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EXCESS CAPACITY AS A BARRIER TO ENTRY: AN EMPIRICAL APPRAISAL*

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This paper examines excess capacity barriers to entry and investment dynamics in a sample of thirty-eight chemical product industries. Logit and log-linear models of investment behavior are estimated, and specific case examples are considered. The results show that incumbents rarely built excess capacity pre-emptively in an effort to deter entry. In general, entrants and incumbents exhibited similar investment behavior.

I. INTRODUCTION

It was not inevitable that [Alcoa] should always anticipate increases in the demand for ingot and be prepared to supply them. Nothing compelled it to keep doubling and redoubling its capacity before others entered the field. It insists that it never excluded competitors; but we can think of no more effective exclusion than to progressively embrace each new opportunity as it opened, and to face every newcomer with new capacity already geared into a great organization, having the advantage of experience, trade connections and the elite of personnel.

Judge Learned Hand,
U.S. vs. Alcoa, 1945.

DOES EXCESS capacity deter entry? And if so, under what conditions is it in the interest of incumbent firms to maintain excess capacity as an entry deterrent? The potential use of excess capacity as an entry barrier has attracted considerable attention as a theoretical issue in industrial economics. However, little empirical evidence has been available. This paper examines the role of excess capacity as an entry deterrent in 38 chemical product industries over a period of more than two decades. The extensive data sample focuses primarily on industries with high fixed costs, sizeable economies of scale, and a relatively small number of producing firms—in short, industries where excess capacity should have its most potent effects, if it proves effective at all.

The paper is organized as follows. Section II surveys the literature on excess capacity as a barrier to entry. Section III describes the chemical industry sample and the variables used in the study. Section IV summarizes the data on market growth and capacity utilization rates prior to the construction of new plants by entrants and incumbent firms. The data show

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that in industries with "lumpier" plants, higher rates of market growth and capacity utilization were required to elicit construction of new plants. However, entrants and incumbents had comparable decision thresholds for new plant investment. This suggests the absence of strategic investment by incumbents to deter entry. In section V, the analysis is formalized as a logit model, which is estimated for new plants constructed by entrants and incumbents. In section VI, the data sample is screened to identify specific cases where incumbents may have maintained chronic excess capacity as an entry barrier. This screening uncovers few products where excess capacity appears to have been held in an effort to deter entry, and even fewer cases where it proved effective for this purpose. Conclusions are presented in section VII.

II. THEORY AND PRIOR EMPIRICAL EVIDENCE

Recent theoretical work in industrial organization offers a rich set of predictions on the role of excess capacity in entry deterrence. However, empirical documentation has been quite sparse. The primary purpose of this study and related work (Lieberman [1986], Gilbert and Lieberman [1987]) is to assess the frequency with which the behaviors identified in theory actually arise in practice.

Firms may construct excess capacity for both strategic and non-strategic reasons. Profit-maximizing firms hold non-strategic excess capacity in markets where demand is cyclical or stochastic, or where plants are inherently lumpy or subject to economies of scale. Optimal excess capacity increases with demand variabilty under a range of structural conditions including monopoly (Smith [1969, 1970]) and perfect competition (Sheshinski and Dreze [1976]). If plants are lumpy, temporary excess capacity normally arises after new plants are constructed, particularly if prices are not completely flexible (Manne [1961], Freidenfelds [1981]). If more than one production technology is available, plants with low fixed but high variable costs may be held in reserve to serve periods of peak demand. Lieberman [1985] shows that in the chemical industry, variations in capacity utilization across products and over time stem largely from these non-strategic motives. The maintained hypothesis of this paper is that excess capacity is non-strategic in nature.

Strategic excess capacity may be built either to deter new entry or to pre-empt existing rivals. The basic entry deterrence argument (Wenders [1971], Spence [1977], Salop [1979], Eaton and Lipsey [1979], Spulber [1981], Perrakis and Warskett [1983], Lyons [1986]) is that excess capacity enables incumbents to threaten to expand output and cut prices following entry, thereby making entry unprofitable. Deterrence is achieved by intensifying the post-entry competition anticipated by the entrant. This hypothesis, that excess capacity is held by incumbents *prior* to announced entry, is the primary strategic hypothesis examined in this paper.

Several theoretical objections to this "pre-entry excess capacity" hypothesis have been raised. Dixit [1980] argues that under linear demand and cost conditions, it is not in the interest of incumbents to increase output following entry. However, Bulow, *et al.* [1985a], [1985b] show that under alternative demand assumptions it proves rational for incumbents to expand output following entry, thereby utilizing available excess capacity.

A second critique of the excess capacity argument is that when there is more than one incumbent, "free-rider" problems may reduce the incentives of incumbents to hold excess capacity, which is in effect a public good (Waldman [1983], McLean and Riordan [1985]). However, other work suggests that these free-rider problems may not be serious, or may be counterbalanced by various incentives (Gilbert and Vives [1986], Eaton and Ware [1985], Waldman [1987]). Kirman and Masson [1986] show that excess capacity may actually prove more effective as an entry deterrent when the industry is structured as a loose oligopoly, since this increases the risk that collusive pricing agreements will unravel if entry occurs.

Market growth and depreciating capital both reduce the potency of excess capacity as an entry barrier. If capital has a limited life, this shortens the post-entry period over which excess capacity can be used, thereby reducing the magnitude of the deterrent (Eaton and Lipsey [1980], [1981]). Similarly, steady demand growth erodes existing excess capacity, unless replenished by additional investment. If growth is rapid and new plants have a long construction lead time, by the date the entrant's plant is completed, excess capacity may have fallen well below its original level. Moreover, if demand growth is stochastic, a large, unanticipated upward shift in demand can absorb the excess capacity held by incumbents, thereby creating a window for new entry.

Available empirical evidence on the excess capacity hypothesis is extremely limited. Hilke [1984] regressed entry rates on excess capacity and other variables for a 16 industry sample. The excess capacity coefficient proved negative, but insignificant at standard statistical levels. Respondents to an industry questionnaire survey by Smiley [1986] indicated that excess production capacity was the least frequently chosen of a number of alternative entry deterrence strategies in industries with mature products.

Capacity built by incumbents *after* the announcement of entry may also serve entry-deterrence objectives. If incumbents have a shorter construction lead time than entrants (e.g., incumbents can expand existing plant facilities more rapidly than an entrant can build a new plant) such behavior may be equivalent to (but less costly than) excess capacity held in advance of a specific entry threat. Even if initial entry occurs, by responding aggressively, incumbents may be able to establish a predatory reputation sufficient to deter further entry (Williamson [1977], Kreps and Wilson [1982], Milgrom and

Roberts [1982]), or to deter continued growth of the entrant (Caves and Porter [1977], Fudenberg and Tirole [1983], Spence [1979]). Lieberman [1986] gives empirical evidence that such post-entry investment and pricing responses were common in concentrated markets in the chemical industry sample.

A final motive for strategic excess capacity is to pre-empt existing rivals. In growing markets, firms that make early investments may be able to deter rivals from expanding, thereby gaining an increased share of industry output and profits (Porter and Spence [1982], Ghemawat [1984], Reynolds [1986], Gilbert and Lieberman [1987]). Alternatively, pre-emptive expansion may provide a signalling mechanism which helps to coordinate industry investment behavior (Smith [1981]).

Whether market growth is captured by entrants or incumbents depends on the rate at which profit declines with the number of firms, and the magnitude of incumbent adjustment costs relative to fixed costs of entry (Hause and DuRietz [1984], Nakao [1980]). Unfortunately, adjustment and entry costs are normally unobservable in practice. In general, however, empirical studies have shown a strong link between industry demand-growth and entry (e.g., Orr [1974], Duetsch [1984], Hause and DuRietz [1984]).[1]

III. DATA SAMPLE AND COMPUTATION OF VARIABLES

The data sample covers the 38 chemical products listed in Table I. There are approximately 20 years of coverage for each product. The starting year varies by product as shown in Table I; the last full year of coverage is 1982.[2]

The chemical product industries included in the sample bear more than a passing resemblance to the stylized industries of economic theory. All products in the sample are homogeneous and undifferentiated.[3] Production capacities are well defined; chemicals with production processes involving significant joint products have been excluded, as have those where production capacity can be switched from one product to another in response to shifts in market demand. Unit variable costs for any given plant tend to be relatively constant up to the level defined by its full production capacity. However, plants for a given product may differ in operating costs, reflecting differences in technology and age of plant.

Output was often consumed captively in firms' downstream operations, but for all products at least 25 percent of industry output was sold through

[1] For a survey of the empirical entry literature, see Geroski [1983].

[2] The basic data include production capacity by product, plant, firm and year, and total industry output for each product and year. The capacity data are primarily from annual issues of the *Directory of Chemical Producers*, published by SRI International. The output data are from various US government sources, including *Synthetic Organic Chemicals*, *Current Industrial Reports*, and *Minerals Yearbook*. These sources are described in detail in Lieberman [1982].

[3] A few products such as polyethylene and polyester fibers are slightly differentiated across producers.

arms-length channels. Also, all products in the sample had positive net output growth from the earliest year of coverage through at least 1975. Thus,

TABLE I
PRODUCTS INCLUDED IN DATA SAMPLE

Product Name	Coverage Period	Average Number of Firms*	Average Number of Plants*	Number of New Plants Constructed by: Entrants**	Incumbents**
Organical Chemicals					
Acrylonitrile	1956–82	5	6	2	3
Aniline	1961–82	5	7	4	1
Bisphenol A	1959–82	4	5	3	2
Caprolactam	1962–82	3	3	2	0
Carbon Disulfide	1963–82	4	5	0	0
Cyclohexane	1956–82	8	10	14	3
Ethanolamines	1955–82	5	6	0	1
Ethylene	1960–82	23	36	9	10
Ethylene Glycol	1960–82	12	15	5	5
Formaldehyde	1962–82	16	46	4	31
Isopropyl Alcohol	1964–82	4	5	1	1
Maleic Anhydride	1958–82	7	8	6	2
Methanol	1957–82	10	13	4	6
Methyl Methacrylate	1966–82	3	5	0	1
Neoprene Rubber	1960–82	2	3	1	1
Pentaerythritol	1952–82	5	6	4	2
Phenol	1959–82	11	14	7	8
Phthalic Anhydride	1955–82	10	14	8	8
Polyethylene-LD	1957–82	12	19	7	10
Polyethylene-HD	1957–82	12	14	7	7
Sorbitol	1955–82	4	4	2	1
Styrene	1958–82	11	13	7	4
1,1,1-Trichloroethane	1966–82	3	4	1	1
Urea	1960–82	31	40	26	24
Vinyl Acetate	1960–82	6	7	4	4
Vinyl Chloride	1962–82	11	15	6	5
Inorganic Chemicals					
Ammonia	1960–82	56	84	28	40
Carbon Black	1964–82	8	31	3	7
Hydrofluoric Acid	1962–82	8	12	0	2
Sodium	1957–82	3	5	0	0
Sodium Chlorate	1956–82	8	11	10	5
Sodium Hydrosulfite	1964–82	5	6	1	4
Titanium Dioxide	1964–82	6	13	0	5
Synthetic Fibers					
Acrylic Fibers	1953–82	5	6	3	1
Nylon Fibers	1960–82	15	24	18	6
Polyester Fibers	1954–82	10	15	18	12
Metals					
Aluminum	1956–82	9	27	9	6
Magnesium	1954–82	3	4	4	0

* Rounded to nearest integer.
** Excludes first three years of coverage period.

the sample represents products with growing demand, although in a few cases output declined after 1975.

While the sample products span a range of producer concentration levels, most are quite concentrated relative to typical manufacturing industries in the US. Despite high concentration and generally high fixed costs, Table I shows that over the long term, entry was seldom completely deterred—only six products show an absence of entry over the coverage period. Moreover, the table indicates that when new plants were built, they were about as likely to be constructed by new entrants as by incumbent firms.

For the statistical analysis, the detailed plant capacity data were aggregated to the industry level for each year. Variables were defined as follows:

$DENT_{i,t}$, a dummy variable set equal to 1 if new entry into product i occurred during year t;

$DINC_{i,t}$, a dummy variable set equal to 1 if one or more incumbent firms completed a new plant for product i during year t;

$DNEW_{i,t}$, a dummy variable set equal to 1 if one or more entrants or incumbents completed a new plant during year t (that is, if either $DENT_{i,t}$ or $DINC_{i,t}$ is positive);

$g_{i,t}$, the average annual growth rate of industry output for product i over the three year period between year $t-3$ and year t;

$U_{i,t}$, the average rate of industry capacity utilization for product i during year t (that is, industry output during year t, divided by the average of beginning and end of year capacity);

$N_{i,t}$, the number of plants producing product i at the start of year t;

$1/N_{i,t}$, the reciprocal of the number of plants (proxy for plant "lumpiness");

t, the last two digits of the observation year minus 1971, the mean year in the sample, and

$N/M_{i,t}$, the average number of plants per firm.

Some additional, supplementary data were collected from the trade literature on announcements of entry that were eventually cancelled or never carried out.

IV. MARKET GROWTH AND CAPACITY UTILIZATION RATES REQUIRED TO ELICIT NEW ENTRY

Rapid demand growth and high capacity utilization signal the need for investment in additional plant capacity. This section examines rates of market growth and capacity utilization that prevailed in the sample just prior to the construction of new plants by entrants and incumbents. If entrants required a higher threshold rate of market growth or capacity utilization, this

TABLE II
GROWTH RATE OF INDUSTRY OUTPUT PRIOR TO COMPLETION OF NEW PLANTS BY ENTRANTS AND INCUMBENTS*

Number of Plants Operating at Start of Year t	*All Observations*	*Observations where Entrant Completed Plant During Year t*	*Observations where Incumbent Completed Plant During Year t*
$N \leqslant 4$	8.4% (125)	15.4% (18)	19.2% (6)
$4 < N \leqslant 8$	7.5% (252)	12.3% (23)	9.7% (24)
$N > 8$	8.3% (412)	11.5% (118)	9.6% (128)

* Average annual growth rate of industry output from year $t-4$ through year $t-1$ (that is, $g_{i,t-1}$). The number of observations in each category is listed in parentheses.

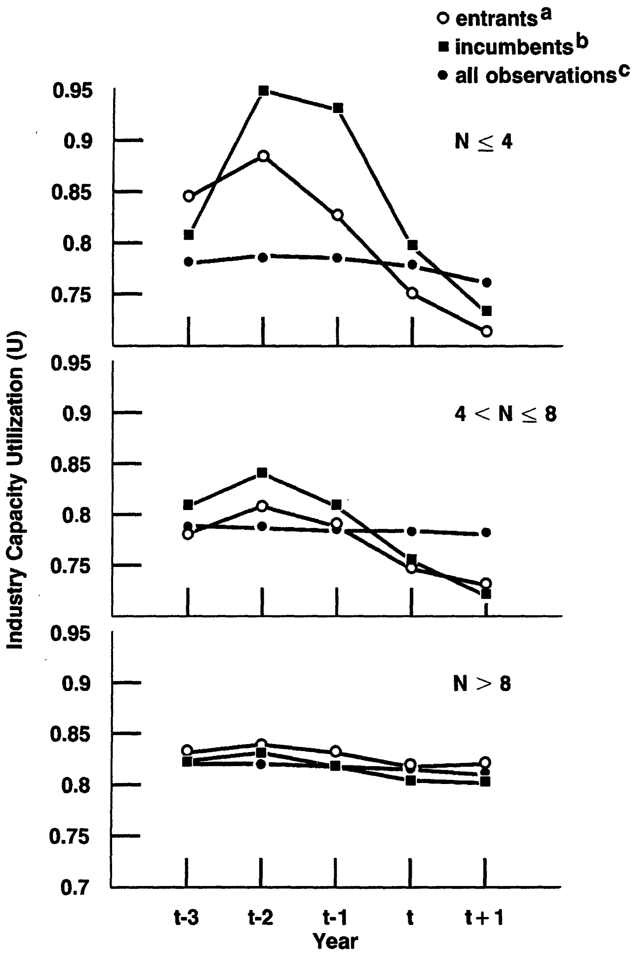
is evidence that entry barriers may have been in effect, or that incumbents expanded pre-emptively at a lower threshold in an effort to deter entry.

In industries where plants are lumpy, a period of overcapacity (or price cutting) typically follows the opening of new plants. Firms that behave non-strategically might be expected to minimize this excess capacity by requiring a higher rate of market growth or capacity utilization before committing to investment in a new plant. Thus, under the maintained hypothesis, higher rates of market growth and capacity utilization would be observed prior to the construction of new plants in industries where plants are lumpy. Moreover, in the absence of strategic entry deterrence behavior, entrants and incumbents would exhibit similar thresholds for new plant investment.

Table II summarizes the data on the growth rate of output over the three-year period prior to the completion of new plants by entrants and incumbents. In the chemical industry, there is, on average, a construction lag of about two years between the date when a decision is made to construct a new plant and the date when the plant becomes operational. Thus, plants that opened in year t were committed to in year $t-2$.[4] The table shows that: (1) new plants were constructed during periods of higher than average growth; (2) relatively higher growth rates were required to elicit construction of new plants in industries with "lumpier" plants; and (3) entrants and incumbents behaved similarly. These findings are all consistent with the maintained hypothesis.

In comparing the data for entrants and incumbents it is important to recognize that even in the absence of strategic deterrence behavior their decisions to build new plants are not exactly symmetric. This is because incumbents can often expand through incremental additions to existing plant, and they may construct new plants purely as replacement investment. These two factors would bias the average growth rates shown for incumbents

[4] Inclusion of output for year $t-1$ in the growth rate assumes that firms could project industry demand accurately through at least the middle of the construction cycle.



Notes: [a] Average of all industry observations where entrant completed plant during year *t*.
[b] Average of all industry observations where incumbent completed plant during year *t*.
[c] Average of all industry observations.
N equals the number of plants operating in the industry at the start of year *t*. See Table II for the number of observations in each category.

Figure 1
Relation Between Capacity Utilization and New Plant Construction by Entrants and Incumbents.

in the last column of Table II in opposite directions. The option of incremental expansion raises the threshold required by incumbents to justify construction of a lumpy new plant. The occurrence of replacement investment would lower the average growth rate shown for incumbents in Table II, since the timing of plant replacement is less sensitive to market growth. The net effect of these two influences is uncertain. Nevertheless, the table fails to show a lower expansion threshold for incumbents in highly concentrated industries ($N \leqslant 4$), where excess capacity might be expected to prove most effective as an entry deterrent.

Figure 1 traces the behavior of industry capacity utilization over a five-year period around the date when new plants were constructed. New plants became operational during year t; hence, their capacity and output are incorporated in the capacity utilization figure for half of year t and all of year $t+1$. The data show that the opening of new plants tended to depress industry capacity utilization below its mean level. This effect appears much greater in industries where plants were lumpy, as expected under the maintained hypothesis. The average capacity utilization level shown for "all observations" also declines slightly over time, reflecting the fact that mean utilization fell at about 0.003% annually in the data sample.[5]

Figure 1 also reveals that both entrants and incumbents built new plants during periods of high capacity utilization. Plant lumpiness influenced the threshold utilization level required to elicit new investment: In industries with lumpy plants, relatively large deviations from mean capacity utilization were required to trigger the construction of new plants. This is again consistent with non-strategic, profit-maximizing behavior.

Figure 1 shows that, in industries with lumpy plants ($N \leqslant 8$), incumbents set a higher capacity utilization threshold for new plant investment than did entrants. This probably reflects the fact that incumbents have the option of expanding existing plants incrementally, so they choose to build new plants only when the need for additional capacity is particularly great. In any case, there is no evidence that on average, incumbents constructed new plants at a lower threshold than entrants, as would be observed if incumbents expanded pre-emptively to deter new entry.

In addition to the data on the timing of plants actually constructed by new entrants, information was collected from the trade literature on entry that was announced but never carried out. A total of 15 such announcements were found where the existing number of plants in the industry was reasonably small, ranging from 4 to 8. Table III summarizes these data on cancelled announcements of entry.

Entry plans may have been cancelled for any number of reasons, but two main possibilities are: (1) industry growth dropped from anticipated levels soon after the announcement date, or (2) other firms pre-empted the invest-

[5] The "all observations" average capacity utilization levels shown in Figure 1 were computed as follows. The observation year t was indexed annually over the sample, starting three years after the initial year of coverage for each product, and finishing in 1981. For each observation year, the capacity utilization values for years $t-3$ through year $t+1$ were recorded; these values were then averaged for observations in each range of plant lumpiness, N. The temporal decline in utilization stems largely from the last few observations for each product, as the chemical industry fell into steep recession between 1979 and 1982.

TABLE III
INDUSTRY GROWTH AND CAPACITY UTILIZATION RATES ASSOCIATED WITH CANCELLED ANNOUNCEMENTS OF ENTRY*

	Average Industry Capacity Utilization in Each Year Following Announcement Year			
	$\hat{t}$	$\hat{t}+1$	$\hat{t}+2$	$\hat{t}+3$
*Cancelled Entry Observations**	0.822	0.818	0.782	0.767
Observations where Entry Occurred ($4 \leqslant N \leqslant 8$)**	0.822	0.795	0.746	0.737
All Observations ($4 \leqslant N \leqslant 8$)	0.785	0.779	0.776	0.772

	Average Industry Growth Rate	
	Year ($\hat{t}-3$) *through year* $\hat{t}$	*Year* $\hat{t}$ *through year* ($\hat{t}+3$)
*Cancelled Entry Observations**	11.5%	9.5%
Observations where Entry Occurred ($4 \leqslant N \leqslant 8$)**	15.6%	11.7%
All Observations ($4 \leqslant N \leqslant 8$)	8.2%	6.6%

* Sample of 15 observations where entry was announced but never completed.
** Assumes that announcement year $\hat{t}$ occurred two years prior to observed year of plant completion.

ment niche originally targeted by the announced entrant. The evidence in Table III points more strongly to the latter. For the cancelled entry sample, the mean growth rate through the announcement year was 11.5%; this is significantly above the overall sample mean but below the average for comparable observations where entry actually occurred. Growth diminished somewhat after the announcement date, but remained well above the overall sample mean. Average capacity utilization in the cancelled-entry sample fell from about 4% above the mean in the announcement year, to slightly below the mean three years later. This fall in capacity utilization, coupled with continued output growth, confirms that other firms indeed expanded capacity. Detailed inspection of the data revealed that in some instances the cancelled-entry firms were pre-empted by other entrants, and in other instances by incumbent firms. The intermediate growth rate shown for the cancelled entry sample suggests that growth may not have been sufficient to accommodate large-scale expansion by more than one or two firms.

V. LOGIT MODEL

The insights of the previous section can be formalized and extended through estimation of a logit model. We begin with a general model of new plant investment, which is then expanded to permit a comparison of entrant and incumbent investment behavior.

Consider an industry with growing demand for a homogeneous product and a well-defined minimum efficient scale that determines plant size. The industry contains N plants of equal size. As the market grows over time, at what point will an additional plant be built?

Assume, initially, that firms invest non-strategically, with the identity of the expanding firm determined in advance so that there is no pre-emptive competition over which firm has the right to build the next plant.[6] Without loss of generality, the parameters can be scaled so that current industry capacity (N plants) equals unity. Thus, an additional plant has capacity $1/N$. The unit cost function is $rk+cx$, where rk is fixed investment cost per period and c is marginal cost per unit x produced. An individual plant has fixed cost of rk/N per period. Industry price is maintained at some arbitrary level, v, above unit cost, that is, $P = rk+c+v$. Assume that demand is growing at rate g, and moreover, that any capacity currently idle is utilized before any new capacity added.

Under these conditions, a new plant will be built at the first point in time that its instantaneous profit, π, exceeds zero. If industry capacity utilization is U_0 at time t_0, then if the plant is opened at time t, its output will equal the residual demand:

$$g(t-t_0)-(1-U_0)$$

on which the firm earns margin $(rk+v)$. An additional plant is built at the first point t' where:

$$\pi = [g(t'-t_0)-(1-U_0)](rk+v)-rk/N > 0 \tag{1}$$

The actual decision to build the plant is made earlier, at time $t'-t_c$, where t_c is the construction lead time. Note that the decision statistic is a positive function of g and U_0, and a negative function of $1/N$.[7]

The threshold decision structure represented by (1) can be estimated using a logit model. For each observation year t, we observe whether a new plant was completed. The underlying investment decision was made previously, in year $t-t_c$, based on rates of industry growth and capacity utilization observable at that time. (We assume that market growth is forecasted as a simple extrapolation based on g_{t-t_c}, the recent historical rate.) A new plant is completed in year t if the unobserved index, y_t' exceeds zero, where:

$$y_t' = -b_1+b_1 t_c g_{t-t_c}+b_1 U_{t-t_c}-b_2 1/N_t+e_t \tag{2}$$

and e_t is a random error term. The coefficients in (2) are determined only up to an arbitrary multiplicative constant: b_1 is proportional to $(rk+v)$, and b_2 is proportional to rk.

[6] If price falls when new capacity is added, or if there is pre-emptive competition among incumbents over the right to build the next plant, the timing of new plant construction is shifted somewhat but has approximately the same structure as in the simple model below. See Gilbert and Harris [1984].

[7] The decision statistic also depends on v/rk, but this ratio cannot be observed empirically.

The above model considers new investment only. Replacement investment also occurs, when old plants are replaced by new facilities. If existing plants depreciate continuously at rate b_3, the expected number of plants that must be replaced in any year equals $b_3 N$. Thus, the logit model becomes

$$y_t' = -b_1 + b_1 t_c g_{t-t_c} + b_1 U_{t-t_c} - b_2 1/N_t + b_3 N_t + e_t \tag{3}$$

This logit model predicts whether a new plant will be constructed in a given year, but it does not distinguish between plants built by new entrants and plants built by incumbents. Assume, initially, that entrant and incumbent new plant decisions are independent and therefore can be tested in similar but separate logit equations. After estimating these separate equations we consider a more complex, log-linear model in which entrant and incumbent coefficients are estimated simultaneously, including possible interaction effects. In both models, if the growth and capacity utilization coefficients for incumbents appear significantly larger than those estimated for entrants, this is evidence that incumbent firms may have expanded pre-emptively in an effort to deter entry.

Time trend effects and multi-plant economies might also be expected to influence investment behavior. As entry occurs and the queue of potential entrants becomes depleted, the proportion of new plants that are built by entrants should decline. Thus, if a time trend, t, is included in the logit

TABLE IV
LOGIT ANALYSIS OF NEW PLANT CONSTRUCTION[a]

	1	2	3	4	5	6
Dep. Var.	*DENT*	*DENT*	*DINC*	*DINC*	*DNEW*	*DNEW*
c	−4.08*	−4.27*	−2.29*	−3.31*	−3.05*	−3.81*
	(0.72)	(0.75)	(0.73)	(0.81)	(0.63)	(0.67)
$g_{i,t-1}$	5.57*	3.35*	3.05*	2.00**	4.90*	2.97*
	(0.86)	(0.92)	(0.96)	(1.03)	(0.83)	(0.86)
$U_{i,t-2}$	3.24*	2.95*	2.12*	1.95*	3.35*	3.14*
	(0.81)	(0.80)	(0.83)	(0.82)	(0.71)	(0.70)
$1/N_{i,t}$	−4.66*	−2.36**	−10.48*	−4.46*	−7.31*	−3.28*
	(1.04)	(1.05)	(1.43)	(1.62)	(1.02)	(1.05)
$N_{i,t}$		0.029*		0.037*		0.040*
		(0.006)		(0.007)		(0.007)
t		−0.091*		−0.055*		−0.078*
		(0.017)		(0.017)		(0.015)
$N/M_{i,t}$		−0.19		−0.06		−0.05
		(0.17)		(0.16)		(0.15)
Log Likelihood	−376.02	−351.27	−371.28	−350.46	−462.11	−431.14
Mean of Dep. Var.	0.195	0.195	0.203	0.203	0.325	0.325
No. of Obs.	839	839	839	839	839	839

[a] Numbers in parentheses are asymptotic standard errors.
* Significant at the 0.01 level, one-tailed test.
** Significant at the 0.05 level, one-tailed test.

equation for plants built by entrants, a negative coefficient should be obtained. Empirical research by Duetsch [1984] suggests that multi-plant economies of scale can create a barrier to entry favoring expansion by incumbents. This can be tested by incorporating the average number of plants per firm (N/M) as a measure of multi-plant operation in the model.

These considerations suggest the following general model:

$$(4) \qquad y' = -b_1 + b_1 t_c g_{t-t_c} + b_1 U_{t-t_c} - b_2 1/N_t + b_3 N_t + b_4 t + b_5 N/M_t + e_t$$

This specification, and that described by (2), were estimated in separate logit equations for new plant investment by entrants ($DENT$), incumbents ($DINC$), and entrants and incumbents combined ($DNEW$). Results are shown in Table IV.

All coefficients in Table IV except the multi-plant measure appear with the expected signs and are significantly different from zero. More rapid market growth and higher capacity utilization served as stimuli for expansion by both entrants and incumbents. Moreover, the threshold required to elicit construction of a new plant was higher when plants were more "lumpy", as measured by $1/N$. As expected, the time trend appears negative for plants by new entrants, but it is also negative and significant for incumbents' plants.[8] The multi-plant measure proves insignificant in the entry equation, indicating the absence of multi-plant entry barriers in this particular industry sample.

The results in Table IV are consistent with the maintained hypothesis that firms made new plant investments to adjust capacity to the level required to effectively service demand. In the entry equations, the coefficients of g, U, and $1/N$ have roughly the relative magnitudes predicted by the specification in (2). In the incumbent equations, the $1/N$ coefficient appears larger than predicted (indicating that incumbents had a higher investment threshold than entrants in industries with lumpy plants, which is consistent with the data in Figure 1). However, this difference in threshold does not prove significant statistically.[9] Most importantly, the growth and capacity utilization coefficients for incumbents do not exceed those for entrants. This is evidence that incumbents did not expand pre-emptively in an effort to deter entry.

To compare the entrant and incumbent coefficients without restrictive assumptions, the two dependent variables must be estimated in the same statistical model, incorporating a common error structure and allowing for the possibility of interdependence. An extended parametrization of the log-linear model (Amemiya [1985], Goodman [1972], Nerlove and Press [1973])

[8] This arises from the fact that growth rates in the sample slowed substantially over time. This slowing growth is imperfectly proxied by the historical growth rate, g, causing the growth coefficient to decline in magnitude when the time trend is included.

[9] Several tests were performed. The $1/N$ coefficients were tested for equality between entrants and incumbents in the logit equations (assuming independence) and in the less restrictive log-linear model. Also, sums of coefficients ($1/N$ and U) were tested for equality between entrants and incumbents. None of these tests proved significant at the 0.05 level.

TABLE V
RESULTS BASED ON LOG-LINEAR MODEL[a]

	DENT	*DINC*	*INTERACTION*
c	−5.08*	−3.85*	3.10
	(0.99)	(1.00)	(1.72)
$g_{i,t-1}$	3.30*	0.90	0.06
	(1.08)	(1.54)	(2.16)
$U_{i,t-2}$	3.67*	2.84*	−3.23
	(1.06)	(1.04)	(2.03)
$1/N_{i,t}$	−2.68**	−6.46*	5.29
	(1.41)	(2.30)	(2.95)
$N_{i,t}$	0.024*	0.030*	0.011
	(0.01)	(0.008)	(0.013)
t	−0.087*	−0.050*	−0.0012
	(0.02)	(0.02)	(0.04)
$N/M_{i,t}$	−0.017	0.014	−0.42
	(0.02)	(0.18)	(0.48)
Log Likelihood			−695.08
No. of Obs.			839

[a] Numbers in parentheses are asymptotic standard errors.
* Significant at the 0.01 level.
** Significant at the 0.05 level.
One-tailed significance test used for *DENT* and *DINC* coefficients; two-tailed test used for interaction terms.

provides a suitable framework. In the extended log-linear model, independence is relaxed by incorporating a set of interaction terms which test the difference between the conditional and unconditional expansion probabilities. For example, a positive interaction constant term implies that the probability of new plant investment by incumbents, conditional on entry during the observation year, exceeded the probability of incumbent investment in the absence of entry. If incumbents accommodated entrants by withholding investment, this interaction term would prove negative, whereas if incumbents responded to entry by increasing investment, it would appear positive. Note that the interaction term provides no information on whether incumbents maintained excess capacity prior to entry. Rather, it reflects the behavior of incumbents once the intentions of entrants had been announced.

The parameterization used in Table V makes the interaction term a function of all of the explanatory variables. If the interaction coefficients all equal zero, then *DENT* and *DINC* are independent, and the log-linear model is equivalent to two separate logit models, as estimated in Table IV.

The interaction coefficients in Table V all prove statistically insignificant at the 0.05 level based on a two-tailed test. This indicates that investments by incumbents and entrants were statistically independent; i.e., the probability of new plant investment by incumbents was not influenced by the occurrence of entry during the year, and vice versa. Two interpretations are possible: (1) entrants and incumbents failed to modify investment decisions in light of announced expansions by the other group; or (2) incumbents accommodated entrants about as often as they responded to entry by increasing investment, so that the net correlation is zero. In either case, there is no evidence of any net accommodation by incumbents. If a one-tailed test is applied to the interaction coefficients, the constant and $1/N$ terms prove significant at the 0.05 level, indicating a positive correlation between entrant and incumbent investment in industries having a small number of plants. This is consistent with results in Lieberman [1986] showing that incumbents accelerated investment following entry in concentrated industries.

The non-interaction coefficients in Table V are similar in magnitude and statistical significance to the logit coefficients in Table IV. None of the individual entrant or incumbent coefficients are significantly different from each other at the 0.05 level. Thus, the hypothesis of identical behavior on the part of both entrants and incumbents cannot be rejected.

These logit and log-linear model results confirm the main conclusions of section IV, that entrants and incumbents acted similarly in their capacity expansion. There is no statistical evidence that incumbents expanded pre-emptively at a lower threshold than entrants, in an effort to deter entry.

VI. CASE EVIDENCE ON EXCESS CAPACITY HELD AS AN ENTRY DETERRENT

Lack of statistical evidence that incumbents built plants pre-emptively to deter entry does not prove that such behavior never occurred. Conceivably, excess capacity may have served as an entry barrier for only a few products in the sample and therefore cannot be detected in the statistical analysis. To check this possibility, the data sample was screened to identify specific cases where excess capacity may have been maintained as a barrier to entry. Products that exhibited chronic excess capacity were examined in detail, using information from the trade literature.

The sample was screened in the following manner. Chronic excess capacity was defined as the persistence of industry capacity utilization below the sample mean (80%) for five or more successive years. Of the sample observations that met this criterion, about a third were for years following 1973. These observations were discarded, as much of the excess capacity observed after 1973 was the result of oil price increases, which obsoleted existing plant and led to declines in industry output.[10]

Based on these criteria, ten products were classified as exhibiting chronic excess capacity. These products were examined in detail using the trade literature to help identify the reasons why excess capacity occurred. In general, these reasons appeared unrelated to strategic entry deterrence. For

[10] Capacity utilization fell below the 80% mark for 35% of the observations prior to 1973. Low capacity utilization typically stemmed from cyclical downturns; only 15% of all observations prior to 1973 were classified as chronic excess capacity.

four products,[11] excess capacity appeared to be a direct consequence of new entry. For two products,[12] excess capacity seemed to have resulted from outbreaks of investment rivalry or over-optimism among incumbent firms. For two more products,[13] excess capacity stemmed at least in part from temporary downturns in demand. However, for one of these products (magnesium) the resulting excess capacity appeared to have been used by the dominant firm as a means to deter entry. Only two products (aniline and sorbitol) exhibited continuous output growth plus evidence that excess capacity was maintained in an attempt to deter entry. These two products and magnesium are considered in greater detail below.[14]

Aniline

Aniline was produced by four firms in the early 1960s. Output grew steadily from 122 million pounds in 1961 to 263 million pounds in 1968. Industry capacity utilization fell below the 80% mark following a major expansion by DuPont in 1962, and remained below that level until 1969.

There is some evidence that incumbents held excess capacity in an unsuccessful attempt to deter entry, which was attracted by market growth. In early 1964, one new firm (Rubicon) announced plans to enter the industry, and two others were cited as potential entrants. Trade sources reported that "with Rubicon's announcement and Cyanamid's expansion, aniline capacity will be more than adequate for the next several years despite the sharp gains being recorded in consumption.... Capacity in 1965 will be 280 million pounds at a minimum, indicating an operating rate of 72% of capacity. On that basis it appears doubtful that any new producers will enter the field."[15] "Deterrents to the entry of new producers are the low price of aniline itself—

[11] Ethanolamines, high-density polyethylene, polyester fibers and urea. See, for example, "Ethanolamines: Too Much Capacity", *Chemical and Engineering News*, February 10, 1958; "High Density Polyethylene Shifts to High Gear", *Chemical and Engineering News*, December 12, 1960; "For Polyester Fibers and Films: New Patent Picture and Producers", *Chemical Engineering*, March 22, 1964.

[12] Pentarythritol and phthalic anhydride. See, for example, "PE Capacity: Running Wild?", *Chemical Week*, September 10, 1955; "PE Capacity Rises Sharply, Far Outstripping Production", *Chemical and Engineering News*, January 27, 1958; "Phthalic: Time of Plenty", *Chemical Week*, July 1, 1961; "Phthalic Anhydride Plants to Rise on Both the East and West Coasts", *Oil, Paint and Drug Reporter*, August 14, 1961; "Phthalic Woes Grow", *Chemical Week*, April 27, 1963.

[13] Sodium and magnesium. See, for example, "Sodium, Long in the Doldrums, Enjoys a Brisk Growth Rate", *Oil, Paint and Drug Reporter*, March 29, 1965; and Lieberman [1983].

[14] Capacity also played an important role with respect to entry into neoprene rubber, the most concentrated industry in the sample. The incumbent firm (DuPont) had historically been able to defend its US monopoly without maintaining substantial excess production capacity. However, in 1965 an explosion destroyed 80% of DuPont's neoprene plant. Several months later Petro-Tex announced plans for entry based on a new production process licensed from a European firm. See, "Neoprene Blast Makes Big Dent in US Capacity", *Oil, Paint and Drug Reporter*, August 30, 1965; "Neoprene: Petro-Tex to be 2nd US Maker", *Oil, Paint and Drug Reporter*, January 10, 1966.

[15] "Aniline Capacity 280 Million Pounds: That's What US–UK Effort Will Do", *Oil, Paint and Drug Reporter*, January 20, 1964.

Cyanamid made an additional 1 cent reduction last month—plus the large capital investment needed to build an aniline plant."[16] Excess capacity did not, however, forestall additional entry. A total of three new firms entered the market between 1965 and 1968.

Sorbitol

Sorbitol had capacity utilization below 70% for more than 14 years, from the beginning of sample coverage in 1955 through 1968. Atlas Powder was the sole commercial producer in the US from 1943 until 1956. (Two drug manufacturers maintained a small amount of capacity for captive use.) The sorbitol market expanded gradually from 50 million pounds in 1955 to 106 million pounds by 1968.

Trade sources suggest that excess capacity held by Atlas may have retarded the rate of entry into the sorbitol market. When the drug producer, Merck, entered in 1957, it was reported that: "Atlas was the sole commercial sorbitol producer since 1943 simply because no one chose to compete. And for a good reason: sorbitol's capacity was reported at 75 million pounds per year; selling price now runs from 15 to 17 cents a pound, depending upon amount purchased. This means that (sorbitol) is a low-unit profit item—one which calls for large capital investment and large volume production before firm gets a fair return on its venture."[17] During the course of the 1950s and 1960s, a total of only two firms entered the sorbitol market.

Magnesium

Dow Chemical dominated the US magnesium industry from World War II through the 1960s, controlling more than 80% of industry capacity and output. Over this period Dow made a number of successful attempts to deter entry, based in part on threatened utilization of excess production capacity.[18] However, Dow did not intentionally build excess capacity for entry deterrence purposes; rather, Dow's surplus plant was constructed by the US government to meet peak demand requirements during World War II, and was purchased by Dow in the late 1950s.[19]

[16] "Aniline Figures Spell Trouble, But Closer Look Reveals Trade Has Reason to be Optimistic", *Oil, Paint and Drug Reporter*, May 3, 1965, p. 3.

[17] "Merck Goes to Sorbitol", *Chemical and Engineering News*, February 11, 1957, p. 100.

[18] For a detailed account of Dow's actions relating to entry deterrence in magnesium, see Lieberman [1983].

[19] The initial postwar episode of entry deterrence by Dow involved the auction in 1957 of a large, low-cost magnesium plant which was owned by the government but operated by Dow. Several years prior to the auction, Dow began to accumulate a stockpile of magnesium ingot which by 1957 had reached a level equivalent to approximately two years of US domestic consumption. Dow proved to be the sole bidder in the auction, and purchased the plant for substantially less than the government's original construction cost. After the auction Dow closed the plant for four years in order to draw down the accumulated magnesium stockpile. (For a theoretical discussion of inventory accumulation as a strategic entry deterrent, see Ware [1985].)

By 1963, growth in magnesium demand and development of a new production process attracted the attention of a number of potential entrants. (Dow's capacity utilization rose from about 35% in 1958 to 74% in 1963.) Three firms announced specific plans to enter the industry, and others were known to be considering entry.

Dow responded to these entry threats by announcing incremental capacity increases and cost reductions. Dow's 1963 annual report stated that "process improvements boosted magnesium production capacity without expansion of our facilities, and also reduced production costs. Additional capacity gains and cost reduction are expected in 1964 and 1965." Dow made a series of additional announcements over the next few years, indicating the potential to boost capacity by 50% by reactivating and modernizing idle plant. Dow also announced plans (which it never carried out) to build a new plant at the Great Salt Lake, the site being contemplated by most potential entrants. Moreover, Dow made substantial price cuts for magnesium sold to the major aluminum companies, who used the metal for alloying purposes and were considered the most likely entrants.

These actions by Dow appear to have deterred potential entry by Kaiser Aluminum, Harvey Aluminum, Norsk Hydro, and others; and delayed entry by Alcoa and National Lead. Successful entry did not occur until the early 1970s, by which time Dow's margin of excess capacity had shrunk to virtually zero.

VII. SUMMARY AND CONCLUSIONS

The empirical evidence presented in this study suggests that the excess capacity entry barriers identified in theory are not very common in practice. While significant excess capacity was held by firms in the sample, most was maintained to accommodate demand variability and investment lumpiness. The statistical tests fail to show that incumbent firms expanded pre-emptively in an effort to deter entry. Moreover, of the 38 products in the sample, in only three cases could any evidence be found that incumbents held excess capacity for entry deterrence purposes. And in all three of these cases, some entry in fact occurred.

These findings do not imply that excess capacity cannot deter entry, but rather that its use is both rare and unlikely to be completely effective. Theory suggests that the potency of excess capacity as an entry barrier may be undercut by market growth, free-rider problems, and demand-related effects. The two products where excess capacity seems to have offered at least partial success as an entry deterrent—magnesium and sorbitol—were characterized by slow market growth, high producer concentration, and high capital intensity. Thus, excess capacity was employed and may have provided some deterrent value in two specific instances where the conditions for its effective use coincided.

Although the data provide little evidence that incumbents built strategic excess capacity in advance of announced entry, there do seem to have been numerous instances of aggressive capacity expansion once the threat of entry became tangible. Such behavior is evident in the cancelled-entry sample and in the interaction coefficients of the log-linear model, as well as in the analysis reported in Lieberman [1986]. Thus, incumbents seem to have built strategic excess capacity in a manner more consistent with "predation" and "mobility deterrence" theories than with the standard excess capacity deterrence argument.

Related empirical evidence on investment by incumbents (e.g., Gilbert and Lieberman [1987]) points to the occurrence of pre-emptive investment behavior in which firms rush to fill new investment niches as they become available. One interpretation of the results obtained here is that in industries where potential entrants are present, incumbents and entrants act to pre-empt these niches in roughly similar manner.

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