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Sunk costs and concentration in homogeneous product industries

(Submitted to a special issue of Strategy Science in honor of Pankaj Ghemawat)

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Abstract

Research by Pankaj Ghemawat and others in the 1980s focused on sunk cost commitments, which can support entry deterrence. Sunk costs can also create exit barriers, potentially increasing the number of firms in an industry. This study combines information on cost structure, production capacity and sales for 31 chemical products to consider factors that determine the number of competitors in a homogeneous product industry. After controlling for market size and cost of entry, the number of producers increased with the ratio of sunk to variable costs. This is consistent with hysteresis—which can inhibit exit from an industry—but not with entry deterrence. Excess entry was greater when plants were geographically dispersed, suggesting that fragmentation into submarkets facilitates firm survival when sunk costs are high.

Keywords: concentration, sunk costs, entry, real options, chemical industries

For this special issue of Strategy Science honoring the contributions of Pankaj Ghemawat, I utilize a unique dataset on production cost structure to investigate how sunk cost investments influence the number of producers in a homogeneous product industry. In his early work, Ghemawat demonstrated that under some conditions, firms could use capital commitments to deter entry and increase market concentration, (e.g., his 1984 analysis of DuPont's expansion in titanium dioxide). But Ghemawat soon recognized that sunk cost commitments were a two-edged sword: while they might support preemptive behavior, more commonly they led to intensified competition among the existing incumbents (Ghemawat and Caves, 1986). Ultimately, Ghemawat abandoned the idea that lumpy sunk investments in physical capital could play a large role in shaping industry concentration. He reached this conclusion based on theoretical arguments and more granular data and case evidence (Ghemawat, 1987). I extend Ghemawat's work by providing large sample evidence from the chemical industry that is inconsistent with the use of sunk costs as a strategic entry deterrent. Furthermore, I show that when transport costs create geographic submarkets, sunk costs lead to an increase in the total number of producers in an industry.

In the early 1980s, when Ghemawat completed his PhD at the Harvard Business School, the field of industrial organization economics was being transformed by the introduction of game theory, and a stream of new theoretical papers demonstrated the potential for firms to make strategic commitments through sunk investments in fixed capital (e.g., Schmalensee, 1978; Dixit, 1980; Eaton and Lipsey, 1981; Fudenberg and Tirole, 1983). Although Sutton (1991, 1998) would later demonstrate how commitments to sunk costs can lead to concentrated market structures when firms making differentiated products invest in advertising or R&D, much of the interest at the time was on understanding the potential for strategic deterrence in homogeneous product industries.

From a research standpoint, one advantage of focusing on homogeneous product industries is that they are comparatively straightforward; the key strategic commitment of competitors relates to investments in capacity, rather than in R&D, advertising, or marketing, which are harder to analyze. In manufacturing industries where output is homogeneous, the primary sunk costs pertain to investments in plant and equipment. The amount of capacity to be built is a decision variable of the firm, but the cost structure of production is not (for competitive firms using best-practice technology). In differentiated product industries, by comparison, sunk costs are determined more endogenously as firms make choices about expenditures on R&D and promotion activities, as well as physical plant. In these industries, sunk costs are not technologically linked to output and are thus more easily subject to competitive escalation.

Syverson's (2004, 2007) studies of the US cement industry nevertheless make it clear that homogeneous product industries are seldom as simple or homogeneous as they may appear at first glance. Spatial differentiation is often a key feature. In industries where output is heavy or bulky, such as cement and many chemical products, spatial differentiation arises from transport costs. Syverson shows that differences in the density of local demand have large effects on producer survival and efficiency. Price competition tends to be more intense in markets with higher density demand. This drives out high-cost producers, who may persist in markets with lower demand density. Furthermore, Hortacsu and Syverson (2007) show that "higher-productivity producers are more likely to vertically integrate and are also larger, more likely to survive, and more likely to charge lower prices." As I demonstrate below, evidence from the chemical industry appears consistent with such patterns.

When spatial differentiation is large enough, homogeneous product industries can be viewed as collections of submarkets that are geographically separated. Thompson (2005) shows that the existence of geographically isolated submarkets in the US iron and steel shipbuilding industry of the 19th and early 20th centuries increased the number of shipbuilding firms and prevented a shakeout as the industry matured. Moreover, such differentiation raises the possibility that entry deterrence may take the form of "entry

diversion” (Uzunca, 2018; Uzunca and Cassiman, 2020). Firms might add capacity or make other sunk investments within their local submarket in an effort to divert potential entrants into other submarkets.

Ghemawat recognized that a key flaw in the early models of preemptive investment was the omission of uncertainty:

As an empirical matter, profitable preemption seems rare – even in capital-intensive industries.... preemption may be easier in principle than in practice. Most formal models of preemption assume perfect information.... (whereas most actual cases) were afflicted by considerable uncertainty— particularly about demand but also in some cases about inputs, technology, government intervention, and rivals’ expansion plans. (Ghemawat, 1987, p. 265.)

If costs or demand are uncertain, an incumbent bent on entry deterrence must choose a higher capacity level than under certainty. This diminishes the attractiveness of deterrence and the range of parameter values under which it can be supported (Maskin, 1999).

An explicit linking of sunk costs with uncertainty in the context of entry and exit decisions came with the introduction of real options theory (Dixit, 1989, 1992; Dixit and Pindyck, 1994). In environments where prices (or demand, input costs, etc.) are fluctuating, sunk costs lead to what Dixit called hysteresis, a gap between the thresholds that induce entry and exit. Firms that are earning losses in an industry may rationally persist on the chance that conditions will improve in the future. Thus, sunk costs can deter firms from exiting an industry that has become unprofitable (O’Brien and Folta, 2009). Similarly, a firm that enters based on erroneously favorable expectations of cost or demand is more likely to remain in the industry if sunk costs are substantial (Cabral, 1997). Such persistence of entrants in markets with sunk costs has been documented in empirical studies (e.g., Bresnahan and Reiss, 1990, 1991). These effects of sunk costs under uncertainty can push industry concentration in the opposite direction of what is predicted by the preemptive investment theory. Indeed, Cabral and Ross (2008) argue that even in the absence of uncertainty, the sunk cost mechanism that creates hysteresis provides a means for entrants to commit to remain in the industry.

Determinants of the number of producers in a homogeneous product industry

Sutton (1991) lays out the basic determinants of the number of producers that can be supported with non-negative profits in a homogeneous product industry. Consider such an industry that operates at a known size, without anticipation of growth or decline. Firms enter simultaneously and can produce without capacity constraint at a constant unit cost c after paying an entry fee, F . Under these assumptions, the maximum number of (identical) firms that can be supported is:

$$N = [k(S/F)]^{1/(1+a)} \quad (1)$$

where S is total industry sales and F is a technologically fixed set up cost. The parameter a represents what Sutton (1991) calls the toughness of price competition; as a becomes larger, additional entry depresses prices more strongly ($a > 0$).¹ Cournot behavior corresponds to $a=1$, under the assumption of constant elasticity demand. Thus, in a static market environment for a homogeneous product, the maximum number of firms that can be sustained is an increasing function of total market demand, and a decreasing function of the fixed cost of entry.

Equation (1) has no scope for strategic deterrence, other than via the fact that firm behavior may influence the toughness of price competition. If F is a simple fixed cost (e.g., a licensing fee) incurred in each period, larger F leads to a smaller number of producers, but the identity of these firms can change in each period. Alternatively, the entry fee may correspond to a set up cost (e.g., a one-time investment required to enter the market), which makes F a sunk cost. With F sunk, firms will persist over time. But if F is the only sunk cost, there is no scope for strategic behavior that affects the number of producers. The effect of F being sunk is simply to guarantee that entrants persist in the industry from one period to the next.

To create entry deterrence, models such as Dixit (1980), Eaton and Lipsey (1981) and Eaton and Ware (1987) add to the sunk entry fee an additional sunk cost of capacity. Consider the “Dixit” cost function, where to produce output x_i , firm i must previously invest in capacity, $k_i > x_i$,

¹ The percentage markup $([P-c]/P)$ is k/N^a (Schmalensee, 1992; Sutton, 1991).

$$C_i = F_i + v_i x_i + r_i k_i \quad (2)$$

where F_i is the set-up cost, r_i the constant cost per unit of capacity, and v_i the constant average variable cost for output. With sequential entry, these models show the potential for the initial entrant(s) to make preemptive investments in capacity, which make the market less attractive for subsequent entrants, thereby potentially deterring entry.

Through this mechanism, early entrants may be able to make credible capacity commitments that lead to higher levels of market concentration. In the models, the ability to deter subsequent entry increases with the sunk cost of a unit of capacity, r_i , relative to variable cost of a unit of output, v_i . Assuming that deterrence is feasible, the number of firms in the market increases with the market size, S ; it falls with the sunk entry fee, F , and with r/v , the investment cost per unit of output relative to the variable cost.

Separate from this potential for deterrence, the ratio, r/v , also defines the gap between entry and exit thresholds (i.e., the difference between the prices needed to induce entry versus exit) that arise under conditions of demand uncertainty (Dixit 1989, 1992). Given this gap, as r/v increases, the number of competitors in an industry could be diminished (since a higher output price is needed to elicit entry), or increased (e.g., if entrants persist as demand falls, or if firms make “entry mistakes”). Below I consider further reasons why r/v could be linked to an increase in the number of competitors through hysteresis-type mechanisms.

Data and Measures

Chemical Products Sample

The data sample includes 31 commodity industrial chemicals for which suitable data on cost structure, plant capacity and total industry output could be obtained for the 1970s and 1980s.² All of the

² The sample includes all industrial chemicals that met the following criteria: (1) data on plant capacity and number of producers are listed in the 1977 *SRI Directory of Chemical Producers, United States*; (2) industry output data are publicly available; (3) plants cannot easily be converted to make other products; (4) engineering cost estimates are listed in the 1977 *SRI Processes Economics Program Yearbook*; and (5) the *Yearbook* shows only a single manufacturing process for the chemical (or if there are multiple processes, their cost structures are very similar).

products are homogeneous (with a chemical composition that is undifferentiated among producers), and all but two (hydrogen peroxide and nitric acid) are petrochemicals. Table 1 lists the 31 chemicals. Although our primary analysis is for the United States, Table 1 shows counts of producers in three separate geographic regions: United States, Western Europe and Japan.

For most products in the sample, total output grew rapidly from the 1950s through the early 1970s, which was the major growth phase of the petrochemical sector in the United States. The cost estimates used in this study pertain to new plants built in the mid-1970s, as indicated by the *SRI Processes Economics Program (PEP) Yearbook*, an engineering data handbook that provides estimates of investment and production costs for a large number of chemical products. The regression analysis links the cost structure information in the 1977 *PEP Yearbook* to the number of producers in 1977. To accommodate lags in adoption of process technology and provide tests for robustness, further analyses were performed using the number of producers in the late 1980s in Europe and Japan as well as in the United States.

By the 1970s the chemical product industries in the sample could reasonably be characterized as mature. Demand growth and technical progress had slowed considerably from the pace of the prior two decades. Moreover, production technology was widely available through licensing, and it had become common for new plants to be designed and built by independent engineering contractors (Spitz, 1988; Stobaugh, 1988; Arora and Gambardella, 1998; Arora, Fosfuri and Gambardella, 2004). Thus, restricted access to technology was not a significant barrier to entry for products in the sample, and firms' internal R&D activities had become relatively unimportant.

For purposes of this study, the 31 chemical products in the sample are treated as separate industries, albeit within the broader chemicals sector. Furthermore, the three geographic regions (United States, Western Europe and Japan) are assumed to be independent. These assumptions are reasonable approximations to conditions in the chemicals sector in the 1970s and 1980s. While chemicals can be shipped internationally, the volume of trans-oceanic trade was very small relative to total output, and the

US market, in particular, was largely autonomous. For all products in the sample, plants are dedicated to the manufacture of a specific product; the sample excludes chemicals whose production processes yield significant joint products and those for which capacity is convertible to the manufacture of other products.³

Number of Producers

The dependent variable for the regression analysis is the logarithm of the number of producers.⁴ In 1977 the number of U.S. producers ranged from three (caprolactam and methyl methacrylate) to fifty-seven (ammonia). Table 1 gives comparable counts for Western Europe and Japan.⁵

These patterns of producer counts are similar across geographic regions and stable over time. For most products in the sample, the number of U.S. manufacturers was growing through the mid-1960s but stable or declining over the period from 1967 to 1987. The correlation coefficient between the 1967 and 1987 U.S. producer counts is 0.95; the correlation between adjacent decades is even higher, as shown in Table 2. The producer counts for Western Europe are highly correlated with those for the United States ($r > .7$). Nevertheless, the fact that U.S. and European markets were almost entirely independent allows the European plant data to serve as instruments for the U.S. regression estimates.

Cost Measures

As noted above, theoretical studies of sunk cost commitment have commonly used the Dixit (1980) cost function: $C(x) = F + rk + vx$, where $C(x)$ is the total cost of producing quantity x ; F is the lump-sum entry fee; r is the investment cost per unit of capacity, k , ($x \leq k$); and v is the materials cost per unit of output. Investments are irreversible in Dixit's model; hence the costs represented by F and r are sunk as well as fixed.

³ Nevertheless, many plants in this study are part of larger chemical complexes which produce a variety of different products.

⁴ The log transformation avoids heteroskedasticity and allows the coefficients to be interpreted as elasticities. Explanatory variables that were not in ratio form were also converted to logarithms.

⁵ The European data are from the 1989 *Directory of Chemical Producers, Western Europe*, published by SRI International. The Japanese data are from the *Annual Survey of Petrochemical Industries*, published by the Heavy & Chemical Industries News Agency. Japanese data were obtained for 20 of the 31 products in the sample.

For most petrochemicals, the Dixit function provides a reasonably accurate representation of cost structure. The engineering estimates used for the present study are from the *1976 Process Economics Program Yearbook* prepared by SRI International, a large technical consulting firm. For each product in the sample, the *Yearbook* gives cost estimates for plants of three different capacities, where the mid-size plant is “representative of sizes of competitive U.S. plants” built in the mid-1970s. Costs are disaggregated into four major categories: “fixed investment,” “materials,” “labor” and “overhead.” The first two of these categories, which constitute the largest cost components, correspond closely to the Dixit concepts.

For the chemical plants in the sample, capital investment costs are almost entirely sunk. Once equipment has been set in place for the production of a specific product in a given facility, the salvage value is minimal. (The cost of equipment removal is normally prohibitive, and scrap value is low.) Labor and overhead costs are fixed but not sunk; while these costs must be incurred to operate the plant, they are virtually independent of plant output.⁶

Figures 1a and 1b illustrate the cost structure for a specific product, low-density polyethylene (LDPE). The mid-size LDPE plant listed in the *Yearbook* was capable of producing 220 million pounds per year, while the smaller and larger plants had capacities of 110 million and 440 million pounds per year, respectively. (There is typically a doubling of capacity between the plant sizes reported in the *Yearbook*.) The unit materials cost, v , was 15.12 cents per pound, independent of plant size. Other cost categories—capital investment, labor and overhead—are subject to scale economies. Given these economies, Figure 1a shows that the estimated average total production cost for LDPE was at 25.32 cents per pound in the smaller plant, falling to 21.47 cents per pound in the larger plant.

Figure 1b, which plots total costs versus plant size, shows how the engineering cost estimates are mapped into the Dixit function. The bold line at the top of the figure connects the estimates of total plant

⁶ The cost structure of the petrochemical industry allows us to ignore labor costs. In most other contexts labor costs are important. Whether labor costs are fixed or variable depends on technology, contracts and other factors.

investment costs for the smaller plant (\$46.3 million), medium plant (\$69.7 million) and larger plant (\$123.1 million), as reported in the *Yearbook*. Extrapolation back to the y-axis shows that a hypothetical plant of capacity “zero” would have required a lump-sum investment of \$22.9 million. This is equivalent to an annual investment flow cost of \$4.58 million, assuming a 10% cost of capital and 10% annual depreciation. In the analysis below, the investment cost of the smaller plant reported in the *Yearbook* (\$46.3 million for LDPE) was taken as the entry fee, F . (Using the investment cost of a “zero capacity” plant gives similar results.)

Figure 1b shows that total investment cost increases in almost-linear fashion with plant capacity and output, x . Materials costs also grows linearly. Labor costs do not, but they are a very small fraction of total costs for all products in the sample. The measure, *SUNKRATIO*, equals the ratio of r/v as shown in the figure. *SUNKRATIO* is the incremental plant investment cost per unit of capacity, divided by the materials cost per unit, calculated for a “medium plant.”

Market Size and Growth

The demand-side measure used in the study is annual industry output, which can be measured in physical or monetary units. Accordingly, two alternate measures of U.S. market size are included in the regressions: *POUNDS* (total industry output, measured by weight), and *SALES* (monetary value of this output, computed by multiplying *POUNDS* by the product’s unit sales value). Data on *SALES* were recorded for 1977 only; *POUNDS* data were collected for 1977, 1987, and a historical period from the 1960s through 1977. For Europe and Japan, only *POUNDS* data are available.

In addition to the level of demand in the observation year, demand uncertainty could affect the number of producers under various plausible theories of sunk costs. Given hysteresis, firms may persist in an industry with high sunk costs following a downturn in demand, with their count exceeding what would otherwise be expected based on current demand. Likewise, if firms make entry decisions in anticipation of historical growth, a drop in the growth rate could lead to more producers as compared with a stable market environment. Other theories imply that with increasing marginal costs of adjusting capacity, rapid

demand growth can outstrip incumbent firms' abilities to expand, thereby facilitating additional entry (Hause and DuRietz, 1984; Nakao, 1980). Furthermore, supra-normal profits that arise during peak periods may enable the survival of a larger number of firms (Sheshinski and Dreze, 1977; Mills and Schumann, 1985). To assess these potential effects, various measures were computed from the historical output data and tested in the regressions (mostly as interaction terms with SUNKRATIO), as discussed below.

For some chemical products, high outbound transport costs give rise to geographic submarkets. Products in the sample differ in their value relative to weight and in the geographic distribution of customers. Although almost all industrial chemicals can be shipped throughout the United States by rail or truck in tanker cars, manufacturing is geographically concentrated for some products whereas it is dispersed for others. Many U.S. petrochemical plants are situated on the Gulf Coast (in southern Texas and Louisiana), a location that provides ready access to feedstocks, a system of pipeline interconnections, and water as well as rail transport.

Thus, the Gulf Coast location provides economic advantages for the manufacture of some products in the sample, and many petrochemical producers are concentrated there, often with integrated facilities. Based on Syverson's findings for cement, we expect that the density of producers (and customers) in the Gulf Coast region would have accentuated price competition and the weeding-out of less efficient plants, as compared to the situation in geographically isolated submarkets where high transport costs give producers greater slack. It is complicated to identify the precise extent of chemical submarkets, given that locational decisions hinge upon a balance between inbound and outbound transport costs as well as the geographic distribution of customer demand. Moreover, division into geographic submarkets is less marked for industrial chemicals than for bulk materials such as cement, given differences in value-to-weight of the respective products.

Even so, we can identify chemical plant locations—and in particular, whether or not plants are situated on the Gulf Coast. This enables the computation of a measure of geographic concentration, NGC

%, defined as the fraction of industry capacity that is located outside the Gulf Coast. Values of NGC% vary greatly, ranging from zero to 96% across products in the sample. The NGC% measure allows us to examine how the number of chemical producers may be affected by geographic concentration or dispersion. More importantly, by interacting NGC% with SUNKRATIO, we can test the hypothesis that sunk costs lead to greater persistence of producers in geographically dispersed submarkets.

Table 3 gives the variable means for the US market in 1977 and a matrix of correlation coefficients. The two measures of market size (*SALES* and *POUNDS*) have strong direct correlation with the number of producers, but the cost measures, *F* and *SUNKRATIO*, do not ($r < 0.10$). These cost measures are, nevertheless, correlated with each other ($r = 0.52$), as both tend to be larger for plants requiring high capital investment. NGC% has a relatively low correlation with all of the other measures.

Empirical Results

Tables 4, 5 and 6 report the regression results, showing how variation in the number of U.S. producers in 1977 can be accounted for by differences in market size and sunk costs. Table 4 provides OLS estimates, Table 5 provides instrumental variable estimates, and Table 6 provides estimates based on a count data model. The results are highly robust across the three estimation methods. The first five regressions in each table use *SALES* as the measure of market size; the last five regressions use *POUNDS*. The *POUNDS* measure fits the data better and raises fewer endogeneity concerns, but otherwise the results are similar for the two market size measures.

The OLS regression results in Table 4 demonstrate a strong fit for parsimonious models that include a measure of market size (*SALES* or *POUNDS*), the sunk entry fee (*F*), and the ratio of sunk to variable costs (*SUNKRATIO*), particularly when this ratio is interacted with the NGC% measure. The *log SALES* and *log F* coefficients in regression 4.2 are roughly consistent with expectations based on Equation (1) under assumptions of Cournot behavior. The coefficients are similar in regression 4.7, where *log POUNDS* is the market size measure. The entry fee, *F*, is significant in all regressions, indicating the existence of fewer firms when the entry cost was higher. Thus, in general, the regressions show that the

number of producers increased with the size of the market and decreased with the fixed (sunk) cost of entry, as would be expected. Regressions 4.6 through 4.10 indicate that differences in market size, when measured in physical units, account for more than half of the variance in the number of producers across products in the sample. The full regression model accounts for more than 90% of the sample variance.

The major tests in this study relate to *SUNKRATIO*, the sunk investment cost relative to the variable production cost, per unit of output (r/v). The entry deterrence models imply a negative coefficient for *SUNKRATIO*, whereas a positive coefficient would be consistent with hysteresis-based explanations. In regressions 4.3 and 4.8, the cost measures, F and *SUNKRATIO*, appear highly significant with opposite signs. The positive *SUNKRATIO* coefficient implies that (after controlling for F) the number of producers increased with degree to which total costs were sunk. This is consistent with explanations based on hysteresis but not entry deterrence or preemption. The coefficients in Regressions 4.3 and 4.8 imply that a one standard deviation increase in *SUNKRATIO* had the effect of increasing the number of producers by about 40%.⁷

This estimated effect for *SUNKRATIO* is large and statistically strong. It is, however, an average effect and thus not definitive; conceivably, preemptive behavior based on sunk cost commitments could have been successful for a small number of products in the sample.⁸ Alternatively, producers in some geographic submarkets may have used sunk costs to defend against potential entrants in the submarket, as suggested by Uzunca and Cassiman (2020).

⁷ This effect of increasing *SUNKRATIO* may be offset in part by potential increases in $\log F$, given that the two measures are correlated. Notably, however, the products in the sample with the highest and the lowest values of *SUNKRATIO* had almost identical values of $\log F$.

⁸ One product in the sample, methyl methacrylate (the raw material for plexiglass) remained highly concentrated, with only three U.S. producers in 1977 in 1987. In his book on the rise of the U.S. petrochemical industry, Spitz (1988, p. 540) observes that with regard to capacity additions, although “there was always too much enthusiasm and gameplaying....there were instances where preemptive moves to add capacity were quite successful (Rohm & Haas’ strategy in methyl methacrylate monomer comes to mind), but more often than not there was oversupply, there were new entrants cutting price to gain market share, and there was insufficient “signaling” by producers, which might have prevented duplication of new capacity.”

To better understand the underlying mechanism suggested by the positive coefficients for *SUNKRATIO*, I experimented with a series of interaction terms.⁹ One set of experiments utilized historical data on industry output going back to the early or mid-1960s for the 31 products in the United States. If products experienced a significant downturn in demand prior to 1977, hysteresis could lead to an elevated number of firms relative to expectations based on the 1977 market size. Although the United States economy went into recession from 1973 to 1975, demand for petrochemicals was generally growing, and only a few products in the sample show output in 1977 significantly below the historical peak. (The largest negative deviation was 15%.) Thus, the standard form of hysteresis was unlikely to operate in the sample.

Another possibility is that firms made entry decisions based on extrapolations of historical demand growth. If so, a drop off in growth prior to 1977 could have led to excess entry, followed by the persistence of entrants in industries with high sunk costs. Tests of measures that captured deviations of growth from historical trends provided no evidence that entrants overshot in this way. Similarly, measures of historical output variability had no significant explanatory effect. Thus, the analyses of market growth dynamics gave no indication that large numbers of entrants were “fooled” by changes in the growth rate, subsequently finding themselves trapped in an industry with high sunk costs.

Despite reasonable ability to forecast demand, it is possible that firms succumbed to other types of “entry mistakes” (Dixit and Shapiro, 1986; Cabral, 1997). Ghemawat (1987) describes many potential sources of entry error stemming from various forms of uncertainty. Uncertainty along dimensions other than product demand could plausibly have led to excess entries. One would expect these “entry mistakes” to be followed by quick exits in environments where sunk costs are low, but to persist in environments where sunk costs are high.

A further possibility is that the persistence of plants and firms in high sunk cost industries is an artifact of the natural process of plant replacement over time. Chemical plants do not have an infinite life.

⁹ The results of these tests (and the full dataset) are available from the author.

The closure of an aging or obsolescent plant opens up space for its potential replacement by a new entrant. In the chemical industry, moreover, gradual technical progress was prevalent, making new plants more efficient than older plants (Lieberman, 1987c). The process of plant replacement works smoothly in a competitive industry in the absence of uncertainty; a new plant enters at the point where its discounted flow of profits first becomes positive, pushing out one or more obsolescent plants. The mechanism that induces the exit of older plants is a dip in prices. As sunk costs become higher, the required price reduction is larger. Under conditions of demand uncertainty, however, obsolescent plants might persist despite (short term) losses, given the incentives demonstrated by real options theory. Similarly, in the absence of perfect competition, competitors might seek to avoid large price reductions, and entrants might build plants early in a preemptive effort to establish their foothold in the industry. This type of preemptive entry would lead to an increase in the number of firms, particularly if there is persistence of obsolescent plants—a situation that becomes more likely when plants have high sunk costs but low operating costs.

Thus, entry “mistakes” and persistence of obsolescent plants are potential explanations for the finding of an elevated number of producers when the sunk cost to variable cost ratio is high. It is difficult to test for these mechanisms. However, one piece of supporting evidence is the fact that similar effects for *SUNKRATIO* are observed across all three geographic regions of the broader data sample. (See Table 7 below.) If the explanation were related to uncertainty in demand, the finding of excess firms should be localized to specific industries during periods of downturn.

Such persistence of plants and firms is likely to be more pronounced in geographically segmented markets, where transport costs insulate producers from the full intensity of industry price competition. This should be observable as a significant interaction effect between *SUNKRATIO* and *NGC%*, the fraction of capacity located outside the Gulf Coast. Producers with less efficient (often older) plants with higher sunk costs may persist in geographically isolated markets but not in Gulf Coast locations where price competition is more intense. Such a mechanism is consistent with Syverson’s findings for the cement industry (Syverson, 2004, 2007; Hortascu and Syverson, 2007).

Regressions 4.4 and 4.9 add the *NGC%* measure directly to the specification without any interaction with sunk costs. Not surprisingly, the *NGC%* coefficient is positive, and the inclusion of *NGC%* in the regression leads to an appreciable increase in the total variance explained. Products with substantial production outside the Gulf Coast were more likely to be characterized by submarkets, and geographic differentiation allows a larger number of producers to survive. Such survival may reflect differences in the intensity of price competition.

Interacting *SUNKRATIO* with *NGC%* provides information on the extent to which survival was enhanced by sunk costs. Regressions 4.5 and 4.10 show that the interaction effect is positive and significant, consistent with this hypothesis. Moreover, the non-interacted *SUNKRATIO* measure falls from significance (and becomes negative in regression 4.5), suggesting that the persistence effect of sunk costs failed to operate on the Gulf Coast. Potentially, more intense price competition prevailing in that region squeezed out less efficient plants comparatively quickly, whereas these plants tended to persist in other geographic markets.

As noted previously, technical progress in the chemical industry creates a dynamic where smaller, older plants are replaced by larger, new plants. The persistence of producers outside the Gulf Coast might reflect such a dynamic, given that older plants are able to cover their variable costs for a longer period when price pressures are less intense and sunk costs represent a larger fraction of total costs. Similarly, entry “mistakes” might be swept away relatively quickly in Gulf Coast locations but persist in other geographic markets. Another possibility is that sunk costs enabled producers in localized markets to defend against new entry, along the lines of the “entry diversion” strategies proposed by Uzunca and Cassiman (2020). These possibilities are not mutually exclusive.

To check the robustness of the OLS results in Table 4, Tables 5 and 6 apply instrumental variables and count data regression models. The IV regressions in Table 5 control for potential endogeneity between industry output and the number of producers. (The entry of more producers into an

industry is likely to depress price and increase output quantity.) Moreover, given the count nature of the dependent variable, count data models may be warranted.

The estimates in Table 5 are based on two stage least squares instrumental variable estimation. Although our focus is not on the coefficients of the market size measures (for which endogeneity is potentially problematic), other coefficient estimates might be affected. Under the assumption that the U.S. and European chemical markets were independent in the 1970s and 1980s, an abundance of instruments can be obtained from data on European plants and their production capacities.¹⁰ Given that European chemical markets have many similarities with those in the United States, the instruments are quite strong, as indicated by the first stage R^2 values shown in the table. The Hausman-Wu-Durbin statistics indicate considerable endogeneity when market size is represented by *log SALES*. These statistics also indicate the virtual absence of endogeneity when market size is represented by *log POUNDS*, and thus, the regression estimates on the right side of Table 5 appear virtually identical to the corresponding OLS estimates in Table 4. While the estimates based on *log SALES* show small differences between Tables 4 and 5, the pattern of the coefficients is very similar in the two tables.

Table 6 reports the results using a negative binomial count data model. (Results using a Poisson model are very similar. The alpha values in Table 6 indicate that over-dispersion is present only in the first few regressions using *log SALES*.) The coefficients and significance levels for the count data model, like those for the IV model, are very similar to the OLS results in Table 4. Thus, the findings prove to be quite robust to the method of estimation.

Potentially, the results in Tables 4, 5 and 6 reflect unique market conditions in the United States in 1977. A few transient outliers could have a large impact on the regression estimates, given the small

¹⁰ The instruments used for the regressions in Table 5 are as follows: the number of producers in France, Germany, Italy, UK, and all other Western European countries (5 instruments); the number of plants in France, Germany, Italy, UK, and all other countries (5 instruments); total capacity in Western Europe (one instrument); and logarithms of Western European total capacity, plants and firms (3 instruments). The counts are for 1989. (To match the US data, European data for 1977 would be preferable, but such data were unavailable to the author.)

sample. To rule this out, Table 7 provides estimates using data for other countries and for a different time period in the United States. In regressions 7.1 and 7.2, the model (as specified by regressions 4.8 and 4.10 of Table 4), is estimated using producer counts and U.S. production data for 1987. In regressions 7.3 and 7.4, the specification in regression 4.8 is estimated for producer counts in Europe and Japan in 1989.

For the United States, the 1987 estimates resemble those for 1977, confirming that the key relationships identified in Tables 4, 5 and 6 remained robust over time. Moreover, the regression estimates for Western Europe resemble those for the United States. The Japanese results are also similar, despite the smaller Japanese sample. Across these regressions, the impact of a higher sunk cost ratio on the number of producers appears positive in all cases, suggesting that hysteresis-type mechanisms operated in European and Japanese markets and were persistent over at least a decade in the United States.

Summary and Conclusions

By combining data on plant investment and production cost with information on industry sales and capacity, this study has examined factors that determine the number of competitors in a homogeneous product industry. Results show that producer concentration in the sample of 31 chemical product industries was largely determined by market size and the structure of costs. As expected, the number of producers rose with market size, S , and fell with the entry fee, F . After controlling for these factors, the number of producers increased with the ratio of sunk to variable costs, r/v . The latter is consistent with hysteresis—which can create barriers to exit—but not with strategic preemption or entry deterrence. Tests of the interaction between the sunk cost ratio and the geographic distribution of capacity show that the impact of hysteresis was minimal in the Gulf Coast region, where strong price competition may have led to the rapid exit of inefficient or obsolescent plants and firms.

The regression models fit the data well. More than 90% of the variation in the number of US producers in 1977 can be explained by three factors: the market size (measured in pounds), the sunk entry

cost, and the interaction between sunk cost intensity and the geographic distribution of capacity.

Furthermore, the results are similar across three continental markets (United States, Western Europe and Japan) and robust over time. Thus, a small number of factors account for vast differences in market concentration across the chemical products sample.

These findings have implications for contemporary research in economics and strategy, and potentially, for public policy. Most notably, the findings reinforce the conclusion that Ghemawat ultimately reached in his studies of sunk cost commitment: theoretical results on entry deterrence break down under real world conditions of uncertainty and market growth (Ghemawat, 1987; Gilbert and Lieberman, 1987; Lieberman, 1987a, 1987b). The present study adds a comprehensive statistical analysis to the collection of evidence that pushed the capital commitment models out of favor.

This is not to say that sunk costs do not affect competition in homogeneous product industries. The cost of entry can matter a great deal in defining industry concentration. Nevertheless, for the 31 products in this study, the sunk entry fee (the capital cost of building an efficient scale plant) failed to be large enough, relative to market size, to promote a highly concentrated market structure. By comparison, a small but prominent set of service industries - such as rail, telecommunications, electric power distribution, and cable - have been highly concentrated at the local level in the United States due to high sunk costs of entry. Producers in these industries can earn substantial returns, depending on market characteristics and the presence or absence of government regulation. A tentative conclusion is that sunk costs of plant and equipment are seldom large enough to create dominant positions in manufacturing industries, but they do have this effect in some capital-intensive service industries where output is homogeneous, and markets are geographically localized.

It is worth pointing out that the sunk cost of entry need not be high in absolute terms to create high concentration. All that is required is that the entry fee be large relative to the size of the market. The U.S. generic drug industry provides a good illustration of problems that can arise when a moderate cost of entry is combined with modest market size. Many essential generic drugs have only one, two or three

producers, due to the cost of entry relative to market size. Producer exits (often due to quality control or other operational problems, leading to plant closures) have created severe shortages for a growing number of such drugs today. New entrants have been slow to fill the market gaps, as their ability to recoup entry costs has been clouded by uncertainty about post-entry prices and regulatory requirements (FDA, 2019; Sardella and De Bona, 2021).

While the primary focus of this study has been on theories of strategic preemption, it is also instructive to interpret the findings through the lens of real options theory. The regression estimates point to the existence of excess entry (specifically, a surplus of firms relative to the number predicted based on the entry fee and market size alone) for products with a high ratio of sunk to variable costs. When sunk costs are combined with price or cost uncertainty, hysteresis can arise, creating barriers to exit. Although details of the hysteresis mechanism in the chemical products sample are not fully clear, the situation in the sample is not the standard case of exit barriers following a decline in demand. Rather, excess entry may have arisen from errors in coordination or other “entry mistakes” made under uncertainty. Alternatively, it may be an artifact of the normal cycle of plant construction and retirement in an industry where technological change drives prices down over time (Lieberman, 1984, 1987c). As price falls, plants with a greater proportion of sunk costs are slower to be shuttered.

The most compelling results in this context pertain to the interaction between the sunk cost ratio and the fraction of capacity located in the Gulf Coast region (the location in the United States with by far the highest density of chemical plants). Producer counts were augmented most when plants with high sunk cost intensity were more dispersed geographically; excess entry was not detected when production was concentrated in the Gulf Coast region. This is consistent with Syverson’s (2004, 2007) finding for the cement industry: higher demand density leads to more intense price competition, which weeds out less efficient plants. A similar mechanism seems likely to operate in the chemical industry; price pressures in the Gulf Coast region induce more rapid correction of “entry mistakes” and more rapid retirements of

obsolescent plants. By comparison, plants and firms tend to persist in isolated geographic submarkets when sunk costs are high.

In general, the regression results are inconsistent with simple forms of entry deterrence based on sunk cost commitments. However, we cannot rule out more subtle entry deterrence mechanisms. For products with geographic submarkets, producers may have engaged in “entry diversion” rather than entry deterrence (Uzunca and Cassiman, 2020); i.e., incumbents built or maintained excess capacity in an effort to convince entrants to build their new plants elsewhere. Potentially, this might account for some of the interaction effects between sunk cost intensity and geographic market dispersion. Alternatively, firms may have invested to delay entry rather than deter it completely (Cookson, 2018). Or they may have chosen to upgrade their plant facilities and systems in order to make further responses to entry more credible (Seamans, 2012). Such forms of entry deterrence identified in recent studies can be difficult to detect.

These observations suggest some potentially fruitful research directions going forward. First, even though we still do not really know the extent of strategic entry deterrence in the economy, it seems clear that when such deterrence occurs it takes forms more subtle than the ones modeled in the early papers. Second, entry and exit are related processes that should be examined jointly, particularly under conditions of uncertainty (Lieberman, Lee and Folta, 2017.) Third, the presence of uncertainty raises the issue of “entry mistakes;” these are seldom considered in the literature but should be studied more frequently. In general, there remains considerable scope for incorporating uncertainty in studies of strategic firm behavior, using real options and other approaches. Most business outcomes are uncertain, but empirical researchers typically ignore that fact.

The results of this study can be generalized, but with important caveats. While the sample has many desirable properties for testing the theories, it may fail to be broadly representative of homogeneous product manufacturing industries. Indeed, the sample is not fully representative of the chemicals sector, given that it focuses on products with relatively large sales, for which data are available. It is conceivable

that preemptive investments based on sunk costs have been more prevalent for specialty chemicals, where market size tends to be smaller.

Moreover, regression analysis by its very nature can only document average affects. It is possible that for a small number of products in the sample, investment behavior consistent with entry deterrence was carried out, based on sunk capacity investments. For example, Spitz (1988, p. 540) describes successful “preemptive moves to add capacity” in methyl methacrylate monomer, and Ghemawat (1984) suggested that DuPont had such a position in titanium dioxide in the 1970s, when the company’s cost advantages coincided with preemptive investment opportunities. Even so, evidence suggests that such preemptive investments are more often oriented toward deterring moves by existing rivals, rather than those by new entrants (Gilbert and Lieberman, 1987; Lieberman, 1987b).

Finally, as emphasized above, this study is specific to homogeneous product industries. Sutton (1991, 1998) has shown that sunk costs play a greater role in determining concentration in differentiated product industries, where firms invest in intangible assets such as advertising and R&D. Such endogenous sunk costs can potentially grow without bound, whereas in chemicals and most other homogeneous product industries, sunk costs are inherently tied to production capacity, which limits their extent.

Although this study finds no evidence supporting the effectiveness of capital commitment to limit entry in homogeneous product industries, it must be recognized that sunk costs are a key element of many business strategies. A holistic perspective on sunk cost commitment must consider a vast range of investments in corporate capabilities, along dimensions that go beyond product promotion and R&D (Ghemawat, 1991). A large and growing literature in the field of strategic management shows how such investments shape the evolution of industries.

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Table 1.

Number of Producers

	United States				W. Europe	Japan	
	1960	1967	1977	1987	1989	1977	1989
Acetic Acid	*	6	7	6	17	7	8
Acetone	*	11	14	13	14	6	6
Acrylonitrile	4	5	4	5	9	6	6
Adipic Acid	*	6	5	3	6	*	*
Ammonia	40	64	57	43	38	*	*
Aniline	4	5	5	5	7	*	*
Bisphenol A	3	5	4	4	6	2	3
Caprolactam	1	4	3	3	8	4	4
Cumene	*	10	12	10	10	*	*
Cyclohexane	3	12	9	6	8	7	7
Ethylbenzene	*	14	15	9	15	*	*
Ethylene	20	20	26	23	34	14	12
Ethylene Glycol	9	12	11	10	13	*	*
Formaldehyde	14	15	18	15	58	*	*
Hydrogen Peroxide	*	6	6	3	19	*	*
Isopropyl Alcohol	3	4	4	4	7	3	3
Maleic Anhydride	4	7	8	5	13	5	6
Methanol	9	12	10	12	7	7	5
Methyl Methacrylate	2	4	3	3	7	*	*
Nitric Acid	*	47	49	43	47	*	*
Phenol	9	12	11	12	10	2	5
Phthalic Anhydride	9	12	9	5	17	7	6
Polyethylene-HD	8	11	12	15	20	10	10
Polyethylene-LD	9	9	13	12	27	10	10
Polypropylene Resins	*	9	9	12	25	10	14
Polystyrene Resins	*	*	18	19	31	8	9
Propylene Glycol	*	8	5	5	8	5	5
Styrene	8	11	11	8	12	9	7
Urea	12	34	33	28	23	*	*
Vinyl Acetate	4	7	6	4	5	9	5
Vinyl Chloride	12	12	10	8	19	17	11
AVERAGE	8.9	13.1	13.1	11.4	17.4	7.4	7.1

*Data not available.

Sources: Directory of Chemical Producers, United States (1960, 1967, 1977, 1987);

Directory of Chemical Producers, Western Europe (1989);
Annual Survey of Petrochemical Industries in Japan (1977, 1989).

Table 2.

**Correlations Between Numbers of Producers:
U.S., Western Europe and Japan**

	<u>U.S. (1977)</u>	<u>U.S. (1987)</u>	<u>W.Europe (1989)</u>
U.S. (1977)	1.00		
U.S. (1987)	.98	1.00	
W.Europe (1989)	.71	.73	1.00
Japan (1989)*	.61	.64	.84

*Sample of 31 products for U.S. and W. Europe; 20 products for Japan.

Table 3

Correlation Matrix of Explanatory Variables

	<u>Mean</u>	<u>Std Dev</u>	<u>Minimum</u>	<u>Maximum</u>
log NFIRMS _{US,1977}	2.28	0.74	1.10	4.04
log SALES	6.11	0.90	4.28	8.01
log POUNDS	7.85	1.25	5.23	10.48
log F	2.87	0.80	1.44	4.57
SUNKRATIO	0.30	0.19	0.06	0.80
NGC%	0.42	0.29	0.00	0.96

	<u>log NFIRMS</u>	<u>log SALES</u>	<u>log POUNDS</u>	<u>log F</u>	<u>SUNKRATIO</u>	<u>NGC%</u>
log NFIRMS _{US,1977}	1.00					
log SALES	0.63	1.00				
log POUNDS	0.81	0.88	1.00			
log F	0.10	0.58	0.38	1.00		
SUNKRATIO	0.01	-0.02	-0.16	0.52	1.00	
NGC%	0.27	-0.26	-0.19	-0.22	0.25	1.00

Table 4.

OLS Regressions: Number of U.S. Producers in 1977¹

	<u>4.1</u>	<u>4.2</u>	<u>4.3</u>	<u>4.4</u>	<u>4.5</u>	<u>4.6</u>	<u>4.7</u>	<u>4.8</u>	<u>4.9</u>	<u>4.10</u>
constant	-.88 (-1.2)	-.98 (-1.4)	-1.60 (-2.4)	-2.15 (-3.4)	-2.27 (-3.5)	-1.48 (-2.9)	-1.26 (-2.5)	-1.90 (-4.7)	-2.30 (-7.0)	-2.33 (-7.2)
log SALES	.52 (4.3)	.71 (5.2)	.87 (6.2)	.85 (6.8)	.95 (7.5)					
log POUNDS						.48 (7.3)	.54 (8.1)	.65 (11.6)	.63 (14.1)	.68 (15.3)
log F		-.37 (-2.4)	-.67 (-3.6)	-.49 (-2.8)	-.52 (-3.1)		-.23 (-2.2)	-.53 (-5.2)	-.37 (-4.3)	-.37 (-4.3)
SUNKRATIO			1.61 (2.5)	.86 (1.4)	-.33 (-0.4)			1.89 (4.7)	1.23 (3.5)	.22 (0.4)
NGC%				.91 (2.8)					.75 (4.2)	
NGC*SUNK					2.53 (2.9)					2.10 (4.5)
R ²	.391	.496	.592	.688	.693	.649	.701	.834	.901	.906
$\overline{R^2}$	.370	.460	.546	.640	.645	.637	.680	.816	.886	.892
No. of Obs.	31	31	31	31	31	31	31	31	31	31

¹ Dependent variable is the logarithm of the number of United States producers in 1977. Numbers in parentheses are standard t-statistics.

Table 5.

Instrumental Variables Regressions: Number of U.S. Producers in 1977¹

	<u>5.1</u>	<u>5.2</u>	<u>5.3</u>	<u>5.4</u>	<u>5.5</u>	<u>5.6</u>	<u>5.7</u>	<u>5.8</u>	<u>5.9</u>	<u>5.10</u>
constant	-1.34 (-1.8)	-1.69 (-2.35)	-2.31 (-3.3)	-2.80 (-4.4)	-2.83 (-4.5)	-1.47 (-2.9)	-1.32 (-2.7)	-1.90 (-4.7)	-2.32 (-7.5)	-2.35 (-7.8)
log SALES	.60 (4.8)	.87 (5.9)	1.04 (7.0)	1.01 (7.8)	1.07 (8.5)					
log POUNDS						.48 (7.4)	.54 (8.4)	.67 (12.2)	.63 (15.2)	.68 (16.6)
log F		-.47 (-3.1)	-.82 (-4.5)	-.64 (-3.7)	-.62 (-3.1)		-.23 (-2.4)	-.54 (-5.7)	-.38 (-4.7)	-.37 (-4.7)
SUNKRATIO			1.98 (3.1)	1.21 (2.0)	-.21 (-0.3)			1.94 (5.1)	1.24 (3.8)	.22 (0.5)
NGC%				.88 (2.9)					.75 (4.6)	
NGC*SUNK					2.71 (3.4)					2.11 (4.9)
R ²	.381	.468	.569	.668	.680	.649	.701	.834	.901	.906
Durbin score	3.5	7.3	8.0	9.6	8.1	.002	.42	1.2	.14	.14
(p-level)	0.06	0.007	0.005	0.002	0.004	0.97	0.52	0.28	0.71	0.71
Sargan Score	20.8	18.3	17.0	13.8	15.5	22.9	25.0	21.7	19.2	19.7
(p-level)	0.08	0.14	0.20	0.39	0.28	0.04	0.02	0.06	0.12	0.10
First Stage F-stat	7.97	4.65	4.63	4.47	6.08	21.1	17.8	14.1	17.4	18.3
No. of Obs.	31	31	31	31	31	31	31	31	31	31

¹ The dependent variable is the logarithm of the number of United States producers in 1977. Coefficients for log Sales and log Pounds were estimated using two-stage least squares with instrumental variables. The instruments consist of counts of producers, plants and capacity in Western Europe, based on the assumption that the US and European markets are independent. The instruments are as follows: the number of producers in France, Germany, Italy, the UK, and all other countries (5 instruments); the number of plants

in France, Germany, Italy, the UK, and all other countries (5 instruments); total capacity in Western Europe (one instrument); and logarithms of Western European total capacity, plants and firms (3 instruments). Numbers in parentheses are z-scores.

Table 6.

Count Data Regressions (Negative Binomial Model): Number of U.S. Producers in 1977¹

	<u>6.1</u>	<u>6.2</u>	<u>6.3</u>	<u>6.4</u>	<u>6.5</u>	<u>6.6</u>	<u>6.7</u>	<u>6.8</u>	<u>6.9</u>	<u>6.10</u>
constant	-1.11 (-1.5)	-1.30 (-1.8)	-1.87 (-2.5)	-2.44 (-4.0)	-2.55 (-4.0)	-1.84 (-3.5)	-1.85 (-3.7)	-2.18 (-4.7)	-2.48 (-6.9)	-2.45 (-6.9)
log SALES	.61 (4.5)	.75 (5.3)	.89 (5.8)	.82 (6.7)	.95 (7.5)					
log POUNDS						.53 (8.5)	.61 (9.1)	.68 (10.6)	.60 (11.8)	.66 (13.8)
log F		-.31 (-2.0)	-.56 (-2.9)	-.29 (-1.7)	-.37 (-2.2)		-.21 (-2.4)	-.46 (-3.9)	-.18 (-1.8)	-.25 (-2.5)
SUNKRATIO			1.43 (2.0)	.33 (0.5)	-1.08 (-1.3)			1.58 (3.1)	.62 (1.4)	-.27 (-0.5)
NGC%				1.27 (4.5)					.95 (5.0)	
NGC*SUNK					3.31 (4.1)					2.40 (4.8)
Pseudo R ²	.087	.105	.122	.191	.182	.182	.205	.248	.341	.332
alpha	.250	.209	.191	.083	.096	.078	.050	.038	.000	.000
No. of Obs.	31	31	31	31	31	31	31	31	31	31

¹ Dependent variable is the number of United States producers in 1977. Numbers in parentheses are z-scores.

Table 7.

OLS Regressions: Comparison Across Regions¹

	<u>7.1</u>	<u>7.2</u>	<u>7.3</u>	<u>7.4</u>
Region:	U.S.	U.S.	W. Europe	Japan
Year:	1987	1987	1989	1989
constant	-2.66 (-6.2)	-3.08 (-7.5)	-.76 (-2.4)	-2.61 (-4.6)
log POUNDS ²	.71 (11.7)	.74 (13.4)	.54 (11.9)	.38 (7.4)
log F	-.49 (-4.8)	-.39 (-3.9)	-.45 (-5.7)	-.27 (-3.3)
SUNKRATIO	1.45 (3.6)	.24 (0.4)	2.06 (6.6)	1.02 (3.5)
NGC*SUNK		1.56 (2.8)		
R ²	.841	.878	.854	.810
No. of Obs.	31	31	31	20

¹ Dependent variable is the logarithm of the number of producers in the region during the year indicated. Numbers in parentheses are t-statistics.

² For the U.S and Japan, POUNDS is total domestic production in the designated year. For Western Europe, production data are not available; total Western European capacity in 1989 is used as a proxy.



