,238

† Numbers in parentheses are asymptotic t-statistics.
** Significant at the .01 level, two-tailed test.
* Significant at the .05 level, two-tailed test.

[10] The full model with interaction terms, model (2), was also estimated with separate constant terms for each product and year to identify factors that might be specific to particular industries or time periods. The inclusion of these dummy variables changed only the sign of the noninteracted growth variable, with no loss of significance for the other variables. This suggests that the qualitative conclusions from the statistical analysis do not reflect circumstances unique to particular industries or points in time.

columns report parameter estimates and t-statistics for restricted models corresponding to the hypotheses of maintaining market share and preemption, respectively. For each model, the parameter estimates are the partial derivatives of the logit probability of expansion with respect to the independent variable, calculated at the sample mean.[11] For example, in model (1), a firm in an industry with a growth rate of 9.8% per year (1% point above the sample mean of 8.8% per year) had, *ceteris paribus,* an expansion probability that exceeded the probability at the mean by .28% per year.

A comparison of models (1) and (2) shows that, across the sample, the larger firms in an industry tend to behave differently from the smaller firms. On average, the *DELSHR* variable has a (weak) negative coefficient, which suggests that there is a slight tendency for firms to invest to compensate for past changes in market share. A different picture emerges, however, when interaction effects with market share (*SHARE*) are included. The coefficient for the *DELSHR* variable becomes positive (and highly significant), and the interaction variable has a negative (and highly significant) coefficient. Thus, the data show that for small firms, investment activity is positively correlated with recent changes in market share (increases in market share are followed by more investment, decreases in market share are followed by less), while larger firms in an industry tend to invest to counter recent changes in their market shares.[12] This is consistent with a view that small firms either fail or mature into larger firms and that larger firms tend to invest to maintain market share. The effects of the *DELSHR* and the *DELSHR* × *SHARE* variables cancel each other at a market share of about 9%. For firms with more than about 9% of the market, the probability of investment is negatively correlated with recent changes in market share.

A similar result occurs with the *BAND* variable. The coefficient of the *BAND* variable is positive at the 5% confidence level in model (1), which excludes the share interaction term. The *BAND* coefficient remains positive (and significant) when interaction effects are included, but the *BAND* variable interacted with *SHARE* is significantly negative. Again, with respect to *BAND*, firms with large market share appear to act differently from firms with small market share.

The coefficient of the capacity utilization variable is positive and significant at the 1% level in model (1). This indicates a positive correlation between industry capacity utilization and the probability that a firm expands, *ceteris paribus.* Model (2) shows that a positive correlation between expansion and industry capacity utilization exists for both large and small firms; moreover, the correlation increases for firms with larger market shares. For example, *ceteris paribus,* if industry capacity utilization rises by 1% above its mean value of 81.8%, the probability of expansion goes up by about .47% for a firm with a 10% capacity share and by about .94% for a firm with a 30% capacity share.

The *GROW* variable shows a positive and significant correlation with expansion in model (1). Unlike in the case of the other explanatory variables, however, interacting *GROW* with capacity share in model (2) does not produce a statistically significant difference in the behavior of small and large firms with respect to market growth. In model (2) the coefficients of *GROW* and its interaction with capacity share are both insignificant.

Model (3) is a restriction of model (2) intended to include only the variables that should have explanatory power in a model of industry investment to maintain market share. Excluded are the variables *SHARE, GROW, CU,* and *CU* × *SHARE.* The first two, *SHARE* and *GROW,* are omitted from this specification because in an equilibrium in which market

[11] If $\hat{\beta}$ is the vector of maximum likelihood estimates of the logit function, the partial derivative of the logit probability with respect to X_k is $(\exp[X'\hat{\beta}])(1 + \exp[X'\hat{\beta}])^{-2}\hat{\beta}_k$. It is the value of this partial derivative evaluated at the sample mean, and denoted a_k, that appears in Table 2.

[12] In what follows "large" and "small" refer to market share, not to absolute size.

share is maintained each firm's investment should be proportional to the product of its market share and the industry growth rate. Hence, the variable *GROW* × *SHARE* should capture the effects of market growth on industry investment in a maintaining-market-share equilibrium. We omit *CU* and the interacted variable *CU* × *SHARE* because capacity utilization should not be a determinant of capacity expansion in such an equilibrium.

The parameter estimates in model (3) do not support the hypothesis of maintaining market share. The coefficients of the *DELSHR* variables are only weakly significant, and their signs are the reverse of those in model (2). Model (3) is easily rejected in favor of model (2) on the basis of a likelihood ratio test.

The weak support for the strategy to maintain market share suggests that the "round-robin" investment cycle of the Cournot-Nash model, which is a special case of maintaining market share, should also be rejected. To examine this further we constructed the round-robin statistic D_{it}, defined in Section 3, for the firms in the sample. Only 24% of the observations on D_{it} were within one unit of its mean value, which is inconsistent with the round-robin hypothesis for firms with identical costs for new plants. This result is not unexpected, given the strong symmetry implied by the investment round-robin and the variations in the amount and timing of capital investment by the sample firms.

The last column in Table 2 shows the parameter estimates and *t*-statistics for a restricted model intended to reflect the elements of preemptive investment behavior. The important variables are *CU* and *BAND*. Industry capacity utilization has a highly significant positive effect on investment for firms of all sizes. As discussed above, this result is necessary for a preemptive strategy to be successful. The effect of the *BAND* variable on investment is positive for small firms and negative for firms with a market share greater than about 30%.

These results are consistent with the hypothesis that firms can successfully preempt at least the larger firms in an industry. Smaller firms have a tendency to invest when other firms announce a capacity expansion decision—the *BAND* coefficient is positive for smaller firms. Larger firms do not tend to follow the investment decisions of their rivals, and their own investments are sensitive to industry capacity utilization. Thus, the parameter estimates support the feasibility of using capacity expansions to preempt investment by (at least) larger firms.

The tendency of smaller firms to invest simultaneously with their rivals suggests that smaller firms are relying on rival investment as a signal of market opportunities. But this begs the question of why smaller firms should follow investment by others, while larger firms tend to invest against the tide. Appendix A provides a derivation of a signalling model in which there exist multiple equilibria corresponding to market expectations with the property that some firms will tend to emulate the investment activity of their competitors. In particular, if larger firms expect that their smaller rivals will follow their investment activities, then there exist equilibria in which this strategy is individually rational. Equilibria also exist in which larger firms follow investments by smaller firms. The fact that this behavior is not observed may depend on other factors that lead to market expectations in which larger firms are considered barometers for future market conditions.

The preemption model (4) omits the *DELSHR* variables relating to attempts to maintain market share. The coefficients of these variables are significant in model (2), and a likelihood ratio test (at the .01 level) confirms that the preemption model must be rejected in favor of the more general model, model (2).

The partial correlations in the general model suggest elements of behavior to maintain market share and at least the potential for preemptive investment. The *DELSHR* coefficient for firms with large market share is consistent with maintaining market share, while the coefficients for the capacity utilization and bandwagon variables provide a basis for investment to have a temporary deterring effect on the probability of expansion by rival firms. But to assess the predicted impact of an investment on the behavior of rival firms, it is necessary to trace the consequences of the effects of all the explanatory variables. We do this below for the general model (2).

The coefficients in Table 2 are defined as

$$\hat{a}_k \equiv \frac{\partial P_{i,\tau}}{\partial x_{i,k,\tau}}, \tag{8}$$

where $P_{i,\tau}$ is the probability that firm i expands in year τ and $x_{i,k,\tau}$ is the kth explanatory variable for year τ. The values reported in Table 2 are evaluated at the sample means.

If firm j expands in year t, this is first recorded in the data as an increase in j's capacity in year $(t + 1)$. But the expansion also increases j's capacity in years $(t + 2), \ldots, (t + n)$, where n is the life of the plant. The effect of j's expanding in year t on firm i's probability of expansion in year τ is

$$\frac{dP_{i,\tau}}{dK_{j,t+1}} = \sum_{l=1}^{n} \frac{\partial P_{i,\tau}}{\partial K_{j,t+l}} \frac{dK_{j,t+l}}{dK_{j,t+1}}. \tag{9}$$

Since we shall be concerned about the effects over only a few years, we can ignore depreciation and take $dK_{j,t+l}/dK_{j,t+1} = 1$. Then, applying the chain rule, using (8), and writing the result in logarithmic form, we obtain

$$\frac{d \ln P_{i,\tau}}{d \ln K_{j,t+1}} = \frac{1}{P_{i,\tau}} \left[\sum_{l=1}^{n} \sum_{k=1}^{K} \hat{a}_k x_{i,k,\tau} \frac{\partial \ln x_{i,k,\tau}}{\partial \ln K_{j,t+l}} \right]. \tag{10}$$

Appendix B lists the derivatives of the explanatory variables with respect to the capacity of firm j. This information permits estimates of the effects of an expansion by firm j on the probabilities that rival firms will invest.

Figures 1 and 2 illustrate the implications of these estimates for a simulation of an industry with five firms. Initially, each firm has the same capacity share. The figures contrast two cases, which are distinguished by the actions of the first firm. In the "no preemption" case, firm 1 does not invest. Its share at date t is 20%, the same as the share of each of its rivals. In the "preemption" case firm 1 (and only firm 1) invests at date t and raises its capacity share from 20% to 40%, while the share of each rival drops to 15% at date t. Figure 1 shows the probability that *any* of the rival firms invests by the indicated date. Figure 2 shows the probability that *three or more* rival firms invest by the indicated date.

The probability of rival investment is close to one by $(t + 10)$ in all of the simulations. This is expected because the probability is cumulative, and with demand growing at 8.8% a year (the sample mean demand growth rate) and hence capacity utilization increasing,

FIGURE 1

PROBABILITY OF RIVAL EXPANSION
MARKET SHARES (20, 20(4)) – (40, 15(4))

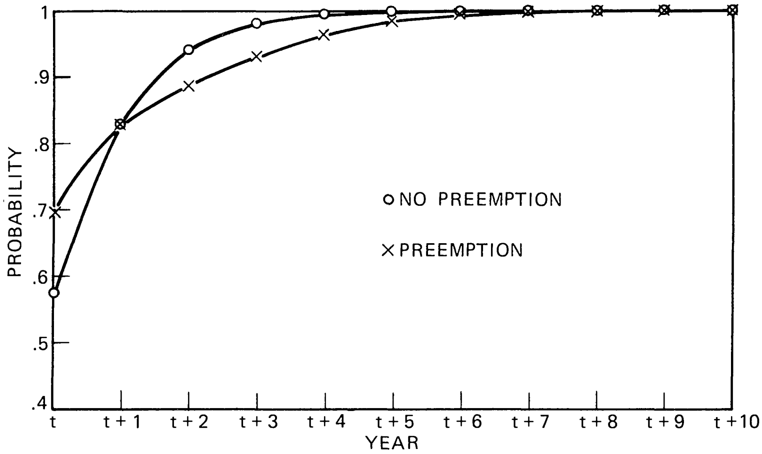
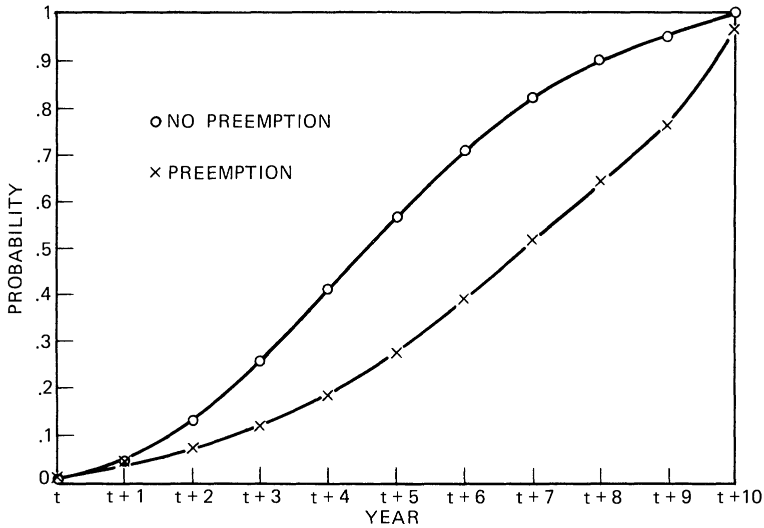


FIGURE 2

PROBABILITY 3 OR 4 RIVALS EXPAND
MARKET SHARES (20, 20 (4)) – (40, 15 (4))



the probability that a rival firm will invest is increasing.[13] In Figure 1 the probability that at least one of the first firm's rivals will invest is high at every date. Preemptive investment by firm 1 has only a modest depressing effect on the probability that at least one rival expands. (It even increases the relative probability in the first year, which is consistent with the "bandwagon" effect for small firms.) The conclusion to be drawn from Figure 1 is that capital investment is *not* effective in preempting investment by all rivals and thereby allowing a firm to achieve a persistent increase in its capacity share. Investment-deterring preemption of the type described by Dixit (1980), Spence (1977), and Fudenberg and Tirole (1985) does not appear to play a significant role in this industry. Simulations of other industry configurations using the econometric estimates also support this conclusion.

Figure 2 tells a different story. The estimates here are of the probability that *three or four* of the rival firms will expand by some date. Expansions by only one or two firms (or none) are not counted. The probability that three or more firms expand within a few years from date t is rather low. But if they do expand, the reduction in industry capacity utilization would have adverse impacts on all of the competitors.

Firm 1's expansion at date t has a significant impact on the probability that three or more rival firms expand. From the years $(t + 2)$ through $(t + 6)$, preemptive investment by firm 1 cuts by approximately half the probability that three or more rivals will expand. This does not guarantee the absence of excess capacity, because the market must contend with the capacity that firm 1 contributed at date t. Indeed, expected capacity utilization could be lower in the preemption case. What Figure 2 does show is that expansion by firm 1 significantly lowers the conditional probability that (many) other firms will invest. Although excess capacity may result, firm 1 is assured that the scales will tip in its favor. Firm 1 has extra capacity, and the probability that an excessive number of other firms will invest is reduced.

Figure 2 reveals that preemptive investment has a coordinating function in that it allows firms to sequence their investments. When firm 1 invests at date t, it significantly reduces the probability that three or more firms will follow. This would not occur if firms

[13] Growing demand does not eliminate the possibility that a firm might preempt by investing in anticipation of market growth, but it does complicate the task.

invested randomly, without regard to the actions of their rivals. Note that this preemptive behavior is effective only for a limited period. Preemptive investment allows the industry to increase the probability of an efficient investment program in which lumpy investments are sequenced over time. Although the preemption shown in Figure 2 helps avoid inefficient simultaneous expansions, there is no evidence that preemption allows a persistent increase in market share.

The evidence of "short-term preemptive" behavior is consistent with the model of sequential preemption in Gilbert and Harris (1984).[14] It is also in accord with the interpretation of preemption as enforced turn-taking by Smith (1981). Furthermore, it is not inconsistent with a tendency for firms to maintain their market shares over an extended time period. Indeed, if an industry is to succeed in achieving a noncooperative equilibrium that sustains supracompetitive earnings, some mechanism to govern the sequencing of capacity investment in the short term is essential.

□ **Other interaction effects.** The theoretical and empirical analysis above presumes that the major asymmetries in firms' investment behavior are based on market share. Nevertheless, it is possible that other asymmetries are important and that market share may simply be serving as a proxy for other factors. Hence, we tested a number of additional variables to determine whether share in fact represented the important asymmetry in investment behavior. We added each of these variables to the full model (2), and virtually all of them proved insignificant.

The other interaction variables we tested included the following.

Level of producer concentration. It is plausible that the investment asymmetries attributed to market share may actually result from differences in industry concentration. Products for which firms have large shares also tend to have high concentration levels. To differentiate the two hypotheses, we computed the Herfindahl index of producer concentration for each product and observation year. We defined a second set of interaction terms (comparable to the share interactions reported in Table 2) by using the Herfindahl index as the interaction variable. We then included these concentration interactions along with the *SHARE* interactions in model (2). When we performed this test, none of the Herfindahl interaction terms proved statistically significant at the .05 level, while all of the *SHARE* interaction terms remained statistically significant. This confirms the importance of individual firm shares rather than industry concentration levels in influencing oligopolistic investment behavior.

Size of firm. The observed asymmetries could also be related to overall firm size rather than capacity shares. To test this possibility, we obtained data on each firm's total book value of assets from the COMPUSTAT files. The logarithm of firm's assets was then interacted with *CU*, *DELSHR*, and *BAND*. These asset interaction terms failed to prove statistically significant; however, the *SHARE* interactions remained significant even when the asset interactions were included.

Major industry group of firm. Most firms in the sample are either large diversified chemical companies (SIC 280), smaller chemical companies (SIC 281–289), or petroleum companies (SIC 291). Conceivably, these groups might differ in their investment behavior. To test this hypothesis we defined dummy variables for each of these three groups of firms. The dummies were then interacted with *CU*, *DELSHR*, and *BAND*, and tested in the logit model. The results showed no significant difference in expansion behavior across groups.

[14] See also Fudenberg and Tirole (1985) for a discussion of preemptive behavior.

Corporate financial liquidity. In the absence of perfect capital markets, firms' investment decisions may be constrained by the limited availability of internally generated funds. Less profitable firms may undertake fewer expansion projects. Moreover, all firms may be less inclined to initiate investments during years of low corporate earnings, and may be relatively more likely to expand during high-profit periods. We tested for such liquidity effects by using yearly COMPUSTAT data on firms' after-tax return on invested capital.

We tested the following liquidity measures as independent variables in the logit equations: the actual level of firms' after-tax (percentage) return during the observation year; the mean level of firms' after-tax return across all observation years; and the deviation of return from this mean level (tested for the observation year and years $(t-1)$ and $(t-2)$, to account for gestation lags in investment). We found a statistically significant positive relation (.05 level) between the deviation from the mean level in year $(t-2)$ and expansion in year t. Otherwise, none of these liquidity variables was found to be a significant influence on the probability of expansion. The liquidity variables were also interacted with *CU*, *DELSHR*, and *BAND*, but these interactions failed to prove statistically significant.

5. Summary and conclusions

■ Both exogenous and market uncertainty contribute to the risk of capital investment. The former stems from the unpredictability of events that determine the size and profitability of markets, while the latter is caused by the actions of rival firms. Market concentration should facilitate behavioral mechanisms to reduce the risks associated with the timing of investment in new plant. Two candidates for market coordination are the maintaining-market-share model of oligopoly and the preemption model. In the former model coordination is achieved by firms' commitments to matching the investments of their rivals. In the latter model investment by one firm deters simultaneous investment by others.

Given the intricacies of dynamic games, it is presumptuous to suppose that actual markets should correspond to a particular view of investment behavior. The data examined in this study reveal elements of both preemptive behavior and a tendency to maintain market shares. The results suggest that firms can use preemptive investment to sequence new additions to industry capacity. The tendency to maintain market shares implies that such preemptive behavior would not be effective in deterring rival investment over the longer term. Thus, the main role of preemptive activity is to coordinate new investment and to promote efficiency by avoiding excess capacity from redundant investment.

Both the potential for preemption and the tendency to maintain market share are more pronounced for firms with large market share, a result that is consistent with the view that these are behavioral responses to reduce the risks associated with the timing of investment in new plant. The costs associated with these risks are more likely to be borne by firms with large market share or by firms in more concentrated markets, as firms with small market share may more easily profit by deviating from a coordinated investment sequence. Thus, these investment data suggest that firm size is associated with investment behavior that can moderate fluctuations in total industry capacity and thereby mitigate an important source of market uncertainty.

Appendix A

■ To see how the bandwagon behavior might come about, consider two firms with initial capacities K_1^0 and K_2^0 $(K_1^0 \geqq K_2^0)$. Inverse demand is linear in total output (equal to total capacity, K) and a random demand parameter, $\tilde{X}$: $P(K, \tilde{X}) = a - bK + \tilde{X}$. Firm i's prior information about $\tilde{X}$ is summarized by a single observation θ_i drawn from an independent normal population with unknown mean and known variance σ^2, which we take to be equal to unity.

Each firm chooses to expand by k or not at all. For firm i the value of an investment depends not only on θ_i (its best estimate of the mean of $\tilde{X}$), but also on the probability p_j that its rival expands. Firm i should invest if θ_i exceeds a critical value $\hat{\theta}_i$. It is easy to see that if the investment decision hinges on the incremental profit from the new plant, the critical value $\hat{\theta}_i$ depends on p_j with $\partial\hat{\theta}_i(p_j)/\partial p_j > 0$: firm i requires a better demand signal to invest if competitive investment is more likely. Furthermore, if the incremental costs of investment are such that (K_1^0, K_2^0) were equilibrium values, given initial expectations, then $\hat{\theta}_1(p) = \hat{\theta}_2(p)$. If $K_1^0 > K_2^0$ and both firms have the same technology for *new* investment, then $\hat{\theta}_1(p) \geqq \hat{\theta}_2(p)$ because firm 1 will suffer higher inframarginal losses. We shall proceed under the assumption that $\hat{\theta}_1(p) = \hat{\theta}_2(p)$.

Suppose that firm i has invested in a new plant. Its competitor has two pieces of information: its own signal θ_j and the information that $\theta_i \geqq \hat{\theta}_i$. The likelihood of these two independent observations, given that the true (unknown) mean of $\tilde{X}$ is μ, is

$$p(\theta_j, \theta_i \geqq \hat{\theta}_i | \mu, \sigma^2 = 1) = \left[\frac{1}{2\pi} e^{-1/2(\theta_j - \mu)^2}\right][1 - \Phi(\hat{\theta}_i - \mu)], \tag{A1}$$

where $\Phi(\cdot)$ is the cumulative of the standard normal probability density function, which we write as $\phi(\cdot)$.

The value of μ that maximizes the likelihood of these observations is the solution to

$$\mu_j^* = \theta_j + \frac{\phi(\hat{\theta}_i - \mu_j^*)}{1 - \Phi(\hat{\theta}_i - \mu_j^*)} \tag{A2}$$

or

$$\mu_j^* = \theta_j + h(\hat{\theta}_i - \mu_j^*), \tag{A3}$$

where $h(\cdot)$ is the conditional probability density function for the standard normal density. Since $h(\cdot)$ is monotone increasing and

$$\frac{d\mu_j^*}{d\hat{\theta}_i} = \frac{h'(\hat{\theta}_i - \mu_j^*)}{1 + h'(\hat{\theta}_i - \mu_j^*)},$$

it follows that firm j's best estimate of the expected value of $\tilde{X}$ conditional on observation of investment by firm i is an increasing function of $\hat{\theta}_i$.

Suppose firm 1 believes that $p_2 > p_1$ (firm 2 is more likely to follow the investment of firm 1 than *vice versa*), and this belief is common knowledge. We shall show that equilibria exist in which these expectations are self-fulfilling. If firm 1 believes that $p_2 > p_1$, firm 2 will be more likely to follow firm 1.

With $p_2 > p_1$, firm 1's critical value for investment exceeds firm 2's: $\hat{\theta}_1(p_2) > \hat{\theta}_2(p_1)$. Since firm i's maximum likelihood estimate μ_i^* of the mean of $\tilde{X}$ is an increasing function of $\hat{\theta}_j$, it follows that

$$E_{\theta_2}[\mu_2^* | \theta_2, \text{firm 1 invests}] > E_{\theta_1}[\mu_1^* | \theta_1, \text{firm 2 invests}],$$

where "firm i invests" is equivalent to the information that $\theta_i \geqq \hat{\theta}_i(p_j)$.

We have the following result. If firm 1 thinks that $p_2 > p_1$, it will invest only when it receives a very optimistic signal about future demand. When firm 1 invests, it is a signal to firm 2 that future demand will be high. The same information transmission occurs when firm 2 invests. But because $p_2 > p_1$, the critical value for firm 2 is lower, and therefore its investment does not require so much optimism as an investment by firm 1.

These expectations are self-fulfilling. If firm 1 thinks that $p_2 > p_1$, firm 2 should take advantage of this belief, and it will be more likely that firm 2 will follow firm 1 than the opposite. Of course, the opposite would occur if initial beliefs were such that $p_1 > p_2$: then firm 1 would be more likely to follow firm 2.

The bandwagon effect can vary systematically with market share if there were a mechanism to establish initial beliefs that depend on market shares. There are several ways this might happen. The data suggest that larger firms tend to make new investments that are larger than the new investments of smaller firms. This would raise the critical value $\hat{\theta}_i(p_j)$ for larger firms and cause an asymmetry in beliefs. Also, if the size differences of firms are the result of historical events and not justified by the incremental costs of new investments, then larger firms would have higher inframarginal losses from new investment. This would imply a higher critical value for the demand signal and would again result in asymmetric investment probabilities. Furthermore, larger firms can exploit scale economies in the acquisition and use of information, and therefore small firms may correctly view the actions of large firms as the result of superior information (see, e.g., Eckard (1982)).

Appendix B

■ Table A1 lists the derivatives

$$\sum_{l=1}^{n} \frac{\partial \ln x_{i,k,\tau}}{\partial \ln K_{j,t+l}},$$

normalized to the capacity share of firm j in year $(t + 1)$. The factor g is the rate of growth of industry capacity, which is assumed equal to the mean growth rate of output. The derivatives for years $(t + s)$, $s > 3$, are the same as for year $(t + 3)$ except that the factor $(1 + g)$ in the *BAND* and *BAND* × *SHARE* terms is raised to the power $(s - 1)$.

TABLE A1 $[SHARE_{j,t+1}]^{-1} \sum_{i=1}^{n} \frac{\partial \ln x_{i,k,\tau}}{\partial \ln K_{j,t+l}}$

	Year: $\tau =$			
Variable: $x =$	t	$t+1$	$t+2$	$t+3$
SHARE	0	-1	-1	-1
CU	0	$-\frac{1}{2}\left(\frac{1+g}{2+g}\right)$	$-\frac{1}{2}\left(\frac{3+g}{2+g}\right)$	$-\left(\frac{1}{1+g}\right)$
CU × *SHARE*	0	$-\frac{1}{2}\left(\frac{5+3g}{2+g}\right)$	$-\frac{1}{2}\left(\frac{7+3g}{2+g}\right)$	$-\left(\frac{2+g}{1+g}\right)$
GROW	0	0	0	0
GROW × *SHARE*	0	-1	-1	-1
DELSHR	0	-1	-1	0
DELSHR × *SHARE*	0	-2	-2	-1
BAND	$\frac{1+g}{g}$	A_{t+1}	A_{t+2}	A_{t+3}
BAND × *SHARE*	$\frac{1+g}{g}$	B_{t+1}	B_{t+2}	B_{t+3}

where

$$A_{t+l} = -[(1+g)^{l-1} - SHARE_{i,t+1}]^{-1}$$

$$B_{t+l} = -\left| \frac{1+(1+g)^{l-1} - SHARE_{i,t+1}}{(1+g)^{l-1} - SHARE_{i,t+1}} \right|^{-1}$$

References

ANDERSON, R. "Quick-Response Equilibrium." University of California, Mimeo, 1984.

BROCK, W. AND SCHEINKMAN, J. "Price-Setting Supergames with Capacity Constraints." *Review of Economic Studies,* Vol. 52 (1985), pp. 371–382.

DIXIT, A. "The Role of Investment in Entry Deterrence." *Economic Journal,* Vol. 90 (1980), pp. 95–106.

ECKARD, E.W., JR. "Firm Market Share, Price Flexibility, and Imperfect Information." *Economic Inquiry,* Vol. 20 (1982), pp. 388–392.

FRIEDMAN, J. *Oligopoly and the Theory of Games.* Amsterdam: North Holland, 1978.

FUDENBERG, D. AND TIROLE, J. "Capital as a Commitment: Strategic Investment to Deter Mobility." *Journal of Economic Theory,* Vol. 31 (1983), pp. 227–250.

——— AND ———. "Preemption and Rent Equalization in the Adoption of New Technology." *Review of Economic Studies,* Vol. 52 (1985), pp. 383–402.

GILBERT, R.J. AND HARRIS, R.G. "Competition with Lumpy Investment." *Rand Journal of Economics,* Vol. 15 (1984), pp. 197–212.

GREEN, E.J. AND PORTER, R.H. "Noncooperative Collusion under Imperfect Price Information." *Econometrica,* Vol. 52 (1984), pp. 87–100.

LIEBERMAN, M.B. "Entry, Excess Capacity, and Market Structure in the Chemical Processing Industries." Research Paper #830A, Graduate School of Business, Stanford University, June 1986.

———. "Excess Capacity as a Barrier to Entry: An Empirical Appraisal." *Journal of Industrial Economics,* Vol. 35 (1987, forthcoming).

MAYER, T. "Plant and Equipment Lead Times." *Journal of Business,* Vol. 33 (1960), pp. 127–132.

OSBORNE, D.K. "Cartel Problems." *American Economic Review,* Vol. 66 (1976), pp. 835–844.

PORTER, M. AND SPENCE, A.M. "The Capacity Expansion Process in a Growing Oligopoly: The Case of Corn Wet Milling" in J.J. McCall, ed., *The Economics of Information and Uncertainty,* Chicago: University of Chicago Press, 1982.

PORTER, R. "A Study of Cartel Stability: The Joint Executive Committee, 1880–1886." *Bell Journal of Economics,* Vol. 14 (1983), pp. 301–314.

RICHARDSON, G.B. *Information and Investment: A Study in the Working of the Competitive Economy.* Oxford: Oxford University Press, 1960.

SMITH, R.L., II, "Efficiency Gains from Strategic Investment." *Journal of Industrial Economics,* Vol. 30 (1981), pp. 1–23.

SPENCE, A.M. "Efficient Collusion and Reaction Functions." *Canadian Journal of Economics,* Vol. 11 (1978a), pp. 527–533.

———. "Tacit Coordination and Imperfect Information." *Canadian Journal of Economics,* Vol. 11 (1978b), pp. 490–505.

———. "Investment, Strategy, and Growth in a New Market." *Bell Journal of Economics,* Vol. 10 (1979), pp. 1–19.

STIGLER, G. "A Theory of Oligopoly." *Journal of Political Economy,* Vol. 72 (1964), pp. 44–61.

SWEEZY, P. "Demand under Conditions of Oligopoly." *Journal of Political Economy,* Vol. 47 (1939), pp. 568–573.