Postentry Investment and Market Structure in the Chemical Processing Industries

Marvin B. Lieberman

The RAND Journal of Economics, Volume 18, Issue 4 (Winter, 1987), 533-549.

RAND Journal of Economics
Vol. 18, No. 4, Winter 1987

Postentry investment and market structure in the chemical processing industries

Marvin B. Lieberman*

This article analyzes the investment response of incumbents to new entry in 39 chemical product industries. The behavior of incumbents in highly concentrated industries differed from that of incumbents in low-concentration industries. In concentrated industries incumbents increased their rate of investment following entry, but reduced investment to accommodate capacity expansions made by other incumbents. This asymmetric response did not arise in less concentrated industries. Significant excess capacity existed in concentrated industries following entry, but there is little evidence that incumbents built such capacity as a deterrent before entry. Thus, the results support "mobility-deterrence" theories rather than the conventional excess-capacity deterrence argument.

1. Introduction

■ How do incumbent firms respond to new entry? In growing markets, do incumbents cut back on investment to accommodate entrants, or do they accelerate investment to limit the entrant's market share and prevent additional entry? Numerous theoretical models of entry and mobility deterrence have been proposed, but there has been little systematic evaluation of empirical evidence.

This article examines postentry investment by incumbents in 39 chemical product industries. The focus on postentry strategic behavior complements the analysis in Lieberman (1987a), which assesses the importance of excess capacity built as a strategic deterrent before announced entry. That study shows that firms in the chemical products sample rarely built excess capacity to deter entry. And when excess capacity did arise, it had only minor effectiveness as an entry deterrent.

This raises the question of whether incumbents invest strategically *following* the initiation of entry to limit the entrant's market share and prevent further entry. Caves and Porter (1977) first referred to such behavior as "mobility deterrence," and there have been a number of more recent efforts to model such behavior theoretically (Spence, 1979; Fudenberg and Tirole, 1983). In this article I present empirical tests of such behavior. Specifically, I estimate models of new plant and incremental investment and focus on the extent to which incumbents accommodated or failed to accommodate entry. Finally, I examine the occurrence of postentry excess capacity.

---

* Stanford University.

I thank Choon-Geol Moon for excellent research assistance. Richard Caves, Curtis Eaton, Richard Gilbert, Pankaj Ghemawat, Alvin Klevorick, Peter Reiss, and an anonymous referee made helpful comments on earlier drafts. The Strategic Management Program at the Stanford Business School provided financial support.

□ **Entry and "mobility" deterrence based on strategic investment.** Numerous theoretical studies have assessed the conditions under which incumbent firms might hold excess capacity in advance of entry as an entry barrier. The standard excess-capacity deterrence argument (Wenders, 1971; Spence, 1977; Salop, 1979; Dixit, 1980; Spulber, 1981; Bulow, Geanakoplos, and Klemperer, 1985b; Kirman and Masson, 1986) is that excess capacity deters entry if it allows incumbents to threaten credibly to expand output and to cut prices following entry, and thereby to make entry unprofitable.

Theoretical and empirical studies have cast doubt on the robustness of this deterrence argument. Threats to utilize excess capacity following entry may fail to be credible (Dixit, 1980), although this depends on the exact form of the demand function and whether entrants expect price competition or quantity competition to prevail after entry (Bulow, Geanakoplos, and Klemperer, 1985a). If capital depreciates or has a limited life, this shortens the postentry period over which excess capacity can be used and thereby reduces the magnitude of the deterrent (Eaton and Lipsey, 1980). Similarly, market growth erodes existing excess capacity unless replenished by additional investment. Thus, in rapidly growing industries excess capacity built before entry offers a transitory deterrent at best. In an empirical study of 26 industries Masson and Shaanan (1986) found that entry rates were sensitive to the existence of excess capacity, but there was no evidence that incumbents deliberately installed such capacity to deter entry. Lieberman (1987a) shows that excess capacity led to identical reductions in the probability of new investment by incumbents and entrants and did not serve as a major entry barrier.

The actual response of incumbents following entry has been largely overlooked as a topic in the empirical literature. Theory offers a near embarrassment of riches, which suggests a wide range of possible responses by incumbents.[1] Most of the early literature (Modigliani, 1958; Dixit, 1980) focused on incumbents' output response. In a growing industry, however, incumbents' investment response is probably more important than any short-run change in output. Investment naturally precedes production of output, and both normally grow in tandem as industries evolve over time.

In theory various postentry investment responses may arise; which one depends on the assumptions made. Accommodation occurs under simple Cournot competition; if entrants and incumbents have identical investment and operating costs, incumbents wait for entrants to "catch up" to the incumbents' capacity level (Gilbert and Harris, 1984). In certain cases the entrant may be able to encourage accommodation by committing to limited capacity (Gelman and Salop, 1983). Under other assumptions, however, incumbents respond to entry with an aggressive investment program. This may be designed to deter continued growth and "mobility" of the entrant (Caves and Porter, 1977; Spence, 1979; Fudenberg and Tirole, 1983) or to forestall additional entry. Aggressive investment and price cutting may also promote a reputation for toughness sufficient to deter future entry (Williamson, 1977; Kreps and Wilson, 1982; Milgrom and Roberts, 1982). This wide range of theoretically supportable outcomes raises the natural empirical question of which responses are prevalent in practice.

One defect of most of the theoretical models is that entry is viewed as an instantaneous, zero-one process. Dynamics are often approximated by considering two periods: pre- and postentry. In reality, entry is typically an extended process involving multiple investments over a period of years or even decades. Indeed, Porter (1985, p. 486) has argued, "The commencing of entry does not mean that resources have been fully committed to the industry, or that the entrant should be viewed as an incumbent. . . . Entry may be terminated or a less ambitious target set, an outcome that has occurred in many industries."

Even in the absence of potential or actual entry, incumbent firms face a problem of

---

[1] Fudenberg and Tirole (1984) and Bulow, Geanakoplos, and Klemperer (1985a) give taxonomies of possible strategic responses.

investment coordination. Errors in expectations about rivals' actions can lead to redundant capacity. Moreover, rivalry among incumbents can touch off simultaneous attempts at market preemption. Gilbert and Lieberman (1987) examined this coordination problem among incumbent producers for a subset of the products in the present study. They found significantly greater coordination of investment among firms with larger market shares.

The remainder of this article examines postentry investment and excess capacity in the chemical products sample. Section 2 describes the data and variables used in the investment analysis. Section 3 develops a benchmark model of nonstrategic investment and a set of testable hypotheses regarding strategic investment behavior. Section 4 reports the empirical results. They reveal that in concentrated industries, incumbents increased their rate of investment following entry but reduced investment to accommodate expansions by each other. This asymmetric response did not occur in less concentrated industries. Thus, the results imply that firms in concentrated industries engaged in "mobility-deterring" investment. Section 5 corroborates these investment findings by examining the magnitude of excess capacity following entry. A final section contains a summary and the conclusions of the analysis.

2. Data and variables

■ **Data sample.** The data sample includes the 39 chemical products listed in Table 1, observed over a period of roughly two decades. The starting year varies by product as shown in Table 1; the last full year of coverage is 1982.

The products in the sample have cost functions that resemble the stylized examples of economic theory. The sample is limited to homogeneous, commodity-type chemicals or related products.[2] Production capacities are well defined; except for chlorine, chemicals with production processes involving significant joint products have been excluded, as have those where capacity can be switched from one product to another in response to shifts in market demand. Marginal cost for any given plant tends to be relatively constant up to the output level defined by the plant's rated production capacity. Plants for a given product may differ in cost, however, owing to differences in technology and age of plant.

The sample spans a wide range of market concentration; the number of producers for any given product ranges from one to 64. The full sample includes more than 1,000 plants operated by about 200 individual firms. 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 had 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 number of cases output declined after 1975. Rapid growth led to considerable entry—Table 1 shows at least one new entrant for nearly all products.

The basic data include production capacity by plant and firm, observed on January 1 of each year,[3] and total industry output of each product, observed over the course of each year.[4] Thus, the capacity data are quite detailed at the individual plant level, whereas the output data are industry-level aggregates for each product.

---

[2] A few products, such as polyethylene and synthetic fibers, are slightly differentiated across producers.

[3] The plant capacity data are primarily from issues of the *Directory of Chemical Producers,* published by SRI International. As this directory was not updated on an annual basis until 1971, for prior years it was necessary to supplement the directory with capacity listings and new plant announcements published in the trade press. Small discrepancies occasionally arose among these published sources; I selected the most conservative figures, or those that were validated by later capacity listings.

[4] The industry output data are from several sources. For organic chemicals the data are from annual issues of *Synthetic Organic Chemicals,* published by the U.S. International Trade Commission. The inorganic chemical data are primarily from *Current Industrial Reports,* M28A, published by the U.S. Department of Commerce. For aluminum, magnesium, carbon black, and titanium dioxide, the data are from annual issues of the *Minerals Yearbook,* published by the U.S. Bureau of Mines. The synthetic fiber data are from *Textile Organon.*

TABLE 1 **Products Included in Data Sample***

		Number of Producers		Number of Greenfield Plants Constructed by	
Product Name	Coverage Period	Minimum	Maximum	Entrants	Incumbents
Organic Chemicals					
Acrylonitrile	1956–82	4	6	2	8
Aniline	1961–82	4	6	4	1
Bisphenol A	1959–82	3	5	3	2
Caprolactam	1962–82	3	4	3	0
Carbon Disulfide	1963–82	3	5	0	1
Cyclohexane	1956–82	2	14	14	3
Ethanolamines	1955–82	4	5	2	3
Ethylene	1960–82	20	26	10	10
Ethylene Glycol	1960–82	10	14	6	5
Formaldehyde	1962–82	14	18	5	32
Isopropyl Alcohol	1964–82	3	4	1	1
Maleic Anhydride	1958–82	4	8	7	2
Methanol	1957–82	8	12	7	6
Methyl Methacrylate	1966–82	3	3	0	1
Neoprene Rubber	1960–82	1	2	1	1
Pentaerythritol	1952–82	4	7	4	2
Phenol	1959–82	9	13	7	8
Phthalic Anhydride	1955–82	8	13	8	8
Polyethylene-LD	1957–82	8	15	7	10
Polyethylene-HD	1957–82	9	14	14	6
Sorbitol	1955–82	3	5	3	1
Styrene	1958–82	8	13	8	4
1,1,1-Trichloroethane	1966–82	3	4	1	1
Urea	1960–82	15	36	29	24
Vinyl Acetate	1960–82	5	7	5	4
Vinyl Chloride	1962–82	9	13	8	5
Inorganic Chemicals					
Ammonia	1960–82	45	64	33	45
Carbon Black	1964–82	7	10	3	7
Chlorine	1961–82	31	40	18	25
Hydrofluoric Acid	1962–82	6	10	0	4
Sodium	1957–82	3	3	0	1
Sodium Chlorate	1956–82	3	11	10	5
Sodium Hydrosulfite	1964–82	3	6	1	4
Titanium Dioxide	1964–82	6	6	1	7
Synthetic Fibers					
Acrylic Fibers	1953–82	3	6	3	1
Nylon Fibers	1960–82	6	23	19	7
Polyester Fibers	1954–82	1	19	18	12
Metals					
Aluminum	1956–82	4	13	9	7
Magnesium	1954–82	1	4	4	0

* Observations used in the regressions begin two to three years after start of coverage period, to enable lagged values to be computed. Figures for "number of producers" pertain to observations used in the regressions; figures for "number of greenfield plants" pertain to full coverage period.

☐ **Explanatory variables used in the investment model.** High capacity utilization and expected market growth are the major factors that elicit (nonstrategic) investment. Let $K_{i,t}$ be total industry capacity to produce product i at the start of year t, and let $Q_{i,t}$ be total industry output of product i during year t. We define average capacity utilization during year t as

$$U_{i,t} = \frac{Q_{i,t}}{.5(K_{i,t} + K_{i,t+1})}. \tag{1}$$

The rate of historical output growth (over the prior three-year period) is

$$g_{i,t} = \left[\frac{Q_{i,t}}{Q_{i,t-3}}\right]^{1/3} - 1. \tag{2}$$

These variables are incorporated in the investment model developed in the next section.

The empirical analysis also distinguishes between high- and low-concentration industries, based on the Herfindahl index computed at the start of each observation year:

$$H_{i,t} = \sum_{j} \left(\frac{K_{i,j,t}}{K_{i,t}}\right)^2, \tag{3}$$

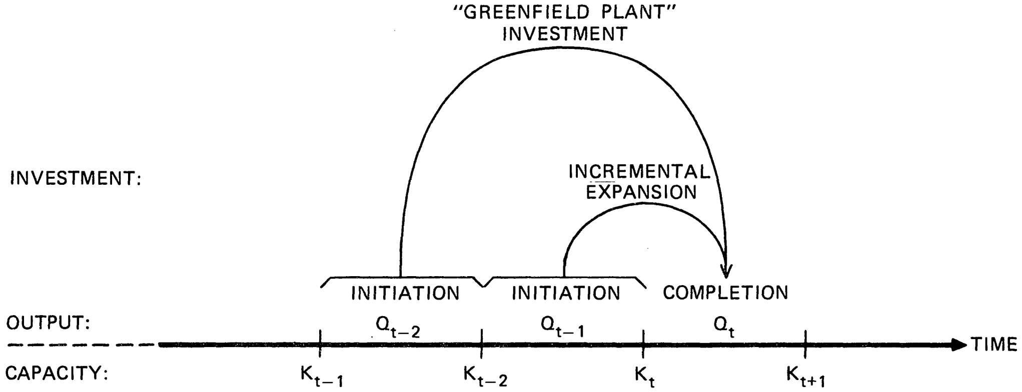
where $K_{i,j,t}$ represents the capacity of firm j to produce product i at the start of year t. For simplicity, I omit the i and j subscripts in all subsequent discussion. High-concentration industries are as those with a Herfindahl index greater than .3 at the start of the observation year; the dummy variable D_{hc} was set equal to unity for these observations.[5]

☐ **Investment measures and dependent variables.** The capacity data are observed as stocks at the beginning of each year, while the output data are flows over the course of each year. Figure 1 illustrates the time structure of the investment process in relation to these stocks and flows. We observe investment completed during year t as the difference between capacity at the start of year t and capacity at the start of year $t + 1$. Given lags in the investment process, the actual expansion decisions occur previously, during years $t - 1$ and $t - 2$.

Investment by incumbents can take two forms: construction of "greenfield plant"—plant at a new site—or expansion of an existing plant. Entrants, by definition, can invest

FIGURE 1

TIME STRUCTURE OF THE INVESTMENT PROCESS



---

[5] All observations with three or fewer producers exceed the $H = .3$ threshold, as do some observations with more than three firms, depending on their size distribution. Of the total observations in the sample, 30% were classified as high concentration. I selected the $H = .3$ threshold by scanning values of H for the cutoff point that maximized the log likelihoods in regressions 3.3 and 5.2. This threshold-type interaction also proved superior to a multiplicative interaction based on H.

only in greenfield plant.[6] The change in total industry capacity during year t has the following components:

ΔK_t^E = greenfield plant capacity completed by entrants;
ΔK_t^I = greenfield plant capacity completed by incumbents;
ΔK_t^+ = total gross incremental expansions of existing plants; and
ΔK_t^- = capacity shut down.[7]

The total industry capacity stock at the start of year t is

$$K_t = \sum_{\tau=0}^{t-1} [\Delta K_\tau^E + \Delta K_\tau^I + \Delta K_\tau^+ - \Delta K_\tau^-]. \tag{4}$$

Gestation lags for new investment must be considered. In the chemical industry there is a construction lag of about two years for greenfield plants.[8] Taking account of this lag, I denote rates of new plant investment by entrants and incumbents as

$$E_{t-2}^t = \Delta K_t^E / K_t, \tag{5}$$

$$I_{t-2}^t = \Delta K_t^I / K_t, \tag{6}$$

where E_{t-2}^t represents greenfield plant capacity initiated by entrants during year $t - 2$ and completed during year t, expressed as a fraction of the capital stock at the start of year t, and I_{t-2}^t has the same interpretation for greenfield plant capacity built by incumbents.

Incremental investment typically has a gestation lag of about one year. The rate of incremental investment (by incumbents) is:

$$\dot{K}_{t-1}^t = \frac{\Delta K_t^+ - \Delta K_t^-}{K_t}. \tag{7}$$

We assume, initially, that incremental investment is perfectly divisible (no lumpiness). Most capacity added by incumbents was incremental; on average across products, only 26% of total capacity added by incumbents took the form of greenfield plant.

3. Investment model

■ **Nonstrategic investment.** Consider, first, the simple case without entry in which all investment takes the form of incremental expansion of existing plant. Assume that the incumbent is a monopolist or perfect cartel so that there is no problem of investment coordination. Demand grows stochastically over time. The incumbent forecasts demand and aims to hold a capacity stock, $\hat{K}_{t+1}$, at the end of year t:

$$\hat{K}_{t+1} = \beta\left(\frac{\hat{Q}_t + \hat{Q}_{t+1}}{2}\right), \tag{8}$$

where $\hat{Q}_t$ represents the expected profit-maximizing output in year t and $1/\beta$ is the optimal rate of capacity utilization, which may be a function of capital costs, demand variability,

---

[6] The data indicate when capacity was installed at a new site where the product was not produced previously. (The firm may, however, have had other manufacturing operations at that site.) We consider the initial lump of capacity at such a site to be "greenfield plant." All later capacity additions are classified as "incremental expansion," even though these expansions were sometimes larger than the initial greenfield plant. By defining "greenfield plant" in this way, we obtain a set of similar investments that can be compared between entrants and incumbents.

[7] Plants were occasionally indicated to be "on standby." I considered such plants to be part of available industry capacity if they subsequently returned to normal operation.

[8] Mayer (1960) documents such a lag, and the empirical results in Section 4 confirm the lag structures described here.

etc. With a one-year gestation lag for incremental investment, the incumbent must forecast future demand during year $t-1$ and take steps to adjust the capital stock accordingly. The desired rate of investment, $\dot{K}^{*t}_{t-1}$, initiated during year $t-1$ and completed during year t, is

$$\dot{K}^{*t}_{t-1} = \frac{\hat{K}_{t+1} - K_t}{K_t}. \tag{9}$$

If expected annual demand growth is $\Delta\hat{Q}$, we can write this as

$$\dot{K}^{*t}_{t-1} = \beta\frac{Q_{t-1}}{K_t} + \beta\frac{1.5\Delta\hat{Q}}{K_t} - 1. \tag{10}$$

Thus, desired investment is basically a function of capacity utilization during year $t-1$ and the expected rate of demand growth. We can express this as

$$\dot{K}^{*t}_{t-1} = \alpha + \beta_1 U_{t-1} + \beta_2 \hat{g}_{t-1}, \tag{11}$$

which is similar to a standard accelerator model.

Empirically, U_{t-1} can be observed, but $\hat{g}_{t-1}$ cannot. We use g_{t-1}, the recent historical rate of output growth, as a proxy for $\hat{g}_{t-1}$. The true expected rate of growth equals this historical rate plus an unobserved component, i.e., $\hat{g}_{t-1} = g_{t-1} + \tilde{g}_{t-1}$.

Now consider the case where incumbent investment may include greenfield plant as well as incremental expansion of existing facilities. Firms meet part of their investment needs with greenfield plant and then cover the remainder with incremental expansion. New plants are lumpy, with size determined largely by technological factors. Let Z^I be the vector of factors that determine the scale of new plants and the relative advantages of new plant versus incremental expansion for incumbent firms. For example, Z^I might include the minimum efficient plant size relative to the total industry capacity stock and the magnitude of technical improvements embodied in new vintages of plant.

Given the lag for greenfield plant construction, an investment decision must be made in year $t-2$ for the plant to open in year t. We make this investment decision a linear function of capacity utilization and anticipated growth at time $t-2$:

$$I^t_{t-2} = \alpha^I + \beta^I_u U_{t-2} + \beta^I_g g_{t-2} + \beta^I_{\tilde{g}} \tilde{g}_{t-2} + \beta^I_z Z^I_{t-2}. \tag{12}$$

In the following year, $t-1$, firms determine incremental investment:

$$\dot{K}^{*t}_{t-1} = \alpha + \beta_u U_{t-1} + \beta_g g_{t-1} + \beta_{\tilde{g}} \tilde{g}_{t-1} + \gamma I^t_{t-2}. \tag{13}$$

Note that all capacity additions completed before the start of year t reduce $\dot{K}^{*t}_{t-1}$ through their effect on capacity utilization, U_{t-1}. The parameter γ indicates the extent to which incumbents adjust incremental investment to accommodate lumpy new plants scheduled to open during year t. Note that investment has a recursive structure, with new plant investment initiated in year $t-2$, followed by incremental investment in year $t-1$, which is targeted to reach the desired capacity stock $\hat{K}_{t+1}$ by the end of year t. If incremental investment is perfectly divisible and flexible both upward and downward, then $\gamma = -1$, i.e., greenfield plant investments initiated in year $t-2$ are perfectly accommodated through reductions in incremental investment the following year.

In practice, there are numerous reasons why such perfect accommodation might fail to occur. With multiple incumbents information or coordination problems may arise. There may also be strategic investment directed against entrants or existing rivals, as we consider below. These features of competitive interaction would lead to incomplete accommodation ($\gamma > -1$). Moreover, if incremental investments are lumpy and it is better to be above the target capital stock than below it, accommodation will be incomplete. An additional factor in the chemical industry is that incremental increases in capacity frequently stem from efforts to eliminate bottlenecks and from other learning-based improvements that arise in the normal course of plant operations. These incremental expansions are often pursued irrespective of current capacity requirements. Thus, they would exhibit little accommodation to rivals' expansions and would comprise an error term in the incremental investment equation.

A final feature limiting accommodation is that existing plant capacity tends to be inflexible downward. Given sunk investment costs, firms in a growing market are unlikely to make permanent plant closures in response to brief market downturns or temporary overcapacity arising from completion of lumpy new plants. In other words, $\dot{K}^{*t}_{t-1}$, the desired rate of investment, will seldom actually be negative. This problem can be coped with econometrically by treating observations with zero or negative net investment identically and using Tobit analysis. We also examine a subsample of the data with relatively rapid market growth, where desired investment was likely to have been positive.

We now expand the model to include investment by entrants, who by definition can invest only in greenfield plant. The full set of equations to account for all capacity completed during year t is as follows.

New plants:

$$E^t_{t-2} = \alpha^E + \beta^E_u U_{t-2} + \beta^E_g g_{t-2} + \gamma^E_I I^t_{t-2} + [\beta^E_{\tilde{g}} \tilde{g}_{t-2} + \beta^E_z Z^E_{t-2} + \epsilon^E_{t-2}], \tag{14}$$

$$I^t_{t-2} = \alpha^I + \beta^I_u U_{t-2} + \beta^I_g g_{t-2} + \gamma^I_E E^t_{t-2} + [\beta^I_{\tilde{g}} \tilde{g}_{t-2} + \beta^I_z Z^I_{t-2} + \epsilon^I_{t-2}]. \tag{15}$$

Incremental expansions:

$$\dot{K}^t_{t-1} = \alpha + \beta_u U_{t-1} + \beta_g g_{t-1} + \gamma^E_{t-2} E^t_{t-2} + \gamma^I_{t-2} I^t_{t-2} + \gamma^E_{t-1} E^{t+1}_{t-1} + \gamma^I_{t-1} I^{t+1}_{t-1} + [\beta_{\tilde{g}} \tilde{g}_{t-1} + \epsilon_{t-1}]. \tag{16}$$

The two equations for new plant investment are determined simultaneously in year $t - 2$. In the absence of strategic behavior the equation for incremental investment is determined recursively in the following year. The vector Z^E represents (unobserved) factors that might influence entry, such as access to process technology and the incentives for upstream and downstream firms to integrate vertically;[9] it also includes determinants of efficient plant size. The vectors Z^E and Z^I include some common elements, such as the availability of more efficient manufacturing processes that might stimulate simultaneous (but nonstrategic) plant construction by both entrants and incumbents. The unobserved variables and error terms are enclosed in brackets in the equations.

Equations (14)–(16) provide the basic equations to be estimated at the industry level in the empirical analysis. We test for strategic behavior by comparing the estimated γ coefficients with those expected under the maintained hypothesis of nonstrategic investment. Under this maintained hypothesis (and in the absence of strategic investment to deter mobility), capacity additions by incumbents and entrants are indistinguishable; thus, the γ coefficients should be equal for incumbents and entrants. In the new-plant equations nonstrategic firms would avoid simultaneous construction of lumpy greenfield plants, so that $\gamma^E_I = \gamma^I_E < 0$.[10] In the incremental investment equation, with perfect coordination and nonstrategic behavior, full accommodation would occur ($\gamma^E_{t-2} = \gamma^I_{t-2} = -1$). Under more realistic assumptions of imperfect coordination and lumpy investment, accommodation would be incomplete, and would thus cause γ^E_{t-2} and γ^I_{t-2} to lie in the range between -1 and 0.[11] In the nonstrategic case we also expect $\gamma^E_{t-1} = \gamma^I_{t-1} = 0$. This is so since with a two-

---

[9] Most entry into the sample industries occurred through vertical integration.

[10] Note, however, that the empirical estimates of these accommodation terms might be positively biased, given that E^t_{t-2} and I^t_{t-2} share a common error structure through expectations in $\tilde{g}$ and possible technological shocks in Z.

[11] Common expectations across the error terms of the equations could contribute some additional positive bias to these γ coefficients. But in the absence of strategic investment, these biases should be the same for entrants and incumbents.

year gestation lag for new plants, incremental investment need not be adjusted to accommodate greenfield plant capacity until shortly before those plants are completed.

□ **Strategic investment.** Now consider the case of strategic investment designed to deter or to limit the extent of entry.[12] In a growing industry such investment could take several forms. Incumbents might build greenfield plants preemptively, thereby denying investment niches to new entrants. More generally, incumbents could add greenfield or incremental capacity well ahead of demand and threaten major price cuts should entry occur. Finally, incumbents might respond aggressively to actual entry to reduce the growth rate of new entrants and to prevent entry by additional firms.[13] The first two strategies, which conform to the conventional excess-capacity deterrence argument, are examined in detail in Lieberman (1987a), which finds little supporting evidence. Here I focus primarily on incumbents' response to the initiation of entry.

In the context of the model, postentry strategic investment by incumbents should be indicated by γ coefficients that differ from those expected under the maintained hypothesis. One possibility is that $\gamma^I_E > 0$, that is, rather than accommodate entrants' capacity, incumbents match that capacity with their own greenfield plant. One might, however, expect most mobility-deterring investment to take the form of incremental expansion, since such investment can be mobilized quickly and constitutes the bulk of incumbent investment. Mobility deterrence implies that incumbents accommodate entrants to a lesser extent than they accommodate each other: $\gamma^E_{t-2} > \gamma^I_{t-2}$, $\gamma^E_{t-1} > \gamma^I_{t-1}$ and potentially, $\gamma^E_{t-2} > 0$, $\gamma^E_{t-1} > 0$.

We expect, moreover, to observe strategic behavior only in more concentrated industries. Denoting high-concentration industries by *hc* and low-concentration industries by *lc*, we obtain a set of hypotheses that can be tested as restrictions on the γ coefficients. Under the maintained hypothesis of nonstrategic investment we have:

Hypothesis 1. $\gamma^E_{lc} = \gamma^I_{lc} = \gamma^E_{hc} = \gamma^I_{hc}$; investments by entrants and incumbents are accommodated equally in both high- and low-concentration industries.

Rejection of this equality constraint suggests the existence of mobility-deterring investment. More specifically, we test:

Hypothesis 2. $\gamma^E_{hc} = \gamma^I_{hc}$.

Hypothesis 3. $\gamma^E_{lc} = \gamma^I_{lc}$.

If mobility-deterring investment occurred in high-concentration industries only, then Hypothesis 2 alone should be rejected, with $\gamma^E_{hc} > \gamma^I_{hc}$. We also test:

Hypothesis 4. $\gamma^E_{hc} = \gamma^E_{lc}$.

This should be rejected if mobility-deterring investment occurred in high-concentration industries only. Similarly, we should reject

Hypothesis 5. $\gamma^I_{hc} = \gamma^I_{lc}$,

with $\gamma^I_{hc} < \gamma^I_{lc}$ if concentration facilitated mutual accommodation of investment by incumbents in the absence of entry.

4. Empirical estimates of investment behavior

■ **Investment in greenfield plant.** Estimation of equations (14) and (15) presents serious econometric difficulties, as we must jointly estimate the undertaking of greenfield plant

---

[12] Strategic investment may also be directed against existing rivals; such investment is examined empirically in Gilbert and Lieberman (1987). The mobility-deterring investment examined here requires that incumbents act more aggressively toward new entrants than toward each other.

[13] Such tactics might also induce recent entrants to exit. Once the entrant's initial investment costs have been sunk, however, there is little incentive to exit, and such exit seldom occurred in the data sample.

investment and the scale at which the investment occurs. Greenfield plants are lumpy and infrequently built, particularly in concentrated industries. Moreover, greenfield plant size is determined largely by unobserved technological factors, which differ across products.[14] A simpler approach is to estimate the undertaking of greenfield plant investment by entrants and incumbents, as indicated by whether $E^t > 0$ or $I^t > 0$ in each observation year. Lieberman (1987a) gives a detailed justification for this approach, which we follow here.

Ignoring initially the interaction between entrant and incumbent investment, we estimate two separate investment equations based on the following logit specification:

$$y_t = \alpha + \beta_u U_{t-2} + \beta_g g_{t-2} + \beta_r 1/N_t + \beta_n N_t + \epsilon_t. \tag{17}$$

The dependent variable, y_t, is a dummy set equal to one if a greenfield plant was built during year t. As defined earlier, U_{t-2} and g_{t-2} represent capacity utilization and historical output growth observed during year $t - 2$. The rate of replacement investment is assumed proportional to N_t, the number of plants operating at the start of the observation year. The reciprocal of the number of plants, $1/N_t$, serves as a proxy for new plant "lumpiness."[15] When plants are more lumpy relative to total industry output, new plants are built less frequently, and a higher growth and capacity utilization threshold is required to justify new plant investment. In the absence of strategic behavior (and ignoring opportunities for incumbents to expand incrementally), the values of β_u, β_g, and β_r should be similar for entrants and for new plant investment by incumbents.[16]

The logit estimates appear in Table 2. All coefficients in equations 2.1 and 2.3 are significantly different from zero with the expected signs. Market growth and high-capacity

TABLE 2 Logit Analysis of Greenfield Plant Construction*

	2.1	2.2	2.3	2.4
Dependent Variable	$1(E^t > 0)$	$1(E^t > 0)$	$1(I^t > 0)$	$1(I^t > 0)$
c	−4.30‡	−4.21‡	−3.36‡	−3.34‡
	(.75)	(.81)	(.78)	(.83)
U_{t-1}		−.32		−.09
		(1.06)		(1.11)
U_{t-2}	2.82‡	3.03‡	1.84†	1.91†
	(0.84)	(1.08)	(.84)	(1.12)
g_{t-2}	4.26‡	4.26‡	2.92‡	2.91‡
	(.76)	(.76)	(.76)	(.76)
$1/N_t$	−2.78‡	−2.77‡	−4.31‡	−4.32‡
	(1.14)	(1.14)	(1.53)	(1.53)
N_t	.022‡	.022‡	.034‡	.034‡
	(.005)	(.005)	(.006)	(.006)
Log Likelihood	−362.96	−362.92	−352.95	−352.95
Mean of Dep. Var.	.194	.194	.202	.202
No. of Obs.	832	832	832	832

* Numbers in parentheses are asymptotic standard errors.

‡ Significant at the .01 level, one-tailed test.

† Significant at the .05 level, one-tailed test.

---

[14] Lieberman (1987b) shows that within each product class, the size of new greenfield plants increased over time at about 8% per year. This trend, which reflects gradual engineering progress, was reasonably consistent across products. On average, entrants built smaller plants than incumbents. This disparity proved uniform across concentration categories and appeared to stem from entrants' lack of production experience, which made them more conservative in their plant size choices.

[15] "Lumpiness" refers to the size of a new, efficient-scale plant, as a fraction of total industry output. Time series data on minimum efficient scale are not available, but $1/N_t$, the fraction of industry capacity corresponding to an average existing plant, is easily computed and is strongly correlated ($R = .58$) with the actual observations of new greenfield plant size relative to total industry output.

[16] Assuming that replacement investment is imperfectly "contestable," we expect β_n to be larger for incumbents.

utilization served as stimuli for new plant construction, and a higher threshold was required when plants were more "lumpy" as measured by $1/N$. Comparison of the coefficients in the entrant equation with those in the incumbent equation is impeded by the fact that the estimation procedure normalizes the variance of the stochastic disturbances to be the same. Because of this difficulty, I also estimated the coefficients by using a parameterization of the log-linear model (Amemiya, 1985) equivalent to two individual logit equations plus an added term corresponding to the ratio of the two disturbances. I performed a likelihood-ratio test by constraining β_u, β_g, and β_r to be identical (up to a multiplicative constant defined by the ratio of the disturbances) for entrants and incumbents. The null hypothesis of coefficient equality could not be rejected. This indicates that incumbents did not undertake greenfield plant investments to deter entry.[17]

We add U_{t-1} to the specification in Table 2 to examine the lag required for new plant investment. The U_{t-1} coefficients appear insignificantly different from zero, and thus reveal that once new plant construction was initiated in year $t-2$, firms carried their plans through to completion, even if capacity utilization fell during year $t-1$. This suggests that capacity expansions by incumbents immediately following announced entry would have failed to deter entrants with construction already in progress, but could have deterred other potential entrants who had not yet begun to build a plant.

☐ **Incremental expansions.** For stronger evidence about strategic investment, we must examine incremental expansions. I used Tobit analysis to estimate equation (16) for incremental investment. The dependent variable, $\dot{K}^t_{t-1}$, gives the amount of net incremental investment during year t, as a fraction of total capacity at the start of the year. To control for the downward inflexibility of existing plant capacity, I truncated $\dot{K}^t_{t-1}$ at zero for observations where the original value was negative. I thus treat observations with zero or negative net investment identically in the analysis.[18]

The estimates are in Table 3. The growth and capacity utilization coefficients appear positive and highly significant.[19] Both U_{t-1} and U_{t-2} are included as explanatory variables, since some incremental investment had a gestation lag of more than a year. The variable U_{t-1} has the larger coefficient, which confirms that in most instances the lag was roughly one year.

The accommodation coefficients are estimated for the full sample and for a subsample having market growth of more than 8% per year. The latter includes about half of the observations. There is evidence of postentry strategic investment in both samples, but it is statistically significant only in equation 3.3, the rapid growth case.

In equation 3.3 the E^t_{t-2} and I^t_{t-2} coefficients are negative (but close to zero) in low-concentration industries, with the entrant and incumbent values roughly equal. This suggests that greenfield plant investments made by entrants and incumbents were accommodated to a similar degree, with the extent of accommodation limited by imperfect information and coordination. As expected, the E^{t+1}_{t-1} and I^{t+1}_{t-1} coefficients are insignificantly different from zero.

In high-concentration industries, by comparison, equation 3.3 shows considerable asymmetry in incumbents' response. Here, the I^t_{t-2} coefficient appears strongly negative, which indicates that incumbents cut back on incremental investment to accommodate new

---

[17] A more extensive parameterization of the log-linear model was also estimated to test for the occurrence of simultaneous greenfield plant investment by entrants and incumbents. Weak evidence of such investment bunching was detected, which may reflect common demand expectations, technological shocks, or strategic behavior.

[18] About one-fourth of the original values are zero; an additional 17% were originally negative but subsequently truncated to zero.

[19] The coefficients are smaller than the model (equation (10)) would suggest. The discrepancy is probably due to measurement error in the aggregate capacity and output data.

TABLE 3 **Tobit Analysis of Incremental Expansions***
(Dependent Variable: $\dot{K}^t_{t-1}$)

	3.1	3.2	3.3
Sample	All Observations	All Observations	High Growth†
Constant	−.47	−.47	−.52
	(.04)	(.04)	(.06)
U_{t-1}	.16	.16	.23
	(.04)	(.04)	(.05)
U_{t-2}	.08	.09	.09
	(.03)	(.03)	(.05)
g_{t-1}	.25	.25	.24
	(.03)	(.03)	(.04)
Low Concentration			
I^t_{t-2}		−.26	−.28
		(.10)	(.12)
E^t_{t-2}		−.12	−.29
		(.10)	(.17)
I^{t+1}_{t-1}		.12	.15
		(.08)	(.09)
E^{t+1}_{t-1}		.02	−.05
		(.12)	(.14)
High Concentration			
I^t_{t-2}		−.24	−.60
		(.06)	(.27)
E^t_{t-2}		.09	.13
		(.13)	(.15)
I^{t+1}_{t-1}		.06	.03
		(.06)	(.09)
E^{t+1}_{t-1}		.23	.48
		(.11)	(.19)
Log Likelihood	171.13	182.11	132.89
No. of Obs.	800	800	375

* Numbers in parentheses are estimated standard errors.

† High-growth subsample includes observations with $g_{t-1} > .08$.

plants built by each other. In contrast, the E^t_{t-2} and E^{t+1}_{t-1} coefficients are both positive: on average, incumbents accelerated their investment after the initiation of entry. The E^{t+1}_{t-1} coefficient suggests an increase in incumbent investment during the year the entrant initiated plant construction, while the E^t_{t-2} coefficient reflects an increase in incumbent investment during the following year, as the entrant's plant was nearing completion. Thus, the results

TABLE 4 **Test of Coefficient Restrictions**
in Incremental Investment Equation*

Hypothesis	Restriction	log L	Reject	P-value
—	none	132.9	—	—
1	$\gamma^E_{hc} = \gamma^I_{hc} = \gamma^E_{lc} = \gamma^I_{lc}$	124.2	yes	.01
2	$\gamma^E_{hc} = \gamma^I_{hc}$	126.6	yes	.01
3	$\gamma^E_{lc} = \gamma^I_{lc}$	132.0	no	—
4	$\gamma^E_{hc} = \gamma^E_{lc}$	126.2	yes	.01
5	$\gamma^I_{hc} = \gamma^I_{lc}$	131.3	no	—

* Likelihood-ratio tests based on Tobit equation 3.3. Each γ in the table represents a vector of two coefficients (e.g., γ^E_{hc} represents $[\gamma^E_{t-2}, \gamma^E_{t-1}]$ for high-concentration industries).

show that in concentrated industries incumbents accommodated greenfield plant investments made by each other, but reacted aggressively toward comparable plants constructed by entrants.

The results of formal hypothesis tests, based on coefficient restrictions under the maintained hypothesis, are shown in Table 4. The test results confirm the existence of strategic investment, with a significantly more aggressive response toward entry in concentrated industries. But the hypothesis that incumbents accommodated each other to a relatively greater degree in concentrated industries fails to prove statistically significant.

5. Excess capacity

■ **Definition and empirical approach.** The results in this section show that strategic investment in concentrated industries led to postentry excess capacity.[20] We also examine whether incumbents in concentrated industries commonly held excess capacity for deterrence purposes in advance of actual entry.

"Excess capacity" has no universally accepted definition, but it is frequently regarded as capacity above that required to produce the firm's current level of output at minimum cost (Cassels, 1937; Morrison, 1985). In other words, excess capacity exists when firms operate on the declining portion of their short-run average total cost curve. In the chemical industry marginal cost for a given plant is roughly constant over the range up to the plant's rated capacity, at which point the cost curve becomes vertical.[21] Average total cost falls over this range. Thus, the difference between a plant's rated capacity and its actual output can be classified as "excess capacity."

On the basis of this definition, I computed two specific measures of excess capacity. Summing across plants for each product and taking account of the annual nature of the data, I computed S_t for each product and observation year as

$$S_t = \begin{cases} \dfrac{K_t - Q_t}{K_t} & \text{if} > 0, \\ 0 & \text{otherwise.} \end{cases}$$

That is, excess capacity existed whenever industry capacity at the start of observation year t exceeded actual industry output during the course of the year. The second measure of excess capacity, S'_t, was computed similarly, but adjusted for differences in the lumpiness of new capacity. When capacity is lumpy, even with perfect coordination firms might hold up to one excess "lump" for nonstrategic reasons. To compute S'_t I omitted from K_t the largest capacity increment added during the prior three years (or during the most recent year of investment if no expansion occurred during the prior three-year period). Excess capacity was a common occurrence in the data sample: S_t exceeds zero for 90% of the observations, and S'_t exceeds zero for 69%.

To assess the strategic component of excess capacity, I regressed S_t on D_{hc} and lagged observations of E^t and I^t. I included additional control variables to account for excess capacity held for nonstrategic reasons.

Firms hold nonstrategic excess capacity when demand is cyclical or stochastic, or when plants are inherently lumpy or subject to economies of scale. Optimal excess capacity increases with demand variability under structural conditions ranging from monopoly (Smith, 1969, 1970) to perfect competition (Sheshinski and Drèze, 1976). If plants are lumpy, tem-

---

[20] The investment equations estimated in Section 4 suggest that excess capacity would have arisen following entry into high-concentration industries, unless incumbents made price cuts of sufficiently large magnitude. Postentry price cutting did occur (Lieberman, 1984), but it was insufficient to absorb the additional capacity.

[21] Plants can sometimes be temporarily operated above rated capacity (e.g., by deferring maintenance). Also, costs for some chemical processes are minimized when plants are operated slightly below rated capacity.

porary excess capacity normally arises after new plants are constructed, particularly if prices are not completely flexible (Manne, 1961; Freidenfelds, 1981). The dependent variable, S'_t, corrects in part for such lumpiness.

I included two variables to control for nonstrategic excess capacity stemming from demand variability.

$1 - \bar{U}_t$ = one minus the Federal Reserve Board index of average capacity utilization in primary process manufacturing during the observation year; and

σ_t = the standard deviation of year-to-year rates of output growth for the product over the period from $t - 5$ to $t - 1$.

The $1 - \bar{U}_t$ measure gives the fraction of total U.S. capacity in primary processing industries that remained idle during the observation year. In the regressions it should control for excess capacity resulting from general macroeconomic downturns.[22] The measure σ_t should indicate excess capacity held to accommodate demand variability of the specific product. I also included a time trend (t) to capture possible time-related factors.[23]

□ **Empirical results on excess capacity.** The results of the excess capacity analysis appear in Table 5. The dependent variables are serially correlated owing to temporal persistence of the capacity stock.[24] The dependent variables are also truncated, since I assume that excess capacity is nonnegative. Partial differencing was used to correct for serial correlation[25] and Tobit analysis to account for truncation. Table 5 shows that the two dependent variables and estimation methods provided similar results.

The nonstrategic control variables in Table 5 perform as expected. Excess capacity was strongly linked to business cycle fluctuations, as recorded by $1 - \bar{U}_t$. Product-specific demand variability, as measured by σ_t, led firms to hold additional excess capacity. There was also some tendency for excess capacity to increase over time.

The high-concentration dummy proves insignificant in the regressions. This indicates that incumbents in concentrated industries did not, in general, hold an increased margin of excess capacity as a deterrent to entry.[26]

The E and I coefficients trace the time path of excess capacity following the construction of greenfield plants by entrants and incumbents. The coefficients show the amount of excess capacity as a rough proportion of total greenfield capacity added. Note, however, that positive E coefficients do not necessarily imply that entrants' capacity was idle; the excess capacity could have been held by either entrant or incumbent firms.

With S_t as the measure of excess capacity, the E and I coefficients reveal that completion of new plants by either group of firms led to a temporary increase in excess capacity. But the magnitude and duration of this excess capacity was strongly influenced by industry

---

[22] Although some products in the sample are included in the Federal Reserve Board index, they constitute a minuscule component, so that there is no serious simultaneity problem when $1 - \bar{U}_t$ is included in the regressions.

[23] One might also expect to observe greater nonstrategic excess capacity for products where high transport costs lead to regional production, or where plants with high marginal cost are held to service peak demand. Although these factors do play a role in the chemical industry, they are relatively unimportant in the data sample. To control partially for these effects, I estimated the model with a separate constant term for each product. These constant terms were not jointly significant at the .10 level, and their inclusion had little effect on the other coefficient estimates.

[24] Serial correlation is not a problem in the investment equations in Section 4, which focus on annual changes in industry capacity.

[25] The Cochrane-Orcutt partial differencing procedure was adapted to account for gaps between product panels in the sample.

[26] To examine possible nonlinear relations between excess capacity and concentration, I also tested the Herfindahl index (H) and the square of the index (H^2) in the excess capacity equation. When I used S_t as the dependent variable, this quadratic relation proved statistically significant, and the coefficients indicated that excess capacity reached a maximum at a Herfindahl concentration level of about .5. But this relation was not significant when I used S'_t, which adjusts for lumpiness, as the dependent variable.

TABLE 5 Excess-Capacity Regressions*

	5.1	5.2	5.3	5.4
Dependent Variable	S_t	S_t	S'_t	S'_t
Estimation Method	C-O	C-O	C-O	Tobit
Constant	−.18	−.38	−.48	−.58
	(.11)	(.12)	(.11)	(.06)
t	.0017	.0042	.0051	.0051
	(.0015)	(.0016)	(.0016)	(.0009)
$1 - \bar{U}_t$	1.15	1.12	1.02	1.40
	(.07)	(.07)	(.06)	(.12)
σ_t	.29	.28	.24	.28
	(.06)	(.06)	(.06)	(.07)
D_{hc}	.013	.021	.012	.019
	(.010)	(.013)	(.013)	(.012)
Low Concentration				
E^{t-1}		.31	.24	.24
		(.06)	(.06)	(.12)
E^{t-2}		.13	.12	.11
		(.07)	(.07)	(.12)
E^{t-3}		.03	.01	−.01
		(.06)	(.06)	(.12)
I^{t-1}		.37	.15	.17
		(.05)	(.05)	(.10)
I^{t-2}		.10	.03	.02
		(.06)	(.05)	(.10)
I^{t-3}		.03	−.04	−.20
		(.05)	(.05)	(.11)
High Concentration				
E^{t-1}		.48	.38	.40
		(.08)	(.08)	(.15)
E^{t-2}		.46	.41	.51
		(.09)	(.09)	(.15)
E^{t-3}		.20	.11	.24
		(.08)	(.07)	(.14)
I^{t-1}		.19	−.05	−.38
		(.06)	(.06)	(.15)
I^{t-2}		.11	−.02	−.14
		(.07)	(.07)	(.11)
I^{t-3}		.06	−.08	−.25
		(.06)	(.05)	(.12)
ρ	.69	.72	.73	
S.S.R.	5.154	4.367	4.106	
Mean of Dep. Var.	.18	.18	.11	.11
% Obs. = 0	10%	10%	31%	31%
No. of Obs.	800	800	800	800

* Numbers in parentheses are estimated standard errors, which are biased in the case of the Tobit model.

concentration. In concentrated industries there was relatively more excess capacity following entry and less excess capacity following incumbent expansions.

I tested the significance of these differences by imposing on equation 5.2 sets of equality constraints similar to those applied to the investment equations. The test results, which appear in Table 6, confirm the main conclusions of the investment analysis in Section 4. In concentrated industries greater excess capacity developed after entry than after comparable plant openings by incumbents (Hypothesis 2a). Postentry excess capacity was greater in high-concentration industries than in low-concentration industries (Hypothesis 4a). There were also significant differences between high- and low-concentration industries in the

TABLE 6 Test of Coefficient Restrictions in Excess Capacity Regression*

Hypothesis	Restriction	SSR	Reject	P-Value
—	none	4.367	—	—
1a	$\beta^E_{hc} = \beta^I_{hc} = \beta^E_{lc} = \beta^I_{lc}$	4.483	yes	.01
2a	$\beta^E_{hc} = \beta^I_{hc}$	4.415	yes	.03
3a	$\beta^E_{lc} = \beta^I_{lc}$	4.373	no	—
4a	$\beta^E_{hc} = \beta^E_{lc}$	4.415	yes	.03
5a	$\beta^I_{hc} = \beta^I_{lc}$	4.409	yes	.05

* Likelihood-ratio tests based on regression 5.2. Each β in the table represents a vector of three coefficients (e.g., β^E_{hc} represents the vector of coefficients for E^{t-1}, E^{t-2}, E^{t-3} in high-concentration industries).

amount of excess capacity that developed when incumbents opened new plants (Hypothesis 5a). Thus, there is strong evidence that incumbents used excess capacity as a strategic weapon directed against new entrants, with most of the relevant investment taking place after entry was initiated, rather than before.

6. Summary and conclusions

■ Theoretical work in industrial organization offers diverse predictions regarding the response of incumbents to new entry. The empirical results presented here help to illuminate theory by documenting the responses that occur most commonly in practice. The results pertain specifically to the chemical processing sector, but they should be applicable to other industries where capacity represents a key strategic variable.

The finding that incumbents in concentrated industries accelerated investment following entry is consistent with dynamic models of mobility deterrence (Spence, 1979; Fudenberg and Tirole, 1983). There is, nevertheless, little evidence that incumbents built excess capacity for deterrence purposes before the initiation of entry. Thus, the findings support mobility-deterrence theories rather than the standard excess-capacity, entry-deterrence argument.

The results also indicate that incumbents coordinated their own investment more effectively in concentrated industries. Excess capacity was largely avoided in these industries when incumbents opened greenfield plants. This is consistent with the finding of Gilbert and Lieberman (1987) that firms with larger market shares exhibited greater coordination of investment.

It is important to recognize that the responses documented here represent averages across numerous observations. The actual behavior of individual firms in the sample varied greatly. The statistical results reveal which responses were most common, but they do not rule out specific types of behavior or the models that imply such behavior. The actual behavior of firms in oligopolistic markets is far more rich and complex than can be captured by any single theoretical or empirical model.

References

AMEMIYA, T. *Advanced Econometrics.* Cambridge: Harvard University Press, 1985.

BULOW, J., GEANAKOPLOS, J., AND KLEMPERER, P. "Multimarket Oligopoly: Strategic Substitutes and Complements." *Journal of Political Economy,* Vol. 93 (1985a), pp. 488–511.

———, ———, AND ———. "Holding Idle Capacity to Deter Entry." *Economic Journal,* Vol. 95 (1985b), pp. 178–182.

CASSELS, J.J. "Excess Capacity and Monopolistic Competition." *Quarterly Journal of Economics,* Vol. 51 (1937), pp. 426–443.

CAVES, R.E. AND PORTER, M.E. "From Entry Barriers to Mobility Barriers: Conjectural Decisions and Contrived Deterrence to New Competition." *Quarterly Journal of Economics,* Vol. 91 (1977), pp. 243–261.

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

EATON, B.C. AND LIPSEY, R.G. "Exit Barriers Are Entry Barriers: The Durability of Capital as a Barrier to Entry." *Bell Journal of Economics,* Vol. 11 (1980), pp. 721–729.

FREIDENFELDS, J. *Capacity Expansion: Analysis of Simple Models with Applications.* New York: Elsevier, 1981.

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 ———. "The Fat-Cat Effect, the Puppy-Dog Ploy, and the Lean and Hungry Look." *American Economic Review,* Vol. 74 (1984), pp. 361–366.

GELMAN, J. AND SALOP, S. "Judo Economics: Capacity Limitation and Coupon Competition." *Bell Journal of Economics,* Vol. 14 (1983), pp. 315–325.

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

——— AND LIEBERMAN, M.B. "Investment and Coordination in Oligopolistic Industries." *RAND Journal of Economics,* Vol. 18 (1987), pp. 17–33.

KIRMAN, W.I. AND MASSON, R.T. "Capacity Signals and Entry Deterrence." *International Journal of Industrial Organization,* Vol. 4 (1986), pp. 25–44.

KREPS, D.M. AND WILSON, R. "Reputation and Imperfect Information." *Journal of Economic Theory,* Vol. 27 (1982), pp. 253–279.

LIEBERMAN, M.B. "The Learning Curve and Pricing in the Chemical Processing Industries." *RAND Journal of Economics,* Vol. 15 (1984), pp. 213–228.

———. "Excess Capacity as a Barrier to Entry: An Empirical Appraisal." *Journal of Industrial Economics,* Vol. 35 (1987a), pp. 607–627.

———. "Market Growth, Economies of Scale, and Plant Size in the Chemical Processing Industries." *Journal of Industrial Economics,* Vol. 36 (1987b), pp. 175–191.

MANNE, A.S. "Capacity Expansion and Probabilistic Growth." *Econometrica,* Vol. 29 (1961), pp. 632–649.

MASSON, R.T. AND SHAANAN, J. "Excess Capacity and Limit Pricing: An Empirical Test." *Economica,* Vol. 53 (1986), pp. 365–378.

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

MILGROM, P. AND ROBERTS, J. "Predation, Reputation, and Entry Deterrence." *Journal of Economic Theory,* Vol. 27 (1982), pp. 280–312.

MODIGLIANI, F. "New Developments on the Oligopoly Front." *Journal of Political Economy,* Vol. 66 (1958), pp. 215–232.

MORRISON, C.J. "On the Economic Interpretation and Measurement of Optimal Capacity Utilization with Anticipatory Expectations." *Review of Economic Studies,* Vol. 52 (1985), pp. 295–310.

PORTER, M.E. *Competitive Advantage.* New York: Free Press, 1985.

SALOP, S.C. "New Directions in Industrial Organization: Strategic Entry Deterrence." *American Economic Review,* Vol. 69 (May 1979), pp. 335–338.

SHESHINSKI, E. AND DRÈZE, J.H. "Demand Fluctuations, Capacity Utilization, and Costs." *American Economic Review,* Vol. 66 (1976), pp. 731–742.

SMITH, K.R. "The Effect of Uncertainty on Monopoly Capital Stock and Utilization of Capital." *Journal of Economic Theory,* Vol. 1 (1969), pp. 48–59.

———. "Risk and the Optimal Utilization of Capital." *Review of Economic Studies,* Vol. 37 (1970), pp. 253–259.

SPENCE, A.M. "Entry, Capacity, Investment, and Oligopolistic Pricing." *Bell Journal of Economics,* Vol. 8 (1977), pp. 534–544.

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

SPULBER, D.F. "Capacity, Output, and Sequential Entry." *American Economic Review,* Vol. 71 (1981), pp. 503–514.

WENDERS, J.T. "Excess Capacity as a Barrier to Entry." *Journal of Industrial Economics,* Vol. 20 (1971), pp. 14–19.

WILLIAMSON, O.E. "Predatory Pricing: A Strategic and Welfare Analysis." *Yale Law Journal,* Vol. 87 (1977), pp. 284–340.