THE ECONOMIES OF SCALE*

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THE theory of the economies of scale is the theory of the relationship between the scale of use of a properly chosen combination of all productive services and the rate of output of the enterprise. In its broadest formulation this theory is a crucial element of the economic theory of social organization, for it underlies every question of market organization and the role (and locus) of governmental control over economic life. Let one ask himself how an economy would be organized if every economic activity were prohibitively inefficient upon alternately a small scale and a large scale, and the answer will convince him that here lies a basic element of the theory of economic organization.

The theory has limped along for a century, collecting large pieces of good reasoning and small chunks of empirical evidence but never achieving scientific prosperity. A large cause of its poverty is that the central concept of the theory—the firm of optimum size—has eluded confident measurement. We have been dangerously close to denying Lincoln, for all economists have been ignorant of the optimum size of firm in almost every industry all of the time, and this ignorance has been an insurmountable barrier between us and the understanding of the forces which govern optimum size. It is almost as if one were trying to measure the nutritive values of goods without knowing whether the consumers who ate them continued to live.

The central thesis of this paper is that the determination of the optimum size is not difficult if one formalizes the logic that sensible men have always employed to judge efficient size. This technique, which I am old-fashioned enough to call the survivor technique, reveals the optimum size in terms of private costs—that is, in terms of the environment in which the enterprise finds itself. After discussing the technique, we turn to the question of how the forces governing optimum size may be isolated.

I. The Survivor Principle

The optimum size (or range of sizes) of enterprises in an industry is now ascertained empirically by one of three methods. The first is that of direct comparison of actual costs of firms of different sizes; the second is the com-

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parison of rates of return on investment; and the third is the calculation of probable costs of enterprises of different sizes in the light of technological information. All three methods are practically objectionable in demanding data which are usually unobtainable and seldom up-to-date. But this cannot be the root of their difficulties, for there is up-to-date information on many economic concepts which are complex and even basically incapable of precise measurement (such as income). The plain fact is that we have not demanded the data because we have been unable to specify what we wanted.

The comparisons of both actual costs and rates of return are strongly influenced by the valuations which are put on productive services, so that an enterprise which over- or undervalues important productive services, will under- or overstate its efficiency. Historical cost valuations of resources, which are most commonly available, are in principle irrelevant under changed conditions. Valuations based upon expected earnings yield no information on the efficiency of an enterprise—in the limiting case where all resources are so valued, all firms would be of equal efficiency judged by either average costs or rates of return. The ascertainment on any scale of the maximum value of each resource in alternative uses is a task which only the unsophisticated would assume and only the omniscient would discharge. The host of valuation problems are accentuated by the variable role of the capital markets in effecting revaluations and the variable attitudes of the accountants toward the revaluations.[1]

The technological studies of costs of different sizes of plant encounter equally formidable obstacles. These studies are compounded of some fairly precise (although not necessarily very relevant) technical information and some crude guesses on nontechnological aspects such as marketing costs, transportation rate changes, labor relations, etc.—that is, much of the problem is solved only in the unhappy sense of being delegated to a technologist. Even ideal results, moreover, do not tell us the optimum size of firm in industry A in 1958, but rather the optimum size of new plants in the industry, on the assumption that the industry starts *de novo* or that only a small increment of investment is being made.

The survivor technique avoids both the problems of valuation of resources and the hypothetical nature of the technological studies. Its fundamental postulate is that the competition of different sizes of firms sifts out the more efficient enterprises. In the words of Mill, who long ago proposed the technique:

> Whether or not the advantages obtained by operating on a large-scale preponderate in any particular case over the more watchful attention, and greater regard to minor gains and losses usually found in small establishments, can be ascertained, in a state

[1] These problems are discussed by Milton Friedman in Business Concentration and Price Policy, pp. 230 ff. (1955).

of free competition, by an unfailing test. . . . Wherever there are large and small establishments in the same business, that one of the two which in existing circumstances carries on the production at the greater advantage will be able to undersell the other.[2]

Mill was wrong only in suggesting that the technique was inapplicable under oligopoly, for even under oligopoly the drive of maximum profits will lead to the disappearance of relatively inefficient sizes of firms.

The survivor technique proceeds to solve the problem of determining the optimum firm size as follows: Classify the firms in an industry by size, and calculate the share of industry output coming from each class over time. If the share of a given class falls, it is relatively inefficient, and in general is more inefficient the more rapidly the share falls.

An efficient size of firm, on this argument, is one that meets any and all problems the entrepreneur actually faces: strained labor relations, rapid innovation, government regulation, unstable foreign markets, and what not. This is, of course, the decisive meaning of efficiency from the viewpoint of the enterprise. Of course, social efficiency may be a very different thing: the most efficient firm size may arise from possession of monopoly power, undesirable labor practices, discriminatory legislation, etc. The survivor technique is not directly applicable to the determination of the socially optimum size of enterprise, and we do not enter into this question. The socially optimum firm is fundamentally an ethical concept, and we question neither its importance nor its elusiveness.

Not only is the survivor technique more direct and simpler than the alternative techniques for the determination of the optimum size of firm, it is also more authoritative. Suppose that the cost, rate of return, and technological studies all find that in a given industry the optimum size of firm is one which produces 500 to 600 units per day, and that costs per unit are much higher if one goes far outside this range. Suppose also that most of the firms in the industry are three times as large, and that those firms which are in the 500 to 600 unit class are rapidly failing or growing to a larger size. Would we believe that the optimum size was 500 to 600 units? Clearly not: an optimum size that cannot survive in rivalry with other sizes is a contradiction, and some error, we would all say, has been made in the traditional studies. Implicitly all judgments on economies of scale have always been based directly upon, or at least verified by recourse to, the experience of survivorship.

This is not to say that the findings of the survivor technique are unequivo-

[2] Principles of Political Economy, p. 134 (Ashley ed.). Marshall states the same argument in Darwinian language: "For as a general rule the law of substitution—which is nothing more than a special and limited application of the law of survival of the fittest—tends to make one method of industrial organization supplant another when it offers a direct and immediate service at a lower price." Principles of Economics, p. 597 (8th ed., 1920).

cal. Entrepreneurs may make mistakes in their choice of firm size, and we must seek to eliminate the effects of such errors either by invoking large numbers of firms so errors tend to cancel or by utilizing time periods such that errors are revealed and corrected. Or the optimum size may be changing because of changes in factor prices or technology, so that perhaps the optimum size rises in one period and falls in another. This problem too calls for a close examination of the time periods which should be employed. We face these problems in our statistical work below.

We must also recognize that a single optimum size of firm will exist in an industry only if all firms have (access to) identical resources. Since various firms employ different kinds or qualities of resources, there will tend to develop a frequency distribution of optimum firm sizes. The survivor technique may allow us to estimate this distribution; in the application below we restrict ourselves to the range of optimum sizes.

The measure of the optimum size is only a first step toward the construction of a theory of economies of scale with substantive content, but it is the indispensable first step. We turn in later sections of this paper to the examination of the methods by which hypotheses concerning the determinants of optimum size may be tested.

II. Illustrative Survivorship Measures

The survivor principle is very general in scope and very flexible in application, and these advantages can best be brought out by making concrete applications of the principle to individual industries. These applications will also serve to display a number of problems of data and interpretation which are encountered in the use of the survivor technique. We begin with the American steel industry.

In order that survivorship of firms of a given size be evidence of comparative efficiency, these firms must compete with firms of other sizes—all of the firms must sell in a common market. We have therefore restricted the analysis to firms making steel ingots by open-hearth or Bessemer processes.[3] Size has perforce been measured by capacity, for production is not reported by individual companies, and capacity is expressed as a percentage of the industry total to eliminate the influence of the secular growth of industry and company size.[4] The geographical extent of the market is especially difficult to determine in steel, for the shifting geographical pattern of consumption has created a linkage between the various regional markets. We treat the market as national,

[3] Crucible steel, which is made by smaller companies on average, is viewed as a separate, but closely related, industry.

[4] Capacity is least objectionable as a measure of firm size in an industry where production is continuous round the clock and the upward trend of output confers relevance on capacity. Both steel and our later example of petroleum refining meet these conditions.

which exaggerates its extent, but probably does less violence to the facts than a sharp regional classification of firms. The basic data are given in Table 1.

Over two decades covered by Table 1 (and, for that matter, over the last half century) there has been a persistent and fairly rapid decline in the share of the industry's capacity in firms with less than half a per cent of the total, so that we may infer that this size of firm is subject to substantial diseconomies of scale.[5] The firms with one-half to two-and-one-half per cent of industry capacity showed a moderate decline, and hence were subject to smaller diseconomies of scale. The one firm with more than one-fourth of industry capacity declined moderately, so it too had diseconomies of scale. The intervening sizes, from two-and-one-half to twenty-five per cent of industry capacity, grew or held their share so they constituted the range of optimum size.

TABLE 1

DISTRIBUTION OF OUTPUT OF STEEL INGOT CAPACITY BY RELATIVE SIZE OF COMPANY

Company Size (Per Cent of Industry Total)	1930	1938	1951
1. Per Cent of Industry Capacity			
Under ½	7.16	6.11	4.65
½ to 1	5.94	5.08	5.37
1 to 2½	13.17	8.30	9.07
2½ to 5	10.64	16.59	22.21
5 to 10	11.18	14.03	8.12
10 to 25	13.24	13.99	16.10
25 and over	38.67	35.91	34.50
2. Number of Companies			
Under ½	39	29	22
½ to 1	9	7	7
1 to 2½	9	6	6
2½ to 5	3	4	5
5 to 10	2	2	1
10 to 25	1	1	1
25 and over	1	1	1

Sources: Directory of Iron and Steel Works of the United States and Canada, 1930, 1938; Iron Age, January 3, 1952.

The more rapid the rate at which a firm loses its share of the industry's output (or, here, capacity), the higher is its private cost of production relative to the cost of production of firms of the most efficient size.[6] This interpretation should not be reversed, however, to infer that the size class whose share is

[5] In 1930 the firm with one-half per cent of the industry capacity had a capacity of 364,000 net tons; in 1951, 485,000 net tons. Of course, we could have employed absolute firm size classes, but they are less appropriate to many uses.

[6] How shall we assess the efficiency of a size of firm which merely holds its share of industry output or capacity? Although more subtle interpretations are possible, it seems simplest to view this size class as one whose trend of industry share is imperfectly estimated from the data, and that with fuller data (i.e., for more firms or a longer period), all firm sizes would display rising or falling industry shares.

growing more rapidly is more efficient than other classes whose shares are growing more slowly; the difference can merely represent differences in the quantities of various qualities of resources.[7] In the light of these considerations we translate the data of Table 1 into a long run average cost curve for the production of steel ingots and display this curve in Figure 1. Over a wide range of outputs there is no evidence of net economies or diseconomies of scale.

Although the survivor test yields an estimate of the shape of the long run cost curve, it does not allow an estimate of how much higher than the mini-

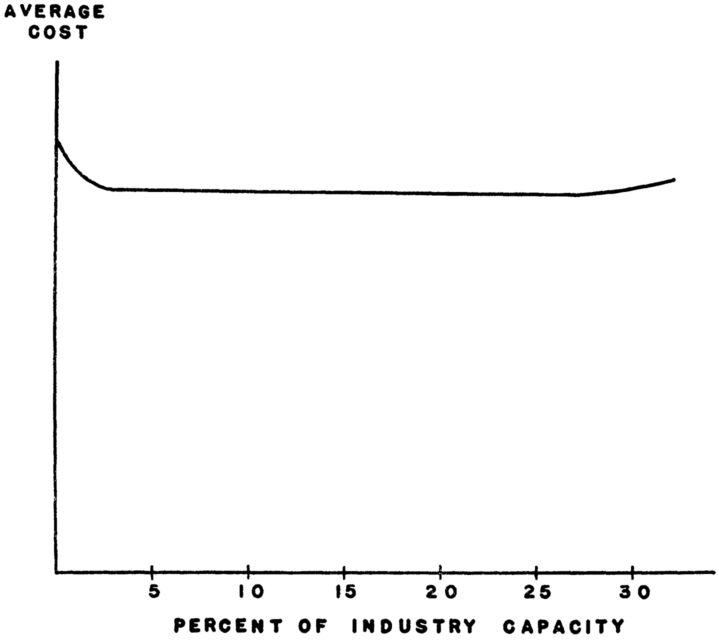

FIG. 1

mum are the costs of the firm sizes whose shares of industry output are declining. Costs are higher the more rapid the rate at which the firm size loses its share of industry output, but the rate at which a firm size loses a share of industry output will also vary with numerous other factors. This rate of loss of output will be larger, the less durable and specialized the productive resources of the firm, for then exit from the industry is easier. The rate of loss will also be larger, the more nearly perfect the capital and labor markets, so that re-

[7] For example, one firm size within the optimum range may utilize superior salesmen, another firm size inferior salesmen (at suitably lower rates of pay), and the relative numbers of the two types will influence the relative growth in the industry shares of the two sizes.

sources can be obtained to grow quickly to more efficient size. The rate of loss will be smaller, given the degree of inefficiency, the more profitable the industry is, for then the rate of return of all sizes of firms is larger relative to other industries.

By a simple extension of this argument, we may also estimate the most efficient size of *plant* in the steel ingot industry during the same period (Table 2). We again find that the smallest plants have a tendency to decline relative to the industry, and indeed this is implied by the company data. There is no systematic tendency toward decline in shares held by plants between $\frac{3}{4}$ per cent and 10 per cent of the industry size. We may therefore infer that the tendency of very small plants and companies to decline relative to the industry is due to the diseconomy of a small plant, and the tendency of the largest company (U.S. Steel) to decline has been due to diseconomies of multi-plant operation beyond a certain scale.

TABLE 2

DISTRIBUTION OF OUTPUT OF STEEL INGOT CAPACITY

Plant Size (Per Cent of Industry Total)	1930	1938	1951
1. Per Cent of Industry Capacity			
Under $\frac{1}{4}$	3.74	3.81	3.25
$\frac{1}{4}$ to $\frac{1}{2}$	6.39	5.81	7.20
$\frac{1}{2}$ to $\frac{3}{4}$	6.39	4.18	3.82
$\frac{3}{4}$ to 1	9.42	12.29	10.93
1 to $1\frac{3}{4}$	21.78	15.56	20.67
$1\frac{3}{4}$ to $2\frac{1}{2}$	13.13	16.73	17.01
$2\frac{1}{2}$ to $3\frac{3}{4}$	23.49	17.18	8.10
$3\frac{3}{4}$ to 5	8.82	12.07	12.46
5 to 10	6.82	12.37	16.56
2. Number of Plants			
Under $\frac{1}{4}$	40	29	23
$\frac{1}{4}$ to $\frac{1}{2}$	20	16	18
$\frac{1}{2}$ to $\frac{3}{4}$	11	7	6
$\frac{3}{4}$ to 1	11	14	12
1 to $1\frac{3}{4}$	18	13	15
$1\frac{3}{4}$ to $2\frac{1}{2}$	6	8	8
$2\frac{1}{2}$ to $3\frac{3}{4}$	8	6	3
$3\frac{3}{4}$ to 5	2	3	3
5 to 10	1	2	3

Source: Same as Table 1.

An equally important and interesting industry, passenger automobiles, uncovers different problems. Here we can use production data instead of capacity, and have no compunctions in treating the market as national in scope. The basic data for the individual firms are given in Table 3.

A striking feature of the automobile industry is the small number of firms, and this poses a statistical problem we have glossed over in our discussion of steel: what confidence can be attached to changes in the share of industry output coming from a firm size when that size contains very few firms? For the automobile industry (unlike steel) we possess annual data, and can therefore take into account the steadiness of direction or magnitude of changes in shares of various firm sizes, and to this extent increase our confidence in the estimates. We may also extend the period which is surveyed, although at the risk of combining periods with different sizes of optimum firms. Aside from recourse to related data (the survivorship pattern of the industry in other countries, for example), there is no other method of reducing the uncertainty of findings for small number industries.

The survivorship record in automobiles (summarized in Table 4) is more complicated than that for steel. In the immediate pre-war years there was

TABLE 3

PERCENTAGES OF PASSENGER AUTOMOBILES PRODUCED IN UNITED STATES BY VARIOUS COMPANIES, 1936–41 AND 1946–55

Year	General Motors	Chrysler	Ford	Hudson	Nash	Kaiser	Willys Overland	Packard	Studebaker	Other
1936.....	42.9	23.6	22.6	3.3	1.5	...	0.7	2.2	2.4	0.8
1937.....	40.9	24.2	22.6	2.7	2.2	...	2.0	2.8	2.1	0.5
1938.....	43.9	23.8	22.3	2.5	1.6	...	0.8	2.5	2.3	0.3
1939.....	43.0	22.7	21.8	2.8	2.3	...	0.9	2.6	3.7	0.3
1940.....	45.9	25.1	19.0	2.3	1.7	...	0.7	2.1	3.1	0.1
1941.....	48.3	23.3	18.3	2.1	2.1	...	0.8	1.8	3.2	0.1
1946.....	38.4	25.0	21.2	4.2	4.6	0.6	0.3	1.9	3.6	0.2
1947.....	40.4	21.7	21.3	2.8	3.2	4.1	0.9	1.6	3.5	0.5
1948.....	40.1	21.2	19.1	3.6	3.1	4.6	0.8	2.5	4.2	0.7
1949.....	43.0	21.9	21.0	2.8	2.8	1.2	0.6	2.0	4.5	0.2
1950.....	45.7	18.0	23.3	2.1	2.8	2.2	0.6	1.1	4.0	0.1
1951.....	42.2	23.1	21.8	1.8	3.0	1.9	0.5	1.4	4.2	0.1
1952.....	41.5	22.0	23.2	1.8	3.5	1.7	1.1	1.4	3.7	...
1953.....	45.7	20.3	25.2	1.2	2.2	1.0		1.3	3.0	...
1954.....	52.2	13.1	30.6	1.7		0.3		0.5	1.6	...
1955.....	50.2	17.2	28.2	2.0		0.1		2.3		...

Source: Hard's Automotive Yearbook 1951, 1955, 1956.

already a tendency for the largest company to produce a rising share and for the $2\frac{1}{2}$ to 5 per cent class to produce a sharply declining share; the smallest and next to largest sizes showed no clear tendency. In a longer span of time, however, the smallest companies reveal a fairly consistently declining share.[8] In the immediate postwar period, the $2\frac{1}{2}$ to 5 per cent size class was strongly favored by the larger companies' need to practice price control in a sensitive political atmosphere, and the same phenomenon reappeared less strongly in the first two years after the outbreak of Korean hostilities. From this record we would infer that there have been diseconomies of large size, at least for the largest size of firm, in inflationary periods with private or public price control, but substantial economies of large scale at other times. The long run average

[8] See Federal Trade Commission, Report on Motor Vehicle Industry, p. 29 (1939).

cost curve is saucer-shaped in inflationary times, but shows no tendency to rise at the largest outputs in other times.

The automobile example suggests the method by which we determine whether changing technology, factor prices, or consumer demands lead to a change in the optimum firm size. We infer an underlying stability in the optimum size in those periods in which the survivorship trends are stable. Indeed it is hard to conceive of an alternative test; one can judge the economic importance, in contrast to technological originality, of an innovation only by the impact it has upon the size distribution of firms.

Before we leave these applications of the survivorship technique we should indicate its flexibility in dealing with other problems which seem inappropriate

TABLE 4

PERCENTAGE OF PASSENGER AUTOMOBILES PRODUCED BY VARIOUS COMPANY-SIZES

	Company Size (as Per Cent of Industry)				Number of Companies	
Year	Over 35%	10–35%	2½–5%	Under 2½%	2½–5%	Under 2½%
1936	42.9	46.2	3.3	7.6	1	5*
1937	40.9	46.8	5.5	6.8	2	4*
1938	43.9	46.1	5.0	5.0	2	4*
1939	43.0	44.4	9.1	3.5	3	4*
1940	45.9	44.1	3.1	6.9	1	6*
1941	48.4	41.6	3.2	6.8	1	5
1946	38.4	46.2	12.4	3.0	3	4
1947	40.4	43.0	13.6	3.0	4	3
1948	40.1	40.3	18.0	1.5	5	2
1949	43.0	42.9	10.0	4.0	3	4
1950	45.7	41.3	6.8	6.1	2	5
1951	42.2	44.9	7.2	5.7	2	5
1952	41.5	45.2	7.2	6.1	2	5
1953	45.6	45.5	3.0	5.8	1	4
1954	52.2	43.7	0	4.1	0	4
1955	50.2	45.4	0	4.4	0	3

Source: Table 3.
* Or more.

to our particular examples. For example, a Marshallian may object that firms must begin small and grow to optimum size through time, so that the size structure of the industry in a given period will reflect this historical life pattern as well as the optimum size influences. In an industry such as retail trade this interpretation would be quite plausible. It can be met by studying the survivor experience of firm sizes in the light of the age or rate of growth of the firms. Again, one may argue that firms of different sizes have different comparative advantages at different stages of the business cycle. Such a hypothesis could be dealt with by comparing average survivorship patterns in given cycle stages with those calculated for full cycles.

Let us now turn to the methods by which one may test hypotheses on the determinants of optimum size.

III. Inter-Industry Analyses of the Determinants of Optimum Size

Once the optimum firm size has been ascertained for a variety of industries, the relationship between size and other variables can be explored. This is in fact the customary procedure for economists to employ, and the present investigation differs, aside from the method of determining optimum size, only in being more systematic than most such investigations. For example, numerous economists have asserted that advertising is a force making for large firms, and they usually illustrate this relationship by the cigarette industry. Will the relationship still hold when it is tested against a list of industries which has not been chosen to illustrate it? This is essentially the type of inquiry we make here.

Although the survivor method makes lesser demands of data than other methods to determine optimum firm size, it has equally exacting requirements of information on any other variable whose influence is to be studied. In the subsequent investigation of some 48 ("three-digit") manufacturing industries, whose optimum firm size is calculated from data in *Statistics of Income,* we have therefore been compelled to exclude some variables for lack of data and to measure others in a most imperfect manner. The industries we study, and the measures we contrive, are given in Table 5; we describe their derivation below.

1. *Size of firm.*—The optimum size of firm in each industry is determined by comparing the percentage of the industry's assets possessed by firms in each asset class in 1948 and 1951.[9] Those classes in which the share of the industry's assets was stable or rising were identified, and the average assets of the firms within these sizes was calculated.[10] The range of optimum sizes is also given in Table 5. An industry was excluded if it had a very large noncorporate sector (for which we could not measure firm size) or gave strong evidence of heterogeneity by having two widely separated optimum sizes (as, for example, in "aircraft and parts").

2. *Advertising expenditures.*—We have already remarked that extensive advertising is often mentioned as an explanation for the growth of large firms, especially in consumer goods industries such as cigarettes, liquor, and cosmetics. The argument supporting this view can take one of three directions. First, national advertising may be viewed as more efficient than local advertising, in terms of sales per dollar of advertising at a given price. Second,

[9] These particular dates were dictated by the data; there were large changes in industry classification in 1948, and no minor industry data were tabulated for 1952. A better, but more laborious, determination of optimum size could have been made if the data for intervening years were utilized.

[10] A rough allowance for sampling fluctuations was made by comparing three-asset class moving averages.

TABLE 5

Basic Data on Forty-eight Manufacturing Industries

Industry	Optimum Company Size (in Thousand Dollars of Total Assets) (1948–51)	Optimum Range Class Limits (in Thousand Dollars) From	To	Average Establishment Size (in Thousand Dollars of Value Added) (1947)	Number of Chemists and Engineers per 100 Employed (1950)	Advertising Expenditure as per cent of Gross Sales (1950)
Motor vehicles, incl. bodies and truck trailers	$827,828	$100,000	$open	$ 3,715	1.5879	0.4395
Petroleum refining	765,716	100,000	open	3,420	6.9171	0.4562
Blast furnaces, steel works and rolling mills	525,485	100,000	open	8,310	2.0956	0.1321
Dairy products	446,483	100,000	open	110	0.7865	1.5221
Distilled, rectified and blended liquors	248,424	100,000	open	2,090	0.9041	1.3674
Pulp, paper, and paperboard	203,794	100,000	open	1,645	1.4927	0.3357
Paints, varnishes, lacquers, etc.	175,404	100,000	open	394	6.0431	1.3539
Railroad equipment, incl. locomotives and streetcars	150,217	100,000	open	3,407	2.7171	0.3611
Tires and tubes	141,600	10,000	open	11,406	2.0974*	0.9453
Grain mill products ex. cereals preparations	128,363	100,000	open	210	1.0344	1.2492
Drugs and medicines	123,662	100,000	open	552	6.2599	8.3858
Smelting, refining, rolling, drawing and alloying of nonferrous metals	100,398	10,000	open	1,658	2.9845†	0.4088
Office and store machines	65,914	10,000	open	1,411	2.5860	1.5812
Bakery products	58,960	50,000	100,000	192	0.2359	2.1335
Yarn and thread	44,375	10,000	open	687	0.4461	0.3238
Carpets and other floor coverings	37,337	10,000	100,000	1,119	1.2391	1.7295
Broadwoven fabrics (wool)	31,265	10,000	open	1,211	0.4461	0.3400
Watches, clocks, and clock work operated devices	31,025	10,000	50,000	705	1.2027	5.3238
Cement	29,554	10,000	100,000	1,600	2.1277‡	0.2726
Malt liquors and malt	28,922	10,000	open	1,750	0.9041	4.7962
Agricultural machinery and tractors	28,291	1,000	open	684	2.1816	0.8956
Structural clay products	24,001	10,000	100,000	253	1.6292	0.4552

* Rubber products.

† Primary nonferrous.

‡ Cement, and concrete, gypsum and plaster products.

TABLE 5—*Continued*

Industry	Optimum Company Size (in Thousand Dollars of Total Assets) (1948–51)	Optimum Range Class Limits (in Thousand Dollars) From	To	Average Establishment Size (in Thousand Dollars of Value Added) (1947)	Number of Chemists and Engineers per 100 Employed (1950)	Advertising Expenditure as per cent of Gross Sales (1950)
Newspapers	$ 23,428	$ 10,000	$100,000	$ 168	0.1348§	0.1948
Knit goods	17,918	10,000	100,000	273	0.1244	0.8522
Confectionery	13,524	5,000	50,000	335	0.5950	2.6281
Commercial printing including lithographing	11,939	5,000	50,000	97	0.1348§	0.6474
Furniture—household, office, public building, and professional	11,378	5,000	50,000	209	0.3990‖	0.9152
Men's clothing	10,077	5,000	50,000	247	0.0456#	0.8795
Dyeing and finishing textiles, excl. knit goods	9,625	5,000	50,000	545	1.1223	0.3472
Canning fruit, vegetables and seafood	6,536	1,000	open	240	0.9144	1.8462
Broadwoven fabrics (cotton)	5,847	50	open	2,595	0.4461**	0.2822
Footwear, exc. rubber	4,359	1,000	100,000	524	0.1474	1.1619
Paperbags, and paperboard containers and boxes	4,127	1,000	100,000	428	0.6939	0.1854
Cigars	3,753	250	50,000	174	0.2274††	2.3188
Meat products	2,665	500	100,000	322	0.5983	0.4264
Nonferrous foundries	2,365	500	50,000	172	2.9845†	0.2793
Fur goods	1,966	1,000	5,000	55	0.0456#	0.4119
Partitions, shelving, lockers, etc.	1,545	500	50,000	121	0.3990‖	0.8678
Narrow fabrics and other small wares	1,382	500	5,000	226	0.4461**	0.3212
Wines	1,304	500	5,000	227	0.9041‡‡	3.5854
Women's clothing	1,304	500	50,000	150	0.0456#	0.9150
Books	1,137	50	50,000	399	0.1348§	2.8796
Periodicals	1,117	250	10,000	307	0.1348§	0.5245
Leather—tanning, curring and finishing	764	0	10,000	720	0.8140	0.1813
Concrete, gypsum and plaster products	762	250	10,000	53	2.1277‡	0.6855
Window and door screens, shades and venetian blinds	667	100	10,000	110	0.3990‖	1.0581
Non-alcoholic beverages	546	100	50,000	75	0.9041‡‡	4.0740
Millinery	468	250	5,000	108	0.0456#	0.4438

§ Printing, publishing and allied industries.
‖ Furniture and fixtures.
†† Tobacco manufactures.
‡‡ Beverage industries.
# Apparel and accessories.
** Yarn, thread, and fabric mills.

long continued advertising may have a cumulative impact. Finally, and closely related to the preceding point, the joint advertising of a series of related products may be more efficient than advertising them individually. We measure the variable by the ratio of advertising expenditures to sales, both taken from *Statistics of Income*.

3. *Technology and research.*—A host of explanations of firm size are related to technological characteristics and research. Complicated production processes may require large companies, or at least large plants. The economies of research are held to be substantial; the outcome of individual projects is uncertain, so small programs are more risky; a balanced research team may be fairly large; and much capital may be required to bring a new process to a commercial stage and to wait for a return upon the outlay.

At present there is no direct measure available for either the importance of research or the intricacy of technology.[11] We use an index, chemists and engineers as a ratio to all employees, that may reflect both influences, but probably very imperfectly. When it becomes possible to make a division of these personnel between research and routine operation, a division which would be very valuable for other purposes also, the interpretation of an index of technical personnel will be less ambiguous.

4. *Plant size.*—Plant size normally sets a minimum to company size, and therefore exerts an obvious influence on the differences among industries in company size. We are compelled to resort to a measure of plant size—value added per establishment in 1947—which is not directly comparable to company size because the 1947 Census of Manufactures did not report corporate establishments at the requisite level of detail.[12]

Preliminary analysis revealed that there is no significant relationship between firm size and advertising expenditures, so this variable was omitted from the statistical calculations. The average ratio of advertising expenditures to sales was 1.97 per cent in consumer goods industries and 0.57 per cent in producer goods industries, but in neither group was there a significant relationship between the ratio and firm size.[13]

A regression analysis confirms the impression one gets from Table 5 that the other variables we examine are positively related to optimum firm size:

$$X_1 = -5.092 + \underset{(10.8)}{34.6\,X_2} + \underset{(12.2)}{42.7\,X_3},$$

[11] In earlier experiments with two-digit manufacturing industries, capital-sales ratios were found to be uncorrelated with optimum firm size.

[12] But even if plants were measured by assets there would be some incomparability arising out of the fact that many large firms operate in many industries but are classified according to their dominant activity.

[13] The respective rank correlation coefficients were −.187 and −.059.

where X_1 is firm size, in millions of dollars of assets,
X_2 is plant size, in millions of dollars of value added,
X_3 is engineers and chemists per 100 employees.

The standard errors of the regression coefficients are given below the coefficients.[14]

An examination of Table 5 suggests that the correlation would be higher if the data were somewhat more precise. The size of plant is unduly low in motor vehicles, because of the inclusion of suppliers of parts. Moreover the plant sizes have not been estimated by the survivor technique. Technological personnel are exaggerated in nonferrous foundries because we are compelled to use the ratio for a broader class, and the same is true of concrete products. The relatively small size of company in footwear, as compare to plant size, is at least partially due to the fact that the machinery was usually leased, and hence not included in assets. Industries which are "out of line" have not been omitted, however, for similar considerations may have caused other industries to be "in line." Yet the general impression is that the correlation would rise substantially with improved measurements of the variables.

The range of optimum sizes is generally wide, although the width is exaggerated, and our measurements impaired, because the largest asset class (over $100 million) embraces numerous firms of very different sizes—growth and inflation are outmoding the size classes used in *Statistics of Income*. In ten industries only this largest size has had a rising share of industry assets, and in another nine industries it is included in the range of sizes with rising shares. When the upper limit of optimum sizes is known, the range of optimum sizes is typically three or four times the average size of the firms in these sizes.

The results of this exploratory inter-industry study are at least suggestive—not only in their specific content but also in pointing out a line of attack on the economies of scale that escapes that confession of failure, the case method. The chief qualifications that attach to the findings are due to the imperfections of the data: the industry categories are rather wide; and the measure of technical personnel is seriously ambiguous. At least one finding—a wide range of optimum firm sizes in each industry—is so general as to deserve to be taken as the standard model in the theory of production.

IV. Intra-Industry Analysis of the Determinants of Optimum Size

One may also examine the varying fates of individual firms within an industry in the search for explanations of optimum size. If, for example, firms

[14] The correlation coefficients are:

$r_{12} = .460$	$r_{12.3} = .400$
$r_{13} = .471$	$r_{13.2} = .413$
$r_{23} = .252$	$r_{23.1} = .046$

moving to optimum size were vertically integrated and those moving to or remaining in nonoptimum size were not so integrated, we could infer that vertical integration was a requisite of the optimum firm in the industry. This approach has the advantage over the inter-industry approach of not requiring the assumption that a determinant such as advertising or integration works similarly in all industries.

TABLE 6

DISTRIBUTION OF PETROLEUM REFINING CAPACITY BY RELATIVE SIZE OF COMPANY

Company Size (Per Cent of Industry Capacity)	1947	1950	1954
1. Per Cent of Industry Capacity			
Under 0.1	5.30	4.57	3.89
0.1 to 0.2	4.86	3.57	3.00
0.2 to 0.3	2.67	2.16	2.74
0.3 to 0.4	2.95	2.92	1.65
0.4 to 0.5	2.20	0	.89
0.5 to 0.75	3.04	4.66	5.05
0.75 to 1.00	.94	0	1.58
1.0 to 2.5	11.70	12.17	10.53
2.5 to 5	9.57	16.70	14.26
5 to 10	45.11	42.15	45.69
10 to 15	11.65	11.06	10.72
2. Number of Companies			
Under 0.1	130	108	92
0.1 to 0.2	34	24	22
0.2 to 0.3	11	9	11
0.3 to 0.4	8	8	5
0.4 to 0.5	5	0	2
0.5 to 0.75	5	8	8
0.75 to 1.00	1	0	2
1.0 to 2.5	6	7	6
2.5 to 5.0	3	5	5
5.0 to 10.0	7	6	7
10.0 to 15.0	1	1	1
Total	211	176	161

Source: Bureau of Mines, Petroleum Refineries, including Cracking Plants in the United States, January 1, 1947, January 1, 1950, January 1, 1954, Information Circulars 7455 (March 1948), 7578 (August 1950), and 7963 (July 1954).

The intra-industry analysis, however, has a heavy disadvantage; it can be applied only to those variables for which we can obtain information on each firm and in industries with numerous firms hardly any interesting variables survive this requirement. Because we could examine so few influences, and because the results were so consistently negative, we shall be very brief in describing our results in the industry—petroleum refining—in which this approach was tried.

The basic survivor experience for companies and plants in petroleum refining is given in Tables 6 and 7, for the postwar period 1947–1954. In each case only operating plants are included, and asphalt plants and companies are excluded. Capacities are measured in terms of crude oil; as in the case of steel plants, actual outputs cannot be obtained for all companies.[15]

There is a family resemblance between the data for petroleum and steel companies: in each case there has been a substantial reduction in the share of the largest company. In the petroleum refining industry, the size range from ½ of one per cent to 10 per cent has contained all the size classes which have stable or rising shares of industry capacity.

TABLE 7

DISTRIBUTION OF PETROLEUM REFINING CAPACITY BY RELATIVE SIZE OF PLANT

Plant Size	1947	1950	1954
1. Per Cent of Industry Capacity			
Under 0.1	8.22	7.39	6.06
0.1 to 0.2	9.06	7.60	7.13
0.2 to 0.3	6.86	4.95	3.95
0.3 to 0.4	5.45	4.99	7.28
0.4 to 0.5	4.53	6.56	4.06
0.5 to 0.75	9.95	10.47	11.82
0.75 to 1.0	5.35	7.07	8.33
1.0 to 1.5	12.11	10.36	13.38
1.5 to 2.5	17.39	23.64	22.45
2.5 to 4.0	21.08	16.96	15.54
2. Number of Plants			
Under 0.1	184	158	138
0.1 to 0.2	64	53	51
0.2 to 0.3	27	19	16
0.3 to 0.4	15	14	21
0.4 to 0.5	10	15	9
0.5 to 0.75	17	16	19
0.75 to 1.0	6	8	10
1.0 to 1.5	10	8	11
1.5 to 2.5	9	12	12
2.5 to 4.0	7	5	5
Total	349	308	292

Source: Same as Table 6.

The plant survivor data suggest that the disappearance of the smaller companies has been due to the relative inefficiency of the smaller plants, for all plant size classes with less than one-half of one per cent of the industry's capacity have also declined substantially. The sizes between one-half of one per cent and 2.5 per cent of industry capacity have all grown relatively, and the top plant size has declined moderately, so that the growth of company sizes beyond 2.5 per cent of industry capacity has presumably been due to the economies of multiple plant operation.

[15] One per cent of industry capacity was 52,508 barrels per day in 1947, and 76,811 barrels in 1954. Tentative calculations for regional markets indicate that the results are not greatly affected by using a national base.

It has been claimed that backward integration into crude oil pipe lines was necessary to successful operation of a petroleum refinery. We tabulate some of the material bearing on this hypothesis in Table 8. There does not appear to be any large difference between the changes in market shares of firms with and without pipe lines. Since all firms with more than 0.75 per cent of industry refining capacity have some pipe lines, a comparison (not reproduced here) was made between changes in their market shares and crude pipe line mileage per 1,000 barrels of daily refining capacity. There was no relationship between the two variables.[16]

The intra-industry analysis has its chief role, one may conjecture, in providing a systematic framework for the analysis of the data commonly employed in industry studies. A complete analysis of the plausible determinants of firm size requires such extensive information on the individual firms in the industry as to make this an unattractive method of attack on the general theory.

TABLE 8

INDUSTRY SHARES OF PETROLEUM REFINING COMPANIES WITH AND WITHOUT CRUDE PIPE LINES IN 1950

Company Size (Average of 1947, 1950, and 1954 Percentage of Industry Capacity)	Companies with Pipe Lines			Companies without Pipe Lines		
	Number 1950	Share 1947	Share 1954	Number 1950	Share 1947	Share 1954
Under 0.1.......	25	1.40	1.12	60	2.87	2.18
0.1 to 0.2.......	17	2.19	2.50	5	0.77	0.77
0.2 to 0.3.......	6	1.48	1.63	2	0.34	0.50
0.3 to 0.4.......	5	1.90	1.63	0	....	....
0.4 to 0.5.......	1	0.40	0.55	2	0.54	1.22
0.5 to 0.75......	7	3.59	4.72	1	0.38	0.61
0.75 to 1.0.......	0	.....	.....	0	....	....
1.0 to 2.5.......	7	11.54	13.10	0	....	....
2.5 to 5.0.......	4	11.11	11.69	0	....	....
5.0 to 10.0.......	7	45.11	45.69	0	....	....
10.0 to 15.0.......	1	11.65	10.72	0	....	....
Not in existence all years............	16	2.30	0.05	79	2.43	1.33
Total..........	96	92.67	93.40	149	7.33	6.60

Source: International Petroleum Register.

V. Conclusion

The survivor technique for determining the range of optimum sizes of a firm seems well adapted to lift the theory of economies of scale to a higher level of substantive content. Although it is prey to the usual frustrations of

[16] A corresponding investigation was made for research laboratories, which are reported in the Directory of Research Laboratories of the National Research Council. That the results showed no relationship between firm size and size of laboratories is not surprising, for the work of the research laboratories would influence only the firm's long-term growth.

inadequate information, the determination of optimum sizes avoids the enormously difficult problem of valuing resources properly that is encountered by alternative methods.

Perhaps the most striking finding in our exploratory studies is that there is customarily a fairly wide range of optimum sizes—the long run marginal and average cost curves of the firm are customarily horizontal over a long range of sizes. This finding could be corroborated, I suspect, by a related investigation: if there were a unique optimum size in an industry, increases in demand would normally be met primarily by near proportional increases in the number of firms, but it appears that much of the increase is usually met by expansion of the existing firms.

The survivor method can be used to test the numerous hypotheses on the factors determining the size of firm which abound in the literature. Our exploratory study suggests that advertising expenditures have no general tendency to lead to large firms, and another experiment (which is not reported above) indicates that fixed capital-sales ratios are also unrelated to the size of firms. The size of plant proves to be an important variable, as is to be expected, and the survivor method should be employed to determine the factors governing plant size. A rather ambiguous variable, the relative share of engineers and chemists in the labor force, also proves to be fairly important, and further data and work is necessary to disentangle research and routine technical operations. The determination of optimum size permits the investigator to examine any possible determinants which his imagination nominates and his data illuminate.