What Determines the Number of Firms?

Cost Structure and Producer Concentration in Homogeneous Product Industries

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ABSTRACT

This study considers how cost structure affects producer concentration in homogeneous product industries. Tests are performed on a sample of 31 chemical products. By applying the “Dixit” cost function to engineering data, sunk costs are parameterized into two elements: (a) the industry “entry fee,” and (b) the ratio of sunk to variable costs. These aspects of sunk cost are shown to have distinct but opposite effects: the number of producers falls with the entry fee but rises with the sunk cost ratio. Thus, sunk costs may contribute to either an increase or a decrease in industry concentration, depending on how the cost components are distributed. These findings help to resolve ambiguities in prior work on sunk costs.

1. Introduction

What determines the number of competitors in a homogeneous product industry? Recent theoretical work highlights the potential influence of cost structure, particularly the presence of sunk costs. A standard result is that the number of firms falls with the investment required for market entry. In addition, if firms make large, irreversible investments in production capacity, incumbent producers may be able to deter new entry strategically. Yet sunk costs also create a gap between an industry's entry- and exit-inducing prices, which can lead to an overabundance of producers and negative economic profits. Economic theory thus gives conflicting predictions: higher sunk costs seem likely to reduce, but may possibly increase, the number of competing firms.

This paper investigates how sunk costs affect producer concentration in homogeneous product industries where capacity commitments are important. Tests are performed on a sample of 31 chemical products for which engineering cost estimates were obtained. These estimates are mapped into the "Dixit" cost function, commonly used in theoretical work. The resulting measures allow the effects of cost structure to be evaluated in a conventional regression analysis, unlike prior studies that have inferred the role of cost structure from information on entry and changes in demand.

Using the engineering data, sunk costs are separated into two components. The first corresponds to the industry's "entry fee." The second reflects the extent to which total costs are sunk. The regression results show that these two features of sunk cost have distinct but opposite effects: the number of producers falls with the entry fee and rises with the proportion of costs that are sunk. Thus, sunk costs may contribute to either an increase or a decrease in industry concentration, depending on how the cost components are distributed. These empirical findings are new and help to resolve the ambiguity raised by theoretical work.

The primary data sample for this study is for producers in the United States, with supplementary information on Western Europe and Japan. In addition to the producer count and engineering cost data, historical information was collected on the annual output of each product, which provides an indicator of demand. The regression results imply that in all three geographic regions, the number of producers was largely determined by cost structure and market size.

The paper is organized as follows. The next section surveys the literature on potential determinants of producer concentration. Section 3 describes the sample of chemical products, the parameterization of cost structure, and the specific measures used in the study. Section 4 presents the regression estimates. A concluding section summarizes the findings and relates them to prior work.

2. Cost Structure and Industry Concentration

Views on the influence of cost structure on market concentration have evolved since the 1950s. Early empirical studies focused on the effects of plant-level economies of scale. These studies typically regressed producer concentration on various proxies for scale economies and found a high correlation, particularly for industries with minimal advertising and R&D expenditures (c.f., Curry and George, 1983). Other work revealed that industry concentration levels were similar across countries (but decreasing, generally, with the size of the national market) which implied a strong underlying force of technological determinism (Bain, 1956; Pashigian, 1969; Pryor, 1972; Scherer, 1973; George and Ward, 1975).

More recently, economists have aimed at more precise assessments by drawing a distinction between costs that are fixed but recoverable, and those that are irretrievably sunk.[1] For given level of demand, the equilibrium number of producers generally declines

[1] Fixed costs may take various forms; e.g., output-invariant fees or input charges, or initial setup costs. Typically, some proportion of setup costs are not only fixed but also unrecoverable, i.e., sunk.

with the magnitude of fixed costs.[2] Sunk costs, however, lead to more complicated dynamic outcomes, where a diversity of theoretical results have been demonstrated.

One line of theoretical research on sunk costs (e.g., Dixit, 1980; Eaton and Ware, 1987) demonstrates how early entrants may be able to preempt a growing market. These models assume a cost structure similar to the chemical industries evaluated in this study: firms undertake investments to enter the industry, and then to expand capacity. Sunk costs provide a means for producers to commit to higher future output. The models show that under some cost and demand conditions, early entrants can invest strategically to deter subsequent entry.

Other research (e.g., Dixit, 1989; Bresnahan and Reiss, 1993) shows that in the presence of uncertainty, sunk costs lead to hysteresis---a gap between the prices that induce entry and exit---which expands the set of equilibrium market structures. If cost or demand are uncertain, firms may rationally enter and persist, even though they are unable, *ex post*, to earn economic profits. Such results are extensions of Marshall's classic model in which firms enter an industry when demand covers fixed plus variable costs and exit only when price falls below variable cost. MacLeod (1987) shows that as the proportion of costs that are sunk increases, it is possible to have a larger number of firms forming an equilibrium market structure. This is the opposite of the predictions of the sunk cost deterrence models.

Sutton (1991) draws an important distinction between exogenous and endogenous sunk costs. He considers exogenous sunk costs to be the technologically determined setup costs required for industry entry.[3] Sutton shows that in homogeneous product

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[2] In models where profits fall with the number of competitors, entry occurs up to the point where an additional entrant is unable to cover fixed costs. With higher fixed costs, this profit constraint leads to fewer firms in the industry.

[3] In his analysis of homogeneous product industries, Sutton considers only the initial "entry fee," ignoring the additional sunk costs relating to expansion of capacity. Both sets of sunk costs are considered in the present study.

[4] For example, R&D, advertising, and other reputational capital are not normally recorded as assets on the firm's books. Measures of tangible capital that are standard items on the balance sheet may be biased by accelerated depreciation accounting.

industries, where sunk costs are mostly exogenous, bounds on producer concentration are defined by the size of the market relative to the setup cost of entry. Increases in market size and reductions in the entry fee lead to (potentially) larger numbers of firms.

Endogenous sunk costs, such as advertising and R&D, serve to enhance the demand for the firm's product. Sutton argues that normal processes of competition induce firms to escalate these investments, thereby reducing the number of firms. This may explain why advertising and R&D-intensive industries are often much more concentrated than would be expected on the basis of manufacturing economies of scale. Sutton's work suggests that the effects of sunk costs in promoting concentration may be greatest in differentiated product industries where the potential rewards to advertising and other intangible assets are unbounded. Sutton presents empirical evidence on the food and drink sector to support these predictions on the effects of exogenous and endogenous sunk costs.

Other empirical findings on the connection between sunk costs and concentration have been more equivocal. This may stem from the theoretical ambiguities described above, or to the difficulty of accurately identifying cost structures. Kessides (1990) found that industries were less concentrated when the sunkenness of capital was limited by rapid depreciation or by the availability of leases or resale markets. This finding is consistent with market preemption based on sunk costs. Gilbert (1986), however, surveyed accounting data for a range of industries and concluded that in most cases the degree of capital intensity is too low for deterrence to be effective. Similarly, Lieberman (1987) found little evidence that incumbents in chemical product markets preempted by building capacity ahead of demand.

In other recent studies that assess the relation between cost structure and concentration (e.g., Reiss and Spiller, 1989; Bresnahan and Reiss, 1990, 1991; Berry, 1992), costs are inferred by observing entry and exit in response to changes in demand. This approach has the advantage that it avoids the use of accounting data, which may be biased.[4] These studies confirm that cost structure and demand factors can jointly explain much of the systematic variation in industry concentration levels. However, the "entry thresholds" demonstrated in these studies fail to suggest widespread preemption or entry deterrence through the use of sunk costs.

Various empirical work points to the prevalence of hysteresis effects. Bresnahan and Reiss (1993) found evidence of hysteresis in the entry and exit behavior of dentists in small rural markets, which they attributed to sunk costs. Ghemawat and Caves (1986) found profits to be negatively correlated with capital intensity, a result consistent with hysteresis but not with predictions of the sunk cost commitment models. Numerous studies in the international trade literature (e.g., Baldwin, 1988) show persistence in trade flows which can be explained by hysteresis in firms' underlying infrastructure investments.

Other studies have focused on changes in concentration over the life cycle of an industry. A common finding is that the number of firms tends to increase as demand grows over time, although at some point a "shakeout" of producers commonly occurs (Klepper and Graddy, 1990). Yet even when concentration remains stable, firm turnover (entry counterbalanced by exit) is often substantial. High turnover rates have been observed for most manufacturing industries, including those in the chemical products sector (Dunne, Roberts and Samuelson, 1988, 1989).

3. Data and Measures

The tests in this study were performed by regressing producer counts for the chemical products on a set of cost structure and demand-side measures. The resulting coefficients can be regarded as reduced form estimates of the determinants of producer concentration. Given that concentration and output are likely to be endogenous (in particular, the price and volume of output may depend upon the number of producers), the regressions were estimated using instrumental variables. The data sample and measures used in the analysis are described below.

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.[5] Table 1 lists these chemicals and corresponding counts of producers in the US, Western Europe and Japan. The 31 products are homogeneous and undifferentiated among producers; and all but two (hydrogen peroxide and nitric acid) are petrochemicals.

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 U.S. petrochemical sector. The engineering cost estimates used in this study pertain to new plants built in 1977. Regression analyses were performed for the number of producers in that year and also in the late 1980s, recognizing that some time may have been required for process technology that was state-of-the-art in 1977 to become widely adopted.

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 (Freeman, 1968; Spitz, 1988; Stobaugh, 1988; Arora and Gambardella, 1998). Thus, restricted access to technology was not a significant barrier to entry, and firms' internal R&D activities had become relatively unimportant.

For purposes of this study, the 31 chemical products in the sample are each considered to represent a separate industry. Furthermore, the three geographic regions (United States, Western Europe and Japan) are assumed to be independent. These

[5] 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).

assumptions are reasonable approximations to reality. The chemical plants represented in the study are each dedicated to the manufacture of a specific product; the sample excludes chemicals whose production processes yield significant joint products, and those where capacity is convertible to other products.[6] While industrial chemicals are shipped internationally in large quantities, the volume of trans-oceanic trade is normally a small fraction of total output, and the US market, in particular, is largely autonomous.

Number of Producers

The dependent variable for the regression analysis is the logarithm of the number of producers.[7] In 1977, the publication year of the engineering data, the number of U.S. producers ranged from three (caprolactam and methyl methacrylate) to fifty-seven (ammonia).[8] Table 1 gives comparable counts for Western Europe and Japan.[9]

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. As shown in Table 2, the correlation coefficient between the 1967 and 1987 U.S. producer counts is 0.95; the correlation is even higher between adjacent decades. 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 are almost entirely independent allows the European data to serve as instruments for the U.S. regressions and vice versa.

Japanese data were obtained for 20 of the 31 products in the sample. The Japanese producer counts are more strongly correlated with Western Europe than the

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[6] Nevertheless, the plants in this study are commonly part of larger chemical complexes which produce a variety of different products.
[7] 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.
[8] The sample is representative of commodity chemicals but excludes the specialty chemicals sector where monopoly and duopoly products are frequently observed.

United States; nonetheless, both correlations were rising over time. These patterns may reflect differences in demand structure and raw materials, and the early role of MITI in regulating entry into the Japanese chemical industry (Hikino, et al., 1998).

Cost Measures

Theoretical studies of sunk cost commitment have commonly used the Dixit (1980) cost function, which takes the form: $C(x) = F + rk + vx$, 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. In their generalization of Dixit's duopoly analysis to the multi-firm case, Eaton and Ware (1987) show that the equilibrium number of firms decreases with the entry fee, F, as well as with the sunk to variable cost ratio, r/v.

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 *1977 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 is set in place for the production of a specific product in a given facility, the salvage value is minimal.[10] Labor and overhead costs are fixed but not sunk;

[9] 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.

[10] Once the equipment is assembled in the plant, the costs associated with removal and reuse are generally prohibitive, and scrap value is low.

these costs must be incurred to operate the plant, but they are virtually independent of plant output.

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.) 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 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. This flow investment cost for a "zero capacity" plant was taken as the entry fee, *F*.[11]

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. 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.

[11] As an alternative, the total investment cost of the smaller plant ($46.3 million for HDPE) was used as a value for *F*. Results were very similar to those reported below. An early version of this paper used a more complex parametrization of the cost function, also with similar results.

The deterrence models of Dixit and Eaton-Ware suggest that the number of firms should fall as *SUNKRATIO* rises. However, *SUNKRATIO* also corresponds to the wedge between the Marshallian entry- and exit-inducing prices in the industry. Given a stochastic entry process arising from uncertainty about demand, technology, costs, or the behavior of rival firms (c.f., Dixit and Shapiro (1986), Cabral (1993, 1997)), industries with higher values of *SUNKRATIO* may tend to exhibit larger numbers of firms. The key test of this study is to determine whether the net effect of *SUNKRATIO* is positive, negative or zero on average.

Many of the early studies of cost structure and concentration attempted to measure the extent of scale economies based on the slope of the cost function. Such a measure of scale economies was developed for the present study. *SCALECON* equals the reduction in total costs associated with a doubling of capacity. In the case of LDPE, shown in Figure 1a, *SCALECON* was computed as 1-(21.47/25.32)^.5 = 7.9%. (Larger figures correspond to greater scale economies.) *SCALECON* was tested in the regressions to determine whether the number of producers is sensitive to the slope of the cost function, rather than the size of the entry fee (*F*) and incremental sunk costs (*SUNKRATIO*).

Early studies also found that concentration and entry were sensitive to the size of the market measured relative to a plant of "minimum efficient scale." To test this idea, an additional measure was developed, corresponding to industry output divided by the capacity of the "mid-size plant," where the latter is identified in the *Yearbook* as being "representative of sizes of competitive U.S. plants."[12]

Market Size and Growth

Other things equal, larger markets can sustain more firms. This basic relation is intuitive and has been identified in virtually all studies on the determinants of producer concentration. This study controls for differences in market size but includes only limited

[12] Alternatively, one might use the size of the smaller plant shown in the *Yearbook*, but in nearly all cases this is half the size of the mid-size plant, so the two MES estimates differ by a simple scaling factor.

measures of other demand characteristics. Detailed demand-side information is not readily obtainable for the chemical products in the sample.

The primary demand-side measure used in the study is annual industry output, which can be measured in either 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.[13]

Using the historical output data, measures were developed to assess whether concentration was influenced by the time path of industry growth (controlling for the final output level). There are various reasons why the growth rate of output, or changes in that rate, could affect the number of producers. Given increasing marginal costs of adjusting capacity, rapid demand growth might outstrip incumbent firms' abilities to expand, thereby facilitating additional entry (Hause and DuRietz, 1984; Nakao, 1980). Further, the number of producers may increase with demand volatility. This would arise if supra-normal profits during peak periods allow the survival of a larger number of firms (Sheshinski and Dreze, 1977; Mills and Schumann, 1985). Moreover, changes in the rate of industry growth may lead to uncertainty in entrants' expectations about the future level of demand. In industries with hysteresis, this may induce an increase in the number of producers.[14] Ultimately, firms may become trapped in an unprofitable industry if costs are mostly sunk and there is a large unanticipated downturn in demand.

To assess these potential effects, experiments were performed by adding to the regressions various measures derived from the historical output data. These measures included the average recent growth rate of output, the maximum annual rate (post-1960), the degree of variability in annual output (measured as the residuals from a quadratic

[13] The U.S. output data were collected annually for most products back to 1960.
[14] Uncertainty could also lead to a smaller number of firms, as it may raise the demand or price threshold necessary to induce entry.

regression of industry output on time), the change in industry growth rate (pre- versus post-1970) and a dummy for industries with declining demand.[15] These measures were also interacted with *SUNKRATIO*, given that some of the effects described above would be expected to increase with the magnitude of sunk costs.

Degree of Multiplant Operation

The SRI engineering data pertain to the cost structure of plants, whereas the theoretical models are based on the cost structure of firms. If multiplant economies are important, the assumptions made above regarding the cost parameters may be inappropriate. A measure of multiplant operation, *MULT*, was used to determine whether factors related to multi-plant operation were important determinants of the number of firms in the sample. *MULT* equals the average number of plants per firm producing the product in question in the United States in 1977. A significant *MULT* coefficient in the regressions would imply that (unobserved) factors relating to multiplant economies of scale had an important influence on the number of producers.

Correlations among the Variables

Table 3 gives a matrix of first order correlation coefficients for the variables in the study. The two measures of market size (*SALES* and *POUNDS*) are strongly correlated with the number of producers, but the cost measures (*F*, *SUNKRATIO*, and *SCALECON*) are not. These cost measures are, nevertheless, correlated with each other, as all three tend to be larger for plants with high capital investment. Nevertheless, the three measures capture different aspects of the cost structure, and their independent effects can be identified in the regressions. The number of plants per firm, *MULT*, is positively correlated with the number of producers, indicating a tendency for greater multiplant operation in less concentrated markets.

[15] Only a few products exhibited declining output prior to 1977, and the extent of these declines was small.

4. Empirical Results

Table 4 reports the regression results for the number of U.S. producers in 1977, based on instrumental variable estimation.[16] (The OLS results, which are almost identical, are in the Appendix.) These regressions show that the number of producers was largely determined by market size and sunk costs.

In regressions 4.1 through 4.5, *SALES* is used as the measure of market size; regressions 4.6 through 4.10 use *POUNDS*. The fit is substantially better with *POUNDS*, but the results otherwise are similar. The *SALES* coefficients are approximately unity, which implies that the number of producers increased in direct proportion with market size, measured in monetary terms. The *POUNDS* regressions yield smaller coefficients but indicate that differences in market size, measured in physical units, can account for well over half of the sample variance in the number of producing firms.

The cost measures, *F* and *SUNKRATIO*, are highly significant with opposite signs. The number of producers fell with the entry fee, *F*. The magnitude of this effect depends on the specification; the *F* coefficient doubles in size and the regression fit improves substantially when *SUNKRATIO* is included. This suggests that consideration of the entry fee alone, without the effects represented by *SUNKRATIO*, leads to a serious underestimate of the relationship. The dramatic improvement in fit when *SUNKRATIO* is added to the specification proved quite robust across time periods and geographic regions. Regression 4.8 shows that for the U.S. data, more than 80% of the sample variance in the number of producers can be accounted for by differences in market size and sunk costs.

The coefficient of *SUNKRATIO* is consistently positive, implying that (after controlling for *F*) the number of producers increased with degree to which total costs were sunk. This is consistent with hysteresis effects, but not entry deterrence or

[16] The set of instruments is described in Table 4. Tests showed the absence of heteroskedasticity in the fully specified regression model (e.g., regression 4.8), but to be conservative Table 4 gives t-statistics based on robust standard errors. The dependent variable is based upon descrete count data with a minimum bound; the residuals nevertheless appear normally distributed when the variable is in log form. Tobit regression, which takes the bound into account, provided estimates very similar to those in Table 4.

preemption. Such evidence is strong but not definitive; conceivably, preemptive behavior based on sunk cost commitments could have occurred for a limited number of products in the sample.

Thus, the entry fee and the sunk cost ratio tend to push the market structure in opposite directions. What, then, is the net effect? Do sunk costs ever lead on balance to an *increase* in the number of firms? One way to answer this question is to estimate the relative influence of the two cost components for each product in the sample. Such estimates are provided in Figure 2, which was obtained by multiplying the *F* and *SUNKRATIO* coefficients in regression 4.8 by the values corresponding to each data point. In Figure 2, the horizontal axis gives the reduction in the number of producers attributable to the entry fee, *F*; the vertical axis gives the increase in number of producers attributable to the sunk cost ratio. These two effects exactly offset each other along the dotted diagonal line.

Nearly all of the 31 products in the sample fall below this diagonal; thus, the net effect of sunk costs was almost uniformly to reduce the number of firms. The one exception is maleic anhydride, whose sunk cost ratio was the highest in the sample, but whose entry fee was only about half the sample average. The regression coefficients imply that the sunk cost ratio for maleic anhydride, considered alone, served to increase the number of producers by roughly a factor of four, whereas the entry fee reduced the number by about a factor of three. Their net effect on the predicted number of firms is therefore slightly positive.

The other cost measure in Table 4, *SCALECON*, proved uniformly insignificant in the regressions when included with *F* and *SUNKRATIO*. Similar results (not shown) were obtained for the measure representing industry output divided by the capacity of a "mid-size plant." These findings suggest that the entry fee and sunk cost ratio represent more suitable constructs than the earlier and less precise concepts of "minimum efficient scale" and degree of scale economies.

Table 4 shows that *MULT*, the average number of plants per firm, was not statistically significant. The European data gave similar insignificant results (not shown). These findings imply that multiplant economies of scale did not play an important role in determining the number of producers in the industries examined in this study.

Experiments were performed to assess whether the historical growth path of industry output had an influence on the number of firms. The results of these experiments were negative; the output growth and variability measures were uniformly insignificant when added to Regression 4.8 and related specifications. Interactions with *SUNKRATIO* were also statistically insignificant. Thus there was no evidence that rapid growth or substantial variability in (annual) demand contributed to an increase in the number of firms. In general, the effects of cost structure on the number of competitors appeared remarkably robust to differences in the profile of industry growth. (NOTE: A table of regression results can be added here, and the discussion expanded.)

If unanticipated shifts in demand were not the primary source of hysteresis effects, what may have led to “excess” entry? In the chemical industry, expectations about costs are likely to have been more important than demand-side factors. Many firms entered in anticipation of attaining cost advantages, based upon potentially superior (newer) technology or access to low-cost inputs. In cases where these expectations were not borne out, but sunk costs were high, entrants would have persisted in the industry despite their inability to cover total costs. And even when entrants did attain a cost advantage, incumbents’ plants would have continued to operate, assuming that prices remained above variable costs.

A further regression analysis was performed to determine whether the observed relationships were robust across geographic markets and over time. To supplement the results for 1977, the model (represented by regression 4.8) was estimated for the number of U.S. producers in 1967 and 1987, as well as for producers in Europe and Japan. These regression results are shown in Table 5.

For the United States, the 1967 and 1987 regression estimates are similar to those for 1977 discussed previously. The coefficients and fit obtained for 1977 and 1987 are nearly identical; for 1967 the fit is slightly poorer and coefficient estimates smaller. Weaker results would be expected for this earlier period, given errors that arise in applying the 1977 cost parameters to the 1967 data. In general, though, these results imply that the relationships identified in Table 4 were robust over time.

Table 5 also shows that the regression results for Western Europe resemble those for the United States. The Japanese results are also comparable, despite the smaller Japanese sample. Regression 5.5 suggests that the influence of cost structure was weaker in Japan in 1977 than in the other regions. This may be due to MITI's role in regulating entry through the mid-1970s. The effects of sunk costs appear more prominent in the Japan regression for 1989; here, the coefficients and R^2 approach the values shown for the U.S. and Europe.

5. Conclusions

Using a unique set of engineering data, this study has examined factors that potentially determine the number of competitors in a homogeneous product industry. The results show that producer concentration in the sample of 31 chemical product industries was largely determined by market size and the structure of sunk costs. The findings are similar for the three geographic regions---United States, Western Europe and Japan---and robust over time.

The two measures of sunk cost identified in this study appear to have had substantial but opposite effects. A larger entry fee led to higher producer concentration, while increases in the ratio of sunk to variable costs led to an increase in the number of firms. The latter findings are consistent with hysteresis effects, but not with strategic preemption or entry deterrence.

These findings help to resolve ambiguities raised by prior theoretical and empirical work on sunk costs. They imply that it is important to distinguish between the entry fee and incremental components of sunk cost. Otherwise, empirical studies will tend to underestimate the impact of each component on market structure and potentially misinterpret their net effect.

In addition to the entry fee and sunk cost ratio, measures were developed in this study resembling those in the earlier literature on scale economies. These measures were found to lack explanatory value. Such findings suggest that the entry fee and sunk cost ratio, which have links with modern economic theory, are more suitable constructs than the earlier but less precise concepts of "minimum efficient scale" and cost curve slope.

The findings also suggest that the dynamics of industry growth have little effect on market structure. While the number of chemical producers was strongly related to the current level of industry output, no connection was found between concentration and the historical path of output. Thus the rate and variability of industry growth had no significant impact on the number of firms. This suggests that adjustment costs and related factors have been relatively unimportant, at least in chemical product industries.

These results must be generalized with caution given the small sample size. Moreover, it should be emphasized that the findings are specific to homogeneous product industries. Sutton's (1991) recent work suggests that sunk costs play a greater role in promoting concentration in differentiated product industries, where sunk investments are mostly in intangible assets such as advertising and R&D. Such costs can potentially grow without bound. In chemicals and other mature homogeneous product industries, sunk costs are inherently tied to production capacity, which limits their extent.

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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 Resin:	*	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.S. (1977)	U.S. (1987)	W.Europe (1989)	Japan (1977)
U.S. (1977)	1.00			
U.S. (1987)	.98	1.00		
W.Europe (1989)	.71	.73	1.00	
Japan (1977)*	.55	.47	.63	1.00
Japan (1989)*	.61	.64	.84	.81

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

Table 3

Correlation Matrix of Explanatory Variables

	Mean	Std Dev	Minimum	Maximum
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	0.28	0.19	0.03	0.74
SCALECON	0.06	0.04	0.01	0.14
MULT	1.38	0.38	1.00	3.00

	log NFIRMS	log SALES	log POUNDS	log F	PCTSUNK	SCALECON
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	0.05	-0.05	-0.13	0.48	1.00	
SCALECON	-0.02	-0.18	-0.25	0.24	0.85	1.00
MULT	0.42	0.16	0.32	-0.17	-0.02	0.16

Table 4.

Regression Analysis of Number of U.S. Producers in 1977[1]

	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	4.10
constant	-1.32 (-1.8)	-1.57 (-1.9)	-2.49 (-3.5)	-2.52 (-5.8)	2.35 (0.4)	-1.55 (-2.4)	-1.36 (-2.1)	-1.89 (-5.4)	-1.86 (-7.6)	-2.37 (-0.6)
log SALES	.59 (5.0)	.84 (5.7)	1.08 (7.7)	1.06 (10.0)	.94 (9.7)					
log POUNDS						.49 (6.2)	.55 (6.0)	.65 (12.2)	.66 (9.5)	.66 (9.1)
log F		-.46 (-2.9)	-.87 (-6.6)	-.84 (-6.2)	-.77 (-6.0)		-.24 (-2.8)	-.50 (-6.3)	-.51 (-5.5)	-.51 (-5.4)
SUNKRATIO			2.30 (4.3)	2.25 (3.9)	2.80 (2.7)			1.83 (5.5)	1.86 (4.4)	1.78 (2.2)
SCALECON					-4.43 (0.9)					.50 (0.1)
MULT				.07 (0.6)	.22 (1.5)				-0.5 (-0.2)	-0.7 (-0.3)
R^2	.391	.495	.633	.640	.662	.649	.701	.828	.828	.828
$\bar{R}^2$	.370	.459	.592	.585	.594	.637	.680	.809	.801	.793
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. Regressions were estimated using instrumental variables for SALES, POUNDS and MULT, which are potentially endogenous. The set of instruments includes total counts of Western European producers, plants and capacity in 1989, and national counts of plants and producers in France, Germany, Italy and the UK. Numbers in parentheses are heteroskedastic-consistent t-statistics.

Table 5.

Comparison of Regression Results Over Time and Across Regions[1]

	5.1	5.2	5.3	5.4	5.5	5.6
Region:	U.S.	U.S.	U.S.	W. Europe	Japan	Japan
Year:	1967	1977	1987	1989	1977	1989
constant	-.78	-1.89	-2.60	-.64	-.07	-2.29
	(-1.9)	(-5.4)	(-7.1)	(-2.3)	(-0.2)	(-3.5)
log POUNDS*	.51	.65	.70	.52	.37	.34
	(8.7)	(12.2)	(12.7)	(10.7)	(5.0)	(6.3)
log F	-.30	-.50	-.46	-.38	-.15	-.22
	(-3.3)	(-6.3)	(-5.4)	(-5.7)	(-1.5)	(-2.9)
SUNKRATIO	1.18	1.83	1.36	1.85	.77	1.00
	(3.2)	(5.5)	(5.0)	(8.1)	(2.8)	(4.7)
R^2	.703	.828	.836	.820	.571	.759
No. of Obs.	30	31	31	31	20	20

[1] Dependent variable is the logarithm of the number of producers. Regressions were estimated using instrumental variables for POUNDS, which is potentially endogenous. Instruments for the U.S. regressions are described in Table 4. U.S. producer counts and output were used as instruments for the Western Europe regression. Both sets of instruments were used for the Japan regressions. Numbers in parentheses are heteroskedastic-consistent t-statistics.

* For the regressions covering the U.S. and Japan, POUNDS corresponds to total domestic output in the designated year. For Western Europe, POUNDS corresponds to total Western European capacity in 1989.

Figure 1a.

Production Cost Structure for Low Density Polyethylene: Average Cost

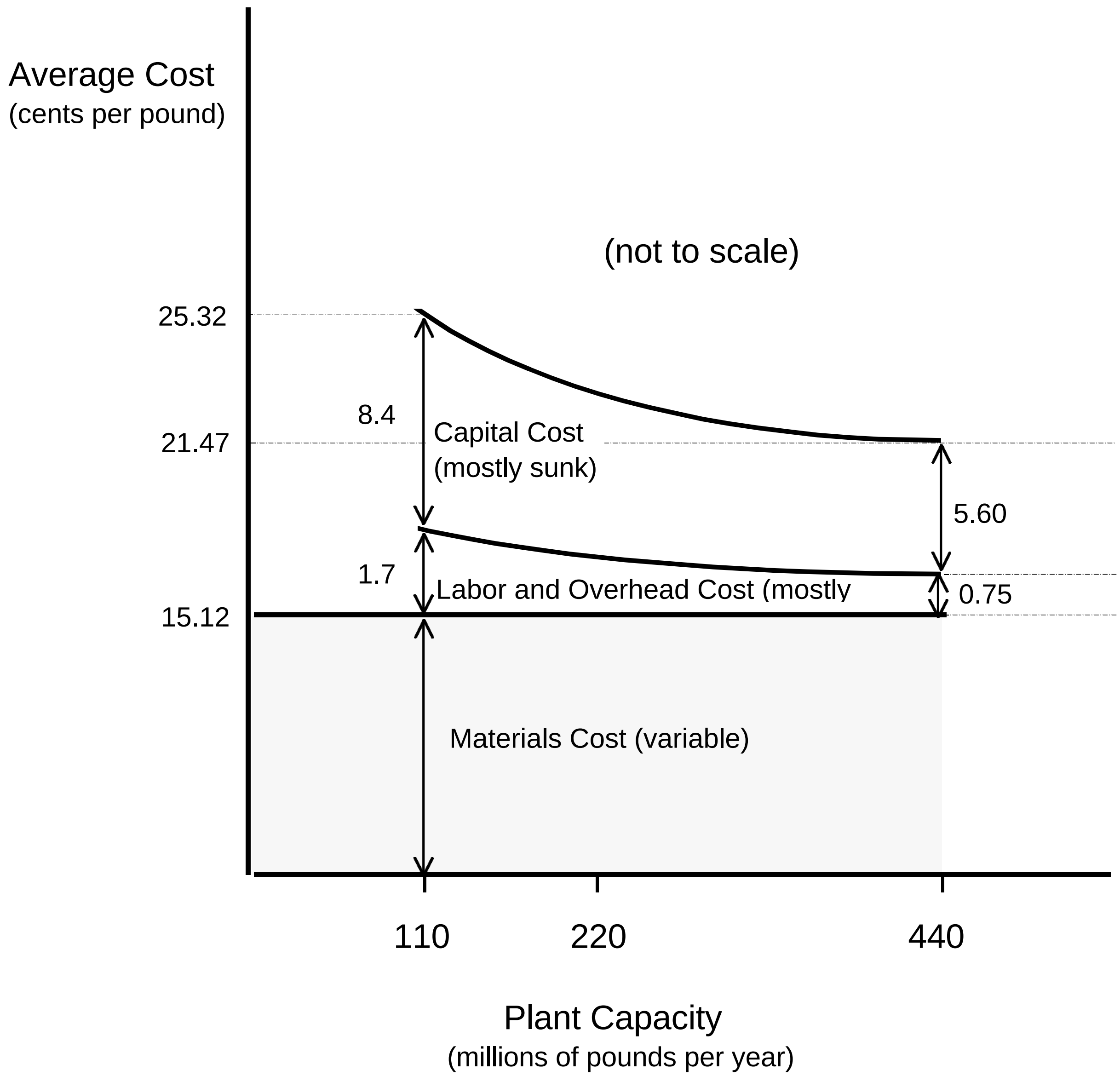


Figure 1b. Production Cost Structure for LD Polyethylene: Total Cost (assuming plant operation at full capacity)

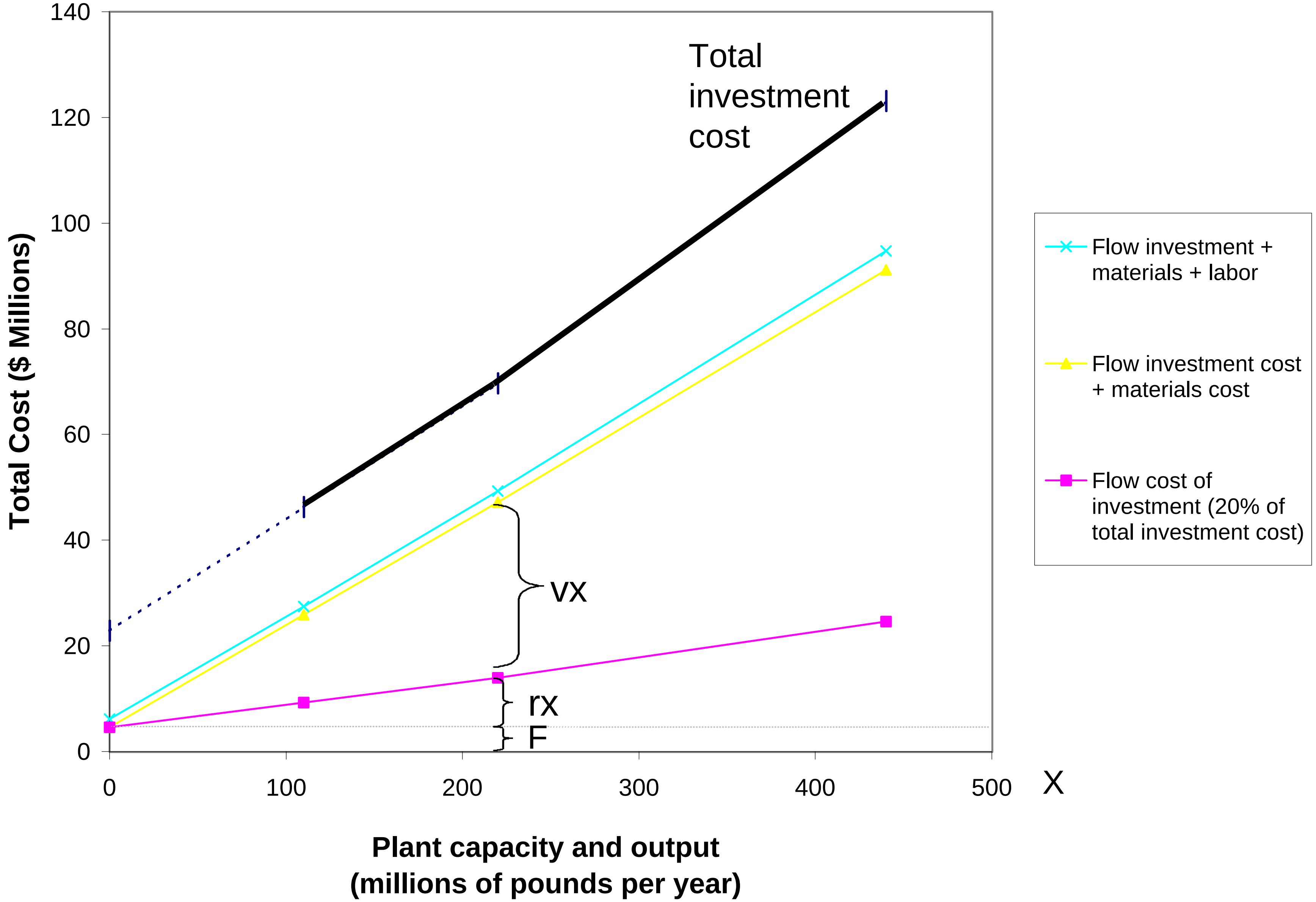
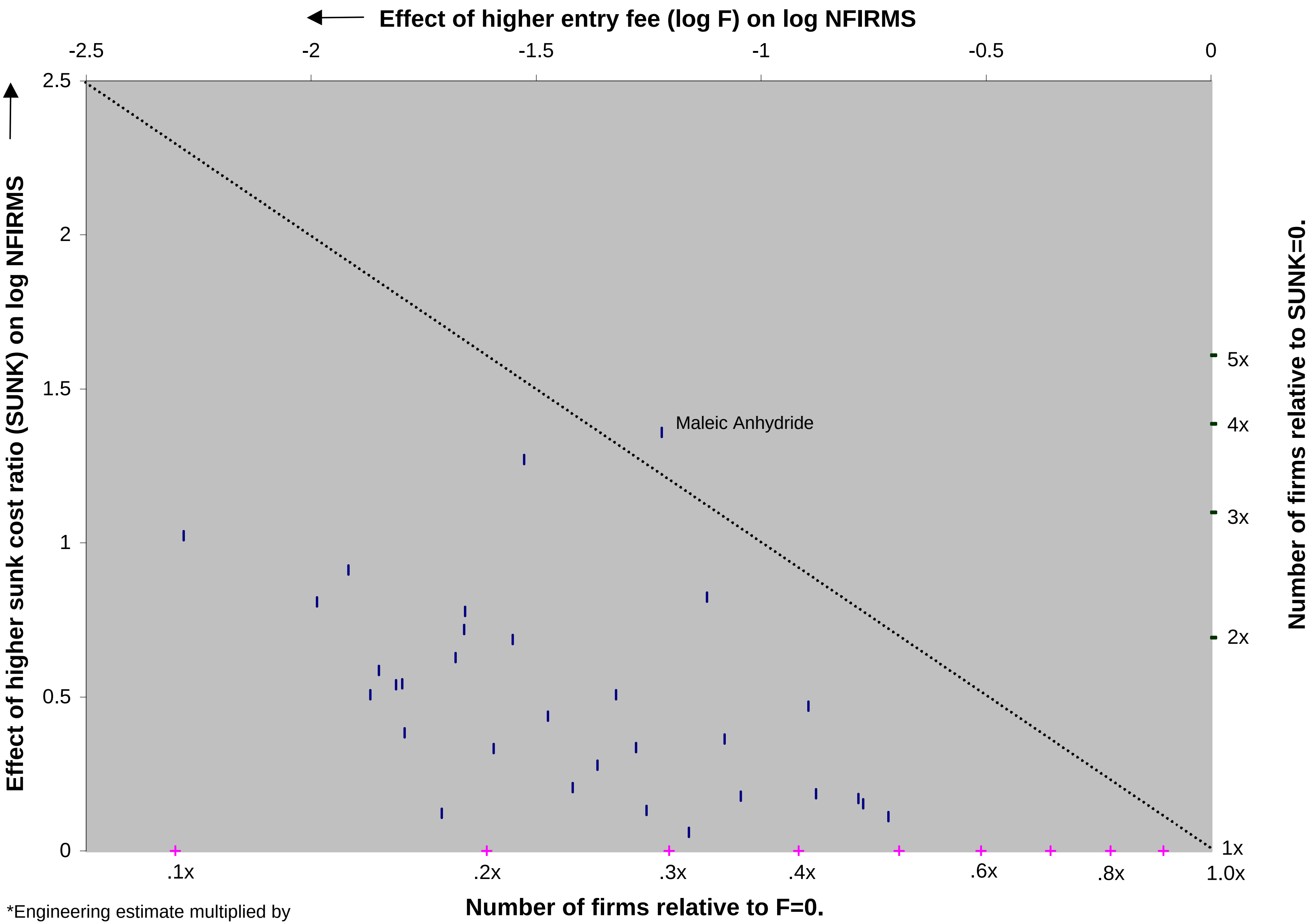


Figure 2. Estimated Effects of Cost Structure on Number of U.S. Producers*



*Engineering estimate multiplied by coefficient in Regression 4.8.